96-0003861

Department of Energy
Richland Operations Office
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Richland, Washington 99352

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96-WSD-234

SEP 27 1996

Mr. John T. Conway, Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue N.W., Suite 700
Washington, D.C. 20004

Dear Mr. Conway:

TRANSMITTAL OF INFORMATION TO COMPLETE DEFENSE NUCLEAR FACILITIES SAFETY BOARD (DNFSB) RECOMMENDATION 93-5 MILESTONE 5.4.3.5c

This letter constitutes completion of DNFSB Recommendation 93-5 Implementation Plan, Revision 1, Milestone 5.4.3.5c, "Letter Reporting Approval of Safety Assessment for Rotary Mode Core Sampling in Flammable Gas Tanks and Documenting Incorporation into the Authorization Basis." The due date for Milestone 5.4.3.5c is September 1996. The U.S. Department of Energy, Richland Operations Office (RL) has completed the actions identified under this milestone and proposes closure of the milestone.

Enclosure 1 is the Safety Assessment (SA) of Rotary Mode Core Sampling in Flammable Gas Single-Shell Tanks developed by the Los Alamos National Laboratory for the Westinghouse Hanford Company (WHC). Enclosure 2 (WHC Engineering Change Notice [ECN] #609990) contains the Interim Operational Safety Requirements (IOSRs) that were developed to implement the SA. Both of these documents were intensively reviewed by the Independent Review Team from Idaho National Engineering Laboratory and my staff with the participation of your staff. The product of the review was the Safety Evaluation Report (SER [Enclosure 3]). This SER was approved by RL in Enclosure 4. The WHC ECN #609990 (Enclosure 2) incorporated the SA and IOSRs into the Interim Safety Basis, which is the Authorization Basis for the Tank Waste Remediation System.

If you have any questions, please contact me or your staff may contact Jackson Kinzer, Assistant Manager for Tank Waste Remediation System, on (509) 376-7591.

Sincerely,

John D. Wagoner
John D. Wagoner
Manager

WSD:PRH

Enclosures (4)

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R. Izatt, EM-2
J. Tseng, EM-4
S. Cowan, EM-30
M. Hunemuller, EM-38
M. Whitaker, S-3.1
S. Trine, RL DNFSB Liaison

cc w/o encls:
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Westinghouse
Hanford Company

P.O. Box 1970 Richland, WA 99352

96/3861

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September 12, 1996

9654064

Mr. J. K. McClusky, Director
Waste Storage Division
U.S. Department of Energy
Richland Operations Office
Richland, Washington 99352

Dear Mr. McClusky:

COMPLETION OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD RECOMMENDATION 93-5 IMPLEMENTATION PLAN, REVISION 1, COMMITMENT 5.4.3.5c, *LETTER REPORTING APPROVAL OF SAFETY ASSESSMENT FOR ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS TANKS AND DOCUMENTING INCORPORATION INTO THE INTERIM SAFETY BASIS*

References:

(1) Letter, J. D. Wagoner, RL, to A. L. Trego, WHC, "Authorization of the Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single-Shell Tanks, WHC-SD-WM-SAD-035, Revision 0a, and Interim Operation Safety Requirements," 96-QSH-042, dated August 30, 1996.

(2) WHC-SD-WM-SAD-035, "A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks: Hanford Site, Richland, Washington," dated August 8, 1996.

(3) WHC-SD-WM-ISB-001, "Hanford Site Tank Farm Facilities Interim Safety Basis," Rev 0-K, dated July 19, 1996.

(4) "Safety Evaluation Report of the Safety Assessment document titled 'A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks: Hanford Site, Richland, Washington,'" Lockheed Idaho Technologies Company, dated July 18, 1996.

(5) WHC-SD-WM-OSR-005, "Single Shell Tank Interim Operational Safety Requirements," Rev 0-E, dated July 18, 1996.

This letter reports completion of Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 93-5 Implementation Plan Milestone 5.4.3.5c, *Letter Reporting Approval of Safety Assessment for Rotary Mode Core Sampling in Flammable Gas Tanks and Documenting Incorporation into the ISB.*

By Reference 1, the U.S. Department of Energy, Richland Operations Office, authorized the Safety Evaluation Report (Reference 4) documenting the review and approval of the Rotary Mode Core Sampling System Safety Assessment

 9654064

(Reference 2) and the related Interim Operational Safety Requirements (Reference 5). The attachment to this letter (Engineering Change Notice #609990) incorporates the Safety Assessment and the supporting Operational Safety Requirements into the Tank Farm Interim Safety Basis (Reference 3).

The due date for submittal of this milestone to DNFSB is September 30, 1996.

Very truly yours,

L. F. Ermold, Director
TWRS Characterization Project
Tank Waste Remediation System

srb

Attachment

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M. A. Mikolanis

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P. R. Hernandez
J. F. Thompson, Jr.
S. L. Trine
N. W. Willis
A. H. Wirkkala (w/o attachment)

PNNL - A. F. Noonan

SAIC - H. G. Sutter

WHC-SD-WM-SAD-035, Rev. 0-a

A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks: Hanford Site, Richland, Washington

Prepared by

Nuclear Systems Design and Analysis Group
Technology and Safety Assessment Division
Los Alamos National Laboratory

Los Alamos
NATIONAL LABORATORY

96/3861

A SAFETY ASSESSMENT OF ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON

by

Waste Tank Safety Analysis Team

Nuclear Systems Design and Analysis Group
Technology and Safety Assessment Division
Los Alamos National Laboratory
Los Alamos, New Mexico

WHC-SD-WM-SAD-035, Rev. 0-a

U.S. DEPARTMENT OF ENERGY

August 8, 1996

LOS ALAMOS NATIONAL LABORATORY

ACKNOWLEDGMENTS

Contributors to the development of this SA include the listed personnel.

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EXECUTIVE SUMMARY

This safety assessment (SA) addresses each of the required elements associated with the installation, operation, and removal of a rotary-mode core sampling (RMCS) device in flammable-gas (FG) single-shell tanks (SSTs). The RMCS operations are needed to retrieve waste samples from SSTs with hard layers of waste for which push-mode sampling is not adequate for sampling.

This SA was prepared using the "Interim Guidance for Preparing Safety Assessments," which was documented in Appendix A of Westinghouse Hanford Company (WHC) report WHC-CM-6-32. The contents of this SA address most of the elements required in the Department of Energy (DOE) Standard (DOE-STD-3011-94) "Guidance for Preparation and Submittal of Basis for Interim Operation (BIO) for DOE Nonreactor Nuclear Facilities." The hazard analysis contained in this SA was performed using the guidance provided in Chapter 2 of the DOE Standard (DOE-STD-3009-94) "Preparation Guide for U. S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports." However, these standards generally apply to a facility as opposed to a system or activity, which is the subject of the current SA. The hazard analysis for the system of interest was performed in parallel with the design. All required design changes (with the required protective equipment credited in the accident analysis) are documented in this SA.

In this SA, potential hazards associated with the proposed action were identified and evaluated systematically. Several potential accident cases that could result in radiological or toxicological gas releases were identified and analyzed and their consequences assessed. Administrative controls, procedures, and design changes required to eliminate or reduce the potential of hazards were identified.

The accidents were analyzed under nine categories, four of which were burn scenarios. In SSTs, burn accidents result in unacceptable consequences because of a potential dome collapse. The accidents in which an aboveground burn propagates into the dome space were shown to be in the "beyond extremely unlikely" frequency category. Given the unknown nature of the gas-release behavior in the SSTs, many design changes and administrative controls were implemented to achieve these low frequencies. Likewise, drill string fires and dome space fires were shown to be very low frequency accidents (<1.0E-6/yr) by taking credit for the design changes, controls, and available experimental and analytical data.

Under the category of waste fires, the possibility of igniting the entrapped gases and the waste itself were analyzed. Experiments were conducted at the BOM to demonstrate that the drill bit is not capable of igniting the trapped gas in the waste. Laboratory testing and thermal analysis demonstrated that, under normal operating conditions, the drill bit will not create high enough temperatures to initiate a propagating reaction in the waste. However, system failure that coincides in a waste layer with high organic content and low moisture may initiate an exothermic reaction in the waste. Consequently, a conservative approach based on the current state of the knowledge resulted in limiting the drilling process to a subset of the FG tanks.

Accidents from the chemical reactions and criticality category are shown to result in acceptable risk. Many accidents are shown to result potentially in containment (tank liner) breach below the waste level. Mitigative features are provided for these accidents. Gas-release events (GREs) without burn also are analyzed, and radiological and toxicological consequences are shown to be within risk guidelines. Finally, the consequences of potential spills are shown to be within the risk guidelines.

Accidents associated with external events also are addressed in this SA. For the SSTs, large seismic events with low frequency of occurrence may result in catastrophic dome failure. However, such events and their consequences are independent of the RMCS operations. Lightning is considered a potential initiator for burn accidents.

The conservative consequences of the accidents are compared with the WHC risk guidelines using accident frequencies obtained on a per-tank and per-year basis. All of the accidents analyzed in this SA are shown to meet the radiological and toxicological risk guidelines. The on-site and off-site consequences of a burn in an SST dome space are high because of a potential dome collapse and do not meet the risk guidelines if not mitigated. Mitigated frequency of the dome collapse accident is shown to be $<10^{-6}$/yr.

This SA is written to cover all FG tanks. As discussed in Section 1, a bounding tank is chosen and a bounding set of parameters are used in the analyses. However, all the SSTs are not screened in determining the bounding set of parameters. To address the issue associated with organic reaction, RMCS is currently allowed in a limited number of tanks. These tanks are explicitly identified in this SA. To encompass the flammable gas issues, a checklist is prepared and included in Section 7 of this SA. The checklist includes tank specific parameters that must be screened against the assumptions made in this SA. This checklist is aimed at complementing the Unreviewed Safety Question (USQ) screening process which would be required to apply this SA to any given tank.

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ACRONYM	DEFINITION
1-D	One-dimensional
2-D	Two-dimensional
AED	Eerodynamic equivalent diameter
AIChE	American Institute of Chemical Engineers
ALARA	As low as reasonably achievable
AMCA	Air Movement and Control Association
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
ARC	Accelerated rate calorimetry
ASA	Accelerated Safety Analysis
ASTM	American Society for Testing and Materials
BOM	Bureau of Mines
CAA	Chronic annual average
CANDU	Canadian reactor licensing
CB	Containment Breach
CC	Concentrated complexant
CEDES	Committed effective dose equivalents
CEL	Chemical Engineering Laboratory
CGM	Combustible Gas Meter
CL	Convective layer
DBA	Design Basis Accident
DBE	Design basis earthquake
DC	Dilute complexed (waste)
DCRT	Double-contained receiver tank
DDT	Deflagration-to-Detonation
DIP	Differential Indicating Probe
DOE	Department of Energy
DOE-RL	Department of Energy-Richland Area Office
DR	Damage ratio
DS	Drill string
DSC	Differential Scanning Calorimetry

ACRONYM	DEFINITION
DSF	Dome space fire
DSSF	Double-shell slurry feed
DST	Double-shell tank
DTA	Differential Thermal Analysis
EDES	Effective dose equivalents
EDTA	Ethylenediaminetetra-acetic acid
ERDA	(US) Energy Research & Development Administration
ERP	Emergency Response Planning
EXF	External fire
FGWL	Flammable Gas Watch List
GRE	Gas-release event
HA	Hazard analysis
HASP	Health and Safety Plan
HAZOP	Hazards and operability
HBD	Hydraulic bottom detector
HEDTA	Hydroxyethyl-ethylenediaminetriacetic acid
HEPA	High-efficiency particulate air (filter)
HIS	Hazards Identification Study
HMS	Hanford Meteorological Station
HTWRS	Hanford tank waste remediation system
I&C	Instrumentation and control
IEEE	Institute of Electrical and Electronic Engineers
IH	Industrial Hygience
IRRAS	Interim Reliabililty Risk Assessment System
ISB	Interim Safety Basis
L/D	Length-to-diameter
LANL	Los Alamos National Laboratory
LASAN	Los Alamos Systems Analysis
LCO	Limiting Conditions for Operation
LFL	Lower (or lean) flammability limit
LOW	Liquid observation well
LPF	Leak path factor
MAF	Mitigated accident frequency

ACRONYM	DEFINITION
MAR	Material at risk
MEI	Maximum Exposed Individual
MIST	Minimum ignition surface temperature
MMD	Mass median diameter
NCPLX	Noncomplexed waste
NEC	National Electric Code
NFPA	National Fire Protection Association
NRC	Nuclear Regulatory Commission
NSSFC	National Severe Storms Forecast Center
NUREG	Nuclear Regulatory Commission Regulation
OSD	Operational safety document
OSHA	Occupational Safety and Health Administration
OSR	Operational Safety Requirement
PEL-TWA	Permissable exposure limit time-weighted average
PG	Purge gas
PIC	Person in charge
PLC	Programmable Logic Controller
PM	Plume meander
PNNL	Pacific Northwest National Laboratory
PPF	Pump pit fire
PRC	Plant Review Committee
PVC	Polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RG	Risk Guidelines
RCV	Ram control valve
RF	Respirable fraction
RLU	Remote latch unit
RMCS	Rotary-mode core sampling
RSST	Reactive Systems Screening Tool
SA	Safety assessment
SC I	Safety Class I
SE	Seismic event
SHMS	Standard Hydrogen Monitoring Systems

ACRONYM	DEFINITION
SMC	Sierra Monitor Corporation
SOV	Solenoid-operated valve
SR	Shielded receiver
SSFGWLT	Single-Shell Flammable Gas Watch List Tank
SMM	Supernate mixing model
SST	Single-shell tank
TC	Thermocouple
TEDE	Total Effective Dose Equivalent
TGR	Toxic gas release
TI	Total Inventory
TLM	Tank layer model
TOC	Total organic compound
TRG	Test Review Group
TSD	Treatment, Storage and Disposal
TWRS	Tank Waste Remediation System
UAF	Unmitigated accident frequency
ULD	Unit-liter dose
UOR	Unusual occurrence report
USQ	Unreviewed safety question
WHC	Westinghouse Hanford Company
ZPA	Zero-Period Acceleration

DEFINITIONS

Dust Devil. A dust devil is a localized wind pattern that moves in a circular motion which spawns and decays quickly and travels at relatively low velocities.

Immediate Shutdown. Immediate shutdown is defined as the time it takes for the PLC to send a shutdown signal to the drill engine upon receipt of a valid shutdown signal with no additional programmed-delay. It is understood that the determination of a valid alarm signal requires approximately 2 seconds.

Independent Verification. Independent task verification is defined as requiring that either a second person verify whether a task is performed correctly after a task is completed or whether the original task performer verifies a task correctly performed at a different time and location.

Rotary Drilling. Rotary drilling is defined as rotation of the drill string greater than 2 rpm, while the drill string is in the tank waste.

Waste-intrusive activities. Waste-intrusive activities are defined to include all actions in which motion of, or motion in, the drill string occurs, while the drill string is in the tank waste, including drilling, gas flows and sample insertion and recovery, while the drill string is in the tank waste. Waste-intrusive also includes the four hours following termination of these activities.

1.0. SCOPE

This safety assessment (SA) addresses each of the proposed elements required to evaluate the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations. These tanks, referred to as flammable-gas tanks (FGTs), are located within the 200 Area in Hanford Site, Richland, Washington. Specifically, this SA addresses the proposed action to install, operate, and remove an FG/RMCS device in the subject tanks.

The objective of this SA is to (1) systematically identify each of the potential hazards associated with these proposed sampling actions, (2) analyze each of the resultant accident sequences, (3) assess the consequences of the accident sequences, and (4) identify the controls and procedures necessary to eliminate or reduce the potential hazards. Section 1 of this SA provides the background information for the proposed actions, discusses the no-action alternative, and outlines the safety assessment approach and scope. Also included in Section 1 is a summary of the significant characteristics of the SST farms.

1.1. BACKGROUND AND PURPOSE OF THE PROPOSED ACTION

The Department of Energy (DOE) is responsible for the management and storage of the waste accumulated from processing defense reactor irradiated fuels for plutonium recovery at the Hanford Site. Currently, there are 177 waste tanks, including 149 SSTs and 28 double-shell tanks (DSTs) located in the 200 area of the Hanford reservation. These wastes, consisting of liquids and solids, are stored in underground storage tanks pending final disposition. A systems approach, managed as part of the tank waste remediation system (TWRS), has been adopted to address the complex and interrelated activities associated with the management and disposal of Hanford tank wastes. The goal of the TWRS is to reduce the environmental, safety, and health risks inherent in the Hanford tank waste operation and remediation. The highest priority for this program is to identify a corrective action strategy for each waste tank safety issue and to mitigate known safety concerns. The four safety issues include (1) flammable-gas generation and concentrations that exceed the lower flammability level (LFL); (2) tanks containing mixtures of ferrocyanide compounds and nitrate/nitrite materials that could, if specific concentrations and conditions were to occur, support an exothermic reaction leading to an explosion; (3) tanks containing organic compounds that could, if locally concentrated, support an exothermic reaction; and (4) Tank 241-106-C, which contains a strontium source generating high heat that requires periodic cooling.

This SA is concerned primarily with SSTs that are on the FGWL or have been recommended by the contractor for inclusion on the FGWL. These tanks are listed and discussed in Section 2.

Rotary-mode drilling is necessary only for the SSTs with hard waste layers where waste samples cannot be obtained using the push-mode sampler. The rotary core sampling yields certain hazards that, if not mitigated, result in consequences beyond those analyzed in the push-mode sampling SA.[1] Therefore, an Unreviewed Safety Question (USQ) evaluation was performed. It was concluded that the FG/RMCS operations are not covered by the current authorization and that a separate SA was needed to perform rotary-mode core sampling operations on FGTs. This SA fulfills that need.

1.2. SAFETY ASSESSMENT—SCOPE AND APPROACH

The scope of this SA is to provide a safety basis for the FG/RMCS operations in the single-shell FGTs. To develop an SA that aims at bounding FG/RMCS operations on all FGTs, the following methodology was implemented. The identification of hazards associated with the installation, operation, and removal of the FG/RMCS was performed in a generic tank. Accident sequences also are developed from the evaluated hazards in a generic way. Accident analysis and resulting controls required the discussion of specific parameters pertinent to each SST. A set of bounding tank parameters was not determined through detailed analysis. Instead, a representative tank was chosen that was shown to have bounding tank parameters by performing a preliminary screening process. The screening process considered important tank parameters, such as the retained-gas amount, measured dome flammable- and toxic-gas concentrations, the observed or anticipated gas-release amount, and the waste type. Among the SSTs on the FGWL, Tank A-101 was found to maximize the parameters of interest. The total waste stored in Tank A-101 is 953 Kgal and is mostly consisted of salt cake (950 Kgal). Tank A-101 waste is classified as double-shell slurry feed (DSSF). Estimated radionuclides in Tank A-101 are Cesium (Cs-137), Strontium (S-90), Plutonium (Pu), and Uranium (U).

Accident analyses were performed with this anticipated set of bounding tank parameters. When the first revision of this SA was issued, the anticipated bounding tank parameters were not screened in detail for all tanks of interest. Furthermore, it can be anticipated that additional tanks will be designated as FGTs in the near future after the completion of this SA. Care must be taken in applying this SA to tanks that are on other watch lists (organic, ferrocyanide, etc.). This SA was concerned primarily with the FG issues; hazards specific to tanks on other watch lists may not have been properly addressed in this document. Thus, a screening process with a checklist of items was developed. The controls produced in this SA will require the review and approval of the screening results against the checklist for performance of the FG/RMCS in specific tanks by the Plant Review Committee (PRC). The PRC may charter a separate technical review group to perform the review and approval responsibilities of the PRC. Also, the Westinghouse Hanford Company (WHC) Design Authority is responsible for all aspects of equipment design.

This SA is developed using the guidelines provided in Ref. 2. The approach implemented in this SA incorporates a systematic evaluation of the potential hazards related to rotary-mode core sampling in tanks with a flammable environment and the activities required for the installation, operation, and removal of the equipment. For the potential hazards identified, evaluations were completed to establish their potential severity and the resultant consequences of accidents that may occur in response to these hazards. These evaluations consisted of detailed analyses and evaluations using analytical and numerical techniques, routine engineering calculations, and/or a review of existing information to establish the consequences, if any, of these hazards. Finally, this SA identifies the procedures and controls implemented to prevent or mitigate the consequences of these hazards.

Commensurate with this approach, an SA format is developed in Ref. 3. Section 2 of the SA describes the equipment, subsystems, and procedures used during FG/RMCS operations. Section 3 then systematically defines the hazards, causes, and potential accident sequences anticipated, not only with the FG/RMCS operational phase, but also with installation and removal activities. Section 4 assesses the identified hazards in Section 3, followed by a consequence analysis of the postulated accidents in Section 5. Section 6 defines both design features and administrative/ procedural controls that are required to ensure an acceptable level of safety during FG/RMCS operations, especially in a flammable environment. In Section 7, a checklist is provided that contains the items that must be addressed in applying this SA to all FGTs.

This format addresses all activity-related elements listed in US Department of Energy (DOE) Guidance document 3011-94 (Ref. 4). Reference 4 is aimed primarily at safety documents developed for a facility, this SA is aimed at a specific activity, namely the RMCS operations in FGTs. Thus, most of the facility-related sections of the 3011 Guidance are not addressed in this SA. However, a brief summary of the significant characteristics of the SST farms and their environment are provided in Section 1.4 of this SA.

1.3. NO-ACTION ALTERNATIVE

Tank characterization is a high-priority activity at the Hanford site, and FG/RMCS is the proposed retrieval technique for SST samples. A "no-action" alternative would prevent or delay full-depth core sampling activities in SSTs that are FGTs. The analysis of these waste samples is very important for the following reasons:

- Addressing the issues associated with the safe storage of the waste, and
- Developing sound strategies for the retrieval and ultimate disposal of the waste.

Currently, there is no engineered or conceptualized design that can replace the FG/RMCS equipment for obtaining samples from hard waste layers for which the push mode sampling is not adequate.

1.4. SUMMARY OF SIGNIFICANT CHARACTERISTICS OF THE SST FARMS AND THEIR ENVIRONMENT

All the SSTs of interest are located in the 200 Area at the Hanford Reservation, as shown in Fig. 1-1. Detailed descriptions of the SSTs and SST tank farms are provided in Refs. 5 and 6. Specific characteristics of the SSTs pertinent to this SA are discussed in Section 2 and other parts of the SA when needed. This section provides a summary of the descriptive information for the site.

A detailed and comprehensive description of the Hanford Site is presented in documents developed by the (US) Energy Research and Development Administration (ERDA), DOE, and Pacific Northwest Laboratory (PNL).[7,9] This section summarizes results presented in these references and others as they apply to the 200 Areas. The DOE Hanford Site lies within the semiarid Pasco Basin of the

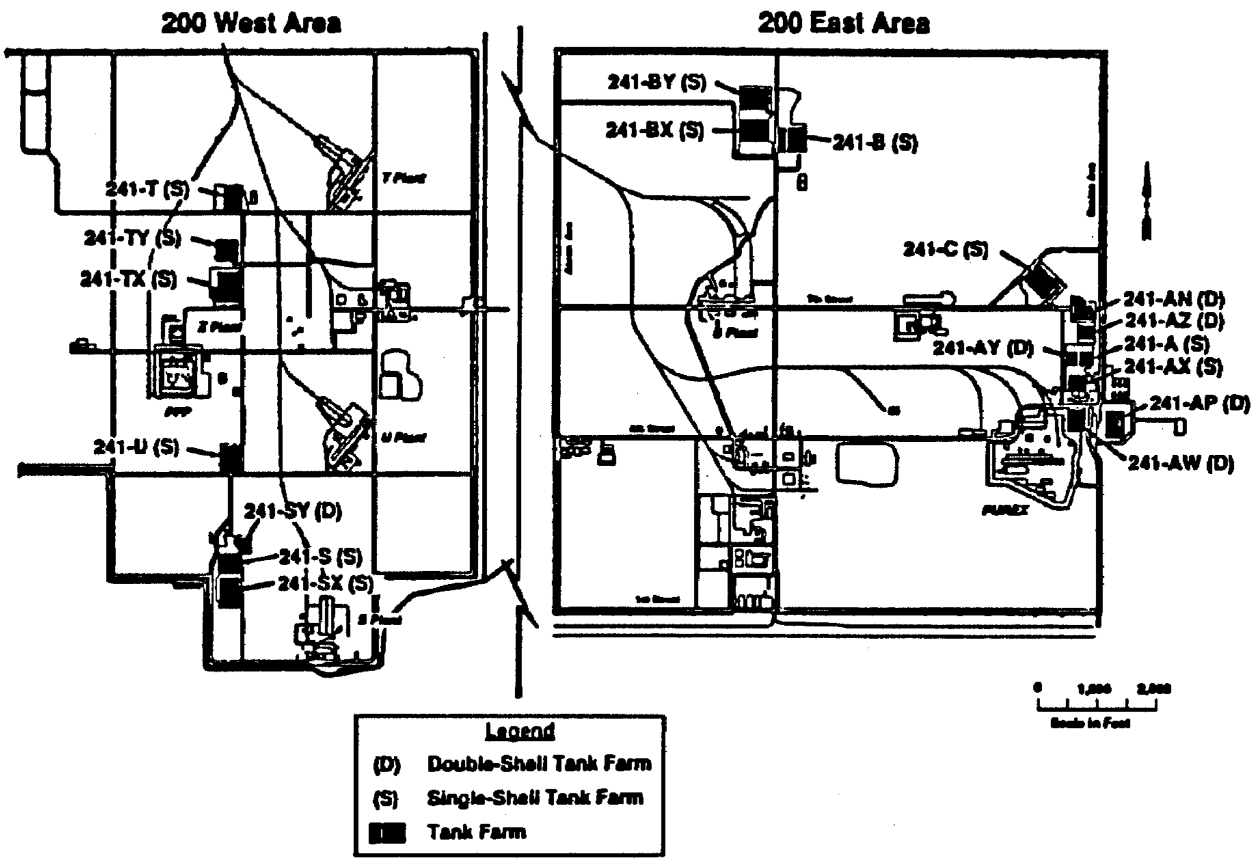


Fig. 1-1. Location of the Tank Farms within the 200 Area.

Columbia Plateau in southeastern Washington State. The Hanford Site occupies an area ~1450 km^2 (570 mi^2) north of the confluence of the Snake, Yakima, and Columbia Rivers. This land, with restricted public access, provides a buffer for the smaller areas currently used for the production of nuclear materials, waste storage, and waste disposal; only ~6% of the land area has been disturbed and is actively used. The Columbia River flows through the northern part of the Hanford Site; turning south, it forms part of the site's eastern boundary (Fig. 1-2).[10] The terrain of the central and eastern parts of the Hanford Site is relatively flat, with evidence in the central part of the Site (including the 200-Area Plateau) of minimal erosion since the deposition of Hanford Formation sediments by glacial floodwaters ~13,000 yr ago. The soil beneath the tank farm consists of silt, sand, and gravel. The principal geologic units beneath much of the 200-West Area are, in ascending order: (1) the Columbia River Basalt Group, with interbedded sediments of the Ellensburg Formation; (2) the Ringold Formation; (3) the Plio-Pleistocene unit; and (4) the Hanford Formation. The Ringold Formation is ~47.2 m (155 ft) below the surface of the SY Tank Farm.[11]

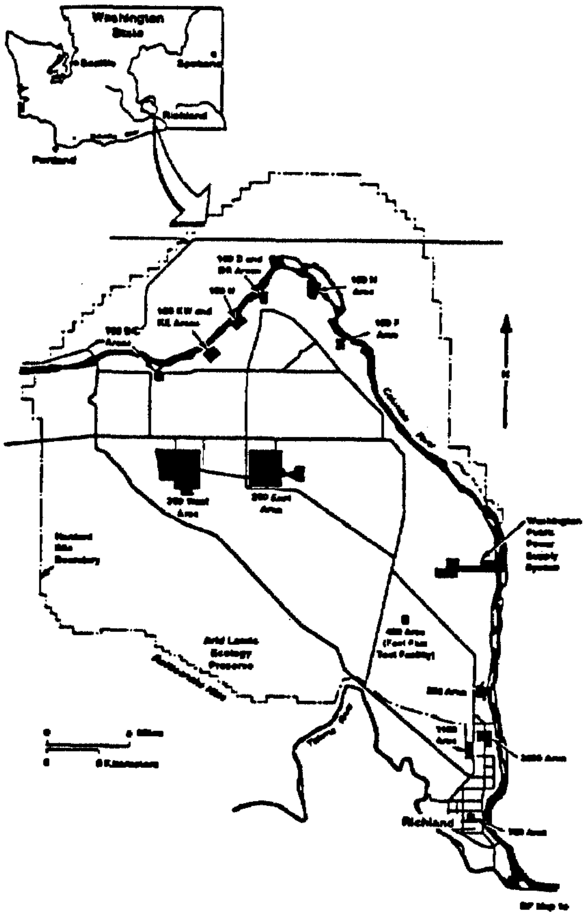


Fig. 1-2. Location of 200 Area within the Hanford Site.

Two areas of shallow, swarm seismic activity, Coyote Rapids and Cold Creek, are located within 16.1 km (10 mi) of the 200-West Area. The Coyote Rapids swarm area has been the site of 8 swarms consisting of 91 shallow seismic events during the period between 1969 and 1986. The depth distribution of these seismic events is bimodal, with maximum activity occurring near the surface and at a depth of 4.0 to 6.9 km (2.5 to 4.3 mi). The Cold Creek swarm area, located 12.9 km (8 mi) south of the 200-West Area, includes 32 events from 1979 to 1986 that occurred at depths up to 4.8 km (3 mi).

Several surface ponds and ditches associated with fuel and waste processing activities are present within the 200 Area (Fig. 1-3).[12] These ponds and ditches are used primarily as wasteways for process and cooling water and sometimes contain small quantities of radionuclides (both fission products and transuranic elements). Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern boundary of the Hanford Site. Both streams drain areas to the west of the Hanford Site and cross the southwestern part of the Site toward the Yakima River. The potential for flash flooding from the Cold Creek drainage system has been examined, and a maximum flood depth of 2.1 m (7 ft) was estimated along the southwestern part of the 200-Area plateau. However, the maximum probable flood has not been well defined for the Cold Creek drainage system. A 100-yr peak stage flood, estimated to be ~0.9 m (3 ft) above the Cold Creek Valley floor, would not reach the 200-West Area.[13]

Wastewater ponds on the Hanford Site have recharged the unconfined aquifer below the 200-Area artificially. The increase in water-table elevations was most pronounced from 1950 to 1960 and had approached equilibrium between the unconfined aquifer and the recharge between 1970 and 1980, when only small increases in water-table elevations occurred. Wastewater discharges from the 200 Area were reduced significantly in 1984 (Ref. 14), with an accompanying decline in water-table elevations. The depth to groundwater currently is ~50 to 60 m (164 to 197 ft) in the 200 Area. Groundwater flow direction is generally in an easterly and southeasterly direction, toward the Columbia River.

Lateral groundwater movement occurs within a shallow, unconfined aquifer consisting of fluvial and lacustrine sediments lying on top of the basalts and within deeper confined-to-semiconfined aquifers consisting of basalt flow tops, flow bottom cones, and sedimentary interbeds.[15] Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia Rivers. Artificial recharge to the unconfined aquifer results from the disposal of wastewater to the ground below the 200 Areas from the surrounding highlands. This recharge to the aquifer [5.5E04 m^3/d (1.5E07 gal./d)] is ~10 times the natural recharge entering the unconfined aquifer below the 200 Areas.[15] Beneath the disposal ponds, groundwater mounds have developed in response to the artificial recharge. Beneath U Pond, located in the 200-West Area, the water table rose ~24.4 m (80 ft) from the start of disposal operations in 1944

(Refs. 16 and 17) until U Pond was decommissioned in 1985. From the recharge areas to the west, the groundwater flows down the gradient to the discharge areas along the Columbia River, interrupted locally by the groundwater mounds in the 200 Areas. The horizontal and vertical extent of these mounds appears to be related directly to the surface discharge of wastewater from facilities in this area.[18]

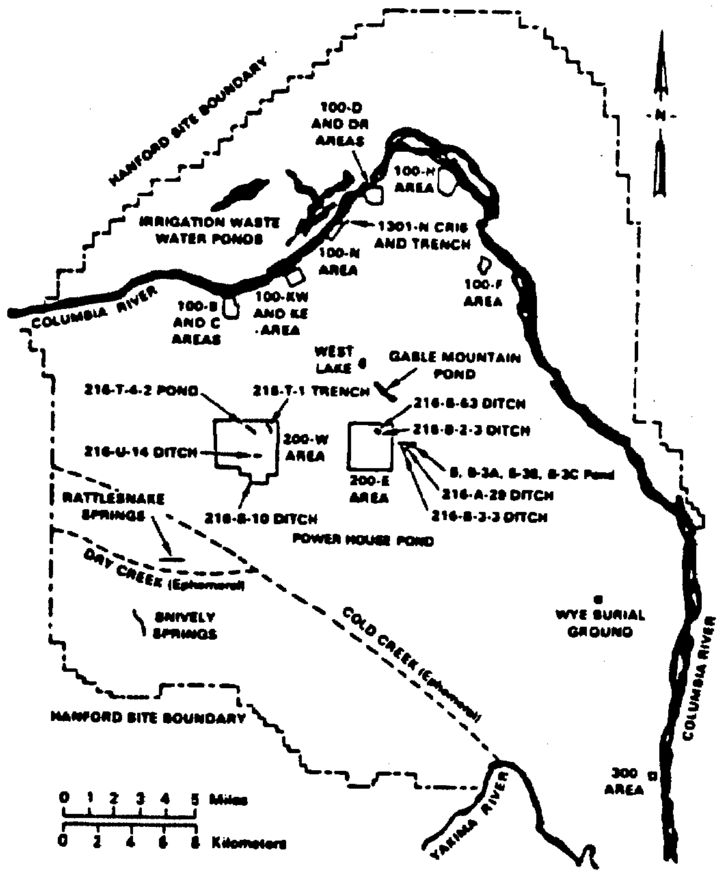


Fig. 1-3. Locations of surface-water ponds, ditches, and ephemeral streams on the Hanford Site.

Climatological data are available from the Hanford Meteorological Station (HMS), which is located between the 200-East and 200-West Areas. Data have been collected at this location since 1945. Temperature and precipitation data also are available from nearby locations for the period of 1912 through 1943. A summary of these data through 1980 has been published in Ref. 19. Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200-Area Plateau.

The prevailing winds on the 200-Area Plateau are from the northwest. Secondary maxima occur for southwesterly winds. Diurnal and monthly averages and extremes of temperature, dew point, and humidity are contained in Stone et al.[14]

Ranges of daily maximum temperatures vary from a normal 2°C (36°F) in early January to 35°C (95°F) in late July. The record maximum temperature is 46°C (115°F) and the record minimum temperature is -32.8°C (-27.0°F). Relative humidity/dew-point temperature measurements are made at the HMS and at the three 61.0-m (200-ft) monitoring tower locations. The annual average relative humidity at the HMS is 45%. It is highest during the winter months (averaging ~75%) and lowest during the summer (averaging ~35%). At the Hanford Site, the severe-weather phenomenon that occurs most frequently and has the greatest effect is the dust storm.[19] The maximum recorded peak gust at 15 m (50 ft) aboveground was 128 km/h (80 mi/h), which occurred in January 1972. A 100-yr return period peak gust of 138 km/h (86 mi/h) has been calculated at the 15-m (50-ft) elevation.

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 16 cm (6.3 in.). Most of the precipitation occurs during the winter, with nearly half of the annual amount occurring in the months of November through February. Rainfall intensities of 1.3 cm/h (0.5 in./h) and persisting for 1 h are expected once every 10 yr. Rainfall intensities of 2.5 cm/h (1.0 in./h) for 1 h are expected only once every 500 yr. The Hanford Site is not a major thunderstorm area. On average, only about 10 thunderstorm days per year are recorded at the Hanford Site, although this number has varied from a low of 3 to a high of 23 thunderstorm days per year. Thunderstorms theoretically can occur during any month of the year; however, they occur most frequently from April through September. The largest number of thunderstorm days recorded in a single month is eight, which has occurred in both June and August. Large differences in electric potential can occur during thunderstorms, which, in turn, can lead to lightning strikes. In general, ~20% of lightning strikes are cloud-to-ground/ground-to-cloud discharges. Lightning strikes in the summer have occasionally ignited range fires in the Hanford Site region. Estimates of the extreme thunderstorm winds, based on peak gusts observed from 1945 through 1980, are given in Ref. 19. Using the National Weather Service criteria for classifying a thunderstorm as "severe" [i.e., hail with a diameter ≥20 mm (0.8 in.) or wind gusts ≥93 km/h (84.8 ft/s)], only 1.9% of all thunderstorm events observed at the HMS have been "severe" storms; all met the criteria based on wind gusts.

The nearest volcano is in the Cascade Range, more than 100 km (62 mi) from the Hanford Site, and most eruption products are deposited within 50 km (31 mi) of their source. There is no evidence that volcanic lava flows, debris flows, or mudflows from the Cascade Range volcanoes reached the Pasco Basin during the Quaternary period.

Flows of lava, debris, and mud tend to be confined to existing drainage channels, and because no streams flow directly from the Cascade Range to the Hanford Site, these types of volcanic deposits are not considered likely at the 200 Area.

Tornadoes are infrequent and generally small in the northwest portion of the United States. The HMS climatological summary and the National Severe Storms

Forecast Center (NSSFC) database list 22 separate tornado occurrences within 161 km (100 mi) of the Hanford Site from 1916 through August 1982. Two additional tornadoes have been reported since August 1982.

1.5. REFERENCES

. N. J. Milliken and G. R. Geschke "Safety Analysis for Push-Mode and Rotary-Mode Core Sampling," Westinghouse Hanford Company report, WHC-SD-WM-SARR-031, Rev. 2 (July 1995).

2. Westinghouse Hanford Company, "Safety Analysis Manual," Westinghouse Hanford Company report WHC-CM-4-46 Rev. 4 (September 30, 1995).

3. Westinghouse Hanford Company, "Interim Guidance for Preparing Safety Assessments," in *Safety Analysis and Engineering Manual: Work Procedures*, Westinghouse Hanford Company report WHC-CM-6-32, Rev. 1 (November 1992).

4. US Department of Energy, "Guidance for Preparation of DOE 5480.22 (TSR) and DOE 5480.23 (SAR) Implementation Plans," DOE Standard 3011-94 (November 1994).

5. H. R. Brager, "Summary of Information on Flammable Gas Watch List Tanks," Westinghouse Hanford Company report WHC-EP-0711 (January 1994).

6. Westinghouse Hanford Company, "Hanford Site Tank Farm Facilities Interim Safety Basis," WHC-SD-WM-ISB-001, Rev. 0, Vol. 1 (August 1993).

7. US Energy Research and Development Administration, "Final Environmental Impact Statement of Waste Management Operations, Hanford Reservation, Richland, Washington," US Energy Research and Development Administration report ERDA-1538, 2 vols. (1975).

8. US Department of Energy, "Draft Environmental Assessment, Reference Repository Location, Hanford Site, Washington," US Department of Energy report DOE/RW-0017 (1984).

9. Pacific Northwest Laboratory, "Hanford Site National Environmental Policy Act (NEPA) Characterization," Pacific Northwest Laboratory report PNL-6451 (1990).

10. M. Gerber, "Legend and Legacy: Fifty Years of Defense Production at the Hanford Site," Westinghouse Hanford Company report WHC-MR-0293, Rev. 1 (1992).

11. "Investigation to Determine Dynamic Soil Properties at the 241-SY-Tank Site," URS/John A. Blume & Associates, Atlantic Richfield Hanford Company (1974).

12. "Environmental Impact Statement, Disposal of Hanford High-Level and Transuranic and Tank Wastes, Hanford Site, Richland, Washington," US Department of Energy report DOE/EIS-0113, Vol. 1-III (1987).

13. R. L. Skaggs and W. H. Walters, "Flood Risk Analysis of Cold Creek near the Hanford Site," Pacific Northwest Laboratory for Rockwell Hanford Operations report RHO-BWI-C-120 (PNL-4219) (1981).

14. W. A. Stone, J. M. Thorp, O. P. Gifford, and D. J. Hoitink, "Climatological Summary for the Hanford Area," Pacific Northwest Laboratory report PNL-4622 (1983).

15. US Department of Energy, "Consultation Draft: Site Characterization Plan, Reference Repository Location, Hanford Site, Washington," US Department of Energy report DOE/RW-0164, Vol. 2 of 9 (1988).

16. C. C. Meinhardt and J. C. Frostenson, "Current Status of 200 Area Ponds," Rockwell Hanford Operations report RHO-CK-798 (1979).

17. J. D. Jamison, "Standardized Input for Hanford Environmental Impact Statements Part II: Site Descriptions," Pacific Northwest Laboratory report PNL-3509, Part 2 (1982).

18. D. A. Zimmerman, A. E. Reisenauer, G. D. Black, and M. A. Young, "Hanford Site Water Table Changes 1950 through 1980—Data Observations and Evaluation," Pacific Northwest Laboratory report PNL-5506 (1986).

19. D. I. Herborn et al., "Hanford Waste Vitrification Plant Preliminary Safety Analysis Report," Westinghouse Hanford Company report WHC-EP-0250 (1991).

2.0 DESCRIPTION OF ACTION

This section presents the detailed descriptions required to evaluate the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations. The safety of RMCS operations in flammable gas tanks has been questioned because of the potential to induce a spark within the flammable environment of the tanks. The descriptions reflect an understanding of the FG/RMCS equipment and processes at the time of the safety assessment (SA) and are provided for the information of the reader only.

This section details the safety criteria surrounding tanks on the FGWL and tanks recommended by the contractor for inclusion on the FGWL, collectively to referred to as FGTs, the gas and ignition phenomenology anticipated during sampling operations in these tanks, and descriptions of the tanks and their characteristics. Descriptions of the equipment and systems required for rotary-mode core sampling follow, along with a summary of the drilling operations under normal, and certain abnormal conditions.

Because tank characterization and sampling are of the highest priority at Hanford as stated in Public Law 101-510, Section 3137, "Safety Measures for Waste Tanks at Hanford Nuclear Reservation," (1990), a suite of sampling methods have been incorporated into characterization and stabilization strategies, including grab sampling, vapor sampling, auger operations, and push-mode sampling. However, rotary-mode core sampling is used for obtaining full-depth core samples in tanks with salt cake waste.

Rotary-mode sampling operations and procedures are similar to push-mode sampling techniques with several differences: the drill bit differs, a nitrogen purge system is activated to cool the drill bit as it rotates, and an exhauster is used to compensate for the nitrogen purge flow and aerosol introduced into the tank dome. In general, a sampling truck capable of rotary-mode sampling, a nitrogen supply system, an exhauster, and a variety of support equipment is set up on or near the tank. The sampling truck is located at the appropriate riser, and the drill string with a universal sampler is inserted into the tank. With the nitrogen purge and exhauster systems activated, the rotary drilling collects a cylindrical waste sample that is withdrawn from the tank, transferred in a shielded receiver to a mobile X-ray system for preliminary examination, then transferred into a cask for transport to the analytical laboratories for full characterization. The drilling/sampling sequence is repeated until a set of samples representing a full-depth core is acquired.

Specific design features and assumptions, provided in Section 6, shall be used to assess the extent to which changes or modifications alter the functions or operational characteristics of the FG/RMCS processes, systems, or components. The Department of Energy (DOE) Order 5480.21, Unreviewed Safety Questions (USQs) process shall be used to assess which SA results could be altered or negated by said changes or modifications, and to what extent SA revisions could be required.

2.1. PRINCIPAL SAFETY CRITERIA

Safety criteria for this section include a consideration of DOE Orders, existing Westinghouse Hanford Company (WHC) documents and procedures, and the more specific criteria associated with FGWL tanks. Because several of the tanks on the FGWL are also on the Organic Watch List, the organic criteria are also provided.

2.1.1. DOE Safety and Design Requirements

The DOE Orders cited in TABLE 2-1, are presently applicable to the design of the rotary-mode core sampling equipment. They are helpful in developing the criteria outlined in Sections 2.1.2, 2.1.3, 2.1.4 and 2.2. The risk criteria are given in Section 5 of this SA.

TABLE 2-1
RELEVANT DOE ORDERS

DOE Order	Title
DOE Order 1540.2	"Hazardous Material Packaging"
DOE Order 4330.4A	"Maintenance Management Program"
DOE Order 5000.3B	"Occurrence Reporting and Processing of Operations Information"
DOE Order 5400.1	"General Environmental Protection Program"
DOE Order 5400.5	"Radiation Protection of the Public and the Environment"
DOE Order 5480.4	"Environmental Protection, Safety, and Health Protection Standards"
DOE Order 5480.5	"Safety of Nuclear Facilities"
DOE Order 5480.7	"Fire Protection"
DOE Order 5480.10	"Contractor Industrial Hygiene Program"
DOE Order 5480.11	"Radiation Protection for Occupational Workers"
DOE Order 5480.19	"Conduct of Operations Requirements for DOE Facilities"
DOE Order 5480.20	"Personnel Selection, Qualification, Training, and Staffing Requirements at DOE Reactor and Non-Reactor Nuclear Facilities"
DOE Order 5480.21	"Unreviewed Safety Questions"
DOE Order 5480.22	"Technical Safety Requirements"
DOE Order 5480.23	"Nuclear Safety Analysis Report"
DOE Order 5480.31	"Start-up and Re-start of Nuclear Facilities"
DOE Order 5483.1A	"Occupational Safety and Health Program for DOE Contractor Employees at Government Owned Contractor Operated Facilities"
DOE Order 5500.2B	"Emergency Categories, Classes and Notification and Reporting Requirements"
DOE Order 5500.3A	"Planning and Preparedness for Operational Emergencies"
DOE Order 5700.6C	"Quality Assurance"
DOE Order 5820.2A	"Radioactive Waste Management"
DOE Order 6430.1A	"General Design Criteria"

2.1.2. WHC General Safety Criteria

WHC standard controls include a series of WHC documents that define the safety envelope for the tank farm. The primary documents include the following:

- "Tank Farm Health and Safety Plan,"[1]
- "Hanford Site Tank Farm Facilities Interim Safety Basis."[2]

Other pertinent WHC documents are referenced as necessary throughout the SA.

2.1.3. Safety Criteria for Tanks on the FGWL

Initially, Hanford tanks were identified for inclusion on the FGWL by qualitatively considering the following:[3]

- The presence of specific types of waste in the tank,
- The presence of a high radiation field in the tank,
- Observation of certain gaseous components in the dome space,
- Observation of pattern changes in the surface level,
- Observation of periodic pressure surges in the dome space, and
- Observations of the axial temperature profiles in the waste.

There are currently 19 SSTs on the FGWL with flammable gas concentrations that can exceed 25% LFL in the dome of a full tank with a decay heat generation of 30,000 Btu/h. They were placed on the watch list more for the *potential* of containing flammable gas rather than the verified presence of hazardous concentrations.

Further details of these criteria are provided in Ref. 3. Currently, there are 25 tanks on the FGWL; 19 of these tanks are single-shell tanks. These tanks are:

A-101	S-102	SX-101	U-103
	S-111	SX-102	U-105
AX-101	S-112	SX-103	U-107
AX-103		SX-104	U-108
	T-110	SX-105	U-109
		SX-106	
		SX-109	

The hydrogen SSTs were placed on the watch list mainly because waste level increases were observed without liquid addition. That is, slurry growth acted as the main criterion for watch list designation. There was concern that the growth of slurry could indicate a situation similar to that experienced with Tank 101-SY, even though the available data indicate total growth values as opposed to episodic-type behavior.

Alternate criteria for tanks included having a surface crust, having a total organic compound (TOC) level >3g/L, or containing B-Plant waste. The B-Plant wastes are organic-bearing wastes generated from the B-Plant fractionation process, primarily during strontium recovery. The compounds making up the organic fractions are complexing/chelating agents or their degradation products.

Recently, a new methodology was developed to identify tanks that may be candidates for inclusion on the FGWL. The new method involves evaluating the waste surface level changes in response to changes in barometric pressure.[4] By applying this criterion, a number of additional tanks were identified as candidates for potential storage of flammable gases. These tanks are

A-103	BY-101	C-104	S-101	TX-102	U-102
	BY-102	C-107	S-103	TX-111	U-106
B-111	BY-105		S-104	TX-112	U-110
B-201	BY-106	T-201	S-105	TX-113	U-111
B-202	BY-109	T-102	S-106	TX-115	
		T-203	S-107	TX-116	
BX-107		T-204	S-109	TX-117	

Hereafter, these 34 tanks along with the original 19 FGWL single-shell tanks are referred to as the flammable-gas tanks (FGTs). Presently, the total number of single-shell FGTs is 53.

2.1.4. Safety Criteria for Tanks on the Organic Watch List

Levels of safety for tanks on the Organic Watch List are addressed in Ref. 5. The safety criteria are based on a set of tests in which dry sodium acetate nitrate/nitrite mixtures exhibited propagating behavior at about 300°C (572°F) with a TOC value greater than 6 wt%. Appendix G evaluates this criteria in detail for each SST.

2.2. PHENOMENOLOGY

Gas phenomena include considerations of gas storage and release mechanisms, gas composition, waste characteristics, and flammability and ignition.

2.2.1. Gas Storage and Release Mechanisms in SSTs

The model and data available that describe gas storage and release mechanisms are discussed in Appendix L. The conclusion is that large and prompt releases are not likely in single shell tanks.

The 19 single-shell tanks on the FGWL were separated by Los Alamos National Laboratory (LANL) in 1994[6] into the following four gas-release categories:

1. Tanks that do not experience episodic behavior nor exhibit long-term growth in the waste level,

2. Tanks for which not enough data are available to evaluate the behavior,

3. Tanks that potentially exhibit episodic gas-release behavior*, and

4. Tanks that exhibit long-term waste growth but do not exhibit episodic gas-release behavior.

*There is only one SST in this category (A-101), and there is no data to suggest that SST exhibit episodic release. However, episodic behavior occurrences are addressed in Appendix L.

TABLE 2-2 provides selected data pertaining to the SSTs on the FGWL, including the designated gas-release category. A similar analysis for all the FGTs currently is not available. TABLE 2-2 also notes which tanks are on the Organic Watch List.

2.2.2. Gas Composition

The gas-concentration measurements in the SST dome space are very scarce compared to some of the double-shell tanks (DSTs) (e.g., Tank 101-SY). The available data obtained from the vapor grab samples are analyzed in Appendix C of this SA. As shown in Appendix C, hydrogen, nitrous oxide, ammonia and methane are detected at varying concentrations in the dome space of the FGTs.

TABLE 2-2
GAS DATA FOR SSTS ON THE FGWL

Tank	FGWL	Organic Watch List	Vapor Space Volume, m^3	Gas-release Category
A-101	•	•	1,454	3
AX-101	•		2,481	2
AX-103	•		4,892	1
S-102	•	•	1,955	4
S-111	•	•	916	1
S-112	•		760	1
SX-101	•		3,283	2
SX-102	•		2,953	2
SX-103	•	•	2,540	1
SX-104	•		2,593	2
SX-105	•		2,422	2
SX-106	•	•	2,972	1
SX-109	•		4,064	1
T-110	•		1,738	4
U-103	•	•	1,433	4
U-105	•	•	1,590	4
U-107	•	•	1,636	4
U-108	•		1,401	4
U-109	•		1,420	4

2.2.3. Waste Characteristics

Sludge and salt cake are generally the two forms of waste in SSTs of concern, although supernatant liquid also exists in some tanks. Sludge results from the precipitates formed during the neutralization of chemical separation wastes and is composed principally of hydrous metal oxides. Salt cake results from actual dewatering by pumping and from thermal evaporation of aged chemical and miscellaneous wastes. For SSTs that contain both types of solids, the salt cake layer is typically on top of the sludge layer. Liquid is present in SSTs as supernatant and/or as interstitial liquid existing in the void spaces of the solid wastes. Data on waste type and volume are provided in TABLE 2-3 for information purposes only.

The waste types found in the SSTs on the FGWL are of four types: concentrated complexant; dilute complexed (DC) waste; double-shell slurry feed; and noncomplexed waste. Concentrated complexant (CC) is a concentrated product from the evaporation of dilute complexed waste. DC waste is characterized by a high content of organic carbon, including organic complexants. Ethylenediaminetetra-acetic acid (EDTA), citric acid, and hydroxyethyl-ethylenediaminetriacetic acid (HEDTA) are the major complexants used. The main sources of DC waste are the salt well liquid inventory from the SSTs. Double-shell slurry feed (DSSF) is waste concentrated just before reaching the sodium aluminate saturation boundary (of 6.5 molar hydroxide) in the evaporator without exceeding receiver tank composition limits. Noncomplexed waste (NCPLX) is a general waste term applied to all Hanford Site liquors not identified as complexed.

TABLE 2-3
WASTE INFORMATION FOR FGWL SSTs

Tank	Waste Type	Total Waste Vol, Kgal	Super-natant Vol, Kgal	Sludge Vol, Kgal	Salt cake Vol, Kgal	Waste Temp, °F	Waste Depth, In.
A-101	DSSF	953	0	3	950	154	354
AX-101	DSSF	748	0	3	745	136	279
AX-103	CC	112	0	2	110	111	48
S-102	DSSF	549	0	4	545	107	207
S-111	NCPLX	596	10	139	447	92	224
S-112	NCPLX	523	0	5	518	83	239
SX-101	DC	456	1	112	343	138	173
SX-102	DSSF	543	0	117	426	151	206
SX-103	NCPLX	652	1	115	536	174	245
SX-104	DSSF	614	0	136	478	167	231
SX-105	DSSF	683	0	73	610	180	256
SX-106	NCPLX	538	61	12	465	111	203
SX-109	NCPLX	250	0	0	250	148	98
T-110	NCPLX	379	3	376	376	63	145
U-103	NCPLX	468	13	32	423	87	178
U-105	NCPLX	418	37	32	349	89	159
U-107	DSSF	406	31	5	360	78	155
U-108	NCPLX	468	24	29	415	88	178
U-109	NCPLX	463	19	48	396	86	176

2.2.4. Flammability and Ignition

Flammability issues are highlighted by two aspects in tanks with a flammable environment, the broad flammability range of hydrogen in air (4% to 75%) and the low energy required for ignition (0.01 mJ). The ignition hazard is increased because nitrous oxide is a strong oxidant and is cogenerated with the hydrogen in amounts that place the gas mixture well within the flammability range before mixing with air. Burning hydrogen releases a relatively large amount of energy. The heat of combustion is 57.8 and 77.3 kcal/g-mol of hydrogen for oxygen and nitrous oxide reactions, respectively. Ammonia has a flammability range in air of 15% to 30%, and the heat of combustion with oxygen is 75.8 kcal/g-mol NH_3 (25°C).

Secondary exothermic reactions in the waste surface crust can also be induced by a hydrogen burn. The surface crust usually contains an oxidant, such as a mixture of sodium nitrate and sodium nitrite, in which various amounts of organic carbon are well mixed.

The presence of flammable gases and the release of chemical energy are compounded by the presence of radioactive waste, thereby increasing the potential consequences of a release. Toxic gases, especially ammonia, are known to be associated with the waste and may have the greatest potential for release during an episodic event.

2.3. FLAMMABLE-GAS TANKS

The 53 FGTs are spread over 11 of the 12 single-shell tank farms: A, AX, B, BX, BY, C, S, SX, T, TX and U. The cylindrical, dome-roofed tanks[8] are constructed of reinforced concrete with a structurally independent mild carbon-steel liner covering the bottom and sidewalls. Each tank is buried with a minimum of 6.5 ft of earth for shielding and heat dissipation from radioactive decay. The tanks were designed to hold approximately 15 to 30 ft of liquid, with a nominal capacity of 530,000, 758,0000, and 1,0000,000 gallons. Of the three possible tank configurations, the 1,000,000-gal.-capacity tank used in Farms A, AX, and SX is schematically shown in Fig. 2-1. The other tank configurations are similar to those given in Fig. 2-1. The BY-, TX- and S-Tank Farm has tanks with 758,000-gal. capacity, but tanks in Farms B, BX, C, T and U have a capacity of 530,000 gallons.

A typical single-shell tank has numerous vertical pipes called risers that penetrate the tank dome and extend to various depths of the tank. The dome risers, which vary in diameter from 4, 12, or 42 in., provide access to the tank interior for a variety of operating and monitoring equipment, such as the breather inlet, a camera observation point, the center pump pit, a dome elevation bench mark, a solids level detector, a liquid observation well, a surface level probe, the temperature thermocouple assembly, and a leak detection drywell.

Most SSTs use a passive form of ventilation[2] that allows airflow through the tanks to be dictated by atmospheric conditions such as temperature and atmospheric pressure. The system, called the breather inlet, minimizes the pressure changes that could damage the tank structure if the tanks were completely sealed. Each breather filter is mounted on a tank riser, and consists of a housing containing a HEPA (high efficiency particulate air) filter, an outlet screen, and a small seal loop that acts as a pressure relief should the filter become plugged. An isolation valve, which is normally open, allows flow between the tank vapor space and the environment through the filter. The flow moves horizontally through the 12 in. x 12 in. filter, and then vertically through the downward-facing exit weather hood. During F(MCS operations, the breather inlet will be fitted with a portable, sealable, 15-ft ta. -in.-diameter stack to control the direction of gases exiting the tank.

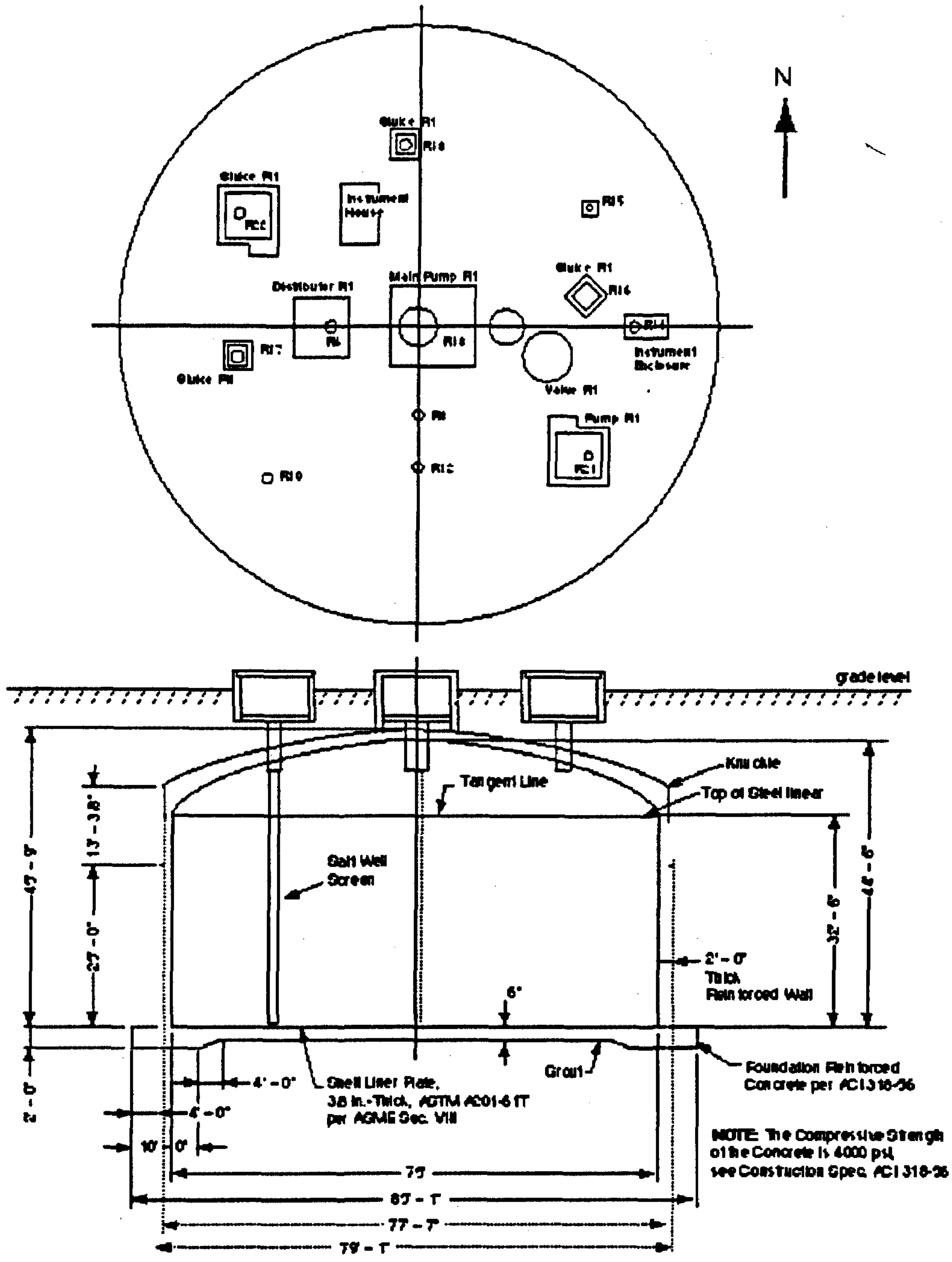


Fig. 2-1. Typical A-Farm SST cross section.

2.4. RMCS SYSTEM AND ASSOCIATED EQUIPMENT

The system required for retrieving waste samples in the rotary-mode consists of the sampling truck, the portable exhauster, the N_2 supply system, the generator, and associated equipment. Primary components associated with the sampling truck include the grapple hoist assembly, the shielded receiver (SR) with remote latch unit (RLU), the drill string (DS), the nitrogen purge system, and the change-out assembly.[9, 11, 12] Associated equipment includes the X-ray machine, cask stand and truck, power distribution trailer, and support vehicles.

Functional criteria for the FG/RMCS are found in Ref. 13. Several critical elements of the former document include the following:

- Equipment with energized circuits that can come in contact with waste degradation gases before dilution by the tank vapor space or other gases shall be protected in accordance with National Fire Protection Association (NFPA) for use in Class I, Division 1, Group B for a flammable hydrogen atmosphere. Protection may be in the form of intrinsically safe electrical components, purging in accordance with NFPA Article 496, or other acceptable method as defined by the requirements of the National Electric Code (NEC) Article 501, for use in flammable hydrogen atmospheres.

- Equipment where energized circuits have the potential, under abnormal conditions, to come in contact with waste degradation gases before dilution by the tank vapor space or other gases shall be protected in accordance with NFPA for use in Class I, Division 2, Group B for a flammable hydrogen atmosphere. Protection may be in the form of intrinsically safe electrical components, purging in accordance with NFPA Article 496, or other acceptable method as defined by the requirements of NEC Article 501, for use in flammable hydrogen atmospheres.

2.4.1. RMCS Trucks

Three RMCS trucks provide mobility to position and move the core sampling equipment from tank to tank. Fig. 2-2, derived from Ref. 15 shows the general arrangement of equipment on the rotary platform that is mounted on the rear of each of the three sampling trucks. The rotating platform supports and positions core sampling equipment, including the platform hoist, the grapple hoist assembly, the drill rig and drill string, and the shielded receiver over the tank riser to be sampled. Five stationary hydraulic jacks act as outriggers to level the truck for drilling operations.

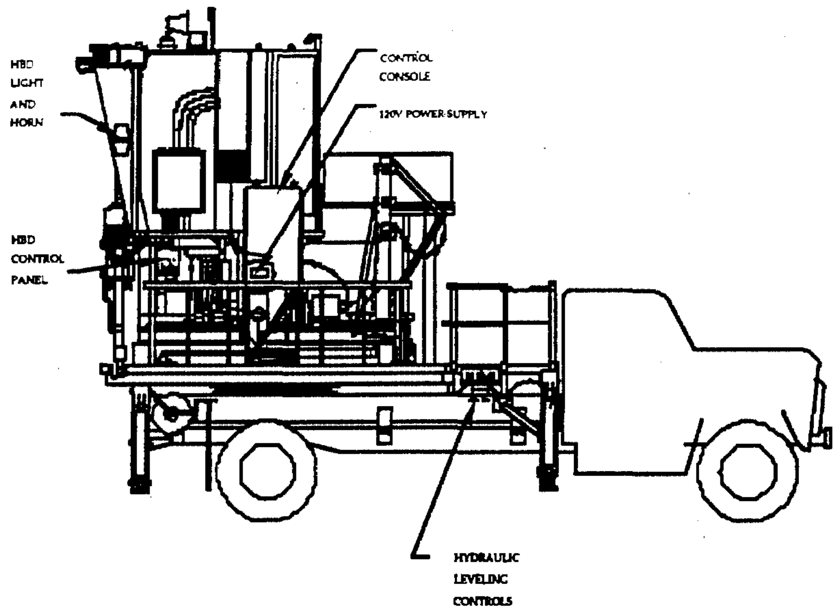


Fig. 2-2. Sampling truck configuration.

Two of the three trucks have diesel engines, while the third truck has a gasoline engine. All drill engines are gasoline fueled.

2.4.1.1. Platform Hoist

The electric platform hoist is located on the rotating platform between the grapple hoist assembly and the shielded receiver assembly. With a capacity of 500 lb, it provides an on-site method to handle riser adapter equipment, insert and remove drill rods, and position the cask stand.

2.4.1.2. Grapple Hoist Assembly

The grapple hoist assembly, shown in Fig. 2-3 consists of an electric motor-driven hoist contained in a pressurized box, the electric motor (external to the pressure vessel), and a grapple connected to the hoist cable. The grapple hoist assembly controls the sampler piston movement.

Grapple Hoist and Box. The grapple hoist box, Ref. 16, houses the grapple cable, cable reel, and a load cell. The grapple box and the pneumatic piping connecting it to the purge gas enclosure provide containment of drill purge gases.

The hoist is used to lower the grapple into the drill string after a sampler has been installed. The 3/4 hp grapple motor lowers the cable at a maximum speed of 58 ft/min, and employs a cable with a breaking strength of 2400 lb. A load cell attached to the cable tension assembly is designed to shut off the motor if the load equals or exceeds 250 lb. Roll pins on the hoist shaft are designed to shear before the hoist motor can exceed the structural capability of the hoist shaft.

Inner and Outer Bellows Assembly. The inner and outer bellows assembly,[17] also shown in Fig. 2-3, provides a collapsible pressure boundary between the grapple box and the quill rod for containment of purge gas.

Grapple. The grapple (sample actuator), Ref. 18, is a spring-loaded device, schematically represented in Fig. 2-4 that is lowered to connect with the pintle rod of the sampler and holds the sampler piston in position while a sample is being taken.

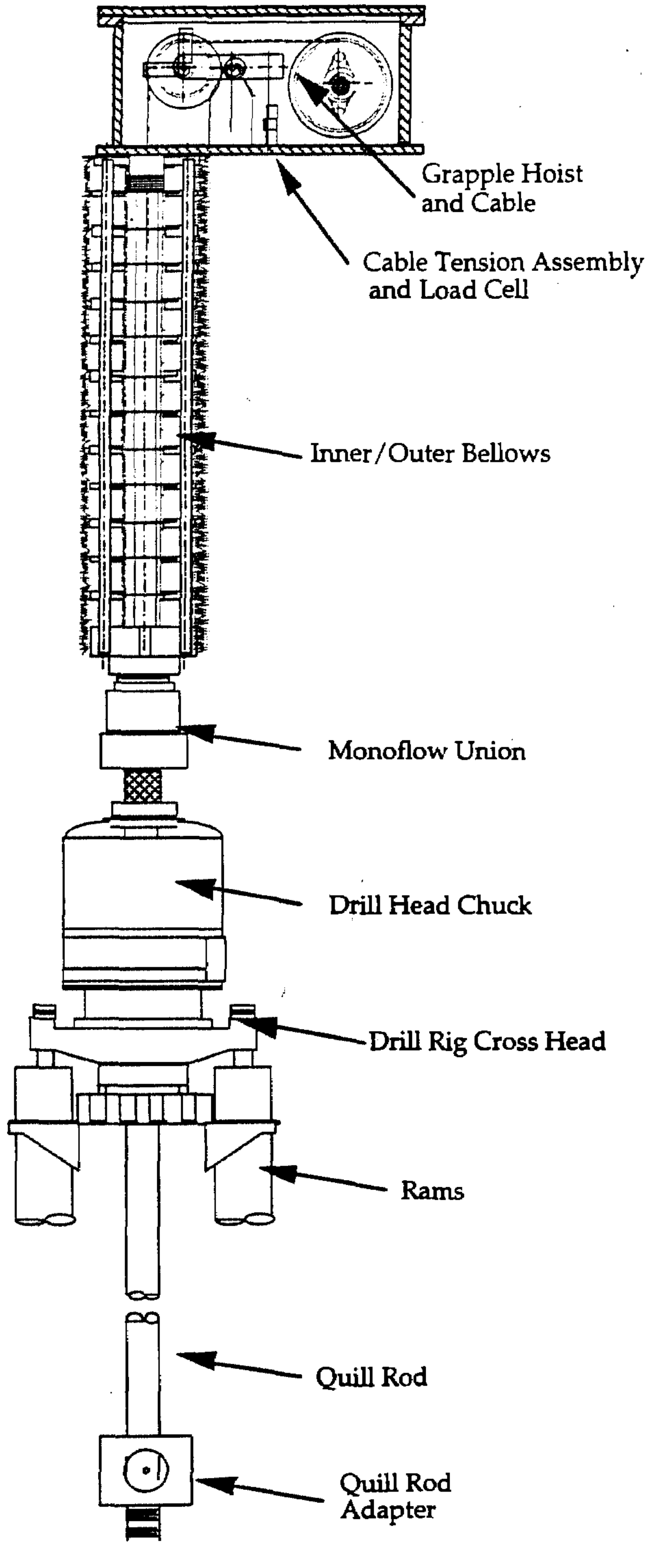


Fig. 2-3. Grapple hoist assembly.

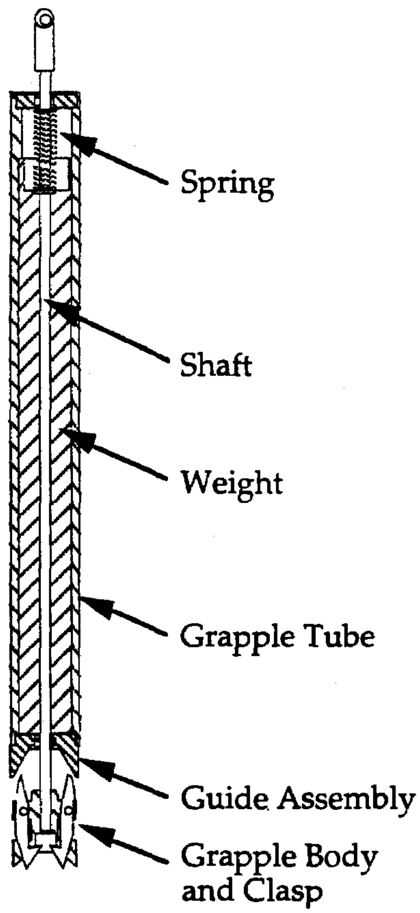


Fig. 2-4. Grapple Schematic.

2.4.1.3. Drill Unit and Quill Rod

The drill unit is composed of the drill rig, the drill head, and a hydraulic chuck that clamps to the quill rod.

Drill Rig. The drill rig engine provides energy through the drill head for drill rotation and through the hydraulic rams for down force to the quill rod, which in turn transfers these motions to the drill string. The drill head raises and lowers the quill rod, and a hydraulically operated chuck clamps the quill rod in place. Manual hydraulic controls are provided for quill rod and shielded receiver positioning.

Quill Rod. The quill rod, Ref. 19, which transfers power to the drill string, is the topmost rod of the drill string. This unit remains in the drill head and transmits power through the hydraulic chuck.

Quill Rod Adapter. The stainless-steel quill rod adapter, Ref. 19, is attached at the bottom of the quill rod and is a 6-in. section with the same diameter as the quill rod. The adapter has a quick connection feature that allows for the addition of water to wash the drill bit. The adapter connection feature is also used for flammable-gas sniffing.

2.4.1.4. Drill String Assembly

The drill string assembly, Ref. 20, is comprised of the drill bit and core barrel assembly, mated to multiple interconnected drill rods.

Drill Bit. The drill bit rotationally bores into the waste to produce a nominal 1-in.-diameter core sample, and acts as the leading tip of the drill string. The bit has a hollow-cored center section surrounded by cutting teeth and holes on the drilling surface for nitrogen purge flow. The commercially available unit (nominally 2.5-in. o.d.) is made of copper-based (sintered bronze) material with teeth designed to "smear" when they come into contact with the bottom of the tank to prevent penetration. Appendices T and F address the safety concerns in regard to material properties.

Core Barrel. The core barrel, when screwed onto the drill bit, forms an assembly that houses the universal sampler. The fluted core barrel with drill bit is 40 in. long with a 2.25-in. o.d (an effective 2.5 o.d. with 1/8-in. flutes). It also is a commercially available unit made of nickel-plated carbon steel. The serrated edges, or grooves, are machined into the inside of the core barrel so that the quadralatch fingers can slide over them easily in one direction (toward the drill bit) but cannot normally slide past in the opposite direction (away from the drill bit). The section of the core barrel containing the serrated edges is made of 304 stainless steel.

Drill Rods. The drill string is comprised of drill rods that are sections of thin-walled pipe that when mated together transmit power between the quill rod and the drill bit/core barrel assembly. The commercially available drill rods used in the waste have a 2.25-in. o.d and 1.91-in. i.d., with a spirally-wound, fluted ribbing (approximately 1/4 pitch) on the nickel-coated exterior surface to remove drill debris; drill rods above the waste surface may be unfluted. Each drill rod has an internally threaded (female) end and an externally threaded (male) end, and is available in 19-in., 60-in., 24-in., 12-in. and 6-in. lengths. The drill string is constructed of rods until the drill bit is just above the waste surface. At that point, only 19-in. rods are attached to the top of the drill string, consistent with drilling 19-in. core samples of waste.

Drill String. The drill string transmits power from the quill rod to the drill bit and core barrel assembly and consists of the drill bit/core barrel assembly and multiple sections of drill rod screwed together. The drill string provides containment for purge and hydrostatic head gases. The total length of the drill string is generally calculated by determining the distance between the bottom of the tank and the bottom of the quill rod on the leveled truck. The equivalent number of differently-sized rods is calculated using the drill string calculation sheet.

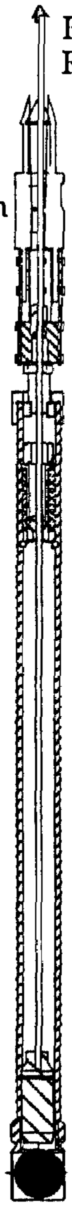


Fig. 2-5. Universal sampler.

2.4.1.5. Universal Sampler

The universal sampler, Ref. 21, is a mechanical device that is used to collect and retain the waste sample. After drilling, the sampler is transferred from the drill string to the shielded receiver, then to a cask for shipment to the analytical laboratory. The universal sampler, as depicted in Fig. 2-5, consists of the quadralatch, the pintle rod, a piston, bearings, seal, and a rotary valve. Latched in the core barrel assembly, the sampler provides a seal to prevent waste from entering the drill string.

Quadralatch. The stainless-steel sampler quadralatch latches the sampler into the core barrel grooves. Subsequently, the remote latch unit in the shielded receiver locks onto the quadralatch fingers and disengages the quadralatch mechanism from the core barrel's internal bore, thus providing a method for retrieving the sampler.

Pintle Rod. The pintle rod attaches to the piston in the sampler and holds the piston in place during sampling when the grapple is attached. A pin on the pintle rod trips the trigger mechanism to close the rotary valve. The grapple removes the pintle rod by releasing a spring clip connecting the rod to the piston.

Seal. A chevron seal is used to prevent the flow of waste into the drill string when hydrostatic pressure is not present.

Rotary Valve. The rotary valve is located at the bottom of the sampler and is rotated closed after completing the sampling of a 19-in. segment of waste. The sample is sealed inside the sampler when the valve is closed by actuating a spring-loaded trigger mechanism as the pintle rod is separated from the piston during the sampling operation.

2.4.1.6. Shielded Receiver Assembly

The SR assembly, Ref. 22, is schematically represented in Fig. 2-6, and consists of the weatherproof cover, sampler hoist box with an enclosed winch system, the shielded receiver tube, the RLU that is attached to the sampler hoist cable, and an isolation ball valve attached to the bottom end of the SR tube. The shielded receiver design is independent of the core sampling mode and provides interim sampler shielding. A power winch internal to the weatherproof covering, a cable, and a reel internal to the sampler hoist box are used to retrieve the sampler from the drill string, and to deposit the sampler in the transfer cask. The SR assembly is also used to remove a clean sampler from the transfer cask and transfer it to the drill string for the next sampling operation. The receiver valves, receiver tube, pressure vessel, and pneumatic piping connecting the shielded receiver to the purge gas enclosure provide containment for hydrostatic head gases. The receiver has a load cell to detect cable tension and slack cable, and has a decontamination spray wash. A mechanical counter and digital encoder are used to determine the depth of the RLU and are attached to the cable reel shaft inside the weather cover.

Sampler Hoist. The 1.5 hp sampler hoist motor, Ref. 23, raises and lowers the cable at a maximum speed of 23 ft/min, and employs a cable with a breaking strength of 3000 lb. A load cell shuts off the motor at a maximum load of 300 lb.

Shielded Receiver Tube. The SR tube, Ref. 24, provides shielding for personnel, thereby reducing radiation exposure, and aids in transferring and depositing samplers into the transfer casks.

Remote Latch Unit. The RLU, Ref. 25, is a mechanical latching device that provides a mechanism for latching onto and releasing the sampler. The configuration shown in Fig. 2-7 schematically represents the most recent design, as provided by WHC personnel in December 1995. The RLU is raised and lowered by the sampler hoist assembly.

Ball Valve. The 3-in. ball valve at the bottom of the shielded receiver tube, Ref. 26, isolates the shielded receiver from the surrounding environment and has a male Kamlok® interface.

Kamlok® adapter assemblies. The Kamlok® adapter assembly, Ref. 27, is a commercially available, two-part, male/female assembly that provides rapid, manually actuated connect and disconnect capabilities. In general, the male

Kamlok® adapter is connected to the female Kamlok® adapter. The design convention was established so that movable components, like the shielded receiver, have a male Kamlok® adapter, and the stationary components that are connected to the shielded receiver, such as the change-out assembly, X-ray system, and cask system, have female Kamlok® adapters.

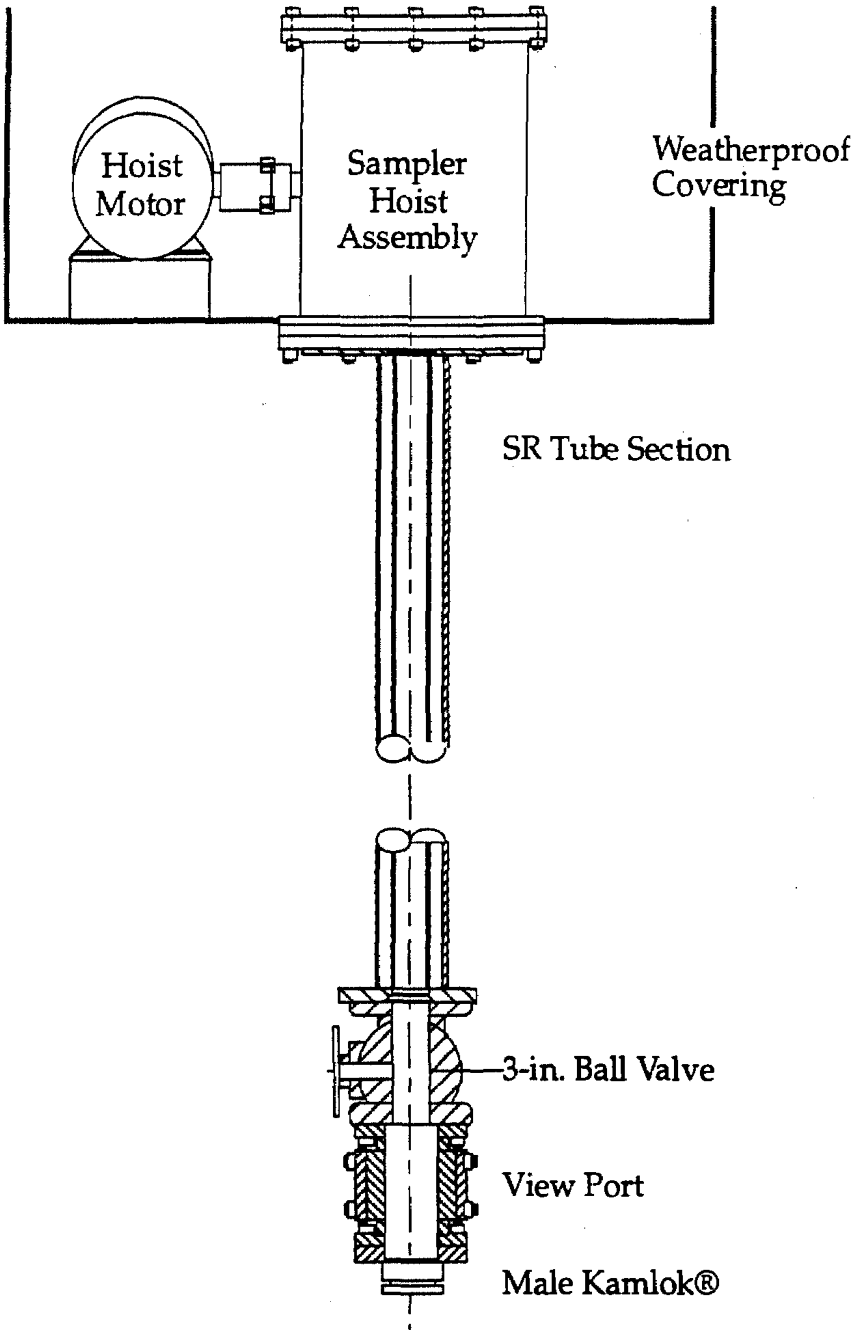


Fig. 2-6. Shielded receiver assembly.

2.4.1.7. Purge Gas Enclosure Assembly

The purge gas enclosure assembly, Ref. 28, is located on the truck's rotary platform, and houses, protects, and includes the pneumatic components used to monitor and distribute the hydrostatic head and purge gas nitrogen supplies (including regulators, solenoid valves, analog gauges, control valves, piping, wiring, and instrument transducers.)

Nitrogen is supplied for five different functions during FG/RMCS operations: the DS purge gas system used during FG/RMCS drilling; the purge through the riser sleeve annulus, the hydrostatic head in the drill string and in the shielded receiver, and the Z-purge (NFPA 496) in the SR weather cover. The systems provide drill bit cooling and cleaning during rotary drilling, help prevent waste flooding in the drill string, and prevent gas accumulation.

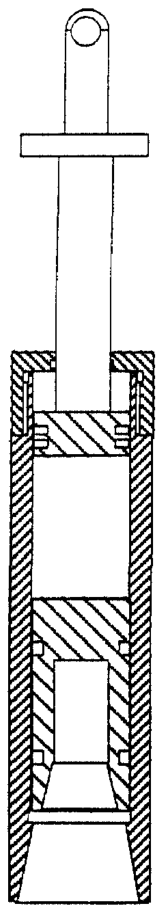


Fig. 2-7. Mechanical remote latch unit configuration.

2.4.1.8. Instrumentation and Control System
This section is primarily focused on the systems for drill engine shutdown, and the instrumentation used by the operator for operational controls.

2.4.1.8.1. Programmable Logic Controller (PLC). The PLC processes out-of-tolerance alarm signals to activate alarm strobe, horn, and indicator lights, followed by engine shut-down signals sent to the shut-down relay. Located in the instrument cabinet, the PLC controls the alarm sequencing and interlock logic for the RMCS Truck System. Alarm contacts from the truck instrumentation and external sources (exhauster) are monitored. When a valid alarm is received by the PLC, it initiates both visual and audible annunciation as appropriate. Additionally, if the received alarm requires a drill rig engine shutdown, the PLC deenergizes the shut-down relay, shutting down the drill rig engine.

2.4.1.8.2. Engine shutdown. The following mechanisms are elements of a safety system referred to as the sampling truck engine shutdown, as defined in Ref. 9. The drill rig engine will automatically shut down for out-of-tolerance drilling parameters, exhauster shutdown, or detection of a GRE.

Shutdown Interlock (K5 relay). The shut-down interlock relay is controlled by the PLC and shuts down the drill rig engine by interrupting electrical power to the drill rig ignition.

RPM (Revolutions per Minute) Measurement. Two drill rotation sensors measure drill rotational speed and send signals to two digital units that display drill rpm. If out of tolerance, an alarm signal is sent to the programmable logic controller, and the drill rig engine is shut down. Exhauster operation and nitrogen purge flow are not terminated under this shut-down condition.

Down Force Measurement System. The down-force measurement system electronically measures and calculates the down force of the drill string, provides a signal to the digital display unit, and digitally displays the measurement. If the down force is above the designated down force limit, an alarm signal is sent to the PLC which shuts down the drill rig engine. Exhauster operation and nitrogen purge flow are not terminated under this shut-down condition.

Riser sleeve Purge. Two differential pressure switches measure the pressure drop across a flow controller, and provide a shutdown signal to the PLC on low differential pressure. Exhauster operation and nitrogen purge flow are not terminated under this shut-down condition.

DS Purge Gas Measurement. The purge gas measurements include three turbines to measure flow and transducers to measure pressure and temperature. Signals are sent from the purge gas enclosure to the three digital flow indicators that display compensated flow in scfm (standard cubic feet per minute) units. Any of the three indicators can detect an out-of-tolerance condition and send an alarm signal to the PLC; the PLC then executes two-out-of-three voting logic to activate drill rig engine shutdown.

Penetration Rate Shutdown. The penetration rate measurement system electronically measures the penetration rate of the DS and provides a signal to the digital display unit, and digitally displays the measurement. If the penetration rate is below the designated limit, an alarm signal is sent to the PLC which shuts down the drill rig engine. Exhauster operation and nitrogen purge flow are not terminated under this shut-down condition.

Exhauster-Induced Shutdown. The exhauster can induce drill rig engine shutdown based on signals from the flammable-gas detection system or based on exhauster operational parameters. The operational parameters that provide a shut-down signal to the PLC to shut down the drill rig engine are discussed in Section 2.4.2 A keylock override switch allows operation of the truck when the exhauster is not needed.

2.4.1.8.3. Instrumentation Cabinet. The instrumentation that the operator has available on a directly accessible panel for control of the sampling operations is discussed in this section.

Enclosure Temperature Instrument/Display. The instrument enclosure is temperature-controlled with separate air conditioning and heating systems. The temperature instrument/display measures and digitally displays the cabinet temperatures, and an alarm sounds for out-of-bounds 50°F < T > 90°F.

Purge Gas Temperature Display. This instrument displays purge gas temperature, and alarms for out-of-bounds conditions that are < 10°F and > 140°F.

Purge Gas Pressure Display. This instrument converts a transducer signal to a digital display of purge gas pressure, and if greater than the currently set value of 0.3 psig, sends a signal to the PLC. This display is for information only during drilling modes.

Shielded Receiver and Drill String Pressure Displays. These instruments convert transducer signals to a digital display of pressure in the shielded receiver and drill string, respectively, and if greater than the currently used value of 0.2 psig, send a signal to the PLC. The displays are used by the operators to ensure sufficient press e for sample change-out operations and to verify that the DS and SR are depr urized when breaking containment. If hydrostatic head pressure is not maintained at the required level, then waste intrusion into the drill string could result.

Other Informational Displays. The Lower Ram Pressure Display converts transducer signals to digital displays for the walkdown or hydraulic bottom function (HBD) setpoint pressure with a selector switch. The Enclosure Indicator Lights provide visual status of various limits and logic controller functions. The Purge Gas Flow Display selects and digitally displays the output from one of three purge gas flow meters.

2.4.1.8.4. Hydraulic bottom detector. When obtaining the final sample, the hydraulic bottom detector detects loss of lower ram pressure, and energizes a solenoid valve to automatically reverse the ram direction to raise the drill head.

2.4.2. Exhauster Assembly

The exhauster train, Refs. 29 and 30, as depicted in Fig. 2-8 is composed of a flexible, conductive duct connecting the exhauster to the riser, a heater to dehumidify exhaust gases, a filter housing containing a prefilter with two high-efficiency particulate air (HEPA) filters in series, and a stack assembly. The exhauster system, designed to operate continuously, is required during all FG/RMCS activities to maintain a negative tank pressure with respect to atmospheric pressure and to prevent uncontrolled particulate emissions.

Exhauster. The exhauster filter train is composed of a prefilter immediately upstream of two HEPA filters in series mounted on a single skid (15 by 7 ft). To limit filter loading, the allowed dose rate on contact with the HEPA filter housing is 100 mrem/h.[29] Flow into the exhauster from nitrogen purge and tank in-leakage is designed for 9.4×10^{-2} m^3/s (200 ft^3/min), resulting in a tank pressure of about -250 Pa (-1 in. w.g.).

The flexible exhauster duct connects the tank riser to the exhauster and is held in place with stand assemblies. The electrically conductive duct is 1/32 in. thick, neoprene over a polyester base. A seal pot assembly is positioned between the riser and the exhauster, and the drain lines to the seal pot are 1/2-in. stainless steel.

Some tanks have high humidity levels. Therefore, a hot-water heat exchanger meeting Class-1, Div.-I, Group-B electrical requirements is supplied upstream of the HEPA filters to lower the relative humidity of the tank gases being exhausted. The heater meets the constraints of the Washington State Operating permit that limits the humidity of the air stream passing through the HEPA filters to be no greater than 80%.

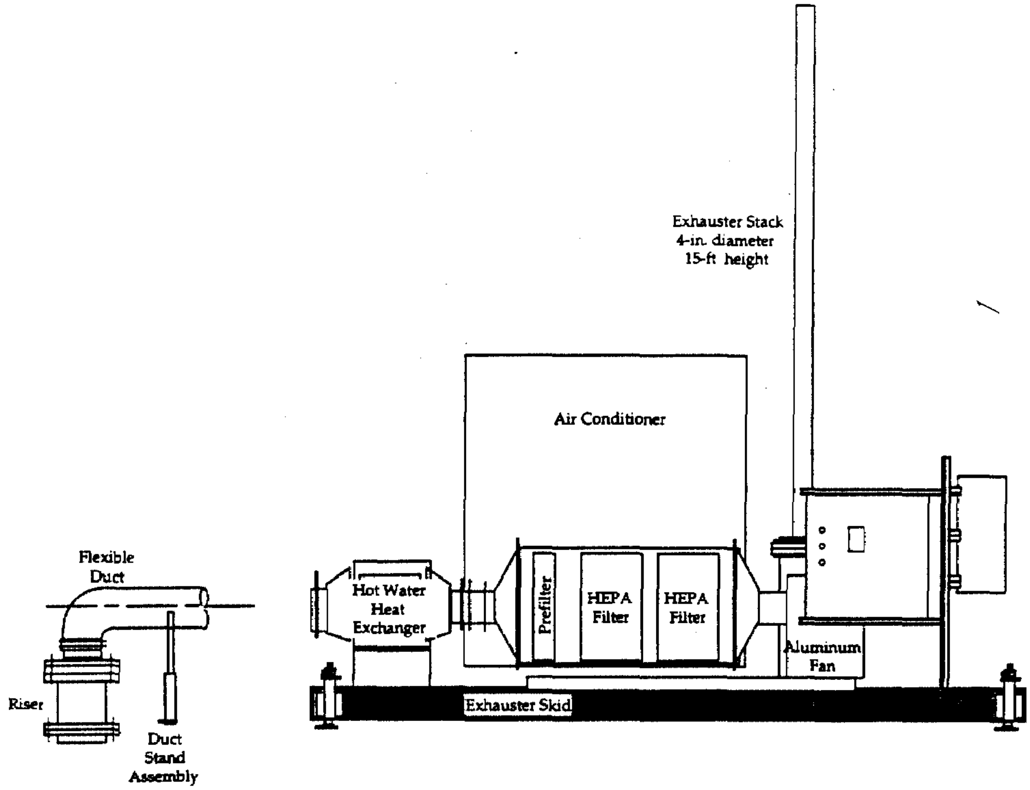


Fig. 2-8. Exhauster system.

Fan and Stack. The fan, driven by a 7.8 hp electric motor, is qualified for operation in a flammable-gas environment, provides the motive force for drawing tank gases from the riser through the filters and prevents tank overpressurization during core sampling activities. The fan/motor combination are capable of drawing 1900 scfm, so the motor has a speed controller to reduce the rpm to obtain the nominal 200 scfm flow rate. The controller uses output from the stack velocity transmitter to automatically adjust motor rpm to maintain constant flow as loading increases and flow decreases.

Exhauster Control and Monitoring. The exhauster is designed to automatically shut down when flow through the stack is greater than 250 scfm for greater than 5 min., or shutdown immediately when flow is less than 150 scfm. Two pressure conditions can also induce automatic exhauster shutdown: when the tank pressure falls to less than -3 in. w.g.; and when the differential pressure across the prefilter/HEPA filter bank is greater than 5.9 in. w.g. Vendor information indicates that the HEPA filter performance is undetermined at a differential pressure of 10 in. w.g. after 15 minutes, but there are no relief valves or vacuum breakers installed to protect the HEPA from excessive delta pressure. In order to protect against filter collapse, the blower is limited to 9 inches of water static pressure.

The tank pressure, HEPA differential pressures, and flow through the exhauster are continuously monitored using intrinsically safe systems in the exhauster. Even though totalized flow is continuously data-logged in the exhauster instrumentation cabinet, only pressure alarms are recorded.

Exhaust gases can be monitored for radionuclides, ammonia, and total vapor space organic compounds at the stack outlet. The exhauster has no organic or toxic vapor control technology.

2.4.3. Flammable Gas Detection System

The flammable gas detection system consists of four primary components; a spool piece with gas sensors to obtain gas samples from the exhaust stream, two identical, separate, electronic packages and a power distribution skid with redundant shut-off contactors. The system is powered by the same source as the exhauster. The flexible duct from the waste tank is attached to the spool piece which is bolted directly to the exhauster heater. The ventilation stream passes through the spool piece and into the exhauster. Attached to the spool piece are two separate flammable gas sensors; a Whittaker hydrogen detector cell and a Sierra Monitor Corporation (SMC) combustible gas detector.

The purpose of the gas sensors on the spool piece is to provide safety shutdown signals for both flammability and toxic hazards during core sampling operations. Out-of-tolerance conditions include concentrations of hydrogen equivalent flammable gas greater than 5000 ppm, or concentration rate increases greater than 100 ppm/s for 10 s. Upon detection of out-of-tolerance conditions, the interlock will initiate drill rig shutdown and alert personnel to evacuate the tank farm.

The Wittaker Cell, an electrochemical cell with a membrane placed between the sample gas and the active element, is very selective for hydrogen and responds directly to the partial pressure of hydrogen on the other side of the membrane. Significant experience with Wittaker Cells has shown them to be stable and reliable in the tank farm environment.

The SMC combustible gas sensor uses a catalyst to "burn" the gas and detects the resulting heat release. To increase sensitivity and decrease drift, the heat detection is done by comparing the temperature of a reference (uncatalyzed bead) to that of a signal (catalyzed) bead. The beads are imbedded in a sintered metal housing which prevents the combustion energy from igniting a flammable mixture. It has the advantage of responding to both ammonia and hydrogen. Appendix U presents functional design requirements of SMC combustible gas sensors as well as Wittaker cells.

Sample flow to each instrument is provided by a pressure differential within the spool piece--no sample pumps are used. Signals from the flammable gas instruments are processed by redundant programmable logic controllers. If flammable gas concentrations exceed 5000 ppm, the rate of change in flammable gas concentrations better 100 ppm/s for 10 seconds, or the tank pressure increases more than two inches water gage in five minutes, the exhauster will remain operational and the truck will be shut down. In addition, the exhauster will shutdown on internal alarms (low and high flow, and HEPA filter differential pressure) when the interlock is used.

If interlock power is lost, or tank pressure falls to less than -3 inches w.g. electric power to the exhauster is terminated. Exhauster shutdown will automatically result in core sampling drill truck shutdown via the existing connection.

2.4.4. Riser and Adapter Equipment

This section discusses equipment attached to the riser as illustrated in Fig. 2-9.

Riser and sleeve. The riser to be sampled will have an internal sleeve of spark-resistant stainless steel with a nominal length of 15 ft. The annulus between the sleeve and the DS will be purged with nitrogen during FG/RMCS operations to prevent the accumulation of flammable gas. The riser purge gas system will have two differential pressure detectors which are interlocked to the PLC and can cause an automatic trip of the drill rig. Each detector's set point will be approximately 40 psid across a flow controller that is sized for 5 scfm. The sleeve has a separate spray wash assembly with operational parameters like the DS spray wash system.

Riser Adapters. The riser adapter, Ref. 31, is basically a flanged plate, located on top of the riser, with an offset orifice to allow for the connection of riser equipment, regardless of the size of the riser.

Drill String Spray Washer/Frisbee Wiper Assembly. The drill string is washed to reduce contamination with a hot-water spray wash of the exterior surfaces as the drill string is being extracted through the drill string spray washer/frisbee wiper assembly.[32] Water is supplied to the spray washer at a temperature less than or equal to 140°F and a flow rate less than or equal to 3 gal./min from the water heater and 55-gal. water supply on the support truck.

The frisbee seal around the drill rod provide a wiping action during drill rod recovery operations and serves to stabilize the drill string during rotation. The frisbee also effectively provides a seal between the tank and the environment by sealing around the drill string outer diameter, and between the spray washer and the foot clamp.

Pneumatic Foot Clamp. The commercially-available pneumatic foot clamp[33] holds the drill string when it is disconnected from the platform hoist, the quill rod, or the shielded receiver. The three-legged, spider-like clamp must be pneumatically opened to release the drill string. If the pneumatic pressure is lost, the clamp fails in the closed position and the spider-like legs rotate for a three-point positioning around the drill string, locking the drill string in place. The foot clamp does not prevent upward motion of the drill string.

Locking wrench. A commercially-available, carbon steel locking wrench[34] is used in conjunction with the pneumatic foot clamp as a redundant mechanism to support the drill string when drill rods are installed or removed, or when the drill string is disconnected from the drill rig. Positioned just above the foot clamp, the fingers of the wrench completely surround the drill string, employing a toothless, ratchet-action grip to grasp the drill string.

Lifting Bale. An electrically-bonded lifting bale is attached to the hoist to support the drill string during installation and removal of drill rods.

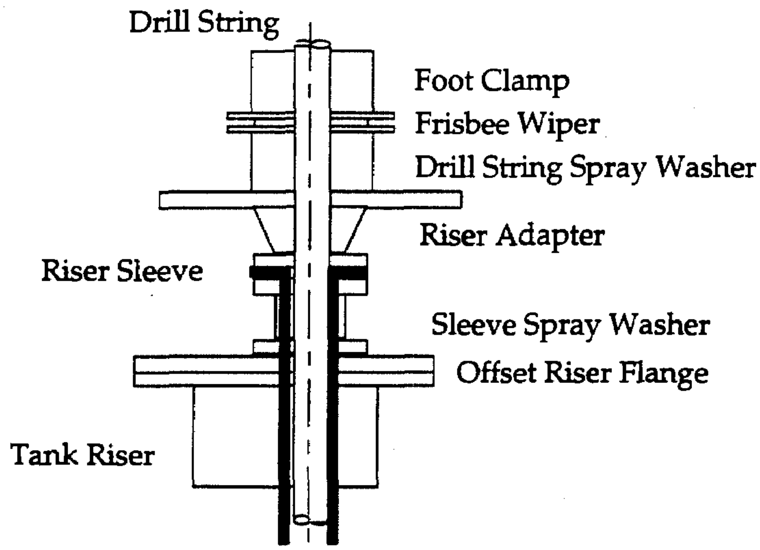


Fig. 2-9. Riser adapter, washer/frisbee wiper assembly and foot clamp.

2.4.5. Cable Spray Washer Assembly and Change-out Assembly

The change-out assembly,[35] Fig. 2-10, is placed on top of the cable spray washer when the drill string is disconnected from the quill rod. It provides a means to isolate and maintain hydrostatic head pressure within the drill string while samplers are exchanged. It also provides containment of hydrostatic head and DS gases. It is comprised of a male Kamlok® adapter assembly, a 3-in. ball valve, and a female Kamlok® adapter. Once attached to the DS, the change-out assembly provides quick connect and disconnect capabilities to the shielded receiver.

Cable Spray Washer Assembly. The cable spray washer assembly[36] connects to the drill string before installation of the change-out assembly in order to wash the internal cables of the shielded receiver and grapple cables, and to internally wash the drill rods if required.

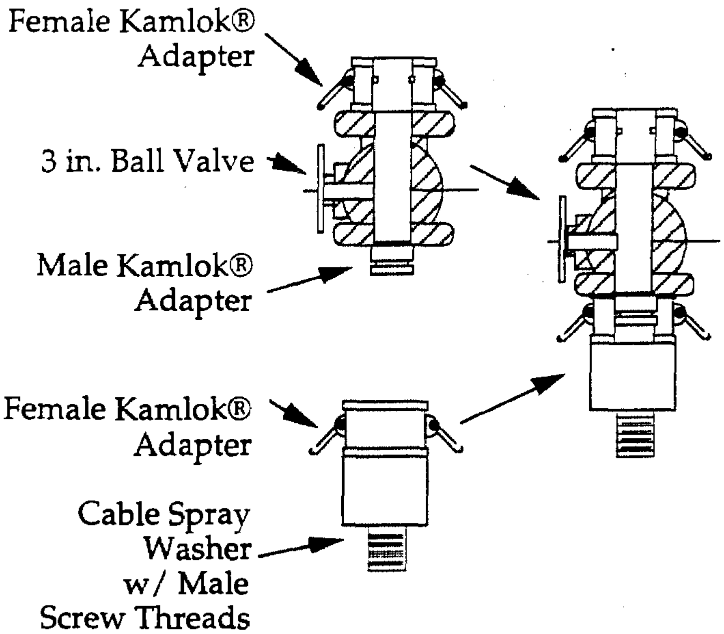


Fig. 2-10. Change-out assembly.

2.4.6. Primary Support Equipment

The primary support equipment for rotary sampling operations include the N_2 supply system, an X-ray imaging capability, power generation and distribution, washer supply systems, and casks and the cask truck. Operational support equipment include the power distribution trailer, the breathing air compressor, the service and support truck and trailers, lights, and the crane used during equipment setup and teardown.

2.4.6.1. Liquid Nitrogen Supply Trailer and Heater

The liquid nitrogen support trailer and vaporizer supply the nitrogen used for the purge and hydrostatic head systems during FG/RMCS operations.

Nitrogen Trailer. In the nitrogen trailer, liquid nitrogen is vaporized by a propane-fired, forced-convection, water bath vaporizer. The 1500-gal. nitrogen tank and liquid supply piping stores liquid nitrogen and includes a passive closed-loop evaporator (to supply tank pressure), valves, piping, regulators, and gauges to accommodate tank filling and liquid nitrogen supply to the vaporizer.

The normal nitrogen system pressure in the N_2 trailer is 100 to 250 psig while the system is in operation, with a tank relief valve set to relieve pressure at 250 psi. Nitrogen provided to the sampling truck is 100 to 150 psi. The nitrogen trailer remains outside of the tank farm at all times.

Vaporizer. The vaporizer vaporizes both the liquid propane to supply the water heaters and the liquid nitrogen to supply the nitrogen gas regulator and supply hose. The vaporizer includes self-igniting, thermostatically-controlled water heaters, a water circulation pump, and closed-loop water piping and expansion tanks. The control panel and instruments automatically regulate water flow and gas exit temperatures. A nitrogen gas regulator with a shutoff valve regulates the pressure of the gas at the exit of the vaporizer. A supply hose with a quick disconnect fitting supplies gas to the core sample truck. The vaporizer is electrically-powered by a propane-fueled engine generator, or alternate 240 v power source.

The vaporizer's propane tank stores pressurized propane and includes piping to supply the water heaters with propane gas, the generator engine with propane gas, and the vaporizer with propane liquid.

2.4.6.2. Mobile X-ray Imaging System

The X-ray imaging system, Ref. 37 is used for a preliminary assessment of the core sample to verify how complete the sample was and the characteristics of the waste form. This assessment is intended to help the operator more accurately set operational controls for the next sample. The system is equipped with a female Kamlok® adapter for connection to the SR.

2.4.6.3. Casks and Sample Transfer Truck

The sample casks and transfer truck are discussed in this section.

Transfer Casks. The transfer casks are held at the sample site in a five-cask holder, or cask stand, in an upright position.[38] The transfer casks are lead-lined chambers that provide shielding and containment for the core samples during shipment to the analytical laboratory. Each cask is 40 in. long, about 6 in. in diameter, and weighs 480 lbs. Casks are equipped with a female Kamlok® adapter for connection to the SR.

Sample Transfer Truck. The sample transfer truck, or cask truck, transports the sampler/cask assemblies to and from the laboratory and moves samples in the field. The truck is capable of carrying three casks at a time, and field positioning is facilitated through an overhead rail chain hoist crane on the truck.

2.4.6.4. Portable Generator Set

Two types of generators are available to support FG/RMCS activities—150 kVA and 200 kVA. The portable generator set described in Ref. 39 provides standalone power for the core sample truck and auxiliary equipment. The grounded generator is powered by a turbocharged-diesel engine to produce power with a rating of 150 kW, 480 Vac, 60 Hz, 3Ø, 4-wire and 120/240 Vac, 60 Hz, 1Ø. The diesel generator remains outside of the tank farm at all times.

2.4.6.5. Power Distribution Trailer

The power distribution trailer distributes power from the generator to the sampling equipment such as the sampling truck, the exhauster, the water heater on the support truck, the X-ray imaging system, the truck's air compressor, and 120V outlets.

2.4.6.6. Breathing Air Trailer/Compressor

The compressor is a two-stage, oil-free design powered by a 30 hp, 480 Vac, 60 Hz, three-phase electric motor. A 30-gal. receiver tank and a 30-gal. surge tank allow the compressor to cycle, and collected moisture is manually drained in the receiver tank. The breathing-air compressor remains outside the fenced area and away from sources of contamination and toxic fumes.

2.4.6.7. Support Truck and Trailer

The support truck transports personnel and miscellaneous equipment, and can be parked on the tank. The support truck acts as a lock-up rack for drill rods, and also carries a drum heater and pump for supplying water. The support trailer, located outside the tank farm, provides equipment storage and shelter for personnel.

2.4.6.8. Crane

A standard crane is used in the setting up and taking down of the sampling activities. It is used on an as-needed basis only and is not normally retained at the job site except when in use.

2.4.6.9. Light Units

Diesel-powered portable light units are used on and off the tank farm during drilling operations. Each light is capable of producing 2500 W of light (5 halogen lights at 500 W per light). The diesel generator units are refueled on an as-needed basis.

2.4.6.10. Tent

A large tent can be installed on top of the tank over the sampling truck and some of the auxiliary equipment. It's purpose is to provide protection against and reduce the impacts of atmospheric weather conditions such as sun, rain, snow, cold weather, wind, etc. The tent weighs 7000 lb and is made stationary with 33,000 lb of weights located on the tent periphery.

2.4.6.11. Video Vehicle

A vehicle weighing 5,000 lb can be used for video documenting the sampling activities. Even though the installation/operation/removal of the video is not within the scope of this SA, the vehicle is mentioned because of its contribution to tank loading.

2.4.7. RMCS System Weights

RMCS operations for single-shell FGWL tanks increase the live weight on the tank dome. TABLE 2-4 lists the calculated weights of various components that could be placed on the tank dome surface.[40] However, all of the listed components are not simultaneously placed on the tank because of tank load limits. The dome loading for SSTs is controlled by limits specified in the approved procedure,[41] and the additional tank dome loading is considered to be a live load in the WHC evaluation of the tank structural integrity.

Tank structural integrity can be at risk if the FG/RMCS drill string falls and impacts the tank bottom. For this reason, the total weight of the drill string suspended over the tank bottom is an important factor. The total weight will be the sum of the core barrel, sampler, and drill string, but will vary as a function of the drill string length. The drill rod nominally weighs 4 lb/ft, and the universal sampler, which includes the quadralatch and pintle rod, weighs 10.3 lb.[40] The combined suspended weight for an FG/RMCS operation will peak as sample operations approach the tank bottom (e.g., 50-ft drill string length effectively would weigh more than 210 lb), but the impa nergy will peak at an intermediate sampling depth because it is a product of the s ended weight and drop height.

TABLE 2-4
RMCS COMPONENT WEIGHT BREAKDOWN

Component	Weight (lb)
Core sample truck (includes grapple hoist assembly and shielded receiver assembly)	30,000
Truck platform	6,000
Universal sampler (11 @ 10.3 lb)	113
Drill String (50 ft @ 4 lb/ft)	200
Change-out assembly	45
Riser adapter and drill rod washer	280
Riser sleeve	200
Inlet breather filter stack	2,000
Support truck	7,000
Cask truck	8,000
Cask stand	300
Casks (5 @ 480 lb)	2,400
Mobile X-ray system	5,000
Exhauster and flammable gas detection systems	12,200
Light plants (2 @ 1000)	2,000
Video vehicle	5,000
Tent	7,000
Tent weights	33,000
People (10 total)	2,000
Total Potential Weight	122,738

2.5. RMCS OPERATIONS

For the purposes of this safety assessment, FG/RMCS operations are divided into four phases as depicted in Fig. 2-11: (1) preinstallation activities, (2) installation, (3) drilling operations, and (4) removal. Key steps and limits are then provided within each phase. The following section describes the operations associated with rotary-mode core sampling, and is a summarization of input from safety analyses in Refs 11, and 12, and verbal discussions with WHC personnel.

The fundamental premise of FG/RMCS operations is to minimize the source of ignition and to ensure the capability to enact safe shutdown upon detection of unacceptable levels of flammable gas and shut down sampling operations until it becomes safe to continue operations.

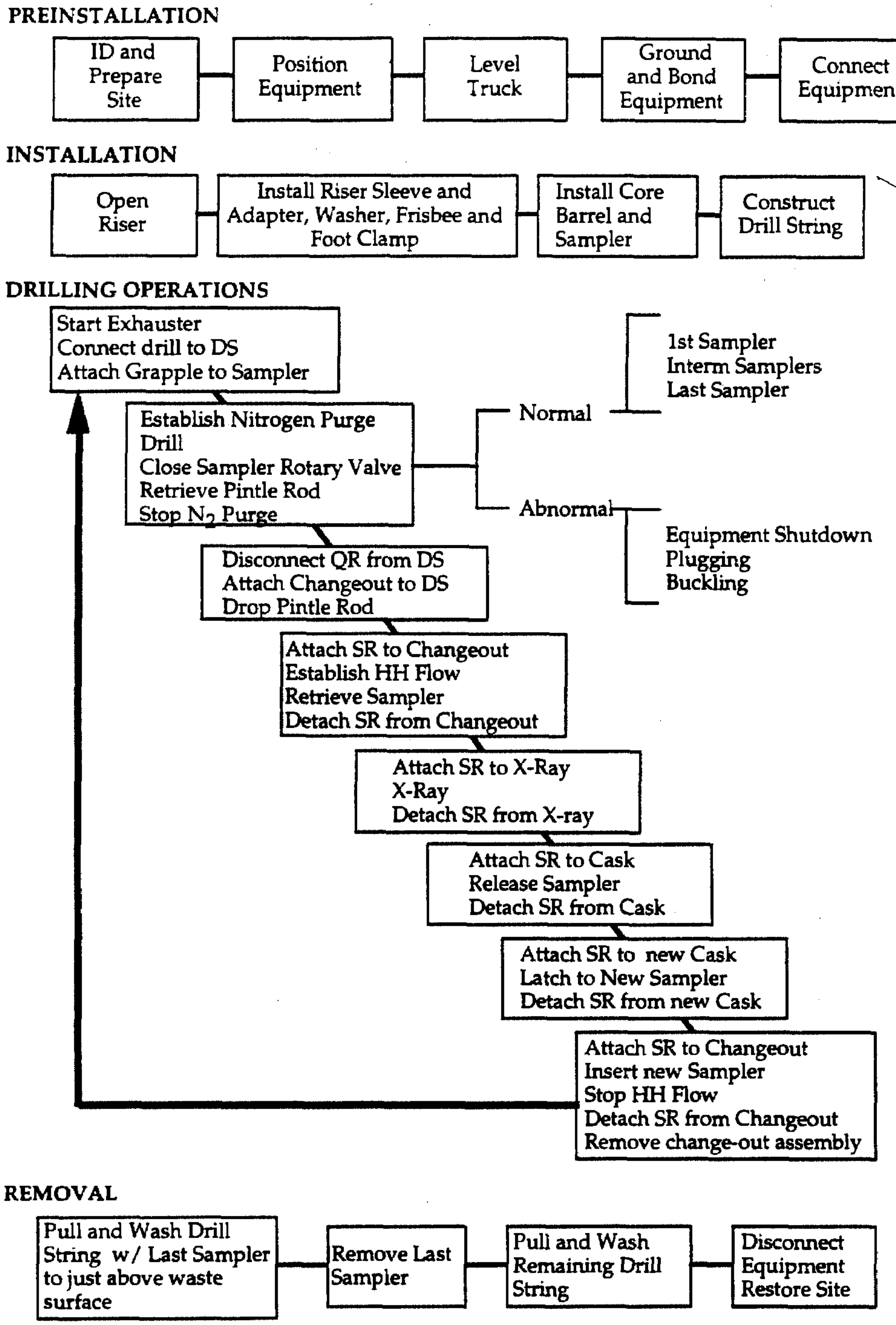


Fig. 2-11. FG/RMCS process.

2.5.1 Preinstallation

Preinstallation activities are assumed to include site preparations, equipment setup and connection, electrical bonding, and verifying critical alarms and trips. Fig. 2-12 schematically shows the relative positions of the pieces of FG/RMCS equipment on and surrounding any given tank, along with the anticipated power requirements.

Setup and operation of all equipment is assumed to be in compliance with appropriate procedures. For information only, several commonly used procedures are listed in TABLE 2-5.

Preinstallation activities include:

- Collect all appropriate procedures.
- Obtain sign off on all necessary conditions, concurrence, forms, and permits.
- Comply with all contractor safety, radiation and contamination, environmental protection, permitting and quality assurance controls, procedural limits and precautions, and records maintenance.
- Investigate and identify farm, tank, and riser locations. Prepare the site. Acquire and stage all supplies and equipment needed to perform operations. Calibrate measurement devices as procedurally required.
- Verify tank ventilation method and operability. Verify spark resistance of tools and lanyard as necessary to prevent tool entry into tank.
- Set up auxiliary support equipment, including the generator, the compressor, power distribution trailer, the support truck with the drum H_2O heater, nitrogen trailer, and service trailer. Position and set up primary systems, including the sampling truck, exhauster, the cask stand with casks, and the mobile X-ray image system.
- Perform grounding and bonding activities. Call the weather service to verify that there are no lightning storms within a 50-mile radius of the sample site.
- Measure the quill-rod-to-riser distance, and determine the number and size of drill rods needed in accordance with the procedure data sheet. Obtain drill rods. Place drill rods in the lockup rack on the support truck.
- Place the quill rod in a full down position, hydraulically level the sampling truck, and verify stability. Verify alarms and annunciators.

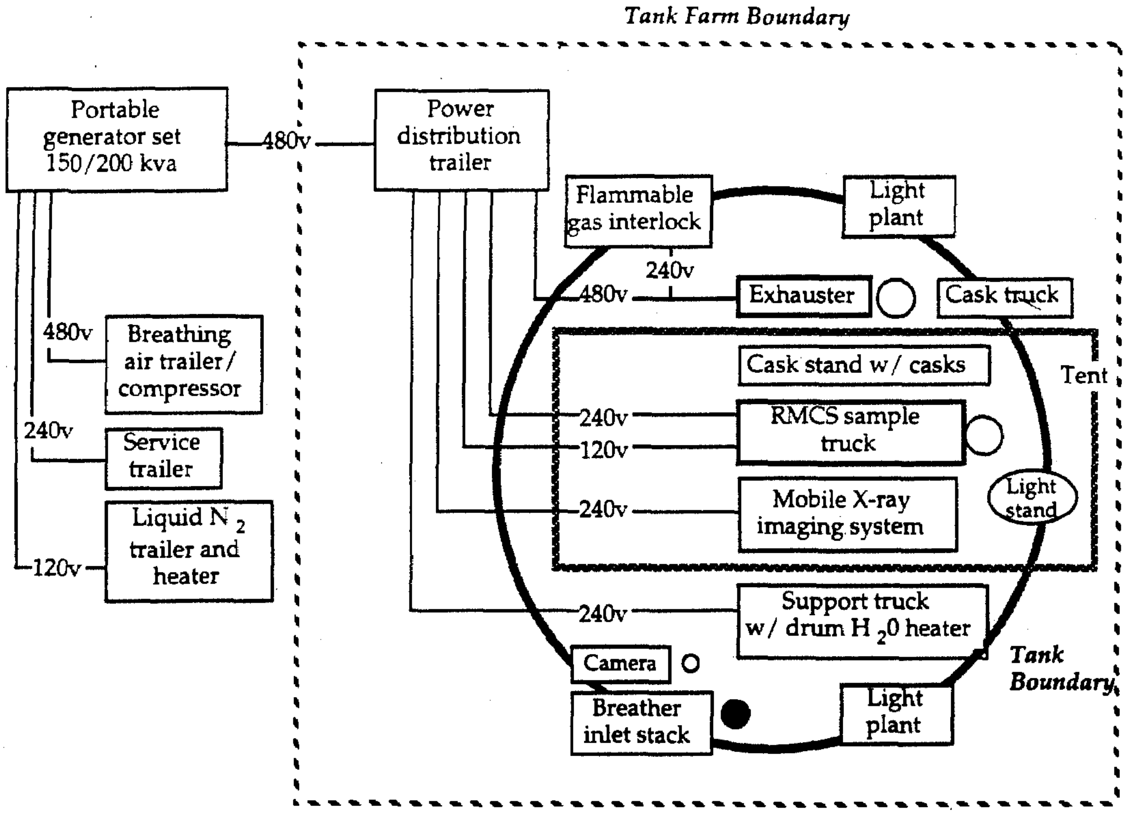


Fig. 2-12. Relative placement of equipment required for core sampling in the rotary mode.

2.5.2. Installation

Installation activities are assumed to include removing the riser blank flange and gasket, installing the riser sleeve and riser equipment (riser adapter, spray washer, frisbee wiper, and foot clamp), and core barrel/drill bit/sampler unit through the riser equipment. It should be noted that during the opening of a riser, either toxic gases (i.e., ammonia, organic vapors, and nitrogen dioxide), and/or combustible gases (i.e., methane, hydrogen) could be released and are monitored in a way consistent with appropriate procedures. Operations may proceed only if the combustible-gas meter, calibrated according to appropriate procedures, reads $\leq$ 25% LFL.

- Crack open the blank flange or pipe cap to off-gas the tank for 5 minutes. Start air sampling. Perform a breathing zone survey and sniff the riser and surrounding area.

- Install the riser assembly, using the mobile crane or the platform hoist. The riser assembly is assumed to include the riser adapter, conductive sleeve, spray washer/frisbee wiper assembly, and foot clamp.

- Screw the drill bit onto the core barrel and gently insert a universal sampler. Attach and install the drill rods in the order specified by the procedural worksheet. Screw the electrically-bonded lifting bail onto each newly attached drill rod, open the foot clamp, and lower the DS with the platform hoist. Close the foot clamp each time before releasing the DS to attach another drill rod.

- Install drill rods until the string is just above the waste surface or until only 19-in. drill rods remain. The predrilling configuration should resemble Fig. 2-13.

TABLE 2-5
EQUIPMENT PROCEDURES USED IN SA

•	Perform Rotary Core Sampling of Ferrocyanide, Organic, Organic/Ferrocyanide Watch-List Waste Storage Tanks[42]	TO-080-056
•	Liquid Nitrogen Trailer, Nitrogen Chiller, and Indeeco Nitrogen Heater Operations	TO-060-345
•	ONAN 150DGFA Generator Set Operation	TO-020-900
•	AEROFLOW Model 2AN137 Breathing Air Compressor Operation	TO-020-056
•	Transfer the On-site Transfer Cask	TO-080-090
•	Sample Transfer Truck Operation	TO-080-075
•	Pick Up/Transport Radioactive Material and Waste Packages	TO-100-010
•	Katolight Model D200FRJ4 Standby Power System Operation	TO-020-825
•	Perform Waste Generation, Segregation and Accumulation	TO-100-052
•	X-ray Procedure	To be specified following SA approval
•	Exhauster Procedure	To be specified following SA approval

2.5.3. Sampling Operations

Sampling operations are assumed to include drilling operations, removal of the universal sampler from the drill string, X-ray imaging, placing the sampler into the receiving cask, obtaining a new sampler, and placing the new sampler into the drill string.

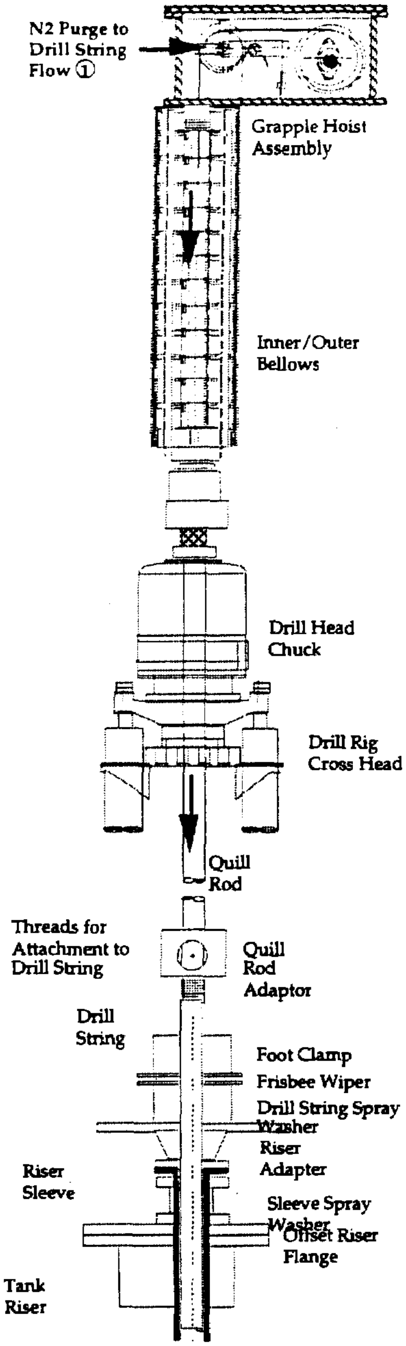


Fig. 2-13. Pre-drilling configuration.

2.5.3.1. Drilling

- Monitor and record flammable-gas concentrations and other appropriate parameters, according to the operational safety document (OSD) requirements.

- Rotate the truck platform to position the grapple hoist assembly/drill unit over the drill string. Attach a 19-in. drill rod to the drill string. Open the drill chuck, connect the quill rod, and close the chuck. Open the foot clamp. Raise the drill rams if necessary.

- Establish nitrogen purge flow through the riser/sleeve annulus.

- Ensure that the exhauster is operating according to the appropriate procedure, verify that the exhauster interlock is activated, and initiate nitrogen purge gas flow through the DS.

- Lower the grapple through the quill rod with grapple hoist until it latches onto the pintle rod of the universal sampler. Record the mechanical grapple counter value. Raise the grapple only enough to remove the slack in the grapple hoist cable.

- If obtaining a final sample, activate the hydraulic bottom detector, with independent verification.

- Establish the nitrogen purge gas flow at about 40 scfm, or as necessary. Engage the clutch, adjust the DS rpm, and proceed with rotary drilling by adjusting the ram control valve to obtain the desired penetration rate, i.e., down force, as appropriate, within the operating parameter envelope. Operational limits on FG/RMCS parameters are provided in Section 2.5.5.1.

- If the drill bit becomes plugged, refer to Section 2.5.5.2.4.

- If the drill string becomes stuck, refer to Section 2.5.5.2.5.

- When a full sample stroke is completed, close the ram control valves, disengage the clutch, and close the nitrogen purge flow control valve.

- Raise the grapple to pull the pintle rod, release the spring clip that separates the pintle rod from the sampler piston, and close the rotary valve at the bottom of the universal sampler. Pull the pintle rod up through the drill string and into the quill rod.

- Raise the drill string about 1 in. to ensure trouble-free installation of the next sampler. Close the foot clamp. Depressurize the grapple hoist box, and verify depressurization.

- Open the chuck, disconnect the quill rod adapter from the DS, and close the chuck. Screw the cap with the male Kamlok® adapter onto the quill rod adapter. Rotate the platform to place the grapple hoist assembly aside from the drill string.

- Screw the cable wash assembly onto the DS. Connect the male Kamlok® of the change-out assembly to the female Kamlok® of the spray washer assembly. Close the change-out isolation valve. Pressurize the DS to maintain hydrostatic head.

- Kamlok®-connect the pintle rod overpack to the bottom of the quill rod adapter, and mechanically release the pintle rod from the grapple into the overpack. Disconnect the overpack from the Kamlok® cap on the quill rod adapter.

2.5.3.2. Removing the Universal Sampler

- Rotate the truck platform to position the SR over the change-out assembly connected to the DS. Connect the Kamlok® on the end of the SR tube to the Kamlok® of the change-out assembly.

- Open the SR ball valve. Establish hydrostatic pressure in the SR. Open the change-out isolation valve. Lower the RLU at full speed to impact on and engage with the quadralatch of the universal sampler.

- If the DS pressure is greater than 0.5 psi times the sample number, vent the excess SR pressure.

- Slowly increase the hoist upward speed to unseat the sampler. The load cell value should read 60 to 70 lbf, but if the value is >150 lbf, then waste could be in the core barrel.

- Raise the sampler through the DS and into the SR tube. Inspect the sampler in the sight glass for cleanliness and record abnormal conditions.

- If the sampler exhibits visible waste material, wash the sampler by connecting the hot water line to the cable spray washer and raising the sampler slowly through the washer. Record water usage on proper data sheets and chain-of-custody documents.

- Raise the sampler into the SR tube. Close the change-out isolation ball valve. Depressurize the SR. Close the SR ball valve. Disconnect the SR Kamlok® from the change-out Kamlok®.

2.5.3.3. Mobile X-ray Image System Operations

- Rotate the truck platform to position the SR over the mobile X-ray image system. Connect the SR Kamlok® to the Kamlok® of the X-ray system.

- Open the SR ball valve. Lower the sampler into the mobile X-ray image system. Complete the imaging and raise the sampler into the SR tube. Close the SR ball valve.

- Disconnect the SR Kamlok® from the Kamlok® of the X-ray system.

2.5.3.4. Sampler Into Receiving Cask

- Rotate the truck platform to position the SR over the receiving cask, and remove the cap from the cask adapter. Connect the SR Kamlok® to the Kamlok® of the cask.

- Open the SR ball valve. Lower the sampler into the cask until the cable is slack. Disengage the RLU from the sampler quadralatch mechanism. Raise the RLU back into the SR tube. Close the SR ball valve.

- Disconnect the SR Kamlok® from the Kamlok® of the receiving cask.

- Prepare the cask for shipping. Remove the PVC sleeve from the cask. Remove the Kamlok® adapter from the cask; install the inner cask container plug, flange, and a new gasket; and install flange bolts. Complete the appropriate data sheets and chain-of-custody documents. Place a Waste Tank Sample Seal on the cask so that the seal must be broken to open the cask.

2.5.3.5. New Sampler Preparation

- If another sample is required, place a new universal sampler into a cask liner, and gently insert the sampler into a new cask.

- Rotate the truck platform to position the SR over the new cask. Connect the SR Kamlok® to the Kamlok® of the new cask.

- Open the SR ball valve. Lower the RLU at full speed to impact on and engage with the quadralatch of the new universal sampler. Visually verify that the sampler is attached while raising the sampler into the SR tube. Close the SR ball valve.

- Disconnect the SR Kamlok® from the Kamlok® of the new cask.

2.5.3.6. New Sampler Insertion into Drill String

- Rotate the truck platform to position the SR over the change-out assembly connected to the DS. Connect the SR Kamlok® to the Kamlok® of the change-out assembly. Open the SR ball valve.

- If directed by the PIC (person in charge), wash the drill bit by adding 0.1 to 0.3 gal. of hot water through the cable wash assembly. Criteria for this direction are circumstances in which the drill string has been idle for >4 hours or purge flow has not been established. Record water usage on the appropriate data sheets and chain-of-custody documents.

- Pressurize the SR. Open the change-out isolation valve. Lower the RLU and new sampler into the DS until the cable is slack (NOTE: there is no indication that the new sampler is fully latched into the core barrel/drill bit assembly.) Disengage the RLU from the sampler quadralatch mechanism. Raise the RLU back into the SR tube. Close the change-out isolation valve.

- Depressurize the SR. Close the SR ball valve.

- Disconnect the SR Kamlok® from the change-out Kamlok®.

- Rotate the truck platform to position the grapple hoist assembly/drill unit next to the drill string.

- Depressurize the drill string. Remove the change-out assembly.

- Return to Section 2.5.3.1 until the last core segment is obtained.

2.5.4. DS Removal

Removal operations are assumed to occur when the DS equipment is washed and removed. The hoist or drill head is connected to the drill string, and the DS is retrieved and externally washed. The hoist or drill head is disconnected, and the drill sections are discarded. Auxiliary equipment is disassembled, and the site is restored.

The drill string is washed as follows. Retain the last sampler in the core barrel, or install a new sampler. Depressurize the drill string, connect the water line to the drill rod washer, disconnect the change-out assembly and cable spray washer, and use the drill head to remove all 19-in. drill rods, washing while removing. Retrieve the final sampler when above the waste surface. Rotate the platform, and use the platform hoist to retrieve the remaining segments of drill rod and the core barrel, washing while removing.

2.5.5. Operational Conditions and Characteristics

RMCS activities include both normal and abnormal operating conditions during drilling and sample retrieval.

2.5.5.1. Normal Operations

Normal operations include normal rotation within the established parameter envelope, a walkdown mode, and a bottom-detection mode. Truck stabilization can also be described in certain cases as a normal condition.

2.5.5.1.1. Normal Drilling and Sample Retrieval. TABLE 2-6 lists pertinent operational characteristics associated with the normal drilling and sample retrieval activities described in Section 2. Nominal values are provided, along with minimum and maximum range values. Alarm and trip points, if appropriate, are specified.

TABLE 2-6
OPERATIONAL PARAMETERS FOR ROTARY-MODE CORE SAMPLING METHOD

Parameter	Normal Range	High Value	Low Value	Alarm	Trip
Down force* (lb)	0 to 750	750	0	750	>750
DS rotational speed* (rpm)	2 to 55	110	2	55	>55
RMCS enable system (rpm)	2	2	2	NA	2
DS purge gas flow (scfm)	30 to 50	100	0.1	30	<30
DS purge gas pressure (psig)	30 to 50	90	0.3	NA	NA
Riser purge gas flow	>40 psid (2-5 scfm)	NA	NA	40 psid	40 psid
Purge gas temperature (°F)	60 to 80 (atmospheric)	140	10	<10 >140	NA
Instrument enclosure temperature (°F)	70 to 80	90	50	<50 >90	NA
Penetration rate (in./min)	3 to 10	25	0	0.75	<0.75
Lower ram pressure (psi) (walkdown mode)	50 to 250	250	20	NA	NA
Hydrostatic DS pressure (psi)	0.5 to 30	35	0.2	NA	NA
Hydrostatic DS flow (scfm)	0.5 to 2	7.8	0.2	NA	NA
Hydrostatic SR pressure (psi)	0.5 to 30	35	0.2	NA	NA
Hydrostatic SR flow (scfm)	0.5 to 2	7.8	0.2	NA	NA

* Limits are given for automatic shut-down features. Appendix N discusses administratively-controlled structural limits. For drill strings shorter than or equal to 45 ft, the down force of 750 lbf and rotational speed of 55 rpm are valid. For drill strings longer than 45 ft, the down force limit is reduced to 650 lbf and the rotational speed is reduced to 40 rpm for structural considerations.

2.5.5.1.2. Walkdown mode. The walkdown mode establishes a setpoint to allow the drill to "walk" through the drill stroke. The mode utilizes a solenoid-operated valve (SOV) to automatically start and stop ram motion by stopping hydraulic fluid flow through the drill rams when the specified pressure is reached.

2.5.5.1.3. Bottom detection. To prevent penetration of the tank bottom, a hydraulic bottom detector (HBD) is activated with the last sample. The four-way valve controls whether hydraulic fluid flows into the top or bottom side of the drill rams, thus controlling the direction of drill ram movement. During normal operation, the flow control valves control the amount of fluid that flows from the downstream side of the drill ram, which controls the drill penetration rate and the amount of force applied to the drill string. When activated, the HBD monitors the pressure on the lower or downstream side of the drill ram. When the hydraulic pressure sensors detect a loss of lower ram pressure, the drill direction is automatically reversed. When the stroke is complete, the HBD alarms may have triggered; the operator will silence the siren, stop the stroke, and disable the HBD.

2.5.5.1.4. Stabilized mode. A stabilized mode for the tank and sampling truck can be defined to include the following:

- If stabilization is required when the tank is open, then the open riser is covered.

- If the sampling truck is connected to the drill string, then it remains connected unless lightning is approaching, in which case, the drill string is disconnected and capped.

- If the sampling truck is not connected to the drill string, then stabilization assumes that the truck is placed in stabilized mode: the sampler is in the drill string; the drill string, the shielded receiver and quill rod are sealed; the shielded receiver and quill rod are above the rotary platform; the skid is traverse centered; the quill rod is to the back of the truck; all control panel breakers on the truck are off, unless otherwise directed by the PIC; the PG, SR and DS Gas switches are off; PG mode switch is positioned to DRILL; PG, SR and DS flow control valves are closed; the foot clamp is closed; the four-way valve is in FLOAT position; the Up and Down ram-control valves (RCVs) are closed; and the hydraulic bypass valve is closed.

- The PIC should record the status of sampling in the log book for recovery from the stabilized mode.

2.5.5.2. Abnormal Drilling Conditions

2.5.5.2.1. Reduced nitrogen flow. If nitrogen purge flow is less than the total of 30 scfm, then the drill rig will be automatically tripped, and drilling will be immediately terminated. The exhauster shall remain operational. The operator will correct the condition that caused the trip before drilling operations are reinitiated.

2.5.5.2.2. Excess rpm or down force on drill string. If the rotational speed exceeds 55 rpm or the down force is greater than 750 lbf, then the drill rig will be automatically tripped and drilling will be immediately terminated. The nitrogen purge and exhauster shall remain operational. The operator will correct the condition that caused the trip before drilling operations are reinitiated.

2.5.5.2.3. Penetration Rate. If the penetration rate falls below 0.75 in./min, then an alarm is triggered, and a 60-second period is provided for operator intervention to increase the penetration rate. If the rate is not increased, then the drill rig will be automatically tripped and drilling will be immediately terminated. The exhauster shall remain operational. The operator will correct the condition that caused the trip before drilling operations are reinitiated.

2.5.5.2.4. Drill bit plugging. If 30 scfm nitrogen purge flow cannot be maintained in normal operations, then the drill bit could be plugged with waste. In this case, the grapple hoist box is depressurized, and 0.1 to 0.3 gallons of hot water are added to the drill string through the quill rod adapter. The water usage is noted on the chain-of-custody for that sample.

Purge flow is then reestablished at 40 to 70 scfm. If the bit is cleared, then operations can resume. If not, then the cognizant engineer is consulted for alternate methods to unplug the bit.

2.5.5.2.5. Stuck drill bit. If the drill bit becomes stuck in the waste, then the grapple hoist box is depressurized if necessary and about 1 gal. of hot water is added to the drill string through the quill rod adapter. The water usage is noted on the chain-of-custody for that sample.

Purge flow is then reestablished at 40 to 70 scfm. If the bit becomes unstuck, then operations can resume. If not, then the cognizant engineer is consulted for alternate methods to loosen the bit.

2.5.5.2.6. DS flooding or structural failure. The procedures for handling DS flooding or unplanned maintenance activities are not covered in this safety analysis. The actions needed to handle DS structural failure or extreme jamming of the DS are not delineated in this document.

2.5.5.3. Loss of exhauster

Exhauster operation can be automatically terminated as a result of exhauster operational issues. Operationally tripping the exhauster will automatically trip the drill rig through the PLC on the truck. Similarly, the PLC also deenergizes the SOV in the nitrogen purge enclosure, which stops the purge flow to the DS.

Operationally, the exhauster automatically shuts down under the following conditions:

- Excessive negative tank pressure (-750 Pa or -3 in. w.g.).
- High differential pressure of 10 in. of water across the optional in-riser prefilter.
- High differential pressure of 5.9 in. of water across the HEPA filter bank.

- Exhaust stack flow greater than 250 scfm or less than 150 scfm.

A seismic event will not invoke automatic shutdown of the exhauster.

2.5.5.4. Gas-release Event

A gas-release event can be measured by the flammable gas detection system, discussed in Appendix U, that is connected upstream of the exhauster, or by the tank pressure system in the tank dome. The flammable gas detection system is setpoint-limited at the equivalent of 5000 ppm hydrogen concentration, or a rate of rise of 100 ppm/second. The flammable-gas detection system is also required to provide a cut off and alarm on out-of-tolerance conditions at 12,000 ppm ammonia for toxic considerations. Likewise, an increase in the tank pressure of 2 in. w.g. above back ground will trip the drill rig.

With out-of-tolerance conditions, the exhauster remains operational, but the drill rig engine operation is terminated. Personnel evacuate the site, don protective clothing, and can return to the tank for further equipment stabilization.

2.5.5.5. Emergency Response

All emergency conditions that could result in personnel injury or equipment damage are handled by the PIC in the following manner.

- Direct personnel to attend to any injured personnel, and evacuate as appropriate. Notify the fire department and the occurrence notification center.

- Depending on the nature of the emergency, and at the discretion of the PIC, stabilize the drill site as much as feasible commensurate with Section 2.5.5.1.4.

- Monitoring should be continued in support of all emergency activities.

- Evacuate personnel, and ensure the prevention of uncontrolled access to the drill site area.

Notify the Sampling Operations and Tank Farms Shift Management of the emergency.

2.5.6. Restart

Restart could be required for numerous reasons, including a power outage, exhauster shutdown, loss of nitrogen purge, exceeding drilling setpoints, or even starting a new work day. In general, the following conditions would be verified before sampling is reinitiated. Restart following off-normal incidents should be performed in a way consistent with the requirements of the Interim Safety Basis.

- Complete the Daily Core Sample/Inspection Data Sheet as required by the procedure.

- Turn all breakers on the truck's Core Sampler Power panel to ON. Acknowledge all alarms, and reset all immediate alarms. Resume exhauster operation. Resume sampling operations.

2.6. REFERENCES

1. "Tank Farm Health and Safety Plan," Westinghouse Hanford Company report WHC-SD-WM-HSP-002, Rev. 0A (September 28, 1993).

2. "Hanford Site Tank Farm Facilities Interim Safety Basis," Westinghouse Hanford Company report WHC-SD-WM-ISB-001, Rev. 0 (August 1, 1993).

3. . D. Hopkins, "Criteria for Flammable Gas Watch List Tanks," Westinghouse Hanford Company report WHC-EP-0702 (August 1994).

4. P. Whitney, "Screening the Hanford Tanks for Trapped Gas," Pacific Northwest Laboratory report PNL-10821 (October 1995).

5. H. Babad and Turner , "Interim Report for Organic Watch List Tanks at the Hanford Site, Westinghouse Hanford Company report WHC-EPP-0681 (1993).

6. "Bounding Gas Release Calculations of Flammable Gas Watch List Single-Shell Tanks," Los Alamos National Laboratory report LA-UR-94-1323, Rev. 0 (1994).

7. B. M. Hanlon, "Waste Tank Summary Report for Month Ending October 31, 1995," Westinghouse Hanford Company report WHC-EP-0182-91 (January 1991).

8. Westinghouse Hanford Company, "Waste Storage Tanks Composite Section," Drawing No. H-2-55911.

9. "Safety Equipment List," Westinghouse Hanford Company report WHC-SD-WM-SEL-032, Rev. 1. (February 15, 1994).

10. Reference deleted.

11. "Safety Assessment for Push- and Rotary-Mode Core Sampling in Ferrocyanide Tanks," Westinghouse Hanford Company report WHC-SD-WM-SAD-013, Rev 3-A (November 1993).

12. "Safety Analysis for the Push Mode and Rotary Mode Core Sampling," Westinghouse Hanford Company report WHC-SD-WM-SARR-031, Rev. 2 (July 1995).

13. "Safety Requirements for Safety Basis for Rotary-Mode Core Sampling Flammable Gas Safety Issue Tanks," Westinghouse Hanford Company report WHC-SD-WM-FDC-048 (September 1995).

14. R. J. Blanchard, "Justification on Functional Criteria for Rotary Mode Core Sample Truck," Westinghouse Hanford Company memo (January 19, 1995).

15. Westinghouse Hanford Company, "Truck Assembly (RMCST)," Drawing H-2-690000 (June 27, 1995).

16. Westinghouse Hanford Company, "Grapple Hoist Assembly (RMCST)," Drawing No. H-2-690057 (March 11, 1994).

17. Westinghouse Hanford Company, "Inner/Outer Bellows Assembly (RMCST)," Drawing No.H-2- 690059 (March 21, 1994).

18. Westinghouse Hanford Company, "Grapple Hoist Rotary Valve Actuator (RMCST)," Drawing No. H-2-690052 (March 7, 1994).

19. Westinghouse Hanford Company, "Quill Rod Assembly (RMCST)," Drawing No. H-2-690051 (February 17, 1994).

20. Westinghouse Hanford Company, "Drill String Arrangements," Drawing No. H-2-821457 (March 29, 1994).

21. Westinghouse Hanford Company, Core Sampler Assembly," Drawing No. H-2-690140 (December 1, 1995).

22. Westinghouse Hanford Company, "Shielded Receiver Assembly (RMCST)," Drawing No. H-2-690020 (March 11, 1994).

23. Westinghouse Hanford Company, "Sampler Housing Assembly (RMCST)," Drawing No. H-2-690030 (March 14, 1994).

24. Westinghouse Hanford Company, "Shielded Receiver Tube Section (RMCST)," Drawing No. H-2-690022 (February 19, 1994).

25. Westinghouse Hanford Company, "Mechanical Remote Latch Unit," Drawing No. H-2-690142 (January 15, 1996).

26. Westinghouse Hanford Company, "3" Ball Valve Modification (RMCST)," Drawing NO. H-2-690023 (February 19, 1994).

27. Westinghouse Hanford Company, "Kamlok Adapter Assemblies," Drawing No. H-2-81845 (August 5, 1993).

28. Westinghouse Hanford Company, "Purge Gas Assembly," Drawing No. H-2-690060 (January 25, 1994).

29. "System Design Description for the Rotary Mode Core Sampling Exhauster," Westinghouse Hanford Company report WHC-SD-WM-SDD-035, Rev. 2 (September 9, 1995).

30. Westinghouse Hanford Company, "Exhauster Assembly Rotary Mode Core Sampling," Drawing No. H-2-818186 (March 3, 1994).

31. Westinghouse Hanford Company, "12 in. to 4 in. Offset Riser Adapter," Drawing No. H-2-99335 (May 1995).

32. Westinghouse Hanford Company, "Drill Rod Washer Housing Assembly and Details," Drawing No. H-2-91670 (September 27, 1994).

33. Guiberson Dresser Company, "Tubing Spider, Type T-40."

34. Parmelee Company, "Pipe Wrench."

35. Westinghouse Hanford Company, "Change-out Assembly," Drawing No. H-2-690133 (December 1995).

36. Westinghouse Hanford Company, "Cable Spray Washer Assembly," Drawing No. H-2-81842 (May 1993).

37. Westinghouse Hanford Company, "Mobile Core Sample X-ray System," Drawing No. H-2-79076 (June 22, 1995).

38. Westinghouse Hanford Company, "Transfer Cask Assembly," Drawing No. H-2-38079 (August 1994).

39. "Tank Farm Operating Procedure, ONAN 150DGFA Generator Set Operation," Westinghouse Hanford Company procedure TO-020-900, Rev. B-3 (July 1995).

40. D. Hamilton, J. Smalley, and J. Criddle, Westinghouse Hanford Company personal communication (November 1995).

41. Boyles, "Operating Specifications for Single-Shell Waste Storage Tanks," Westinghouse Hanford Company report OSD-T-151-00013, Rev. 0 (1994).

42. "Tank Farm Operating Procedure, Perform Rotary Core Sampling of Ferrocyanide, Organic, Organic/Ferrocyanide Watch-List Waste Storage Tanks," Westinghouse Hanford Company procedure TO-080-056, Rev. A-1 (October 10, 1995).

3.0. IDENTIFICATION OF HAZARDS

This section presents the methodology and results of a hazards identification study used to formally identify all hazards associated with the proposed action of the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations. This process, called hazard identification, is equivalent to the hazard analysis (HA) or hazard evaluation process in a safety analysis report. The final product of this hazard identification process is a list of design-basis accidents (DBAs) that will be examined in more detail in the accident analysis section of the safety analysis (SA).

According to Ref. 1, hazard is defined as "A source of danger (i.e., material, energy source or operation) with the potential to cause illness, injury or death to personnel or damage to an operation or to the environment." A hazard is not an accident initiator, cause or deviation. Rather, it is a property, typically radiological and toxicological, inherent to the danger. Based on this definition, the hazards associated with the FG/RMCS operations in flammable-gas tanks are summarized in Table 3-1.

The major consequence of accidents in the flammable-gas SSTs is the release of radioactive and toxic materials that might expose the public sector and/or on-site personnel to unacceptable doses. Airborne, underground, and surface release pathways are considered in the study. In addition, any structural damage of the tank that would cause major damage in the dome area or leaks in the liquid region are evaluated. Radiological and toxicological consequences resulting from dome collapse are also evaluated in this safety assessment. Leaks below the waste level, however, are identified as potential environmental hazards and the long-term consequences are not evaluated.

3.1. METHODOLOGY

The guidance used to perform the hazard identification (or HA) is DOE-STD-3009 (Ref. 1). DOE-STD-3009 provides the following guidance on the requirements for a complete hazards analysis. A complete hazards analysis should (STD-3009, p. 31)

1. Consider the complete spectrum of accidents that may occur as a result of facility operations;

2. Analyze potential consequences to the public and worker;

3. Estimate the likelihood of occurrence;

4. Identify and assess associated preventive and mitigative features;

TABLE 3-1
SUMMARY OF POTENTIAL HAZARDS

HAZARDOUS MATERIALS		
MATERIAL	**LOCATION**	**FORM and QUANTITY**
Flammable Gases	Stored in the waste with potential release to - the dome space, - the drill string, drill unit and shielded receiver - the environment (above ground)	Major species are hydrogen, ammonia, methane, nitrous oxide (oxidizer), and oxygen. Composition and quantities vary. See discussions in Appendixes C and L.
Flammable Solids and Liquids	In the waste.	Organic compounds with oxidizers. Composition and quantities vary. See discussion in Appendix G.
Radioactive Solids and Liquids	In the waste	Bounding dose is discussed in Appendix R.
Fissile Materials	In the waste	Bounding quantity discussed in Appendix R.
Toxic Gases	Stored in the waste with potential release to the environment.	Major species are ammonia and nitrous oxide. Composition and quantities vary. See discussion in Appendix C.
Toxic Solids and Liquids	In the waste	Bounding dose is discussed in Section 5 of this SA.
ENERGY SOURCES		
ENERGY	**LOCATION**	**FORM and QUANTITY**
Electrical (spark sources)	- Dome space - Ventilation system - Truck - Above ground near risers.	- Various electrical equipment - Material with potential electrostatic charge built-up.
Mechanical (spark sources)	- Dome space - Ventilation system - Above ground (near risers) - Truck - Inside the drill string - In the waste	- Drill bit and drill string with kinetic (rotational and linear) and potential energy - Truck and other vehicles with kinetic energy - Moving parts with kinetic energy (pumps, motors, etc.) - Heavy equipment with potential energy - Tools with spark potential - Ventilation fan with kinetic energy - Compressed gases - Air motion caused by active ventilation

TABLE 3-2 (cont)
SUMMARY OF POTENTIAL HAZARDS

ENERGY SOURCES		
ENERGY	LOCATION	FORM and QUANTITY
Chemical	- Tank - Truck (on the tank) - Tank Farm	- Propane tank - Diesel and gasoline - Lubricants - Water and nitrogen added to the waste
Radiant	Truck (on the tank)	- X-Ray machine - Waste samples
External Events	Tank Farm	- Lightning/Tornadoes/Heavy Rains - High Winds/Dust Devils - Earthquake/Volcanoes - Range fires

5. Identify safety-significant structures, systems, and components; and
6. Identify a select subset of accidents to be formally defined in accident analysis.

In the hazards identification performed for rotary-core mode drilling, four of the six requirements listed above were met in full. Namely, (1) a complete consideration of the spectrum of accidents, (2) analysis of the potential consequences, (3) estimation of likelihood, and (6) identification of a select subset of accidents for accident analysis (the end product for this hazard identification). However, two of the requirements, (4) the identification of preventive and mitigative features; and (5) identification of safety-significant structures, systems, and components, were only partially met. For the rotary core mode drilling activity, hardware design and procedures were being developed during the hazard identification (hazard analysis) process. Therefore, at that time, preventive and mitigative procedures were not fully identified. By not identifying the preventive and mitigative features, the identification of safety-significant structures, systems, and components could also not be performed. However, identification of preventive and mitigative systems is performed in the design change/control implementation phase of this SA and documented in Section 6. A list of equipment significant to safety is provided in Section 6.

Hazard identification is the first step in the safety analysis process. The goals of hazard identification for this SA are a subset of the hazard analysis requirements presented earlier, namely;

- Consideration of the complete spectrum of potential accidents,

- Qualitatively assess the consequences to the worker and the public,
- Qualitatively estimate the frequency (or likelihood) of occurrence,
- Identification of a select set of representative and unique accidents (DBAs) for further evaluation.

Because of the relative complexity of the rotary-core drilling system and its unique intrinsic hazards, a detailed hazards identification study was performed considering all phases and aspects of the rotary-core drilling operation. The intent was to meet the requirements of Department of Energy (DOE) Order 5480.23 (Ref. 2) to identify all the hazards and accidents scenarios. The rotary-core drilling hazard identification process was performed by a multidisciplinary team consisting of Los Alamos and Westinghouse personnel, using a combination of two standard techniques, the hazard and operability (HAZOP) technique and "what if" checklist techniques. The operations examined were the installation of the equipment, the individual steps of the rotary-mode sampling, and the removal of the equipment. The operation was tracked in this way to ensure completeness of the HA.

At the beginning of the HA, the Westinghouse Hanford Company (WHC) Characterization Project Engineering and Operations personnel presented and described the operations. Subsequently a process-flow diagram was prepared to describe all phases of the installation, operation, and removal of the rotary-mode sampling equipment on a typical tank. Previous safety analyses, the available design documentation, and the operating procedures were reviewed before another meeting with FG/RMCS engineering and operations personnel. The hazards analysis was developed based on the process-flow sheets and the questions that resulted from the documentation review. Hazards identified in previous safety assessments[3,4,,6] were reviewed and included in this study. The results of the hazards identification study are documented in Appendix A.

The HA includes estimates of the frequencies and consequences of the hazards that have been combined to provide a risk ranking. The risk ranking is one factor used to select the accidents. The accident database was examined and nine accident classes were selected for further analysis. Section 4 of this SA evaluates these nine accident classes. Alternative groupings are possible, and inevitably the grouping in some cases is not very clear. However, although the boundary between the groups may be subjective, the grouping process was complete, and all of the identified hazards are captured in these groupings.

This SA discusses all of the hazards identified and how they are managed to acceptable levels of risk. Some of this will be a discussion of the design features and controls. In some cases, analyses are used to show that the accident cannot happen physically. Also, analyses are presented to quantify the bounding consequences in the event that preventative and mitigation features are ineffective.

3.2. RESULTS OF THE ROTARY-CORE DRILLING SYSTEM HAZARDS IDENTIFICATION

The hazard identification conducted for the proposed action examined three processes; installation, operation, and removal of the rotary-core drilling unit. The hazards associated with transportation, of a contaminated rotary-core drilling unit or its auxiliary equipment from the tank farm or its ultimate decontamination and disposal are not considered. Transportation of the cask where core samples are stored also is not considered. These activities are included in the safety analysis reports for site transportation waste storage, and handling (see Ref. 7), and are subject to the applicable controls listed there. Operations evaluated included X-ray examination and storing the core sampler in the cask.

The results of the hazards identification indicate that the potential contributors to the release of radioactive and toxic materials and structural damage to the tank can be categorized in nine general categories of accidents. In Appendix A, details of the hazards identification and the general accident categories are presented. A total of 180 scenarios resulting in waste and toxic-gas releases were identified. The individual accidents are evaluated based on their qualitative accident frequency and resulting consequences. In Appendix A, a frequency and a dose class are assigned to each accident in order to rank them. The dose rates indicated in Appendix A are qualitative values. Likewise, frequency determination did not include a detailed failure-rate evaluation, but qualitative frequency estimates are provided. Selection of representative and unique accidents consider frequency and consequence in order to rank individual hazards. These representative unique accidents are categorized in nine groups based on their release characteristics.

The results of the hazards identification process are summarized in Tables 3-2 to 3-10. For each accident category, a separate table is given. The accident, the applicable scenario, principal causes, and design safety features are given for each case.

Specific design-related features, primarily those provided to manage identified hazards, are included because their failure may cause an accident.

The relationship between hazards and accident analyses is determined for each accident in a given category. The accident analysis is cross-referenced to the section in Chapter 4 where the potential accident is evaluated. In some cases, the same accident analysis covers more than one hazard or initiator. In other cases, several accident analyses will be required to assess the various manifestations of the hazard.

The following is the summary of the tables in which the different accident hazard groups are summarized. Industrial hazards such as installations in the wrong tanks or risers, operation of the liquid nitrogen tank, traffic accidents, slips, falls, etc., are beyond the scope of this safety assessment.

SUMMARY OF TABLES

Group	Table
Aboveground fire	Table 3-2
Dome fire	Table 3-3
Drill string fire	Table 3-4
Waste fire	Table 3-5
Chemical reactions and criticality	Table 3-6
Containment breach	Table 3-7
Gas releases	Table 3-8
Spills and radiation exposure	Table 3-9
External events	Table 3-10

TABLE 3-2
ABOVEGROUND FIRE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Flammable-gas release to exhauster and burn	• Flammable-gas release from waste into exhauster and ignition source. • Ignition in the exhauster and burn back to the tank dome (see Dome Fires)	• All electrical equipment in the exhauster flow stream must be rated to Class-1, Div.-I, Group-B environment. • Do continuous exhausting with spark-resistant fan. • Use heavy-duty, tear-resistant, conductive hose. • Use redundancy/diversity in gas-release detection system (flammable gas and pressure).	Sec. 4.1.1.
Flammable gas release through torn duct and burn	• Gas release through torn hose	• Use heavy-duty, tear-resistant, conductive hose. • Nonqualified equipment behind deflectors or in enclosures.	Sec. 4.1.2.
Flammable-gas release and burn outside an open riser	• Flammable-gas release from waste through open risers and ignition source • Ignition above the tank and burn back to the tank dome (see Dome Fire)	• Inlet and exhaust have a stack height of 5 m (15 ft). • All electrical equipment near open risers must be rated to Class-1, Div.-I, Group-B environment or Class-1, Div.-II, Group-B environment with automatic shutdown. • N2 purge of riser liner	Sec. 4.1.2.1.
Flammable-gas release and burn in shielded receiver.	• Flammable-gas release from shielded receiver, drill string, and ignition source.	• Use hydrostatic head purge in the shielded receiver. • Electrical equipment is designed for Class I, Division 1, Group B in the shielded receiver. • Spark-resistant mechanical RLU/sampler. • Cable hoist structural strength prevents RLU drop.	Sec. 4.1.2.2.
Flammable-gas release and burn in the X-ray or cask	• Flammable-gas release into X-ray machine and into storage casks.	• X-ray sample liner is made of plastic. • No unqualified equipment in Class I, Division 1 or Class I, Division 2 space in x-ray machine. • Liner is painted with conductive graphite paint, and grounded and bonded.	Sec. 4.1.3.
Flammable-gas release and burn	• Flammable-gas accumulation or release from the loss of electrical power and ignition source	• No unqualified equipment in Class I, Division 1 or Class I, Division 2 space	Sec. 4.1.4.

TABLE 3-2 (cont.)
ABOVEGROUND FIRE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Flammable-gas release and burn	• Release from propane tank on nitrogen trailer	• No credited design feature.	Sec. 4.1.5.
Flammable material and burn	• Flammable diesel and gasoline fuel	• No credited design feature.	Sec. 4.1.6.
Equipment fire	• Collision caused by trucks and other equipment	• No credited design feature.	Sec. 4.1.7.

TABLE 3-3
GAS RELEASE AND DOME FIRE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Flammable gas and burn	• Drill string break	• Automatic shutdown on high flammable gas.	Sec. 4.2.1.
Flammable gas and burn	• Equipment, tools, or drill string/ component drop on riser induces mechanical spark.	• Use spark-resistant tools.	Sec. 4.2.2.
Flammable gas and burn	• Equipment, tools, or drill-string/component drops on crust.	• Pneumatic clamp is designed to fail closed. • Use of spark resistant tools. • Use of locking collar	Sec. 4.2.3.
Flammable gas and burn	• Frictional spark in the riser.	• Use stainless-steel sleeve in the riser. • Inject nitrogen into riser sleeve to prevent hydrogen penetration. • Automatic shutdown on loss of sleeve purge. • Automatic shutdown on high flammable gas. • Unique connectors for sleeve purge.	Sec. 4.2.4.
Flammable gas and burn	• Electrostatic spark in the riser	• Equipment grounded and bonded.	Sec. 4.2.5.

TABLE 3-3 (CONT)
GAS RELEASE AND DOME FIRE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Flammable gas and burn	• Frictional spark caused by drill bit on crust	• Drill bits do not have spark-inducing carbide teeth. Cutting teeth are copper-based soft material. • Drill bit design must be qualified by testing to non sparking. • Automatic shutdown on high rpm and down force. • Use of walkdown function and HBD.	Sec. 4.2.6.
Flammable gas and burn	• Spark sources – in the dome – in the ventilation system, – in connected tanks	• All electrical equipment in the dome and ventilation system is rated for operations in Class-1, Div.-I, Group-B environment or Class-1, Div.-II, Group-B environment with automatic shutdown.	Sec. 4.2.7.
Dust explosions	• Aerosol accumulation	• Use of qualified exhauster.	Sec. 4.2.8.

TABLE 3-4
DRILL STRING FIRE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Flammable gas in the drill string	• Failure of sampler chevron seal • Hydrogen diffusion • Waste in the drill string • Depressurization of waste • Loss of N_2 • Incompatible material	• Sampler chevron seal. • Drill string purge gas. • Hydrostatic head purge. • Shut down on low nitrogen flow. • Use of compatible material.	Sec. 4.3.1.
Flammable gas and burn in drill string	• Drop impact on drill bit by sampler, remote latch unit, or grapple	• Components within the drill string must be qualified to the requirements of Appendix T, or prevented from dropping. • Sampler chevron seal.	Sec. 4.3.2.
Flammable gas and burn in drill string	• Ignition caused by assembly/ disassembly of drill strings • Ignition by drill-rod/quill-rod adapter impact	• Components must be qualified to the requirements of Appendix T	Sec. 4.3.3.
Flammable gas and burn in the drill string	• Unqualified in the drill head or SR	• Electrical equipment meets Class I, Div. 1, Group B requirements	Sec. 4.3.4
Flammable gas and burn in drill string	• Drill string failure	• Use N_2 purge of drill. • Sampler chevron seal	Sec. 4.3.5.
Ignition source and flammable gas in the drill string	• Friction • bearings • RLU • Grapple	• Use N_2 purge. • RLU/grapple insertion rate limited to 1 ft/s.	Sec. 4.3.6.
Flammable gas in the drill string	• Shear pin break	• Use N_2 purge. • Shear pin is replaced by a clip.	Sec. 4.3.7.

TABLE 3-4 (cont.)
DRILL STRING FIRE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Detonation and ejection	• Flammable gas ignition in the drill string	• Sampler chevron seal. • Electrical equipment meets Class-1, Div.-I, Group-B requirements. • Shut down on low nitrogen flow. • Components within the drill string must be qualified to the requirements of Appendix T, or prevented from dropping. • Use of compatible materials.	Sec. 4.3.8.
Ignition in the drill string caused by lightning strike	• Lightning strike	• No credited design feature.	Sec. 4.3.9.
Ignition in drill string caused by static electricity	• Static electricity between O-rings • Static electricity on the Frisbee	• Maintain continuous contact with metal and is bonded. • Sampler design maintains contact with drill string.	Sec. 4.3.10.

TABLE 3-5
WASTE FIRE-HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Drill bit over-temperature	• Loss of N_2 • Down force • Rotational speed • Low penetration rate	• Automatic shutdown on loss of N2 purge. • Automatic shutdown on high RPM. • Automatic shutdown on high downforce. • Use bottom detector and walkdown function. • Automatic shutdown on low penetration rate	Sec. 4.4.1.
Exothermic reactions	• Incompatible materials	• Use of compatible material.	Sec. 4.4.2.
Impact on crust of waste	• Drop of drill string or tool	• No credited deesign feature..	Sec. 4.4.3.
Gas fire under surface	• Spark induced with drill bit impact • Inadvertent increase in force and rpm	• Components in contact with the waste must be qualified to the requirements of Appendix T. • Automatic shutdown on high rpm, down force. • Automatic shutdown on low nitrogen purge flow and penetration rate.	Sec. 4.4.4.

TABLE 3-6
CHEMICAL REACTIONS AND CRITICALITY HAZARD RESULTS

Accident	Scenario	Design Safety Features	Analysis
Criticality	• Drilling operation	• No credited design feature	Sec. 4.5.1.
Gas release caused by water addition	• Water addition	• Limited supply of water. • Temperature control on water heater.	Sec. 4.5.2.
Exothermic runaway reactions Waste melting	• Drill bit frictional energy • Water addition • Loss of N_2 purge • Plugged purge holes	• Carry out N_2 purge during rotation. • Automatic shutdown on high rpm, and down force. • Automatic shutdown on low penetration rate and nitrogen purge flow.	Sec. 4.5.3.
Energy transfer to/from the waste	• Frictional heating • Loss of N_2 purge	• Automatic shutdown on high rpm, and down force. • Automatic shutdown on low penetration rate and nitrogen purge flow.	Sec. 4.5.4.
Impact sensitive compounds	• Drilling • Pushing	• No credited design feature.	Sec. 4.5.5.

TABLE 3-7
CONTAINMENT BREACH HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Dome Loading	• High static loading • Dynamic loads • Truck falls off platform • Crane drop	• No credited design feature.	Sec. 4.6.1.
Vacuum	• Exhauster failure • Inadvertent closure of inlet riser	• Automatic shutdown on exhauster with high vacuum. • Seal loop on breather filter.	Sec. 4.6.1.
Tank bottom penetration	• Drill into bottom • Drill string drop and penetration	• Use hydraulic bottom detector. • Use soft drill bit material. • Automatic shutdown on high down force. • Use of pneumatic foot clamp.	Sec. 4.6.2.
Drill-string break	• Excessive down force • Excited frequency	• No credited design feature.	Sec. 4.6.3.
Riser damage	• Equipment (conductive sleeve and drill string) and tool drops	• No credited design feature.	Sec. 4.6.4.
Side penetration	• Drill string failure	• No credited design feature.	Sec. 4.6.5.

TABLE 3-8
GAS RELEASE WITHOUT BURN HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Toxic-gas release	• Drilling operations • Multiple release modes • Additional N_2 purge	• Automatic shutdown on high gas concentration. • Use exhauster stack for worker protection. • Use of inlet breather filter stack.	Sec. 4.7.1.
Unfiltered release	• Ventilation failure • Tank pressurization	• Use of qualified exhauster HEPA and breather HEPA filters	Sec. 4.7.2.
Steam release	• Drill temperature induces steam	• No credited design feature.	Sec. 4.7.3.
N_2 addition	• Accumulation in waste causing a gas-release event • Ammonia scrubbing	• Use of qualified exhauster. • Automatic shutdown on tank pressure and gas concentration.	Sec. 4.7.5.

TABLE 3-9
SPILLS AND RADIATION EXPOSURE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Exhauster releases	• HEPA failure	• Use ΔP limits. • Use high- and low-flow shut down exhauster. • Loss of exhauster flow shuts down N_2 and drill.	Sec. 4.8.1.
Exhauster continuous release after filter failure	• HEPA failure	• Use ΔP limits. • Use high- and low-flow shut down exhauster. • Loss of exhauster flow shuts down N_2 and drill.	Sec. 4.8.2.
Inlet duct failure	• Breather HEPA filters fail	• No credited design feature.	Sec. 4.8.3.
Aerosol	• Loss of ventilation flow and failure to shutdown purge	• Use of qualified exhauster. • Use of breather inlet HEPA filter stack. • Use of exhauster stack.	Sec. 4.7.2.
Sprays	• No initiators	• No credited design feature.	NA
Drop sampler	• Operational hazard	• No credited design feature.	Sec. 4.8.4.

TABLE 3-9 (cont.)
SPILLS AND RADIATION EXPOSURE HAZARD ASSESSMENT RESULTS

Accident	Scenario	Design Safety Features	Analysis
Open sampler	• Stuck ball valve	• Use viewing window. • Use transfer to shielded cask through closed system.	Sec. 4.8.5.
Spill in core barrel	• Waste accumulation in core barrel	• Cable spray washer.	Sec. 4.8.6.
Drop of contaminated drill string	• Ineffective decontamination and drop	• Spray wash system.	Sec. 4.8.7.
Radiation exposure	• High loading in HEPA • Spills • Open riser • Failure of decontamination	• No credited design feature.	Sec. 4.8.8.

TABLE 3-10
RESULTS OF HAZARD ASSESSMENT FOR EXTERNAL EVENTS

Accident	Accident Scenario	Design Safety Features	Analysis
Lightning	• Ignition of flammable gases	• No credited design feature.	Sec. 4.9.1.
Winds	• Flow induced vibration • Static electricity buildup • Spread of contamination • Operator errors/equipment drop	• Conductive duct. • Heavy skid. • Exhauster stack and inlet breather HEPA stack is designed for high winds.	Sec. 4.9.2.
Range fires	• Ignition of flammable gases	• No credited design feature.	Sec. 4.9.3.
Seismic	• Tank failure • Gas-release event	• No credited design feature.	Sec. 4.9.4.
Tornadoes	• See lightning/flooding/high winds	• No credited design feature.	Sec. 4.9.5.
Flooding/ heavy rains	• Tank overfill • Equipment malfunction • Operator errors	• No credited design feature.	Sec. 4.9.6.
Volcanoes	• Flooding, gas ignition, dome loading	• No credited design feature.	Sec. 4.9.7.
Dust devils	• Spread of contamination • Operator error/equipment drop	• No credited design feature.	Sec. 4.9.8

3.3. REFERENCES

1. "DOE Standard Preparation Guide for U. S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports," DOE-STD-3009-94 (July 1994).

2. "Safety Analysis Report," US Department of Energy Order 5480.23 (April 30, 1992).

3. N. J. Milliken and G. R. Geschke, "Safety Analysis for Push-Mode and Rotary-Mode Core Sampling," Westinghouse Hanford Company report WHC-SD-WM-SARR-031, Rev. 2 (July 1995).

4. N. J. Milliken, "Safety Assessment for Push-Mode and Rotary-Mode Core Sampling in Ferrocyanide Tanks," Westinghouse Hanford Company report WHC-SD-WM-SAD-013 (June, 1993).

5. Reference deleted.

6. R. L. Koontz, "Hazards Identification and Evaluation for Waste Tank Core-Sampling Equipment," Westinghouse Hanford Company report WHC-SD-WM-SAR-007 (June 1985).

7. H. E. Adkins, Jr., "Safety Analysis Report for Packaging on Site, on Site Transfer Cask," Westinghouse Hanford Company report WHC-SD-TP-SARP-002, Rev. 0-o (November 11, 1995).

4.0. HAZARD ANALYSIS

In Section 3, the hazards associated with the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations, were identified, and the resulting accidents were grouped into nine categories. In Section 4, each accident category is quantitatively discussed in the following subsections:

- Section 4.1: Aboveground Fire Accidents
- Section 4.2: Dome Fire Accidents
- Section 4.3: Drill String Fire Accidents
- Section 4.4: Waste Fire Accidents
- Section 4.5: Chemical Reactions and Criticality Accidents
- Section 4:6: Containment Breach Accidents
- Section 4.7: Gas Releases without Burn
- Section 4.8: Spills, Releases, and Hazardous Material and Radiation Exposure
- Section 4.9: External Events

Radiological and toxicological consequences of the above accidents are discussed in Section 5 of this safety assessment (SA).

In this section, the frequencies are estimated and discussed for each accident in the corresponding subsection. Both the unmitigated accident frequency (UAF) and the mitigated accident frequency (MAF) for each accident are provided in which credit is taken for the administrative controls established in this safety assessment (SA) and in other safety basis documents. In Appendix D, the equipment reliabilities are computed for each FG/RMCS activity. An FG/RMCS activity is defined to include preinstallation equipment setup, installation of the FG/RMCS equipment, the collection of a complete set of core samples representing an entire tank depth, and removal of the FG/RMCS equipment. One hundred forty-four hours are required to complete an entire activity. Within this 144-h period, 40 h (approximately 2 samples collected per shift) are required to retrieve the 11 samples (based on an average SST waste depth). Total drilling time is approximately 4 h (20 min. per sample). Exhauster and truck shutdown instrumentation systems and calibration are checked and calibrated every six months. Assuming there are two FG/RMCS activities per year per tank, the accident frequency is calculated per year per tank.

There are several key assumptions that underlie assigning a probability to a given event (Appendix E). The probability of a human error was assumed to be 0.003 based on assumptions defined in NUREG-CR-4772[1] and listed in Appendix E. FG/RMCS operations are required to comply with these assumptions. Therefore, they are listed in Section 6 as administrative controls.

Also considered in determining the accident frequencies is the probability of phenomenological events such as gas-release events (GREs), fraction of the waste causing propagating exothermic reaction, spark generation, and propagation of fire into the dome or into the waste.

The major hazard associated with FG/RMCS operations in flammable-gas tanks is the existence of flammable material. Consequently, four of the nine accident categories identified in the SA are burn scenarios, which generally result in the highest radiological and toxicological consequences because a dome space deflagration in an SST is likely to result in a catastrophic dome failure (see Section 5 of this SA).

To eliminate a fire hazard, either the fuel, the oxidizer, or the ignition source must be eliminated or controlled, and for the safety of FG/RMCS operations, one or more of these factors is controlled under different conditions. Each identified ignition source was analyzed and is discussed in terms of how each is managed by either controls or design safety features. In analyzing the fire risk associated with the proposed FG/RMCS activities, the following multistep approach was used in the following specified order:

1. The most important issue was to develop and implement a spark-management strategy that is appropriate for a hazardous flammable-gas environment. In summary, the spark-management strategy provides a minimum of two protective system barriers against spark sources (including mechanical sparks) so that no single failure leads to a sparking condition. The details of the spark management strategy are summarized in Appendix B.

2. After implementing the spark-management strategy, the reliability of the equipment used to protect against fire accidents was quantified (Appendix D). Considering the type of operation, failure probabilities on the order of 10^{-4} to 10^{-5} per activity for the protection systems were used to provide reasonable assurance that all practicable preventive measures would be taken against burn accidents.

3. After completing the first two steps, the probability of a GRE was introduced to assess realistic accident frequencies. In this SA, GRE is

defined as any gas release that exceeds the steady-state releases in the SSTs by either volume or rate. The probabilistic model of GREs is discussed in Appendix L.

It is recognized that the order of steps differ from the order one would use to quantify the event trees. Typically, the GRE would be the initiating event and the probability of a burn accident would be the product of the following sequence probabilities:

Burn Probability = (Probability of a GRE causing flammable conditions locally)

x (Failure probability for the protective system)

x (Probability of a spark that can ignite the gas mixture)

x (Probability of flame propagation).

However, in the beginning of the SA process, it was recognized that there is much uncertainty in the magnitudes and probabilities of a GRE for the SSTs as defined in the first term of the above equation, and that design decisions and design controls could not be based on a poorly quantified event probability. Therefore, our initial assumption was that the probability of a large GRE is high, and that flammable gases exist continuously in the areas where potential spark sources are located. Thus, design-changes and design-controls were conservatively developed without taking credit for the GRE probabilities.

System reliabilities are estimated in Appendix D. Table 4-1 gives a summary of the system reliability quantification (see Appendix D for details). Frequency estimates for the initiating event are given for the activity. These frequency estimates are used in event trees for the postulated accidents discussed in this section to determine the accident frequencies. The final accident frequency estimates are also listed in Appendix E.

After completing the assessment of equipment reliabilities, the GRE probability was evaluated. Based on the analysis provided in Appendix L, it is assumed that GREs would occur during the FG/RMCS operations. However, the frequency of having a resulting flammable-gas concentration exceeding the lower flammability limit (LFL) in the dome space with the dome pressure being positive is estimated as 7.0E-5 per activity. The bounding period of the dome concentration being greater than the LFL limit during the FG/RMCS operations was computed to be <0.12 min./activity, assuming that the ventilation system is continuously operational during a GRE. The time period during which the LFL is exceeded (time-at-risk) divided by the 144-hour mission time of FG/RMCS operations per activity is 1.4×10^{-5}, which is the probability of a GRE during FG/RMCS activities for accidents involving a random spark. For certain accidents, the GRE probability based on the exposure period to flammable gas is not adequate. These are accidents in which the spark sources are not random in time. In those accidents, the GRE probability of causing the dome pressure to be positive is more appropriate. Thus, depending upon the accident scenario, a GRE probability of 7.0E-5 or 1.4E-5 is used.

TABLE 4-1
SUMMARY OF SYSTEM RELIABILITY QUANTIFICATION

Initiating Event Frequency (1/activity)	Probability of Subsequent Failures	Frequency (1/activity)
Excessive force used while taking any sample except last sample, 0.05 per sample, 0.55 total for 11 samples.	Failure to detect excessive force and stop drill, 7.9E-5.	4.3E-5
Excessive force used while taking last sample ,0.05.	Failure to detect excessive force and stop drill, 7.9E-5.	4.0E-6
Total for excessive force with failure to stop drill.		4.7E-5
High H_2 level in exhauster, 1.0.	Failure to detect hydrogen, 7.6E-4. Failure to detect hydrogen and trip the drill string 1.6E-3	7.6E-4 1.6E-3
High H_2 rate of rise in exhauster, 1.0.	Failure to detect hydrogen, 7.6E-4. Failure to detect hydrogen and trip the drill string 1.6E-3	7.6E-4 1.6E-3
High dome pressure caused by H_2 release, 1.0.	Failure to detect hydrogen, 7.7E-4. Failure to detect hydrogen and trip the drill string, 1.7E-3	7.7E-4 1.7E-3
H_2 from waste, 1.0.	Failure of drill string N_2 hydrostatic system, 6.4E-3.	6.4E-3
H_2 from waste, 1.0.	Failure of shielded receiver N_2 hydrostatic system, 6.4E-3.	6.4E-3
H_2 from waste, 1.0.	Failure of both drill string N_2 hydrostatic system and shielded receiver N_2 hydrostatic systems, 6.9E-4	6.9E-4
Drill string held above waste with foot clamp, 1.0.	Foot clamp drops drill string onto waste surface, 3.0E-5.	3.0E-5
Excessive rpm during drilling , 0.011.	Failure to trip drill string on excessive rpm, 6.2E-4.	6.8E-6
Perform drilling operation, 1.0.	Total loss of N_2 cooling and failure to stop drill, 3.3E-6.	3.3E-6
Perform drilling operation, 1.0.	Loss of drill bit N_2 cooling from N_2 bypass leakage, 1.6E-5.	1.6E-5
Total for overheating drill bit caused by inadequate N_2 cooling.		1.9E-5
Take a sample, 11.0.	Failure of rotary valve in sampler to completely close, 0.1.	1.1
Perform drilling operation, 1.0.	Failure of sampler chevron seal.	3.3E-2
H_2 from Waste, 1.0.	Failure of H_2 sniff in drill string, 4.6E-3 (3.0E-3 operator, 1.6E-3 hardware).	4.6E-3
Excessive filter DP , 1.0.	Fail to trip exhauster on filter DP, 2.6E-3.	2.6E-3
Contact rock in waste, 0.1.	Failure of penetration rate and failure of N_2 cooling to drill bit systems, 3.3E-6.	3.3E-7

The third term in the burn probability equation is the probability of a spark, which is also not easy to evaluate for a general case. It was assumed that the probability of a spark is high, given that flammable conditions exist near nonqualified electrical equipment. Sparks caused by materials with potential electrostatic discharges are also assumed to occur with a probability of 1.0 when the environment is flammable. Ignition as a result of sparks caused by mechanical impacts and drops are, in general, evaluated by performing mechanical ignition tests.

Propagation of a fire from the tank top into the tank dome is assumed to be likely for certain accidents (especially for gas releases through openings at the top of the tank). The velocity of the released gas could be small enough to allow fire propagation to occur.

In the following subsections, the accidents of concern are quantitatively discussed. In each subsection, the accident, its causes (dominant failures), and mitigation or credited assumptions or controls are defined in evaluating accident frequencies. The accident frequency based on credited assumptions or controls is defined as the MAF. The UAF does not consider the effects of credited assumptions or controls listed in Tables given in the rest of this section. Appendices D and E provide the details of how the UAFs and MAFs are obtained. Appendix E provides two sets of event trees; one for mitigated accidents and one for unmitigated accidents. The mitigated and unmitigated accident frequencies are given in the summary tables and used primarily to identify the level of the controls.

4.1. ABOVEGROUND FIRE ACCIDENTS

Accidents in this category include all fire initiators on the top of the tank for which FG/RMCS activities are performed. For this accident scenario, it is postulated that waste-intrusive FG/RMCS operations may cause a large GRE resulting in a flammable-gas environment above the tank through possible leak paths. If a fire occurs at the top of the tank, it could propagate into the tank dome. The fire propagation into the tank may result in structural damage to the tank and in significant material releases.

4.1.1. Flammable-Gas Release to Exhauster and Burn (Ignition in the Exhauster, Electrostatic and Electrical/Mechanical, and Other Spark Sources, Operation, and Removal)

Preinstallation and installation phases do not include waste-intrusive activities. Therefore, a gas-release event is not expected in single-shell tanks during these phases. Westinghouse Hanford Company (WHC) standard controls require verification that the tank dome does not have flammable gas before starting the installation phase. The preinstallation phase also includes testing of critical alarms. The exhauster and its safety system, as briefly discussed in Section 2, are required to be operational during FG/RMCS operations, including drilling and sample retrieval activities. Drilling starts by turning the nitrogen purge flow to the drill bit at a rate >

30 scfm. Any time the nitrogen purge flow is terminated, a 16-hour, post-drilling exhauster operation is required. During this period, sample retrieval, or other FG/RMCS-related activity could occur. If drilling is resumed during this period, the 16-h requirement must be reestablished after termination of the nitrogen purge flow. The 16-h requirement corresponds to the time in which the equivalent of 4 dome-volumes is circulated at a minimum nominal flow rate of 200 scfm, primarily to remove aerosols and flammable-gas accumulations created during the drilling. To completely circulate the equivalent of one dome volume, the exhauster needs to operate approximately 4 hours. It is expected that the 16-h post-drilling exhauster operation will remove more than 95% of the accumulated aerosol and flammable gases.

The exhauster must be turned on at least one hour before drilling begins in order to

- Mix any potential flammable-gas pockets,
- Reduce the flammable and toxic-gas concentrations,
- Obtain flammable-gas concentration and pressure data, and
- Perform flammable-gas meter verifications as necessary.

In the current system design, when the flammable-gas detection system detects concentrations higher than those specified in this SA, exhauster operation is continued without interruption while the drilling operations are automatically terminated through a separate interlock. The exhauster will be operational during and after a GRE until the flammable concentration falls below acceptable levels.

There are numerous ways to initiate a fire in the exhauster. The possible ignition sources in the exhauster are as follows:

1. Static electricity from the flexible duct or other parts of the exhauster,
2. A lightning strike to the exhauster,
3. An electrical spark from nonqualified electrical equipment,
4. Mechanical frictional sparks from crane load or other heavy equipment /tool drops on the exhauster (note that in order to damage the duct it is not necessary to have drop accidents involving cranes; any other equipment drops can cause damage to the duct), and
5. Mechanical frictional sparks from the fan and housing contact.

The first four causes are independent of whether the ventilation system is active or not.

4.1.1.1. Static Electricity

Static electricity in the flexible exhauster duct is managed by grounding the conductive duct and exhauster to the tank using WHC standard controls for grounding and bonding. The flexible duct is 1/32 in. thick and made of neoprene over a polyester base, and is conductive from the inner to the outer layer.[2] Vendor information indicates the conductivity of the duct material is 100,000 ohms per square inch, which is within the standards issued by the Institute of Electrical Electronics Engineers (IEEE) 142-1991,[3] paragraph 3.2.6.2, which states that a resistance of 1.0E6 ohm is adequate for static grounding. Robinson[4] measured the resistivity of the conductive duct (across the 10-in. diameter of the duct). In all samples the resistivity was measured between 500 and 900 ohms. These values are much lower than 1.0E6 ohm/in^2 required to prevent static build up. Therefore, the conductive duct meets the requirements of IEEE standards and is not expected to cause a static electricity discharge.

Failure to bond/ground the exhauster duct is unlikely because the duct is connected at both ends to the metal flanges of grounded and bonded components. Mechanical failure of grounding also is considered unlikely. The procedural steps requiring a physical inspection of the ground system before the operation help prevent this failure. Procedural steps requiring the physical inspection of the resistance between the exhauster and the tank are performed by WHC as a standard requirement.

Materials such as plastic bags must be carefully controlled because of the potential for static sparking.

Based on these considerations, static electricity concerns associated with the exhauster flexible duct are considered to be properly managed and will not cause a burn accident.

4.1.1.2. Lightning

Details of a lightning strike and a burn accident initiated by lightning strikes are provided in Section 4.9.1.

4.1.1.3. Electrical Spark from Nonqualified Electrical Equipment

Appendix B-concludes that the tank dome space must be treated as a Class-I, Div.-1, Group-B environment during active waste-intrusive FG/RMCS operations. The FG/RMCS exhauster flow path has a direct path to the tank and therefore is also treated as a Class-I, Div.-1, Group-B environment.

Emission control requirements for the exhauster are not discussed in this SA, but based on the information provided by WHC, Washington State permits exhauster operation without stack monitoring.[5]

All of the electrical equipment in the exhauster air stream is either intrinsically safe or deenergized. The fan motor is outside the exhauster duct. The shaft between the motor and exhauster fan is purged with nitrogen. The measurement devices for exhauster flow and the differential pressure across the high-efficiency particulate air

(HEPA) filter unit are electrical components that have been made intrinsically safe. The exhauster has a heater to prevent condensation in the HEPA filter. The heater was originally an electric heater but has been replaced with a heat exchanger driven with hot water supplied by a heater located in an unclassified area.

Based on these design features, it is believed that an electrical spark in the exhauster is not considered as a credible initiator of a burn accident.

4.1.1.4. Mechanical Sparks

One credible mechanical, frictional spark source can result when heavy equipment or tools are dropped on the exhauster or flexible duct. Generally, WHC has a standard practice of not transferring heavy equipment and tools over the exhauster or other equipment critical to safety. Administrative controls prohibiting the transport of equipment over the exhauster are established in the SA to manage this source of frictional sparking.

The frequency of a fire accident as a result of dropping equipment on the exhauster during operation is determined as 9.5E-12/yr in Appendix E, and that value is very low. The accident is caused by failure to terminate the lifting operation, given a high tank dome pressure, hydrogen concentration, or a high rate of hydrogen concentration increase, failure to observe lift-over-tank control, and a crane load drop and exhauster impact.

Another mechanical spark source is the exhauster fan that is built to the Air Movement Division of the Air Movement and Control Association (AMCA) Standard 99-0401-86.[6] The standard requires the following:

> All parts of the fan in contact with the air or gas being handled should be made of nonferrous material. The hole where the shaft passes through must be made so that ferrous materials could not rub. Steps must be taken to ensure that the impeller, bearings, and shaft are adequately attached and/or restrained to prevent lateral or axial shift in these components. The fan must be so constructed that a shift of the shaft or impeller must not allow two ferrous parts to rub. No bearings, drive components, or electrical devices must be placed in the air or gas stream unless they are constructed or enclosed in such a manner that failure of that component cannot ignite the gas. However, the customer must accept both the type and design with full recognition of the potential hazard and the degree of protection required.

The WHC fire protection engineer has determined that the construction requirements for AMCA Type A adequately address the spark-resistant criteria in National Fire Protection Association (NFPA) 91. However, there is no requirement to demonstrate that if the fan and housing come into contact because of bearing failure, the contact is not capable of igniting a potential flammable atmosphere. For the frequency of this event, it is assumed that if a bearing fails 10% of the time, it results in contact between the fan and the housing, with a conditional frequency of 6.4E-10/yr.

However, this event is not considered a credible source of ignition because WHC performed an assessment study, including a literature survey, on the possibility of generating sparks as a result of aluminum fan-to-aluminum housing impact.[7] Based on the findings of this study, the following recommendations are made:

- Fan material should be made of aluminum alloys containing less than 0.8% Mg,

- The housing or any place where impact of the fan is possible should not include iron alloys,

- All surfaces should be aluminum, and

- Any lubricant that may cause sparking should not be used on surfaces where impact is possible.

The exhauster fan meets all the conditions recommended above. In addition, Appendix P investigates the possibility of a hot spot for rubbing aluminum surfaces and found no credible evidence to conclude that if the fan mechanically fails and impacts the housing, sparks capable of igniting hydrogen-air and hydrogen-nitrous oxide mixtures could be created. Although the vendor did not have data to confirm this conclusion, they confirmed that there have been no accident reports indicating this type of failure. Consequently, it was concluded that the failure of the fan is not a credible initiator for a burn accident, and the frequency is designated as $<< 10^{-6}$/yr.

4.1.1.5. Summary of Exhauster Fires

Table 4-2 summarizes the above discussions. The bounding accident frequency for exhauster fires is 1.1E-10/yr caused by lightning strikes. For bounding consequences, it was conservatively assumed that a fire initiated in the exhauster would propagate into the dome, resulting in a dome collapse accident, as discussed in Section 5 of this SA.

4.1.2. Flammable-Gas Release Through Torn Duct and Burn (Operation)

This event postulates a GRE occurring at a high rate, creating a positive tank pressure, which results in an ignition of flammable gases that have escaped through the torn exhauster duct. The ignition source for this scenario is potentially nonqualified electrical equipment at the exhauster skid and around the exhauster duct.

If the exhauster duct has torn and a GRE occurs, some region around the duct must be assumed as a Class-I, Div.-2 environment, based on the diameter of the leak. The undetected leak diameter is assumed to be ≤ 1 in. Based on the criteria given in

Appendix B, nonqualified equipment with no automatic shut-down features should be 18 in. away from the leak. Therefore, an exclusion zone should be established 18 in. from each side of the exhauster duct, and no equipment with sparking potential should be placed within this exclusion zone. This control protects the tank from fire initiated through a torn duct. All electrical equipment currently on the skid not meeting Class-I, Div.-1 requirements is protected by enclosures, and most is 18 in. away from the point where the exhauster duct is attached to the metal flange near the heater.

TABLE 4-2
SUMMARY OF FIRE ACCIDENTS IN EXHAUSTER

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Lightning strike causes dome fire.	MAF and UAF << 1.0E-06	Random lighting strike hits risers or other equipment on top of tank that connects to tank interior.	Do not drill if a lightning strike is observed within a 50-mile radius.
Drop of equipment from crane onto exhauster leads to dome fire.	MAF and UAF << 1.0E-06	Equipment is dropped from crane onto exhauster.	No equipment lifts over exhauster.
Ignition of flammable gas in the exhauster is caused by fan failure.	MAF and UAF << 1.0E-06	Failure of fan bearings results in fan housing mechanical sparking.	No controls are credited.

Even though the flexible duct is heavy and difficult to tear,[2] the following requirements are established to prevent duct damage. The flexible duct must be made stationary before operations start to prevent any motion that may result in damage to the duct when there is a strong wind. A control requires the termination of FG/RMCS operations when the sustained wind velocity is greater than 25 mph because of concerns about possible structural failure of the flexible duct. A control to inspect the flexible duct for possible leaks before operations begin also is established, as well as the control to preventing the transport of any equipment or tools over the exhauster or duct.

The MAF is calculated as 1.4E-9/yr, and the UAF is 5.6E-8/yr, as discussed in Appendix E. Note that no credit was taken for the probability of the propagation of fire into the dome. Dominant failures are summarized in Table 4-3. The consequence of this accident is conservatively considered to be the dome collapse discussed in Section 5 of this SA.

TABLE 4-3
ABOVE-TANK FIRE ACCIDENTS CAUSED BY TORN EXHAUSTER DUCT

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Tear in the exhauster duct exposes flammable gas to nonqualified electrical equipment leading to dome fire.	MAF = 1.4E-9 UAF = 5.6E-8	Big tear occurs in the duct during operation. Tear in the duct is not detected.	Inspect the duct for tears before operation. Locate unqualified equipment at a distance >18 in. from exhauster duct, or provide deflectors/enclosures for equipment located within 18 in.

4.1.2.1. Flammable-Gas Release through Open Riser (or Possible Leak Paths) Driven by Gas Release Event and Burn (Operation and Removal)

This event postulates that a large GRE occurs, releasing flammable gas from openings in the tank, exposing the flammable gas to equipment with possible spark sources, resulting in a fire on top of the tank. This event is of concern during operation and removal phases of FG/RMCS. None of the auxiliary support equipment on top of the tank is qualified to operate in a flammable-gas environment.

Preventing flammable-gas exposure to this equipment is managed in several ways. Open paths from the tank dome to the tank top include the exhauster stack, the breather inlet riser, open risers, drill string riser, and other possible tank leak sources (unsealed risers, pits, etc.). It is assumed that inspection of tank top penetrations for potential leak paths will find leak paths with a 1-in. effective leak diameter. Therefore, it is assumed that undetected leak paths with a 1-in. effective leak diameter could exist. Therefore, the top of the tank must be examined to identify leaks other than risers used for passive/active ventilation, and when identified, leaks greater than or equal to 1-in. effective leak diameter must be sealed.

A portable stack over the breather inlet HEPA system will be used during waste-intrusive FG/RMCS operations. The portable stack is at least 15-feet tall, has an upper 4-in. diameter, is sealed at the ground level, and is grounded. The purpose of using a portable stack over the breather inlet is two-fold:

- The gas release would be released through the stack, resulting in increased atmospheric dilution and reducing the toxicological consequences of a GRE.

- Any nonqualified equipment on the top of the tank around the breather inlet HEPA system would be protected from flammable-gas exposures.

The positioning of the drill truck, the X-ray machine, the light plant or other auxiliary equipment that could be a spark source is based on the criteria given in Appendix B. It is required that any nonqualified electrical equipment must be placed at least 36 diameters away from an open riser during waste-intrusive operations. If a GRE occurs, immediate personnel evacuation is required.

Another control also requires that when the drill truck needs to be parked over an unused, closed riser or pit, the riser or pit must be sealed. Note that the riser or pit considered here is not the riser being sampled but the one that the front part of the truck is parked on. If the truck is parked over an unused riser or pit, the potential spark location is not considered random, and no credit can be taken for the probability of a random placement. However, the leak size from pit or riser is assumed to be no bigger than 1 in. There are at least 3 feet between the top of the pit/riser and any potential ignition sources on the truck. A control was established to make sure the distance between potential ignition sources on the truck and the top of the pit/riser is $\geq$ 36 in. Combining the failure probability to seal the riser/pit and violate the 36 in. distance criteria and the GRE probability that makes the dome pressure positive, the accident frequency is determined as 2.1E-8/yr. This frequency is low. However, the unmitigated frequency becomes 1.4E-4/yr if the control to seal the riser/pit and 36 in. distance criteria are not implemented.

The flammable-gas release could occur from other unused risers if they have undetected leak paths. The control requiring the examination of risers before operations reduces the probability of having an unknown open path. It is assumed that leaks from threaded junctions, flanges, and cover plates could be identified with an effective leak diameter greater than 1 in. If a GRE occurs and nonqualified equipment is located close to these unknown openings, the accident frequency of an above-tank fire becomes 1.8E-7/yr. This frequency includes the probability of a GRE based on exposure time (Appendix L) and the probability of a temporal random spark. It also assumes that 50% of all risers on the top the tank leak after the initial inspection is performed. The existence of a spark on the equipment located around risers is also assumed. The unmitigated accident frequency is 2.8E-5/yr for this accident scenario; therefore, the control requiring that leaks be limited before the FG/RMCS operation is important.

The last accident scenario includes the ignition of a flammable-gas release from an intentionally opened riser during FG/RMCS activities. This may be needed for other daily activities. Appendix E gives the event tree for a fire accident. A control is required not to place any nonqualified equipment within 36 diameters of the riser being opened during waste-intrusive operations. Considering this control and a GRE probability based on exposure time including a temporal random spark, the mitigated accident frequency becomes 4.2E-8/yr. This number is conservative because it was not considered that the riser may be open for only a fraction of the mission time. The unmitigated accident frequency is 1.4E-5/yr.

The combined mitigated frequency of these three events is 2.4E-7/yr. Note that the fire propagation into the dome conservatively is assumed to be 1.0. This number is conservative because it is assumed that nonqualified equipment does include a spark source and the probability of a random spark in time is based on a conservative dome concentration.

Positioning the drilling truck needs special attention. The closest release path to the truck is the drilling riser that can momentarily be open to the environment during installation and removal of FG/RMCS equipment, even though the riser is sealed with a rubber frisbee during operation. However, because some drill rods are fluted, it is likely that the frisbee can be damaged, and a leak can result. A nitrogen purge is provided in the annulus between the drill string and the conductive riser sleeve. This purge flow is designed to provide 5 standard cubic feet per minute (scfm) flow for all postulated tank dome conditions.[8] The purge system has redundant differential-pressure alarms across the flow controller. Necessary controls for this system will be discussed in the dome fires accident category (ignition in the riser).

For a gas release to occur from the riser path, the nitrogen purge would have to fail, and a GRE would have to occur. However, even if a 1-in. effective leak diameter path exists through the frisbee, potential ignition sources on the FG/RMCS truck are at least 3 ft away. There is a direct path from the frisbee to the top of the platform when the shielded receiver or the drill rig are connected to the drill string. However, the spark-generating electrical motors are located at the top of these components and meet the 36-equivalent-leak-diameter distance requirements of Appendix B. This distance is acceptable because the rotating platform also acts as a jet deflector. The nitrogen instrumentation and piping enclosure have solenoid valves, but they are in an enclosure (not leakproof but reasonably sealed) and protected from direct flammable-gas jet impingement. The major spark contributor is the drill engine and it is at least 3 ft away from the frisbee. In summary, if a leak occurs from the frisbee, the gas would not reach the spark sources on the truck with a flammable concentration.

To further reduce the likelihood of a gas release from the drill string during removal, the drill string must not be removed from the waste without a sampler or a dummy sampler in the string. The drill string and frisbee hole must comply with the 36 equivalent-leak-diameter distance requirements during waste-intrusive activities.

The summary of this accident is given in Table 4-4. With the above controls in place, it is believed that the ignition from the truck or any other nonqualified equipment is adequately controlled as demonstrated by the low magnitude of the MAF.

4.1.2.2. Flammable-Gas Release through Shielded Receiver (SR) and Ignition in the Shielded Receiver (Operation)

There are two cases for this accident, depending on the operating condition:

- When the shielded receiver (SR) is connected to the drill string during sampler recovery, and
- When the SR is isolated from the drill string while the sampler is being transferred to the X-ray machine or the shielded cask.

This section treats the cases where the SR is isolated from the drill string. The other case is examined in Section 4.3.2 along with drill string fires. Flammable gas may accumulate in the SR either by a gas transfer from the drill string or flammable gas may be released from the sampler into the SR.

TABLE 4-4
ABOVE-TANK FIRE ACCIDENTS CAUSED BY GAS RELEASES FROM OPEN RISERS

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Release of flammable gas from riser/pit that the drilling truck is parked on leading to dome fire.	MAF = 2.1E-8 UAF = 1.4E-4	Fail to seal to riser or pump pit. Fail to locate potential ignition sources on the FG/RMCS truck within 36 in. of the riser/pit.	Seal the riser or pump pit being parked on. Distance between the potential ignition sources on the FG/RMCS truck and the riser/pit is greater than or equal to 36 in. or provide enclosures/deflectors for equipment located within 36 in.
Releases of flammable gas to unqualified electrical equipment from unknown leaks leading to dome fires	MAF = 1.8E-7 UAF = 2.8E-5	Randomly located unqualified equipment is located too close to riser/pit not in use.	Limit leakage from all unused risers/pits to less than 1 in.-effective leak diameter.
Releases of flammable gas to unqualified electrical equipment from an intentionally open riser during FG/RMCS waste-intrusive activities leading to dome fire	MAF = 4.2E-8 UAF = 1.4E-5	Equipment located too close to open riser/pit. Randomly located unqualified equipment is located too close to open riser/pit.	Restrict location of equipment to greater than 36 diameters from open risers/pits or provide enclosures/deflectors for equipment located within 36 in. Inlet stack 15 feet tall is installed on HEPA inlet riser.

For gases to be released into the SR from the drill string, the hydrostatic head must fail. Calculations provided in Appendix J show that as long as the hydrostatic head purge of 0.3 sfcm exists, the flammable gas in the drill string does not diffuse back upstream. There are two sources of hydrostatic head purge while the SR is connected to the drill string. One purge is connected to the SR, and another is connected to the change-out assembly. Considering the operating procedures, the analysis shows that failure of both purges and not detecting this failure combined with a frequency of dropping the core sampler, which is the only credible spark source in the SR, results in an ignition frequency of 1.9E-6/yr.

The consequences are small when the SR is isolated from the tank, and the quantity of gas in the SR also is small.

Besides being transported from the drill string, the flammable gas can accumulate in the shielded receiver in two other ways as follows:

- Waste accumulation in the SR resulting in a gas accumulation; and
- A gas release from the sampler.

The maximum waste release into the SR is the equivalent of one full sampler (0.39 kg). Gas that could be retained in this amount of waste is small. If the sampler is full of gas at approximately 2 atm, the maximum gas volume at atmospheric pressure would be 611 cm^3. The volume of the receiver is 120,000 cm^3. Thus, the resulting flammable-gas concentration would be less than the lower flammability limit (LFL), and ignition would not be possible. There is no incompatible material inside the SR, so that additional gas generation caused by chemical reaction is not a concern.

The SR has a load cell to measure the weight on the cable. This load cell is protected by an intrinsic safety barrier. Therefore, an electrical spark inside the SR is not a concern.

The RLU is based on a mechanical design. A frictional spark caused by RLU motion may be considered as a spark source. The electrical motors controlling RLU use are direct current (dc) pulse width modulated power. The hoist motor for the RLU has a 150:1 worm-gear reduction, and because of the gearbox, the RLU does not freewheel if the motor fails. The normal hoist velocity is less than 1 ft/s. Studies have been done to examine the characteristics of mechanically-produced sparks that lead to the ignition of tank-like gases. Krok and Shepherd[9] carried out frictional spark ignition studies of H_2/air and $H_2/N_2/N_2O$/air mixtures in which they used rusted steel and aluminum plates impacted by steel or aluminum bars. A pneumatically-actuated piston made of steel or aluminum was stroked on an inclined, rusted-steel plate. The impact velocity varied from 0.5 to 2.5 m/s (1.64 to 8.2 ft/s). These experiments showed that the frictional ignition in a mixture of 10%

or 15% H_2 in air at 1 atm was very unlikely. Based on this data, a frictional spark caused by the normal RLU motion is not expected.

Radiation exposures were calculated in Appendix R for possible doses if a full sampler were to be released in the SR. Based on these calculations, measurable quantities of waste would be recorded by manual radiation readings. WHC has radiation controls performed by the health and safety personnel, but an additional radiation control limits the SR dose rate to 100 mrem/h on contact. This radiation monitoring must be performed once per shift during waste-intrusive activities to prevent waste and flammable-gas accumulation in the SR.

One other possibility of frictional spark occurrence is an equipment drop in the shielded receiver. The RLU may be dropped because of a mechanical failure, or the sampler may drop from the RLU. In order for the RLU to drop, the core sampler should be stuck and the operator should fail to respond. The hoist cable is designed to fail at loads higher than 2000 lb. The hoist motor fails at about 800 to 1300 lb. Thus, the cable cannot fail before the electrical motor fails. Because of the gearbox, the RLU does not freewheel if the motor fails. It is concluded that an RLU drop is not a credible event. In addition, dropping a 5.2-lb stainless-steel piece from a 44-in. height to simulate the quill-rod-to-carbon-steel impact showed no ignition in a bounding flammable gas environment (see Appendix T and Witwer[10]). Note that the weight of the RLU is higher than 5.2 lb but the drop height in the shielded receiver is much smaller than 44 in. The core sampler drop can be bounded by the ignition tests performed on quill-rod adapter to drill string impact because its weight is comparable and the drop height is small. Because BOM tests showed no ignition (Witwer[10]), all accidents discussed in this section are considered to be not credible. The drill string is sniffed before it is connected to the shielded receiver. The sampler rotary valve needs to fail in order to cause a gas release in the shielded receiver. Considering these failures, this accident is assumed to be incredible, as shown in Table 4-5.

The core sampler may drop from the RLU. The conditional MAF is estimated as 2.8E-5/yr in Appendix E and given in Table 4.5. Ignition caused by dropping the core sampler in the shielded receiver was investigated by tests conducted by the Bureau of Mines (BOM). Appendix T describes the test requirements and Witwer (Ref. 10) summarizes the results. Tests are performed by dropping the core sampler in the drill string from a 60-ft height. No ignition is observed in a stoichiometric hydrogen-air mixture. The drop height in the shielded receiver is much smaller than 60 ft. Therefore, this accident is considered to be not credible.

If ignition occurs in the SR with low concentrations, the burn pressure, 1.2 atm, does not exceed failure pressure.[11] The SR maximum design pressure is 52 psia (Ref. 12). The ball valve isolating the SR fails at very high pressures (1100 psia). Therefore, no failure and release is expected if ignition occurs in the SR.

TABLE 4-5
ABOVE-TANK FIRE ACCIDENTS IN SHIELDED RECEIVER

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Flammable gas in drill string (DS)/SR during sampler handling leading to fire in SR (core sampler drop). (Fire does not propagate back to the dome.)	Without BOM test results: MAF = 1.9E-6 UAF = 2.8E-3 With BOM test results: MAF and UAF <<1.0E-6	Nitrogen purge to both drill string and to SR fails. RLU drops sampler.	Leak test of N_2: hydrostatic systems is done for both drill-string and for shielded receiver. Unique connections for N_2: purge systems for both drill string and SR are used (design feature). Verification of N_2 purge: supply to both drill string and SR during activation of hydrostatic mode of N_2 supply is carried out. Controls over operation of RLU are used.
Flammable gas in SR with SR isolated from drill-string results in aboveground fire (RLU or core sampler drop). (Fire does not propagate back to the dome.)	Without BOM test results: MAF = 2.8E-5 UAF = 3.0E-4 With BOM test results: MAF and UAF <<1.0E-6	Waste prevents closure of sampler rotary valve leading to gas release as sample is retrieved and depressurized. Flammable gas is not sniffed or detected. RLU drops sampler.	Controls over operation of RLU are used.

A control has also been established for a visual inspection of the sampler through the sight glass as it is withdrawn from the drill string. This visual inspection does not directly indicate the failure of the sampler rotary valve, but it may indicate leaking from either the rotary valve or rotary valve seal. An administrative control shall be developed for handling a leaking sampler. An additional control prohibits putting a known leaking sampler into the x-ray machine.

One other concern is the release of gas from the SR. For this accident to occur, the manually operated SR ball valve would have to be opened before it is connected to the x-ray machine, which would be a violation of the procedures. The engine has several potential ignition sources. The likelihood of this event is low because several failures have to occur; inadvertent opening of the ball valve, failure of the rotary ball valve, and dropping the sampler at the same time. In addition, the operator must fail to identify the leak by visual inspection. Besides, the flammable gas may not come from the bottom of the pipe but may accumulate at the top of the horizontal section of the shielded receiver. Even if flammable gas comes from the valve, the maximum amount of flammable gas that can be accumulated in the receiver is limited to 611 cm^3. It is expected that the consequence of the accident is insignificant because of the limited amount of flammable gas present and because there is no entrained waste. The fire cannot propagate back to the tank because the shielded receiver is not connected to the drill string. The only concern in terms of material release would be dropping the waste on the ground when the valve is opened. This accident is discussed along with the spill accidents in Section 4.8.

4.1.3. Flammable Gas and Ignition in X-ray or Cask

If the flammable gas were accumulated in the SR, it could be discharged into the x-ray machine or into the shielded cask when the SR is connected to these components. The concern with this scenario is a fire in the cask or x-ray machine with a local release of radioactive material and possible propagation of fire into the tank dome.

If the flammable gas in the SR is discharged into the cask or the x-ray machine, ignition is not expected. No unqualified electrical equipment in a Class-I, Div.-1 or Class-I, Div.-2 space exists in the x-ray machine.[13] The cask does not contain a spark source. The only ignition source identified is dropping of the sampler into the plastic x-ray container or the cask. The x-ray container may not produce frictional sparks but rather static electric charges. However, the plastic container is grounded and bonded by a graphite paint as a coating surrounding the interior of the plastic container.

Appendix E examines the probability of ignition in these components. The accident frequencies are found as 1.6E-9/yr and 2.8E-5/yr for the x-ray and the cask, respectively, as indicated in Table 4-6. The x-ray and cask are grounded and bonded through the SR, and the sampler is inspected for external contamination. Even if the ignition occurs, the available flammable gas that can come from the SR or sampler is limited so that the flame would not propagate to the tank. For propagation to the tank to occur, there would have to be hydrogen in the dome and a flammable pathway, which does not exist. Under these conditions, operations would not be conducted.

4.1.4. Flammable Gas Accumulation or Release Caused by the Loss of Electrical Power and Ignition Source (Installation, Operation, and Removal)

In case of loss of electrical power, the FG/RMCS truck is shut down. When the electrical power is lost, the nitrogen shutoff valve closes. If the sampler is being removed or installed, the hydrostatic head purge that keeps the waste from entering the drill string is lost, allowing the drill string to flood. Flammable-gas accumulation in the dome, drill string, drill unit, and shielded receiver is of concern in this scenario. Waste can flood the drill string and release flammable gas into the drill string and the SR. Appendix J shows that the diffusion of hydrogen is relatively fast. Flammable gases also could be released as a result of depressurization of the waste.

The management of ignition sources in these components has been discussed previously. No attempt was made to evaluate the failure probabilities of the loss-of-power accident. An administrative control must be developed for the startup after loss of power considering the possibility of the presence of flammable gas. A control requiring the purging of the shielded receiver, drill string, and drill unit long enough to evacuate the possible flammable gas in the drill string is established. If the drill string is flooded, the SA requires that the drill string be washed before the operation is restarted.

4.1.5. Propane Release from Refueling of Nitrogen Trailer Propane Tank and Fire (Installation, Operation, and Removal)

This accident scenario involves a propane spill during the refueling of the propane tank. The main concern is the propagation of fire to the tank being sampled or to another tank in the farm. The propane tank is kept outside of the tank farm. Drilling on the tank being sampled is prohibited during refueling. This is a typical industrial accident and is not discussed in detail. WHC standard controls already exist to prevent this type of accident.

4.1.6. Flammable Diesel and Gasoline Fuel Fire (Installation, Operation, and Removal)

This accident scenario involves a spill of diesel, gasoline, or hydraulic fluid during the refilling of the FG/RMCS equipment. The main concern is the propagation of fire to the tank because the refueling occurs when the truck is already over the tank dome.

The SA requires that all engines or motors on affected equipment be shut down during refueling. Exhaust pipes on affected equipment must be cool. No drilling operations, open risers, or open drill string or non-RMCS activities on affected equipment are allowed on the tank being sampled during refueling. A restricted smoking area is required, and all possible ignition sources need to be kept outside of the refueling area. These controls are established to prevent fire propagation to the tank. In addition, proper fire extinguisher equipment in the vicinity of the drilling truck must be available in case of a local fire.

4.1.7. Collision Caused by Trucks and Other Equipment (Installation, Operation, and Removal)

This accident involves frictional sparks created by the collision of trucks or other equipment with the riser. The drill truck and other equipment must be operated safely on top of the tank. In the unlikely event that the truck impacts an open riser, all operations must be stopped, and possible gasoline or diesel leakage into the tank must be evaluated. The introduction of flammable material into a flammable-gas tank may have serious consequences. Thus, the Tank Farm Operations management must be notified, and approval must be granted before operations may resume.

TABLE 4-6
ABOVE-TANK FIRE ACCIDENTS IN X-RAY MACHINE AND CASK

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Flammable gas in x-ray machine leads to aboveground fire. (Propagation into dome not possible.)	No fire propagation into the dome: MAF = 1.6E-9 UAF = 1.6E-8 Fire propagation into the dome: MAF and UAF << 1.0E-6	Waste prevented previous closure of the sampler rotary valve leading to gas release as sample is retrieved and depressurized. Previous sniff in shielded receiver failed to detect flammable gas. RLU drops sampler. Plastic receiver breaks. Isolation barrier volume fails.	Use sealed plastic sampler receiver surrounded by isolation barriers. Use controls over operation of RLU.
Flammable gas in cask leads to aboveground fire. (Propagation into dome not possible.)	No fire propagation into the dome: MAF = 2.8E-5 UAF = 2.8E-4 Fire propagation into the dome: MAF and UAF << 1.0E-6	Waste prevented previous closure of sampler rotary valve leading to gas release as sample is retrieved and depressurized. Operator fails to perform sniff for flammable gas. RLU drops sampler.	Use controls over operation of RLU.

Before installation, standard WHC controls are implemented to prevent an unexpected flammable-gas release from the tank dome. Frequent and large natural-gas release events are not expected in single-shell flammable-gas tanks. The tank vapor space must be sampled before installation, and the flammable gas must be less than 25% of the LFL. If a GRE were to occur, operations would be stopped.

A possible scenario is the flammable-gas accumulation in the dome and failure to detect it before FG/RMCS tank-intrusive activities. If there is flammable gas in the riser, a fire can be initiated by a frictional spark from a collision. During the removal phase, the tank dome and drill string must be sniffed before drill string removal and other riser activities. If flammable gas is detected above limits, all operations must be stopped, including drilling. For this accident to occur, the detector systems would have to fail simultaneously with a collision. This event is not considered credible.

Without fire, the consequence of collision is damage to the tank riser. The tank liner is not connected to the riser or to the dome. Thus, the damage would be to the riser, which can be sealed if this accident occurs. Standard WHC safe practice requirements are required to prevent the collision. The likelihood of serious consequences of this type of accident are not considered credible.

4.1.8. Summary of Aboveground Fire Accident Category

The total conditional accident frequency for the aboveground fires that lead to a dome fire is 2.4E-7/yr. The dominant contributor to this frequency is gas release to nonqualified equipment. Randomly located unqualified equipment too close to risers that have an open path results in the highest accident frequency of 1.8E-7/yr. The consequence of an above-tank fire is treated as a dome collapse. Dome collapse consequences are discussed in Appendix I. The total frequency for aboveground fire accidents, 2.4E-7/yr, is added to the other three frequencies considered in the next section to determine the frequency of dome collapse.

4.2. GAS RELEASE AND DOME FIRE ACCIDENTS

The postulated accidents in this category consider fires initiated in the dome space of the tank. Most of the cases discussed in this section can occur during the operation phase of the drilling. The flammable gas in the dome is the first necessary condition for a fire scenario to occur. The gas can be released when the drill bit penetrates the crust or waste sludge.

Below, each identified spark source in the dome is examined closely, and the associated control systems are discussed.

4.2.1. Ignition of Flammable Gas as a Result of a Drill String Break (Operation)

This accident is caused by a mechanical spark created by the drill string breakage during the drilling. This failure is assumed to occur at a portion of the drill string that is in the dome. The flammable-gas detection system is the primary protection against this accident. This system prevents drilling operations when the flammable-gas concentration is above 25% of the LFL in the dome.

The force applied to the drill string is measured. The force limit, based on drill bit heating (Appendix F), is set to 750 lbf. There are other down force and rotational speed limits caused by structural concerns as discussed in Appendix N. The drill truck has a torque capacity that is more than that required to break the drill string. Several drill-string breakages have occurred in the past. A control is established not to exceed the buckling limit (down force) and not to operate at a rotational speed that could excite the drill string at its natural frequency (Appendix N). The MAF listed in Table 4-7 for this accident is determined as 4.8E-10/yr (see Appendix E). The UAF is 2.8E-7/yr. Controls to prevent drill string buckling and resonance are given in Section 4.6.3.

TABLE 4-7
DOME FIRE ACCIDENTS CAUSED BY DRILL STRING BREAKAGE

Accident	Frequency of failure 1/year	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Drill-string break in dome leads to dome fire.	MAF = 4.8E-10 UAF = 2.8E-7	Fail to shut down drill string on detection of H_2. Drill string breaks by jamming in waste causing overtorque or buckling.	Drill string automatic trip when high H_2 level, high rate of change of H_2 level, or high dome pressure occurs.

4.2.2. Ignition of Flammable Gas in the Riser Caused by the Drill-String, Equipment or Tool Drop (Installation and Removal)

This accident is postulated to occur when there is flammable gas in the dome, and equipment, drill string, or tools are dropped into or onto the riser during the installation or removal phase. As discussed previously, the riser condition must be determined before installation to make sure there is no flammable gas in the riser or dome. During the removal, gas may exist in the dome only if the flammable-gas release detectors fail. This accident analysis covers the friction in the riser caused by these drops. The more limiting case is the dropping of the drill string with an impact on the crust; this accident is examined in the next section. The friction in the riser as a piece of equipment falls through the riser is not considered to be a significant contributor and is bounded by the tool drop on the crust in the next section. Nevertheless, Appendix E determines the accident frequency of this scenario as 1.4E-9/yr as given in Table 4-8. The unmitigated frequency is also small, and 2.8E-9/yr. BOM testing performed by Witwer (Ref. 10) also included frictional spark tests for drill-string-to-drill-string impact and quill-rod adapter to drill string impact. These tests showed no ignition and bound the tool drop into the riser.

4.2.3. Flammable-Gas Release and Burn Caused by the Drill String or Tool Drop on Crust (Installation, Operation, and Removal)

This accident involves dropping the drill string or other tools that may create frictional sparks on the crust and thus results in ignition of the flammable gas in the vicinity of the crust.

General practice at Hanford site is to use spark-resistant tools during activities around the riser. Riser covers are also grounded and bonded. Standard procedure requires sampling of the dome space when opening a riser. The crust reaction/burn from impact heat is considered separately in the waste burn accident category.

There are several simultaneous conditions required to cause a dome collapse if the drill string is dropped. First of all, there must be a drop, and flammable gas must be present in the dome or in the vicinity of the impact point. Debris is found in the tanks from contaminated or unwanted material being disposed of in the tanks. There must be debris at the impact point, and the impact energy must be large enough to cause a frictional spark. A gas pocket large enough to sustain propagation must exist immediately beneath the surface where impact occurs.

The drill string is held by a pneumatic foot clamp. The drill string is manually inserted into the rubber frisbee by an operator. A lubricant is used to insert the drill string because the inside diameter of the frisbee is smaller than the outside diameter of the drill string. The rubber frisbee creates a frictional force of 200 lbf. However, this value may go down to 40 lbf when the lubricant is used. As the drill rods are added to the drill string, weight increases and exceeds the frictional force of the rubber frisbee. The maximum drop weight may be as high as 210 lb (Appendix G). The pneumatic foot clamp supports the drill string when it is not supported by the hoist or connected to the drill. The pneumatic foot clamp is designed to fail-close. To open the pneumatic foot clamp, the operator must activate the foot clamp pedal. The drill string is then raised about 1/2 in. before the foot clamp can be actuated, although this is not necessary by design but is caused by the seal used in the system (no credit is taken for this feature). The drill string is held by the foot clamp for a short period, about 4 minutes, during the collection of one sample. Considering the short lifting period, the drop accident frequency is estimated at 3.0E-3 /activity (see Appendix D).

In order to reduce the drop frequency further without taking into account additional events necessary to cause a dome collapse, the use of a locking collar when the drill string is held by the hydraulic foot clamp is required for all modes. The use of a locking collar reduces the drop frequency to 6.0E-5/yr. The collar needs to be installed before the drill string is disconnected from the drill unit. This requirement prevents flammable-gas exposure from the drill string during the installation of the collar.

The rotary drill bit is made of nonsparking copper-based material. Appendix T describes ignition tests performed for core sampler drops at BOM. In these tests, the core sampler is dropped in the drill string from a height of 60 ft in a flammable hydrogen-oxygen mixture. The impact includes a contact of a stainless-steel core sampler and copper-based drill bit. Witwer[10] performed these tests and found no ignition. Drill string impact on metal objects is not bounded with these tests. However, test results indicate that the probability of a spark from the drill string dropping on the crust or metals in the crust may not be high.

As mentioned above, additional events may be required to cause a local hydrogen burn that could result in a dome collapse. These events must occur simultaneously and are as follows: having metals in a dry environment at the impact point that might cause sparks, having hydrogen in sufficient amounts to cause propagation in the waste in order to cause a dome collapse, or the occurrence of sparks from impacts with nonsparking materials on metals. Considering these additional probabilities and a low drop frequency, this accident is concluded not to be a cause for a dome fire. However, the possibility of a waste burn is considered in Section 4.4.3. The conditional frequency of tool drops on/into a riser is estimated as 1.4E-9/yr and is already small.

4.2.4. Ignition of Flammable Gas in the Riser Caused by a Frictional Spark (Installation, Operation, and Removal)

In this subsection, the main concern is the ignition of flammable gas in the riser caused by frictional sparks. There are several ways a frictional spark can be initiated in the riser. These possibilities and their management methods are discussed below.

A flanged, 2.9-in. i.d. (3-in., Schedule 80), and 15-feet-long conductive stainless-steel riser sleeve must be installed in the riser. The installation requires that the piece is bonded. The insertion and removal velocity of the conductive sleeve should be no more than 1 ft/s to prevent frictional sparks in the riser. The riser must be sniffed before insertion of the sleeve as a part of WHC standard control before opening a riser.

The other concern is frictional heating from the drill string rotating in contact with the conductive sleeve, leading to ignition in the riser. This situation is analyzed in Appendix P, and the conclusions are summarized below.

The expected temperature is less than the autoignition temperature for hydrogen in air for the period of the calculation (Appendix P). Given the conservative nature of the problem assumptions, frictional ignition in the tank dome from drill-string-to-sleeve contact is considered unlikely. This determination is confirmed by BOM ignition test results obtained by Witwer (Ref. 10). App. T describes the experiments, and Witwer's results showed no ignition of stoichiometric hydrogen-air mixtures.

A nitrogen purge system is designed to provide flow into the annulus between the riser sleeve and the drill string. This system gives a minimum flow of 5 scfm at any tank pressure. There are two differential pressure detectors for riser sleeve purge gas. Either detector could cause an automatic trip of the drill. The set point is 40 psid across a flow controller sized for 5 scfm. The probability of a GRE pressurizing the dome by 3 in. w.g. is very low. Furthermore, a control is established to stop drilling when the dome pressure increases by 2 in. w.g. in any 5-min period. The differential pressure across the flow controller is monitored and set to sound an alarm to detect a loss of flow. The purge flow also further prevents the hot spot that could occur at the drill string and sleeve contact point. This system provides the necessary protection to prevent ignition in the riser sleeve.

TABLE 4-8
DOME FIRE ACCIDENTS CAUSED BY EQUIPMENT AND TOOL DROPS INTO RISER

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Drop of raised drill string onto waste ignites H_2 below the crust leading to a dome fire.	Drop frequency: MAF = 6E-5 UAF = 2 Burn Frequency: MAF and UAF <<1.0E-6 from BOM test results for core sampler drops and other necessary probabilities.	Foot clamp spuriously fails open. Locking collar is not used or fails.	Pneumatic foot clamp fails, closes upon loss of air. A second locking collar is used. Collar needs to be installed before drill string is disconnected from the drill unit.
Drop of tool into open riser leads to dome burn.	Drop frequency: MAF = 1.4E-9 UAF = 2.8E-9 Burn frequency with credit from BOM tests: MAF and UAF << 1.0E-6	Tool is dropped into open riser.	Operator uses spark-resistant tools within 36D of open riser.

If the nitrogen purge system fails, the ignition of flammable gases is possible. In order to demonstrate that sparks cannot be generated from drill string and sleeve contact, ignition testing experiments were performed by the BOM. The test conditions' requirements and acceptance criteria are discussed in Appendix T. BOM tests showed no ignition in stoichiometric hydrogen-oxygen mixtures (see Ref. 10).

Another case considered is the accumulation of hydrogen in the riser, but not in the dome. In this case, flammable-gas detection and the shut-down system could not interrupt drilling. Protection is provided by the riser purge with a failure probability of 6.5E-3 (Appendix E). The accident frequency is calculated in Appendix E and given in Table 4-9. Based on the sparking tests of the drill against the riser sleeve at the BOM and the calculation that was done for frictional heating, ignition is not expected to occur in this potential pocket of gas. In addition, if it did, the volume would be small and not lead to a dome collapse.

TABLE 4-9
DOME FIRE ACCIDENTS CAUSED BY FRICTIONAL SPARKS IN THE RISER

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
H_2 in riser during drilling leads to dome fire.	Without BOM test results MAF = 3.1E-10 UAF = 2.8E-5 (assumes drill string-sleeve contact may spark) With BOM test results: MAF and UAF <<1.0E-6	Fail to shut down drill string upon detection of H_2. N_2 supply to riser sleeve fails.	Drill-string automatically trips when high H_2 level, high rate of change of H_2 level, or high dome pressure. Leak check of N_2 supply to riser sleeve is done. DS trips on loss of N_2 to riser sleeve. Unique connector for N_2 supply to riser sleeve is required. N_2 supply to sleeve during actuation of system is verified.

Even though the MAF is small, BOM experiments were needed (to verify that the ignition of a bounding hydrogen-oygen mixture is not credible, Appendix T) because of the uncertainties associated with the GRE probabilities. This test showed no ignition (Witwer[10]).

4.2.5. Ignition of Flammable Gas in the Riser Caused by Electrostatic Spark (Installation, Operation, and Removal) (Rubber Frisbee and Drill String)

For this event, the concern is with the electrostatic discharge from the rubber frisbee as the drill string rotates on this piece. The rubber frisbee diameter is slightly smaller than the drill-string diameter so that there is always a force exerted by the frisbee on the DS. A lubricant is applied to the DS in order to ease the rotation and insertion. The use of this lubricant can reduce the probability of the static electricity discharge during drilling. The frisbee is in contact with the grounded DS and washer, and the DS is connected to the drill unit that is grounded through the drill truck. The riser sleeve is purged with a nitrogen flow. The probability of failure of the nitrogen purge to the riser sleeve is very low; thus, a static discharge is not an issue. However, a control requires the use of the lubricant as a part of the procedure because it also helps to reduce the likelihood of damaging the rubber.

The resistivity of the frisbee is measured, and the findings show that the frisbee is not a good conductor. However, although the frisbee is composed of a nonconductive material, and if the drill string is always grounded by either the foot clamp or the hoist/truck, no credible spark source has been identified. Therefore, the SA does not consider a dome fire accident caused by this initiator and does not require the replacement of the frisbee as a mandatory control.

4.2.6. Ignition of Flammable-Gas Release Caused by Crust Penetration and Frictional Sparks Caused by the Drill Bit (Operation)

This accident analysis deals with the ignition of flammable gas that could exist in the crust or under the crust during the drill-bit penetration through the crust or waste sludge. The possibility of metal objects at the waste surface or in the crust always exists because it is known that manual tapes, wires, and metal pieces have been dropped through the risers. A frictional spark caused by the drill bit can ignite the hydrogen. The ability of the drill bit to cause a frictional spark when rotating on a steel plate has been observed. In testing discussed by Keller,[14] the drill bit had carbide teeth and was operated on a steel piece in the dark. Sparks were observed. All carbide teeth are eliminated in later designs. New drill-bit cutting teeth are made of a proprietary sintered bronze with small tungsten chips in the bronze matrix. This material can wear easily when the drill bit is operated on metal objects or hard materials. The core sample drill bits used by FG/RMCS are Longyear (trademark of Longyear Incorporated) Part Number 100IVD/8 (currently used). It is known that the probability of sparks from copper-based materials is not high. Nevertheless, the inability of the drill bit to cause a frictional spark in a bounding flammable-gas mixture needed to be demonstrated by testing.

A series of ignition tests were conducted to demonstrate that the present drill bit design does not ignite a sensitive flammable-gas mixture. This testing addressed the frictional spark when the drill bit encounters a metal object that could be in the waste. Tests were designed to simulate the action of a drill bit striking a hard object inside a waste tank, such as a piece of structural steel or a rock. Tests were conducted in a bounding stoichiometric hydrogen oxygen and ammonia nitrous oxide mixture. The detail of the testing procedures are provided in Appendix T.

Controls and automatic shut-down features are used to keep the down force and rotational speed within the limits (750 lbf and 55 rpm) at any time during operations. As long as these limits are not exceeded, the accident frequency is very much less than 1.0E-6. In addition, the BOM tests demonstrated no ignition, as discussed in Appendix T and by Witwer (Ref. 10). If the controls are exceeded, it is assumed that an ignition could occur if there is enough flammable gas. The frequency of the failures of down force and rotational speed, assuming that the controls are exceeded, is determined in Appendix E and given in Table 4-10. In order to initiate a dome burn when the drill bit is penetrating the crust, other necessary conditions must exist: (a) rocks (or other hard material) must exist at the surface or in the crust, (b) flammable gas with sufficient concentrations must exist, and (c) flammable-gas volume must be significantly high to cause propagation into the waste or the dome (propagation to the dome requires flammable gas be in the dome). Because failure frequencies are already small, the consideration of additional probabilities to cause a dome burn makes this scenario incredible. However, the same initiator when the drill bit is in the waste will be considered in Section 4.4 to address the flammable-gas ignition in the waste.

TABLE 4-10
DOME FIRE ACCIDENTS CAUSED BY DRILL BIT FRICTIONAL SPARKS

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Excessive drilling rpm leads to ignition of flammable gas resulting in dome collapse.	MAF = 1.4E-5 UAF = 2.2E-2 With qualification of drill bit, per test specified in Appendix T, UAF<<1.0E-6	The rpm setting is too high. Drill string fails to trip on high rpm.	Control over speed setting is used. Drill string auto trips on excessive rpm.
Excessive down force on drill leads to ignition of flammable gas resulting in dome collapse.	MAF = 9.4E-5 UAF = 1.2 With qualification of drill bits, per test specified in Appendix T, UAF <<1.0E-6	Excessive down force is used. Drill string is on excessive force with either force detector or walkdown detector.	Control over down force is used. Auto trip drill string on excessive force is needed: force detector and walkdown detector function for all samples except last; force detector and bottom detector for last sample are needed.

4.2.7. Ignition of Flammable Gas in the Dome (Operation)

This event considers the possibility of an ignition caused by the existence of energized equipment in the dome or domes of connected tanks or connecting ventilation systems. Any activity in the connecting tanks may initiate a fire that may propagate into the tank being sampled. Appendix B requires that all equipment in the dome be rated for operations in a Class-I, Div.-1, Group-B environment or a Class-I, Div.-2, Group-B environment with automatic shutdown. Any equipment that does not meet this requirement must be deenergized during FG/RMCS waste-intrusive operations. No other activities in the connecting tanks or on the same tank are allowed during FG/RMCS waste-intrusive operations. These controls reduce the likelihood of ignition caused by existing equipment in the tank dome and the domes of connecting tanks. Violation of this control may result in an unanalyzed initiator.

4.2.8. Ignition Of Dust and Flammable Gas in the Dome (Operation and Removal) (Static Electrical Charges and Other Causes)

In this accident scenario, the ignition of aerosols generated in the dome is analyzed. In Appendix H, a bounding analysis is performed to show that the energy contribution of combustible dust is negligible and that the addition of dust in a hydrogen-air mixture would not result in explosion.

4.2.9. Summary of the Dome Fire Accident

The drill string break resulting in a dome fire is the dominant fire initiator in the dome space. The principal contributor to the accident sequence is exceeding the operating limits. The resulting dome fire MAF is 4.8E-10/yr. The UAF is 2.8E-7 and is low. The consequence of this accident is the dome collapse analyzed in Section 5 of this SA.

4.3. DRILL STRING FIRE ACCIDENTS

Drill string fire accidents consider all possible fire initiators inside the drill string. Each ignition initiator determined for this category is discussed separately. The ignition source may exist as a result of normal as well as abnormal operations.

The consequences of a drill string fire vary and may end up with small amounts of waste release as well as a dome collapse. Examples of how a drill string fire may propagate to other accidents are discussed in Appendix A. It is assumed that the fire in the drill string (if it occurs) propagates to the tank and results in dome collapse. As explained in the introduction, this assumption is conservative, and there is only one consequence, dome collapse, if a drill-string fire occurs. The conditional frequency of each accident scenario, however, is discussed and the adequacy of preventive features is demonstrated.

4.3.1. Flammable-Gas Penetration into the Drill String (Operation)

Section 3 identified the fact that there may be several reasons for hydrogen penetration into the drill string:

- Failure of the chevron sampler seal between the drill bit and the drill string,
- Hydrogen diffusion,
- Waste in the drill string,
- Failure of the core sample ball valve on the core sampler,
- Depressurization of waste in the drill string,
- Loss of hydrostatic pressure,
- Incompatible material, and
- Failure to latch the sampler.

The hydrogen can be generated in the drill string if there is waste penetration into the drill string. A leaky chevron seal may allow waste penetration into the drill string. If the sampler encounters large gas pockets in the waste (although credible evidence for this mechanism is not provided), the sampler could be filled with flammable gas. Failure of the core sampler valve in the drill string could release hydrogen into the drill string. Failure to latch the sampler to the core barrel can cause flooding and gas generation in the drill string. However, as long as hydrostatic pressure during sampler retrieval and nitrogen purge during drilling are available, the hydrogen release into the drill string from the sampler or waste is not of concern because there is enough flow rate to purge or prevent diffusion up the drill string. Appendix J concludes that the minimum flow rate at which hydrogen could diffuse against the flow is 5E-4 scfm, which is lower than a minimum flow rate of 0.3 scfm provided by the purge system.

One other mechanism that can produce flammable gas is the use of incompatible material in the drill string design. The drill string is made of steel, and steel is known to be compatible with the waste in terms of violent chemical reactions that would result in gas releases or other undesirable consequences. WHC recently reviewed the sampler to ensure that there were no incompatible materials used in the construction; in particular, they examined the design for the presence of aluminum. Also, the drill bit and seals used in the design have been used in actual waste and found to be compatible (Ref. 15).

There are three major causes for hydrogen accumulation in the drill string:

1. Failure of nitrogen flow during drilling,

2. Failure of hydrostatic flow during retrieval, and

3. Failure of the chevron seal before the change-out assembly is installed.

The sampler is designed to prevent waste and flammable-gas penetration into the drill string through a chevron seal located at the end of the core sampler. It is a one-way seal and allows nitrogen flow from the drill string into the tank waste. When the drill string is rotated, the core barrel rotates around the core sampler while the seal is slightly compressed to allow nitrogen flow. When the sampling is finished and the purge flow stopped, the seal provides a barrier between the tank waste and the drill string. Flammable gas may penetrate into the drill string if the seal does not provide an adequate barrier. It is reasonable to assume that the seal may fail partially if not completely before the retrieval of the sampler (as change-out assembly is installed). Calculations (Appendix J) show that hydrogen can diffuse in nitrogen relatively fast.

It is required that the drill string be purged to evacuate flammable-gas accumulation following a procedure developed by WHC for the following conditions:

- The sampler is left in the DS without nitrogen flow or hydrostatic pressure for $\geq$ 60 minutes, or

- DS hydrostatic head is lost with no sampler in place.

If these conditions occur, the grapple or remote latch unit should not be operated unless the nitrogen purge criteria are met. The hydrostatic head pressures for each sampler need to be calculated before operation.

4.3.2. Ignition of Flammable Gas in the Drill String Caused by Drops (Operation)

The remote latch unit and the grapple are lowered and raised during the insertion and removal of the sampler. Each unit is driven by an electrical motor through a gear box. Each is mechanically attached to a driving system through a cable. The insertion and removal rates of the remote latch unit and grapple are specified as less than 1 ft/s.

In this section, accidents resulting from frictional sparks in the drill string as a result of dropping the grapple, remote latch unit, and core sampler are considered. In the case that the hoist systems for the grapple and remote latch unit or electrical motors used to raise or lower these units fail, the grapple and remote latch unit may be dropped on the core sampler. The keys or pins connecting the shaft to the drum can be broken as a result of a stuck core sampler, grapple, or remote latch unit. The following are assumed to cause frictional sparks:

- Multiple drive train failures,
- Failure of keys or pins connecting the shaft to the drum, and
- RLU failure.

Studies have been performed to examine the characteristics of mechanically produced sparks that could lead to ignition of hydrogen-nitrous oxide mixtures. Drop velocity could be as high as 19.8 m/s and is well above the range given by Krok and Shephard's work.[9] Therefore, if the remote latch unit or sampler is dropped in the drill string, it is assumed that an ignition source can be created.

The remote latch unit and grapple are driven with DC pulse-width modulated electric motors. Their principal operating parameters are given in Section 2. Because of the worm-gear reduction boxes, failure of these motors would not result in a drop. However, a drop accident may occur as a result of the failure of the metal key or pins that are used to attach the shaft to the cable drum. These pins are the weakest points of the system and may fail if the grapple or the RLU is stuck or overweighted because of some unknown reason.

The operation of the RLU is entirely mechanical and is discussed in Section 2. When the RLU is lowered and the sampler comes to rest at the bottom of the drill string, the cable stops when the load cell detects the cable going slack. As the tungsten weights cause the dashpot piston in the RLU to descend, the load cell again engages the downward motion of the hoist.

When the sampler is being raised or lowered in the drill string, the hydrostatic head must be in operation. There are two independent sources of hydrostatic head, one through the shielded receiver and one through the change-out assembly.

Drops caused by failure of the remote latch unit were concluded in section 4.1.2.2 to be not credible. However, the grapple can be dropped in the drill string if the shear pin on the drum fails. The load on the grapple is measured. The load cell automatically trips the electrical motor when the reading is out of tolerance. A control is established to not exceed a maximum load of 250 lb. For an ignition to occur, flammable gas must be present, which means that the hydrostatic head purges and chevron seal must have failed. Before the pintle rod is removed, the hydrostatic head must be established. This requirement is established as a control. The probability of a drop is estimated as 1.4E-7, based on the controls established for load measurements. The MAF of this accident is calculated as 6.0E-11/yr in Appendix E and is given in Table 4-11. The UAF is 1.3E-3/yr. Because the MAF frequency is so small, no special ignition testing is required for the grapple drop caused by ignition accidents. However, the established control becomes important.

The frequency for dropping the core sampler has been estimated as 1.9E-6/yr in Section 4.1.4. The estimated frequency is not <<1.0E-6/yr. Therefore, drop tests simulating the drop of the core sampler on the drill bit were performed by the BOM (test description and requirements are given in Appendix T). A prototypical core sampler was dropped from a height of 60 feet through the drill string with the drill bit attached to the lower end of the drill string. The test chamber and the drill string were filled with a stoichiometric hydrogen-air mixture. The tests were repeated ten times. Ignition did not occur as reported by Witwer (Ref. 10). Therefore, this accident is not considered further.

4.3.3. Ignition of Flammable Gas in the Drill String Caused by Assembly/Disassembly of Drill Rods or Drill Rod-Quill Rod Adapter Impact

Ignition of the flammable gas in the drill may be caused by impacts that could be created during drill-string or drill-string-to-quill-rod assembly or disassembly. The postulated accident can occur when the drill string is in the waste or dome. Accident frequency is different for these two cases because of the assumption regarding to the flammable gas. Flammable gas exists in the dome only if a GRE occurs while it is assumed to exist in the waste.

A spark during the disconnecting of the quill rod from the drill string has been observed.[16] The quill rod adapter and drill string were made of carbon steel. Any misalignment between the drill string and quill rod caused by undesired platform movement or operator errors could create a relatively fast impact between the quill rod and drill string when the drill string is disconnected. There is no instrument to detect the misalignment or any stress level on the drill string or quill rod adapter. Therefore, it is very difficult to evaluate the condition of the drill string to quill rod adapter before disconnecting the drill string. Because a spark is observed in the operation, one must assume that the likelihood of this event is high.[16]

The drill string is assembled by adding drill rods. The operator picks the drill rod from the storage location and lifts and screws it onto the drill string by hand. Then the lifting bail is attached to the drill string.

During insertion, drill-rod-to-drill-string impact is very possible. Impact can be caused by dropping the drill string or operator error. Drop height is limited with the drill rod length. However, the operator can also cause a lateral impact. It is determined that a realistic impact velocity is around 10 ft/s. It is not clear that the impact with this velocity would not cause a spark that is capable of igniting the flammable-gas mixtures of concern. A spark is possible because the drill rods are made of carbon steel and assembling/disassembling is performed for each sample.

The cable spray washer is installed after the drill string is disconnected from the quill rod adapter. Dropping the cable spray washer may produce a spark. Next, the change-out assembly is installed on the cable spray washer. Dropping the change-out assembly on the cable spray washer may produce a spark. In order to have an ignition in the drill string, the flammable gas must exist in the drill string. The drill string must be sniffed before it is disconnected from the quill rod adapter.

A drill string fire initiated by a spark caused by the drill-rod-drill-string or the drill-string-quill-rod adapter impact is discussed in this section. Event and fault trees for this scenario are given in Appendix E. Sniffing the drill string before the drill string is disconnected from the quill rod adapter through a port on the quill rod is required. The reliability of the inspection is limited with the reliability of the sniffing equipment, which is on the order of 1.0E-3. If the change-out assembly is installed immediately (within half an hour), no other sniffing is required. If, however, the drill string is capped and the change-out assembly is installed later, there is a need for a second sniffing from a port on the cap sealing the drill string while the drill string is closed. This is because of the possibility of hydrogen diffusion through the chevron seal (Appendix J).

TABLE 4-11

DRILL STRING FIRE ACCIDENTS–DRILL STRING IMPACT, GRAPPLE, AND CORE SAMPLER DROP

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Drop of grapple in the drill string	MAF = 6.0E-11 UAF = 1.3E-3	Nitrogen hydrostatic head system fails. Load cell fails to trip electrical motors. Cable inspection fails. Chevron seal fails.	Controls are applicable to nitrogen hydrostatic head system. Electrical motor automatically trips when the load is ≥ or equal 250 lb. Inspect the cable for possible damage every 6 months.
Drop of core samplers in the drill string	Without BOM test results MAF = 1.9E-6 UAF =2.8E-3 With BOM test results MAF and UAF << 1.0E-6	Nitrogen hydrostatic head system fails. RLU drops the sampler.	Controls are applicable to nitrogen hydrostatic head system.

TABLE 4-11 (cont)

DRILL STRING FIRE ACCIDENTS–DRILL STRING IMPACT, GRAPPLE, AND CORE SAMPLER DROP

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Spark from assembly/disassembly of drill string sections or drill string to quill rod impact when the drill string is in the waste (does not contribute to the total frequency of dome collapse)	Without BOM test results MAF = 7.6E-5 UAF = 1.6E-2 With BOM test results MAF and UAF << 1.0E-6	Sniff for flammable gas is not performed in the drill string. Sampler chevron seal fails.	Sniff enclosed volume for hydrogen in drill string. Presence of sampler with chevron seal in drill string prevents hydrogen movement into drill string.
Spark from assembly/disassembly of drill string sections or drill string-quill rod impact when the drill string is in the dome (does not contribute to the total frequency of dome collapse)	Without BOM test results MAF = 1.1E-9 UAF = 2.3E-7 With BOM test results MAF and UAF << 1.0E-6	Sniff for flammable gas is not performed in the drill string Sampler chevron seal fails.	Sniff enclosed volume for hydrogen in drill string. Presence of sampler with chevron seal in drill string prevents hydrogen movement into drill string.

The chevron seal failure probability is estimated as 3.3E-2. The frequency of operator error causing drill-rod-to-drill-string impact is 0.5/activity. Considering the reliability of sniffing, an accident frequency of 7.6E-5 /activity is calculated if the drill string is left in the waste (note that the probability of hydrogen in the waste is assumed to be 1.0). This frequency is valid for a fire accident caused by drill-string-quill-rod impact. The drill string could be in the dome. In this case, hydrogen must exist in the dome in order to penetrate into the drill string. Thus, a GRE is required.

Considering the GRE probability, the accident frequency becomes low, on the order of 1.1E-9/yr. These frequencies are summarized in Table 4-11. The accident frequency when the drill string is in the waste is high; therefore, laboratory ignition testing is designed to demonstrate that ignition is not possible.

The following design changes were made to manage the above-mentioned mechanical sparks. First, the quill rod adapter material was changed from carbon steel to stainless steel. Second, all pipe compounds and lubricants used in FG/RMCS operations were reevaluated.[16] It was found that one of the pipe joint compounds, Bostik Never-Seez Anti-Sieze and Lubricating Compound, showed evidence of enhanced sparking. Necessary procedural changes were made to use only acceptable joint thread compounds listed in Ref. 16. In addition, a series of ignition tests were performed as described in Appendix T. These tests address the drill-rod-to-drill-string impact, drill-string-to-quill-rod-adapter impact, the change-out assembly-to-cable spray washer impact, and cable-spray-washer-to-drill-string impact.

The first series of tests simulated the carbon-steel drill strings impact by dropping a prototype 19-in. drill string on another vertically oriented prototype drill string from a height of 3 feet. The height of 3 feet corresponds to the impact velocity of 14 ft/s, and impact masses are conserved. Tests are performed 30 times. These tests also address the ignition caused by the drop of the change-out assembly. Witwer (Ref. 10) reported that no ignition was observed in the above-mentioned ignition tests. Therefore, they are considered to be incredible as indicated in Table 4-11.

The quill rod adapter impact test (see Appendix T) used a section of the same type stainless-steel pipe dropped on its end onto the end of a section of carbon drill string. A maximum kinetic energy during drill string/quill rod misalignment is estimated as 115 in. × lb. A safety factor of two was employed, raising the value to 230 in. × lb. A 5.22-lb piece was dropped 44 in. onto the carbon-steel pipe. The gas mixture used both in the drop tube and the test chamber was stoichiometric hydrogen and oxygen. The test chamber and drop pipe were both sufficiently purged before the drop. Tests were repeated ten times. The tests results reported by Witwer (Ref. 10) and showed no ignition. Therefore, the accident is considered to be incredible as shown in Table 4-11.

4.3.4. Ignition of Flammable Gas in the Drill String Caused by Unqualified Electrical Equipment in the Drill Head or Shielded Receiver (Operation)

This accident is concerned with the ignition of the flammable gas by electrical sparks. The SR and grapple box have load cells. These load cells are used to measure the tension on the cable that is attached to the remote latch unit or grapple. The load cells are protected by intrinsic safety barriers. WHC quality assurance requirements ensure that these barriers are certified. Thus, the load cells are not electrical spark sources. The electrical motors are located outside of the grapple box and the SR, which are sealed containers. There is no other equipment in the SR and the drill unit that can cause electrical sparks.

4.3.5. Ignition of Flammable Gas in the Drill String Caused by Drill-String Failure (Operation)

This scenario is very similar to the event discussed in the dome fire (drill string break). The difference is this scenario assumes that the fire starts in the drill string (flammable gas is in the drill string, not in the dome). The initiating event is the drill string failure, causing a hot spot in the vicinity of the failure location. This hot spot ignites the hydrogen in the drill string. The propagation of the fire in the drill string into the waste is considered to be possible. Therefore, this postulated accident may result in dome collapse.

Two failures must occur for this scenario to occur; hydrogen in the drill string and failure of the drill string. Hydrogen is not expected to be in the drill string during drilling because it requires a failure of the nitrogen flow and the chevron seal. The conditional mitigated frequency of this accident (1.3E-8/yr) is the frequency of the undetected nitrogen purge failure (1.9E-05), the failure of the chevron seal (3.3E-2), and the frequency of the drill-string breakage (1.0E-2).

4.3.6. Ignition of Flammable Gas in the Drill String Caused by Frictional Sparks (Operation)

This accident scenario considers an ignition of hydrogen in the drill string caused by frictional sparks. Hydrogen can exist in the drill string because of the failure to latch a sampler, a leaking chevron seal, etc. The drop cases were treated in Section 4.4.2. The possible sources for mechanical sparks are

- Failure of bearings,
- Frictional sparks caused by operation of the remote latch unit, and
- Frictional sparks resulting from the operation of the grapple,

Acceptance testing has verified the operability of bearings. The sampler and these bearings are used only once. The only time the bearing sees relative motion is during rotary sampling at which the time nitrogen purge is present. Waste penetration into the bearings is minimized because they are out of the waste path entering the sampler. Therefore, the failure of bearings resulting in sparks is not credible.

Metal-to-metal sparks are managed by limiting the velocity of movement of the remote latch unit and grapple to no more than ~0.3 m/s (1 ft/s). This velocity is adopted from previous studies[17] concerning a similar hazard of lowering or raising a metal pipe through a riser. It has been shown that mechanically produced sparks that could lead to ignition of tank-like gases is not likely when the frictional impact velocity is less than 2.5 m/s (8.2 ft/s) (Ref. 9).

A gear reducer and electric motor are used to limit the grapple and remote latch unit motion to 1 ft/s and 0.4 ft/s, respectively. Therefore, frictional sparks are not likely. The frictional sparks caused by a drop accident are discussed in Section 4.3.2.

A credited design feature controls the insertion or removal speed of the grapple and the remote latch unit to no more than 0.3 m/s (1 ft/s). In addition, a purge pressure equal to hydrostatic head pressure before insertion or removal of the grapple or remote latch unit is established. Sniffing the drill string each time the drill string is disconnected from the quill rod adapter reduces the possibility of hydrogen accumulation.

4.3.7. Ignition of the Flammable Gas in the Drill String Caused by Frictional Sparks from the Shear Pin Break (Operation)

This accident has been identified during the hazard identification process that considered a design involving a copper pin used to attach the piston to the pintle rod. The pintle rod release mechanism was redesigned to rely on a mechanical release instead of the copper wire shearing, and it is a metal clip. The use of a metal clip is not expected to produce a spark. Thus, this event is not considered to be credible. During the pintle rod removal operation, the hydrostatic head purge is established, and this provides additional protection.

4.3.8. Detonation in the Drill String and Drill-String Ejection (Operation)

Appendix J discusses the possibility of detonation in the drill string. It assumes that there is hydrogen in the drill string and that it can be ignited. Theoretical detonation pressure for hydrogen-air mixtures in a pipe can be calculated by using a numerical method to solve the differential equation for isentropic compression in the burn gas. From the analysis given in Appendix J, the overpressure and the rate of pressure rise during a burn in the drill string are 630 kPa and 2279.5 bar/s, respectively. During a detonation in the drill string, the overpressure and the rate of pressure rise are 15 bars (1.5×10^6 Pa) and 3×10^6 bar/s, respectively. As explained in Appendix J, the induction distance for the H_2-N_2O mixture is short relative to the maximum drill string length. Therefore, a deflagration-to-detonation transition (DDT) may occur in the drill string. The rate of pressure rise is so high (3×10^6 bar/s) during the detonation, that the structure of the drill string is expected to fail.

This conclusion is important from the consequence point of view. If the detonation in the drill string causes ignition in the waste with propagation, then a dome collapse would be expected. However, the consequence of dome collapse is not increased by this initiator because the dome collapse accident considered in Appendix I is already conservative and includes bounding waste release amounts. However, detonation may only fail the drill string and result in ejection of the core sampler. In this case, the consequences of this accident may be a release of the waste in the sampler. In Section 5, a waste release of 0.39 kg is considered.

4.3.9. Ignition in the Drill String Caused by Lightning

The lightning strike is discussed in Section 4.1.1. The controls developed to prevent ignition caused by lightning in Section 4.1.1 are applicable to this section as well.

4.3.10. Ignition in the Drill String Caused by Static Electricity Between Seals and Rotating Parts

In this scenario, the concern is the static electric discharge between the seals and the rotating parts in the sampler. The core sampler motion is in the closed space. The rotational or penetration speed is slow, and there is always direct contact with metals.

4.3.11. Summary of Drill-String Fires

All of the initiators previously identified in Section 3 were found not to cause fire in the drill string because of safety design features and experimental results obtained from ignition testing. The accident frequencies of hydrogen penetrations into the drill string are developed in Appendix E and summarized for this category in Table 4-12. The drill string fire accident frequency is 1.3E-8/yr.

4.4. WASTE FIRE ACCIDENTS

Accident sequences considered in the waste fire category include waste ignition as well as flammable-gas ignition in the waste. The waste in single-shell flammable-gas tanks includes organics. Below, the initiators that could result in waste fire accidents are discussed.

4.4.1. Waste Fire Caused by Drill Bit Over-Temperature (Operation)

Wastes including mixtures of sodium nitrate and sodium nitrite with organic compounds can produce violent exothermic reactions (Appendix G). Increasing the temperature of the waste in the vicinity of the drill bit can cause a thermal runaway. There are several hazards that are associated with a local thermal runaway, and they are discussed in Appendix G. Two major important hazards are the ignition of the flammable gas and the initiation of a self-propagating exothermic reaction in the waste. Reactions in mixtures containing relatively small amounts of organic compounds can result in temperatures greater than the autoignition temperature of hydrogen mixtures, so the ignition of flammable gases is the more limiting condition. However, a self-propagating reaction would produce very high temperatures, which would cause structural damage to the tank. The consequences of a self-propagating reaction could be severe.

Because the possibility of a flammable-gas mixture cannot be eliminated, the approach used in this Safety Assessment is to take all practical measures to eliminate ignition sources. A local runaway reaction is a potential ignition source, so the requirement that there be no local runaway reaction is consistent with the philosophy used in this SA. Preventing a local thermal runaway is also protection against a propagating exothermic reaction, and it eliminates the possibility of generating additional flammable gas as a result of elevated temperatures. Appendix G discusses runaway reactions and waste ignition in great detail.

TABLE 4-12
DRILL STRING FIRE ACCIDENTS-CONDITIONAL FREQUENCIES OF HYDROGEN PENETRATION INTO THE DRILL STRING

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Drill string break leads to a fire in the drill string.	MAF = 1.3E-8 UAF = 6.6E-4	Drill String fails to shut down on loss of nitrogen purge. Drill string breaks by jamming in the waste causing overtorque or buckling.	Drill string automatically trips when the nitrogen purge to the DS is lost.
H_2 in drill string/shielded receiver during sampler handling leading to waste fire. (does not contribute to the total frequency of dome collapse)	Without BOM tests results MAF = 1.9E-6 UAF = 2.8E-3 With BOM test results MAF and UAF <<1.0E-6	N_2 hydrostatic systems to both drill string and to shielded receiver fails. RLU drops sampler.	Leak test of N_2 hydrostatic systems for both drill string and for shielded receiver are done. Unique connections for N_2 hydrostatic systems for both drill-string and shielded receiver are used. Verification of N_2 hydrostatic supply to both drill-string and shielded receiver during activation of hydrostatic mode of N_2 supply is made. Controls over operation of RLU are used.

Basic conclusions of Appendix G are that local runaway reactions can be prevented by establishing waste temperature limits. The following temperature limits are established:

- The temperature of small waste fragments produced at the drill tip must not exceed 180°C.

- The temperature of the drill bit and the average temperature of the waste affected by drilling must not exceed 160°C for more than 10 minutes.

Because the consequences of a propagating exothermic reaction are severe, FG/RMCS should not be performed in tanks in which a propagating exothermic reaction may occur.

New envelope testing has been performed by WHC to determine the operating parameters, rotational speed, down force, and nitrogen purge flow to comply with the safety criteria given above. Witwer[18] discusses the details of testing and the results obtained. Tests and results are also summurized in Appendix F.

As a summary, results of envelope testing (Witwer, Ref. 18) and their analysis (Appendix F) showed that the drill bit surface temperature correspondingly the waste substrate temperature can be kept below 160°C, including an uncertainty of 10°C, if the following limits are applied: a down force ≤750 lbf, a rotational speed ≤55 rpm, a minimum nitrogen flow ≥30 scfm, and a penetration rate ≥0.75 in./min. The chip temperatures under these conditions are also limited to 180°C as required. If a trip is initiated when one of the set points for these four parameters is exceeded, drilling must be stopped. After a shutdown there must be a waiting period of 10 minutes before drilling can continue. The waiting period of 10 min is based on the experimentally determined cooling time. The testing and the analysis included plugged holes on the drill bit.

The minimum purge flow must be greater than 30 scfm; however, it is possible that necessary cooling to the drill bit would not be provided if there were a leak from the nitrogen purge system between the flow measurement location and the drill bit. As indicated in Table 4.13, the leak rate from the nitrogen system must be checked once every 6 months. This control requires that the leak rate must be within the uncertainty range of instrumentation or less than 2% of the nominal flow.

Drill rods are threaded to each other. An O ring is used to provide a seal. The leaks are possible if the O rings are left out. WHC[19] determined the possible leak rates could not be higher than 0.3 scfm when the O rings are not used. This is less than 1% of a nominal flow of 30 scfm and negligible. With the use of O rings, the leak rate also was measured and was shown to be negligible. Therefore, O rings on the drill rod are not required, and the nitrogen purge flow for drill bit cooling is sufficient when set to a minimum of 30 scfm.

There is one event that would include an unknown leak path as a result of failure of the drill string during drilling. If the drill bit or string becomes embedded in the waste momentarily because of debris in the waste, torque could continue to be applied to the drill string at a constant rate. If such a condition occurs, there is a possibility that the drill string could partially fail. Continuing to operate with a partially failed drill string could result in a nitrogen flow bypass through the failed area. This concern is assessed below.

Appendix N examines the possibility of over-torquing the drill string. The drill string is considered as having torque applied from the upper end, but the rotation of the lower end is not allowed. Appendix N presents two methods to determine the time necessary to break the drill string. Linear elastic methods are applied as a first approximation to obtain the lower bound failure estimate. Second, strain-energy methods are used to determine an upper bound by assuming that the ultimate shear strain in the drill rod is proportional to the shear modules. It is estimated that failure would occur in less than 15 seconds for all rotational speeds. Note that Appendix N did not take any credit for the threaded drill rods. Experience shows that the drill string always fails at the threaded sections. The real failure time is expected to be in a few seconds because of the stress concentration factor for threaded sections. Therefore, it is concluded that a drill string tear without a break is very unlikely.

Envelope testing measured the rate of increase in the drill-bit surface temperature when nitrogen flow is terminated at steady-state operating conditions. The test results are summarized in Appendix F and by Witwer (Ref. 18). Results showed that an average heat-up rate of 2°C/s is observed in the time period of 0 to 20 seconds after the nitrogen flow is shut down. This rate corresponds to a temperature increase of 30°C in 15 seconds in which the drill string would be broken when overtorqued. Envelope testing established the operating parameters so that the drill bit and waste temperature is less than 150°C. Considering a 30°C heat-up of the drill bit for this accident, the drill bit/waste temperature would be 180°C. Appendix G shows that the waste temperature would be allowed to be at the minimum exothermic-reaction temperature of 180°C for a short period of time because the induction time of reaction is expected to be much larger than 10 to 20 seconds. Therefore, it is concluded that if the drill fails because it is over-torqued it would fail in a time period in which the waste in the vicinity of the drill bit would not experience runaway reactions.

4.4.1.1. Summary of Controls for Drilling Operation.

Envelope testing shows that a maximum drill-bit temperature corresponding to the maximum waste substrate temperature increase is limited to $\Delta T = 60^{\circ}C$ when the rotational speed, down force, and nitrogen purge flow are 750 lbf, 55 rpm, and 30 scfm, and there is good penetration (penetration rate is higher than 0.75 in./min). These parameters consider a partially plugged drill bit and ensure that waste chip temperatures are bounded by the safety limit of 180°C. In order to meet the safety criteria established in this SA, the down force and the rotational speed must not exceed 750 lbf and 55 rpm. The minimum nitrogen flow rate must not be lower than 30 scfm. The penetration rate must not be less than 0.75 in./min. The probability of having a hard layer in the waste is 0.1. This is obtained with the assumption that 20% chance for a need for rotary drilling in an activity and 50% chance of hard layer in rotary mode drilling.

When a trip value is reached in one of the three parameters, down force, rotational speed, and nitrogen purge flow, the drilling must be stopped within the time period that data acquisition activates the shut-down signal. The alarm set point may be chosen lower than the trip values. If the alarm set points are set to trip values, 750 lbf, 55 rpm, and 30 scfm, the programmable logic controller (PLC) sends a shutdown signal to the drill engine upon receipt of a valid shutdown signal with no additional programmed-delay. It is understood that the determination of a valid alarm signal requires approximately 2 seconds. The penetration rate is alarmed at 0.75 in./min and shut down occurs with a 60-s cumulative time in any 3-min period. This gives a chance for the operator to penetrate a thin, hard layer (if encountered), provided that the force, rotational speed, and nitrogen purge controls are not violated. There must be at least a 10-min waiting period following the trip before the continuation of drilling.

The nitrogen inlet temperature to the drill string must be maintained between 10°F to 140°F.

4.4.1.2. Accident Frequency of Waste Ignition

Failure to shut down the drilling when limiting operating parameters are exceeded is assumed to cause runaway reactions in SSTs. The reliability of the nitrogen purge system and control system for the rotational speed and down force are examined in Appendix D. In Table 4-13, conditional accident frequencies are given. The accident frequencies caused by loss of cooling, excessive rotational speed, down force, and low penetration rate are estimated as 3.8E-5, 1.4E-5, 9.4E-5, and 7.4E-5/yr. These numbers consider the use of a bottom detector or walkdown option to shutdown. These frequencies are added to obtain the conditional frequency of a waste fire accident caused by drilling operations. The combined frequency is 2.3E-4/yr.

4.4.2. Waste Fire as a Result of Exothermic Reaction Caused by Incompatible Materials (Installation, Operation, and Removal)

Aluminum is known to be incompatible with tank waste. The existence of an exothermic chemical reaction between aluminum material and the waste has been observed. The reactions can produce large quantities of flammable and toxic gas, and heat. This material must not be used inside the waste tank. Inadvertent placement of this material in the waste tank environment presents itself as one of the more logical sources of an accident initiator. Use of this material in the drill-string column could lead to a rapid chemical reaction.

All that is required for this accident to occur during the core-sampling phase is for the sampler seal to leak waste into the drill string. Personnel exposure to this hazard occurs when the drill string is opened to add a section. At this point, the pressure balance across the seal provided by the nitrogen gas has been removed, and the string is at atmospheric pressure. This allows the waste to rise up into the column. When the waste encounters incompatible aluminum material, an exothermic reaction occurs.

TABLE 4-13
WASTE FIRE CAUSED BY FRICTIONAL HEATING FROM THE DRILL BIT

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Loss of drill-bit cooling leads to waste fire.	Without probability of reactive waste MAF = 3.8E-5 UAF = 2.0 With consideration of probability of reactive waste for selected tanks (Appendix G) MAF <1.0E-6	N_2 cooling holes in the drill bit are partially blocked, there is no trip of the drill string on low N_2 flow, and there is localized overheating of sections of drill bit.	Auto trip of the drill string occurs on low N_2 purge gas flow. Annunciation of high N_2 purge gas temperature is required. N_2 purge system is tested for bypass leakage. Test results show that N_2 leakage from drill string with section O rings not installed is acceptable. Analysis shows that a drill string tear without a break is very unlikely.
Excessive drilling rpm leads to waste fire.	Without probability of reactive waste MAF = 1.4E-5 UAF = 2.2E-2 With consideration of probability of reactive waste for selected tanks (Appendix G) MAF <1.0E-6	The rpm setting is too high. Drill string fails to trip on high rpm.	Control over speed setting is used. Drill string auto trips on excessive rpm.

TABLE 4-13 (cont)
WASTE FIRE CAUSED BY FRICTIONAL HEATING FROM THE DRILL BIT

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Excessive down force on drill leads to waste fire.	Without probability of reactive waste MAF = 9.4E-5 UAF = 1.2 With consideration of probability of reactive waste for selected tanks (Appendix G) MAF <1.0E-6	Excessive down force is used. Drill string on excessive force with either force detector or walkdown detector.	Control over down force is used. Auto trip drill string on excessive down force: force detector and walkdown detector function for all samples except last; force detector and bottom detector for last sample. The drill bit type tested by BOM is used.
Slow penetration rate results in waste fire.	Without probability of reactive waste MAF = 7.4E-5 UAF = 0.2 With consideration of probability of reactive waste for selected tanks (Appendix G) MAF <1.0E-6	Operator fails to act.	Provide a 1 of 1 system for detection of penetration rate. Auto trip on slow penetration rate. One minute is available for operator to recognize slow penetration conditions and stop drilling.

To mitigate this hazard, the materials used in the FG/RMCS and drill string were chosen to be compatible with the contents of the tank so that neither chemical action nor materials failure is expected as a result of expected or accidental contact with the waste. WHC performed a compatibility study on seal components as well as for the drill bit using an ammonia-saturated environment. Additionally, these materials have been used in actual waste. No significant degradation was observed. Study results summarized in Ref. 15 confirm these observations.

Using aluminum tools around the open risers could have a potential for a drop ⁻ident. Administrative controls and work plans must be enforced to ensure that ·sonnel near an open riser do not use waste incompatible tools.

o minimize the potential for exothermic chemical reactions, aluminum pans and ntainers must not be used in contact with significant quantities of tank waste.

⁻he drilling truck has some aluminum parts around the rotating platform. ·fowever, the tank waste is not normally handled above these parts.

A review of the compatibility of aluminum with the tank gases has been conducted and determined to be without detrimental effect and is therefore not considered further.[20]

Based on References 15 and 16, pipe compounds, lubricants, seals and tapes in contact with the DS or tank waste that contain spark-inducing or waste-incompatible materials must not be used.

4.4.3. Crust Burn Caused by Drop Impact (Installation, Operation, and Removal)

In this section, the drop of the drill string or tools on the crust or waste surface is analyzed. The frictional spark aspect of this accident has already been discussed. In this section, crust reaction and the possibility of waste ignition are discussed. The drill string impact is a bounding impact accident.

Appendix G assesses the possibility of crust ignition and propagation following a drop of the drill string. Based on the analysis summarized in Appendix G, the maximum crust temperature produced by impact is 126°C, which is much less than the limit of 160°C given in Section 4.4.1.1 for preventing local exothermic reactions. Therefore, no local exothermic reactions are expected.

It is concluded that with the limited energy input possible and with the crust-burning characteristics, propagation is impossible.

4.4.4. Flammable-Gas Ignition under the Waste Surface Caused by Friction From the Rotation or Penetration of the Drill Bit (Operation)

One of the safety concerns of sampling with the rotary-mode drill in flammable gas tanks is the ignition of the flammable gas in the waste by the frictional sparks created by the drill bit. The condition of waste in terms of hardness is not known before the operation. A possibility of penetrating a very hard waste layer in a tank exists. In addition, there may be some metal debris lost or dropped from the riser in the past. Hard materials such as rocks or metals can also exist in the waste. Thus, it is likely that the drill bit may strike against metal and other hard objects during drilling.

Ignition caused by frictional sparks is evaluated by performing ignition testing in bounding conditions. Appendix T discusses the ignition testing requirements and acceptance criteria. The objective of the tests is to demonstrate that the operation of rotary-core drilling in a bounding frictional environment with bounding gas composition does not cause an ignition. Testing was performed by the Witwer[10] and BOM personnel and showed no ignition.

The conditional frequencies of a fire accident resulting from exceeding the rotational speed and down force are estimated as 1.4E-5 and 9.4E-5/yr as indicated in Table 4.13. Controls are established to trip the drilling operation when the rotational speed and down force exceed 55 rpm and 750 lbf. There is no delay time for the trip except the delay time from the data acquisition system. If needed, the alarm points will be set at lower values. However, drilling must stop when the trip value is reached. The FG/RMCS operations must use only the drill bit type meeting the requirements listed in Appendix T.

Some of the early tests performed at the BOM showed some interesting results. The first series of tests were conducted at a down force of 1360 lbf and rotational speed of 65 rpm. Frictional tests performed with metal objects did not ignite the hydrogen-oxygen mixture. Ignition was observed while testing an experimental bit that had carbon-steel pins embedded in the tooth region against rocks. No ignition was observed using a bit where the carbon-steel pins were not in the tooth region. The tooth region is defined as the material beneath the carbon steel blank. Therefore, this SA requires that no spark-inducing materials be located in the tooth region. Because the drill bit base also is made of carbon steel, an additional control requires that the drill bit must be replaced if drilling is shut down four times consecutively as a result of a low penetration rate, and if the cumulative penetration is <0.3 in. for the last three attempts. This conclusion was confirmed by Witwer (Ref. 10).

During frictional ignition tests using the current bit with assorted rocks and with a test period of 3 min, no ignition was observed. The last test was run to failure. Ignition occurred in the hydrogen-oxygen mixture within the sixth minute. It was postulated that the ignition occurred because the autoignition temperature at the teeth surface was reached. The test was repeated and ignition was observed at almost the same time. The bit teeth were not worn significantly to cause the carbon steel blank to be exposed to the rock. Additional tests without flammable gas were performed to determine the interface temperature. In one of the tests, a thermocouple was placed 1/8 in. beneath the assorted rock. The rock was not worn significantly; therefore, the temperature just beneath the rock could be measured. The rock temperature 1/8 in. beneath the surface was 236°C 6 minutes after testing has started. An infrared temperature probe was also used to determine the teeth surface temperature. Four minutes into the test, temperatures up to 400°C were observed. These tests indicate that the autoignition temperature would be reached between 4 and 6 minutes.

The analytical and experimental program described in Appendix T provided the data to verify that the ignition observed in these tests was indeed caused by the interface temperature reaching the autoignition temperature (see Witwer[10]).

A penetration control is established in order not to operate in the frictional mode of cutting that results from worn teeth. However, this control is established to set the substrate temperature within the limits. In order to cause a hot spot on a substrate, the penetration rate control must be violated. Appendix F shows that with reasonable penetration, the substrate temperature is less than 160°C. Appendix F also concludes that as long as a nitrogen purge flow of 30 scfm is provided, down force is less than 750 lbf, or rotational speed is less than 55 rpm, the substrate temperature does not increase above 150°C. Therefore, to reach an autoignition temperature of hydrogen nitrous oxide ammonia mixtures, a triple failure needs to be obtained; penetration rate and purge flow; penetration rate and force; or penetration rate and rotational speed (see Table 4-14). These results were verified by using rocks in the envelope testing discussed in Appendix F (Witwer[18,10]).

TABLE 4-14
FLAMMABLE-GAS IGNITION UNDER THE WASTE SURFACE CAUSED BY FRICTION FROM THE ROTATION OF THE DRILL BIT

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Drill bit hits a rock and spark leads to ignition of flammable gas and consequently waste fire.	Without BOM data: MAF=6.6E-7 UAF=0.2 With BOM Data MAF and UAF <1.0E-6	Rocks are contacted in the waste. Penetration rate detector fails.	Auto trip occurs on slow penetration rate and a loss of or low N_2 drill string purge gas flow results.

4.4.5. Summary of Waste Fire Accidents

The waste fire accidents considered various initiators. The overheating of waste or the drill bit and the ignition of flammable gas by friction that could be created by drilling are the dominant initiators. Experiments have been conducted to define safe operating parameters at which these two initiators could not cause ignition. The critical operating parameters are down force, rotational speed, nitrogen purge flow, and penetration rate. Failure to control these parameters could result in dome collapse. The total accident frequency is found to be 2.3E-4/yr.

The analysis of the waste ignition did not account for the probability of encountering a waste layer where the burn propagation is expected. The proportion of the reactive waste in each SST is considered in Appendix G. As shown in Appendix G, only some tanks satisfy the low fraction of reactive waste criterion. The accident frequency for these tanks becomes less than 1.0E-6/yr.

4.5. CHEMICAL REACTIONS AND CRITICALITY ACCIDENTS

4.5.1. Criticality Caused by Drilling (Operation and Removal)

The criticality issues associated with the FG/RMCS operations are addressed in Appendix R. The analysis given in Appendix R concludes that nuclear criticality within the single-shell flammable-gas tanks could not occur as a result of FG/RMCS.

4.5.2. Water Addition and Temperature Limits (Operation and Removal)

These accidents address the possibility of excessive water additions to the tank that would cause the level to rise above what is allowed by safety controls. It also addresses the effect of the water addition on the waste temperature and gas releases. In the limit, flooding could result from the release of tank materials into the environment caused by hydrostatic failure of the tank. Flooding from natural events is considered in Section 4.9.

Also, water addition can have several effects: (1) changes of the waste temperature, (2) release of gases, (3) changes in pH level, and (4) an increase in radiolysis activity. Appendix O discusses the effect of water additions. It is concluded that, if done within the specified limits, water addition does not cause a safety concern.

4.5.3. Waste Ignition and Melting (Operation)

Waste ignition as a result of exothermic chemical reactions is discussed in the waste fire accident category. In this section, the waste melting hazard is addressed. The estimation of the melting temperature of waste depends upon the waste composition. A mixture of sodium nitrate, sodium nitrite, and sodium acetate melts at 175°C (Ref. 21). In addition to these components, the waste contains sodium hydroxide, sodium aluminate, sodium carbonate, sodium sulfate, sodium phosphate, and a host of minor components. Adding additional salts lowers the melting point. Therefore, the melting point of waste is expected to be much lower than the 175°C observed for mixtures of sodium nitrate, sodium nitrite, and sodium acetate. The maximum allowable drill-bit temperature is 160°C, which is probably above the melting point of the waste. Thus, waste melting may occur during drilling.

One consequence of melting could be a gas release, but it is not expected that the gas release will be significant. At worst, the FG/RMCS perturbs the temperature in the neighborhood of the drill bit. Thus, the affected volume is small. Much larger gas releases are considered in the consequence analysis.

Melting has been proposed as a necessary precursor to runaway exothermic reactions. Melting would cause different chemical components to be brought into contact with each other. Although melting may be necessary for a runaway reaction, it is not the only consideration. Appendix G discusses the temperature limit to prevent runaway exothermic reactions based on experiments conducted on simulants, real wastes, and waste surrogates. These experiments already include the melting phenomenon. Therefore, melting as an initiator of runaway reactions is not considered as a separate hazard.

The drill bit holes can become totally or partially plugged during drilling. Such a scenario could cause overheating of the drill bit, resulting in waste ignition. Envelope testing discussed in Appendix F includes testing with plugged holes. It is demonstrated that the plugging would not cause overheating within the bounds of the operating parameters controlled in Section 6 of this SA.

4.5.4. Energy Addition to the Tank (Operation)

As discussed in Appendix O, energy additions or nitrogen cooling during FG/RMCS operations do not cause a safety concern, provided the operations are performed within the specified limits.

4.5.5. Impact-Sensitive Compounds

The presence of impact-sensitive explosive materials was evaluated by Martin[22] and Beitel.[23] It was concluded that impact-sensitive compounds are not considered to be credible initiators for chemical reactions.

4.6. CONTAINMENT BREACH ACCIDENTS

A loss of confinement of the toxic and radioactive waste from a structural failure of the tank liner is an important safety issue. Installation, removal, and/or decontamination operations potentially constitute hazards to the structural integrity of the tank. The following subsections discuss the assessment made of these situations.

4.6.1. Excessive Static and Dynamic Tank Dome Loading (Installation, Operation and Removal)

Appendix N examines static and dynamic dome loading and its consequences. The static load capacity of the tank dome is monitored carefully, and an overload state that could precipitate a structural failure must be avoided. The equipment required on the surface of the tank to support FG/RMCS sampling operations qualifies as a live load (see Appendix N). The tank loads study permits a 50-ton live load on the tank dome. Even though the weight of all FG/RMCS equipment exceeds 50 tons, administrative procedures will limit the tank loading to less than 50 tons. Therefore, the dome loading must be controlled by the dome loading limits for SSTs as specified in OSD-T-151-00013 (Ref. 24).

The dome would be subjected to dynamic dome loads if a truck were to fall from the hydraulic jack or from a platform. Appendix N considers this scenario and analyzes the consequences of the dynamic loading caused by dropping the truck. It is concluded that the dome could withstand the impact force of the 30,000-lb truck dropping on it from the 3-ft-high platform.

Excessive vacuum in the dome is another accident identified as a result of exhauster operations. The exhauster design prevents the occurrence of excessive vacuum because the shutoff head is 14 in. w.g. A dome collapse would not occur until -15 in. w.g. Also, the inlet HEPA filter has a vacuum breaker to prevent excessive negative tank pressure. The vacuum breaker is set at about -4 in. w.g.

4.6.2. Penetration of Tank Bottom, Drill String Drop, and Drilling against the Liner (Installation, Operation and Removal)

The drill string is restrained from falling and impacting the tank bottom by the pneumatic foot clamp. After numerous sections of the drill string have been added, the suspended weight could cause the drill string to fall if the clamp is released because the force of gravity exceeds the frictional forces of the frisbee. Initially, the frictional force developed at the riser seal interface exceeds the string weight. The frictional force is produced by the rubber frisbee that girths the outside diameter of the drill string. This constant force eventually is overcome by the column weight as the drill rods are added. The drill string extending nominally halfway into the tank poses the largest hazard to the integrity of the tank bottom from an impact. The impact force that would occur if the drill string were released was evaluated.[25]

Appendix N includes a ballistic impact analysis for different drop heights. The resulting stress level is expected to challenge the ultimate strength of the liner material despite the inherent ability of the carbon-steel liner to withstand higher stresses under high strain rate conditions. Because this accident can lead to a breach of the waste confinement, it is a major concern and must be avoided through the application of administrative controls. The very low expected accident frequency associated with this drop significantly ameliorates the risk. This mitigating consideration is discussed next.

The pneumatic foot clamp provides a positive grip around the string due to gravity and interference fit. Even when deenergized, the clamp provides positive restraint to prevent the string from falling. Although gravity and the interference fit prevent the string from falling under gravity, it does not preclude upward motion. Several events must occur for the drill string to fall and impact the tank bottom. Appendix E determines that the frequency of a DS drop impacting the tank bottom is 3.0E-5/yr. The consequence of this drop of the drill string is damage to the bottom liner resulting in a radioactive liquid release into the ground.

Sampling near the bottom of the tank introduces the possibility of contacting the tank bottom. Precautions are taken in setting up the drill string simply by recording the string depth during installation. Nonetheless, in the rotary-mode sampling method, the drill string can produce an axial force of 750 lb. The force produced on the drill string by hydraulic action neither causes the drill string to penetrate the tank liner nor threatens the tank's structural integrity in any way. The drill string is a very long, slender column when fully extended to the tank bottom. This column buckles at a load less than the ram capacity force of 5370 lb. As an added protective feature, the FG/RMCS incorporates a bottom-contact sensor that reverses the hydraulic ram pressure used in the drill string operation. The pressure reversal causes the sampling operation to cease and pulls the drill bit away from the tank bottom.

Because the axial forces that can be produced by the FG/RMCS during sampling are significant, contacting the tank liner may pose an unacceptable risk to the tank's structural integrity. Therefore, a control is established not to drill closer than 3 in. from the tank bottom (see Appendix N for the basis of this control). Note that the failure probability of the walkdown and force plus the hydraulic bottom detector protection systems to detect the bottom are low and are estimated as 3.0E-5/yr.

4.6.3. Failure of the Drill String (Installation, Operation, and Removal)

The failure of the drill string during drilling is evaluated as a fire hazard. A torque and axial load are applied to the drill string during drilling. Buckling of the drill string from the application of axial force and torque as well as excitation of the drill string with natural frequency could yield drill string failure. The down force is limited to prevent drill bit overheating. The other limit on the down force should be based on the buckling limit. Appendix N discusses the structural buckling limit under various boundary conditions. The buckling limits as a function of the drill string length are given in Fig. N-1 of Appendix N.

Appendix N concludes that the drill string could not be excited with natural frequency as a result of torque only. Figure N-4 of Appendix N plots the first and second mode-resonance rotational speed as a function of the drill string length. The suggested range of rotational speeds is tabulated in Table N-2.

When the drill string length is less than 45 ft, down force must be limited to 750 lbf, and rotational speed is limited to 55 rpm. When the drill strength length is > 45 ft, administrative controls must be established to limit the speed to 40 rpm and down force to a maximum of 650 lbf.

Buckling loads and rotational speed to prevent resonance are established as required controls in Section 6. The frequency of the exceeding force limits is 9.4E-5/yr (Appendix E). The consequences of drill string breakage are several. The major concern is to cause a hot spot resulting in a fire in the dome (assumes that a failure occurs in the dome space and coincides with the existence of flammable gases). In Section 4.2.1, the fire accident caused by the drill string breakage was discussed. The other concern is the operational difficulty of removing the broken drill string. This SA does not address the removal of damaged drill strings.

4.6.4. Riser Damage (Installation, Operation, and Removal)

The risers in the SSTs, although differing in diameter and overall length, share common support features. Each riser is anchored into the concrete tank dome with horizontal studs. The risers are not welded to the primary tank liner because the primary liner does not cover the tank dome. Failure of these studs conceivably would result in the riser being driven into the tank space. This prospect is an unlikely event for small-diameter risers.

Riser loads have been investigated by Miller.[26] The stress produced in the riser from this impact is directly proportional to the square root of the falling body's kinetic energy and the material modules of elasticity, and is inversely proportional to the riser volume. Thus, stress buildup in the riser pipe is not only influenced by the riser cross-sectional area but also by pipe length.

The drill string is to be placed on and removed from the riser during installation, operation, and removal activities. The new drill rods are lifted manually and threaded to the drill string. Even if they are dropped, their weight is only about 7 lb. An analysis of the drop height performed by Miller shows that a maximum height exists that depends upon the mass of the object to be dropped. The analysis further indicates that the scaling of the mass is a linear function of the ratio of the masses. Miller calculated a 1.7-in drop height for the studs to fail if an object with 363 kg (800 lb) is dropped. Using this information and the weight of a drill string, the scaling ratio is 800/7, or 114.3. The maximum lift height associated with a drill rod is 5.0 m (16.4 ft). This height is larger than the distance between the rotary platform and the riser. Considering all of the arguments above, riser damage from a drill-rod drop is not expected.

During operation, the drill string rotates in the conductive sleeve installed in the riser. Because the riser would be subjected to lateral loading, excessive stresses could be introduced on the riser's lower lip, upper flange, the drill string, or to the conductive sleeve, causing either or both to fail. Lateral loads can result from many factors, including misalignment or excessive lateral movement of the drill string, wasteberg impact on the submerged portion of the drill string, or attempts to remove a bent drill string. The failure of the riser lower lip has no consequence other than a possible sparking source as it plastically deforms from the load application; however, failure of the upper flange results in a breach of confinement from an inability to properly close the riser. The failure of the drill string has other consequences, including portions of the unit falling into the tank or deformation of the drill string so that it cannot easily be removed from the riser. Removal of a stuck drill string is not in the scope of this SA. Dropping of a broken drill string could only occur when the drill string is submerged into the waste. There are controls on the downward load requiring it to be less than the buckling limit. If the control is violated and this results in a failure, the drill string would not sink because the high load would not cause penetration. Therefore, the only consequence from this type of event is that the riser could become unusable and need to be sealed.

During operation, the hydraulic capacity of the drill head and shielded receiver can also apply a vertical load to the foot clamp and the riser when the foot clamp is closed. This sequence can result in riser damage, so that the riser may become unusable and need to be sealed.

Riser damage is a more likely event in the preinstallation phase. In this phase, the vehicles are positioned on the tank top and could inadvertently run into the riser, resulting in damage to the riser. This type of accident is considered an industrial accident, and standard WHC controls prevent this from occurring.

Riser damage resulting in the ignition of flammable gas is prevented by cessation of all activities upon receipt of a flammable-gas alarm.

Heavy equipment, such as casks and exhauster skids, are positioned on the tank top using cranes. Failure of the cranes during the positioning would cause riser damage. WHC safe practice standards provide the necessary protection for the proper handling of components.

4.6.5. Tank Wall Penetration (Operation)

A tank-wall penetration accident addresses the cases in which the drill string could damage the vertical section of the tank liner. This accident is considered to be incredible. Appendix N presents a calculation to estimate the bounding horizontal load to break the drill string at the riser. It was found that the drill string could be broken if a 610 lbf is applied. The deflection of the drill string is estimated as 5.7 in. Thus, before the drill string reaches the tank wall it should be broken already. When the drill string is broken, the debris would not cause a threat to the side wall because the waste in single-shell, flammable-gas tanks is very viscous. Both the consequences and the frequency of this accident are bounded by the bottom penetration accidents.

4.7. GAS RELEASES WITHOUT BURN

4.7.1. Toxic-Gas Releases (Installation, Operation, and Removal)

The toxic gases of interest are ammonia and nitrous oxide. The consequences of toxic-gas releases are divided into anticipated, unlikely, and very unlikely bins and are discussed in Section 5 of this SA.

4.7.2. Unfiltered Releases

The consequences of unfiltered waste releases associated with the gas-release events also are discussed in Section 5 of this SA. The consequences are analyzed in anticipated, unlikely, and very unlikely accident bins, consistent with the toxic-gas release accidents.

4.7.3. Steam Release and Moisture Removal from Tank (Operation)

Mass removal by evaporation caused by drill bit heating and by ventilation operations are discussed in Appendix O. Water can also be evaporated as a result of an energy release by local exothermic reactions. However, operating parameters prevent the drill bit temperature being close to the critical reaction temperature. The analysis shows that water removal during FG/RMCS operations is not a safety concern.

4.7.4. Undetected Gas Release (Operation)

In this accident, the concern is an undetected release path at the top of the tank. The consequences of this accident may be a fire as considered in the above tank fire accident category. Toxic-gas releases are bounded by the releases from the riser.

4.7.5. Nitrogen Additions (Installation, Operation, and Removal)

Nitrogen gas is added to the tank during the normal FG/RMCS operation. Nitrogen is added to waste at the rate of 0.3 to 100 scfm. Nitrogen addition to the waste is discussed in Appendix M. Although very unlikely, a nitrogen addition may cause a gas-release event. The exhauster must be operable during drilling.

4.8. SPILLS, RELEASES, AND HAZARDOUS MATERIAL AND RADIATION EXPOSURES

Because the tank waste contains toxic, radioactive, and hazardous materials, it is possible that workers or the environment could be exposed to harmful levels of hazardous materials.

It is possible that personnel could be exposed to toxic or hazardous materials in activities that require handling potentially contaminated components. This accident scenario does not consider exposures associated with a GRE or with fires, both of which have been discussed. The subject of this section is the potential for exposure associated with contaminated components and equipment and aerosol releases from spills.

4.8.1. HEPA Releases as a Result of Excessive Loading and HEPA Failures (Operation and Removal)

Appendix R evaluates the HEPA particulate loading based on results reported by Francis.[27] The total mass from out of the riser and to the HEPA filter is reported as 901 g, a value based on continuous operation of the exhauster, a total drilling depth of 266 in., and a schedule of 40 min of drilling (19 in.) followed by a 60-min delay before starting the next drilling period. The results take into account settling of the aerosol created.

If the HEPA filters fail, a 1% release is assumed as given by Voice[28] who gave some experimental values for the release fractions of blowout incidents. The experimental estimated values are smaller than 1%. The release from HEPA would be less than 9 gr.

Differential pressures across the HEPA filters are measured. Failure to detect high HEPA loading and failure to shut down the exhauster may result in HEPA failure. The frequency of this accident is estimated as 1.6E-5/yr. (Appendix E, Table 4-15).

4.8.2. Exhauster Continuous Release after Filter Failure (Operatio and Removal)

This accident is considered in the unfiltered release accidents in Section 4.7.2. addresses the failure of HEPA filters following a continuous release with a flow rate of 250 scfm.

4.8.3. Inlet Duct Failure (Operation and Removal)

This accident addresses the release of aerosol from the riser where the breathing HEPA filter is installed. It is assumed that a HEPA filter fails, and a GRE occurs. The consequence of this accident is bounded by the gas releases from an open riser as discussed in Section 4.7.1.

4.8.4. Releases from Core Sampler Drops (Operation)

This accident addresses the releases to the atmosphere if the failed sampler (ball valve is open) is dropped from the shielded receiver. The maximum amount of waste in one sampler is 0.39 kg. A conservative airborne release fraction of 2E-4 is used (Appendix S). The aerosol release is 0.08 g for this accident. A control is established to inspect the sampler during sampler retrieval. The ball valve cannot be closed if the sampler is not inserted completely in the shielded receiver when held by the RLU.

The frequency of an accident depends upon the failure rate of the rotary ball valve and the probability of a drop or inadvertent opening of the ball valve. The frequency of this accident is determined as 8.6E-9/yr (Appendix E) as shown in Table 4.15. There are two administrative controls that are credited in obtaining this frequency.

TABLE 4-15
SPILL ACCIDENTS CONTROLS

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Radioactive aerosols are released from the HEPA filter blowout.	MAF = 1.6E-5 (not a dome fire) UAF = 1.6E-5	Excessive differential pressure occurs.	No controls are credited.
Spill results from dropped sampler in shielded receiver. (Similar accidents are spills from drops of sampler in x-ray machine or in cask but they are of lower frequency.)	MAF = 8.6E-9 (not a dome fire) UAF = 0.02	RLU drops sampler. Sampler rotary valve fails, given drop of sampler. Ball valve in shielded receiver is inadvertently left open.	Controls over operation of RLU are used. Control to close ball valve when shielded receiver is used.
Waste from contaminated drill string interior is released above ground.	MAF = 6.2E-7 (not a dome fire) UAF = 2	N_2 hydrostatic systems fail to both drill string and shielded receiver. Contamination is not detected during removal of drill string sections.	Leak test N_2 hydrostatic systems for both drill string and for shielded receiver are used. Unique connections for N_2 hydrostatic systems for both drill string and shielded receiver are used. Verification is made of the N_2 hydrostatic supply to both drill string and shielded receiver during activation of hydrostatic mode of N_2 supply. Monitoring for radioactive contamination during removal of drill string sections is done.

TABLE 4-15 (cont)
SPILL ACCIDENTS CONTROLS

Accident	Frequency of Failure 1/yr	Dominant Failures	Controls Credited in Calculating UAF and MAF Values
Waste from contaminated drill string exterior is released above ground.	MAF = 4.4E-6 (not a dome fire) UAF = 2.0	Wash of drill string exterior surface is ineffective before removal of drill string. Contamination is not detected during removal of drill string sections.	A water wash of the drill string exterior surface is done before removal of drill string. Monitoring is done for radioactive contamination during removal of drill string sections.

4.8.5. Open Sampler Spills (Operation)

The concern is the spill of 0.39 kg of waste from the core sampler. For this to occur, the rotary ball valve needs to fail with the inadvertent opening of the shielded receiver valve. The release fraction is estimated as 2.0E-4 (Appendix S), and the release to the atmosphere would be 0.08 gr. The frequency of this accident is the same as for the previous accident and is estimated as 8.6E-9/yr (Appendix E).

4.8.6. Spill from Accumulated Waste in Core Barrel

If waste collects inside the core barrel or drill rods, handling could cause a release. Even though accumulated waste may be discovered by radiological monitoring, this would only aid workers in preparing to catch the spill that could follow removal. This release would be a spill. Considering that the length of the core barrel is 1.1 m (40 in.), and the diameter is 5.08 cm (2 in. i.d.), there could be 3.3 kg (7.3 lbm) of waste. The release fraction is recommended as 2.0E-4 (Appendix S). Thus, the material release would be 0.66 gr.

The frequency of this accident is dominated by failure of the nitrogen hydrostatic system and failure to detect contamination as indicated in Table 4.15. The frequency of spills is estimated as 6.2E-7/yr.

4.8.7. Ineffective Decontamination and Drop of Drill String

If decontamination is not effective and cannot be made effective, some spilling of contamination from the drill rod could be expected. The quantity of material on the exterior of the drill string can be no more than 0.37 kg assuming a 3-mm waste film on a drill rod. The frequency of spill is calculated by considering a failure to detect the contamination and an ineffective wash as indicated in Table 4.15. A spill of the maximum quantity of material assumes no provisions to catch and contain the spill once the failed decontamination system is discovered. For conservatism, the spill quantity is assumed to be the maximum possible, however. The frequency of the ineffective decontamination and drop is estimated as 4.4E-6/yr. A release fraction of 2.0E-4 (Appendix S) gives 0.75 gm of waste to be released.

4.8.8. Radiation Exposures (Installation, Operation, and Removal)

It is possible for personnel to be exposed to excessive levels of radiation in association with proposed operations for the FG/RMCS. Several accidents are posed and discussed below. It is important to remember, however, that the exposure calculations are performed using the bounding nuclide inventory for all the SSTs (see Appendix R). Thus, such high exposure levels are not expected in any given SST.

4.8.8.1. Exposures from HEPA filters

Appendix R represents a calculation for possible radiation doses from HEPA filters. Using the code MicroShield (Appendix R), a filter geometry of 24 in. x 24 in. x 11.5 in. containing SiO_2 at a density of 0.1 g/cm^3, it is found that the exposure at 1 cm from the surface is 317 mrem/h at the end of 100 minutes of operation. This exposure may be scaled with units of 100 minutes of time because it is based on an average mass flow rate. Controls are established to survey the radiation level from HEPA filter housing each shift during waste-intrusive operations.

4.8.8.2. Radiation Doses from the Shielded Receiver

Appendix R represents the radiation calculation from a full sample when it is in the SR. The bounding value of exposure calculated is 211 mrem/h at 1 cm from the surface of the receiver. It would be expected that there would be no samples that would actually produce this value because the samples would contain liquid that has a lower source strength. In addition, the source strength used here is the maximum found in any waste sample.

Administrative controls are established to survey radiation levels from the SR per WHC procedures.

4.8.8.3. Radiation from the X-ray Machine.

The requirements for operating the x-ray machine are explained in the document entitled "Requirements for Mobile Core Sample X-Ray Systems Number 2, 3, and 4" that the WHC provided.[29] Some of the safety requirements for shielding are listed below (taken from the reference). Radiation Shielding and Safety Requirements satisfy all the safety requirements dictated in American National Standards Institute (ANSI) N43.3, 21, CFR Section 1020, Chapter 246-243 WAC.[30]

The maximum allowable dose rate at any accessible area 5 cm from the outside surface of the enclosure must not exceed 0.5 mrem/h. This is demonstrated or measured using calibrated equipment before final acceptance of the system.

Particular attention is placed on the dose rate at the Kamlock® adapter coupling. The rest of the safety requirements are available in the above-mentioned document.

4.8.8.4. Excessive Radiation Exposure as a Result of Personnel Being in a Direct Line of Sight to the Tank Waste (Installation and Removal)

Ionizing radiation from inside the tank caused by radioactive waste produces a nearly constant radiation field when viewed from an open riser. The maximum radiation field at the throat of an open 4-in. riser has been determined to be in excess of WHC limits for areas not considered to be high in radiation. Controls are required to ensure that workers do not receive excessive exposure during installation and removal, during which a direct line of sight to the tank wastes is possible. Because the FG/RMCS essentially fills the riser, there is little chance for workers to be exposed to a direct line of sight during operation. Only through the failure of workers to follow procedures limiting the exposure or through improper development of work plans can workers be exposed to excessive levels of waste on the FG/RMCS if the decontamination system is not effective. This issue is discussed in the next section.

4.8.8.5.Excessive Personnel Radiation Exposure during FG/RMCS Decontamination

The FG/RMCS may be contaminated by tank waste during removal or operation phases. The amount of waste on the FG/RMCS can increase the radiation caused by tank shine. Workers are required to aid in the assessment of decontamination effectiveness during removal actions. Therefore, workers could be exposed to the combined fields of tank waste on the drill string and tank shine.

A hand-held radiation monitor is used by radiological health technicians to ensure that radiation levels are acceptable for unrestricted work. Protective equipment and other work limitations (such as work duration) are specified by tank radiological and industrial health authorities, according to established procedures. All open-riser work requires respiratory protection, as indicated in Section 6 of this SA.

The likelihood that workers could be exposed to this high level of radiation depends on whether the decontamination system and handling procedures are effective. WHC has experience with other similar activities,[31, 32] and what can be expected for the FG/RMCS should not result in increased personnel risk. In general, the water decontamination method is successful in removing hazardous levels of waste from the exterior surfaces of components, particularly if the components are designed to facilitate decontamination, as in the FG/RMCS.

In summary, workers could be exposed to high levels of radiation; however, this is a very unlikely occurrence because the controls are strictly enforced and monitored, and workers are highly trained in both radiation protection techniques and the types of exposure possible at the tank farm.

4.9. EXTERNAL EVENTS

In this section, the accidents associated with external events are evaluated. It is concluded that the risk associated with lightning, wind, fire, earthquake, tornado, flood, volcanoes, and dust devils are acceptable as long as the activities are performed in accordance with the available administrative controls. Before and periodically during FG/RMCS operations, at the discretion of the person in charge (PIC), external event status must be verified with meteorological stations or appropriate authorities. WHC is required to identify an acceptable meteorological station and acceptable verification authority.

4.9.1. Lightning

The Hanford Site is not a major thunderstorm area. On average, only ~10 thunderstorm days per year are recorded at the Hanford Site, although this number has varied from a low of 3 to a high of 23 thunderstorm days per year. Thunderstorms theoretically can occur during any month of the year; however, they occur most frequently from April through September. The largest number of thunderstorm days recorded in a single month is eight, a number of days that has occurred in both June and August. Large differences in electric potential can occur during thunderstorms, which in turn can lead to lightning strikes. In general, ~20% of lightning strikes are cloud-to-ground/ground-to-cloud discharges. Lightning strikes in the summer occasionally have ignited range fires in the Hanford Site region.

A lightning strike could initiate a hydrogen burn during FG/RMCS operations. Lightning is a generic source for all the fire accident categories analyzed in this section. Lightning strikes are discussed in this section only, and this section will be referred to when discussing the same issue in other parts of Section 4.

Lightning hazards have been extensively treated by Cowley.[33] For background and detailed treatment, the reader is referred to this reference. Relevant features of that analysis that are pertinent to the FG/RMCS operations are discussed below.

- Lightning strikes at Hanford have a frequency of 1 per km^2/yr.
- A rough rule of thumb is that a grounded vertical rod attracts any lightning that would have struck the ground in a circle around the rod with a radius equal to the height of the rod.

Conclusions from the analysis are

- Where the object struck is not directly attached to a tank riser, the lightning could not be an ignition source for flammable-gas mixtures in the tank.

- Strikes to control panels/enclosures, power lines, backup supplies, structures, and ventilation systems result in accident situations that are insignificant, covered by interim operational safety requirements, or analyzed in the interim safety basis (ISB).

Umman says that the structure of an SST, the large quantity of rebar in the concrete, and the fact that the tank is buried gives an SST some of the properties of a Faraday cage. However, the lack of a complete steel inner liner makes the SST less effective than a double-shell tank (DST) as a Faraday cage. Construction drawings do not indicate that any effort was made during construction to make electrical connections between the risers on the SSTs and the rebar in the concrete. Therefore, there are electrically noncontinuous paths through the tank that can result in arcing. The paths are as follows:

- Arcing between inadequately bonded equipment extending through risers and the risers.
- Arcing between the riser or equipment and the rebar in the concrete dome.
- Arcing between an equipment item and the waste surface.
- Arcing at bolted flanges.
- Ohmic heating of the waste by conduction of a current into the waste by an equipment item such as a thermocouple (TC) tree.

In his report, Cowley assumes that any lightning strike on a riser or riser-mounted equipment will have enough energy to ignite a flammable mixture. To minimize the probability of a lightning strike, all FG/RMCS equipment (including the drill string) must be bonded to the riser or inserted into the tank, and must be grounded, using existing or an alternate grounding methods consistent with the principals outlined in Cowley's report (Ref. 33). WHC has developed and implemented appropriate grounding/bonding procedures. Equipment not attached to the riser or inserted into the tank must be grounded following adequate WHC grounding and bonding controls consistent with the NFPA requirements.

Lightning could strike the exhauster or any other auxiliary system or drill truck during a thunderstorm. This cannot be prevented. Therefore, no FG/RMCS waste-intrusive activities can proceed during thunderstorms, or when thunderstorm activity or lightning strikes are reported or predicted within a 50-mile radius. This reduces the likelihood that drilling would cause flammable-gas conditions in the dome when there is a high probability of a lightning strike. The drill string could be left in the riser for different reasons. When it needs to be left in the riser, and the truck is not manned, the drill string needs to comply with the grounding requirements developed by WHC.

Grounding systems and bonding need to be verified as being adequate before initiation of operations. If the strike occurs, a fire is assumed to result. Assumptions and event trees in estimating the frequency of fire accidents caused by lightning are given in Appendix E.

The low probability of a lightning strike during a GRE and during FG/RMCS operations combine to make a lightning-induced burn frequency beyond extremely unlikely.

4.9.2. Wind

At the Hanford Site, the severe-weather phenomenon that occurs most frequently and has the greatest impact is dust storms (Ref. 34). The maximum recorded peak gust at 15.24 m (50 ft) above the ground was 35.8 m/s (80 mi/h), which occurred in January 1972. A 100-yr return period peak gust of 38.4 m/s (86 mi/h) has been calculated at the 15.24-m (50-ft) elevation.

Procedures governing FG/RMCS operations constrain operations to be performed only when the sustained wind velocity is less than 11.1 m/s (25 mi/h). This limit reduces the risk of wind-caused accidents.

4.9.3. Fire

The tank farm area has been subject to range fires in the past. Procedures governing FG/RMCS operations involving installation, operation, and removal prevents operations if a range fire is within 8.0 km (5 mi) of the tank being sampled. The FG/RMCS operation may be terminated very quickly once a fire is detected within an 8-km (5-mi) radius. In addition, procedures require limitations on flammable material in the vicinity of the tank, and fire extinguishers need be on hand before beginning installation or removal operations.

4.9.4. Earthquake

An earthquake occurring during FG/RMCS installation and removal operations does not change the risk assessed in this SA significantly because the operation period of FG/RMCS is short. The low probability of a large earthquake occurring during FG/RMCS installation, operation, and removal operations is acceptable risk, and accidents that could result as a consequence of this initiator are not considered in this report.

The design-basis earthquake has a return period of 7500 yr (frequency > 1×10^{-4}/yr). SSTs are designed to withstand a 0.2-g zero-period acceleration (ZPA), but there is a high probability that a stronger earthquake with a magnitude exceeding 0.2 g may produce structural failure of the dome.

4.9.5. Tornado

Tornadoes are very rare in the vicinity of the Pasco Basin and, on average, the state of Washington experiences just over one tornado each year. Reference 35, "Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards"[36] are used for natural phenomena loadings for nonreactor facilities. This document states that tornadoes are not considered a viable threat or hazard at the Hanford Site and are eliminated as an external initiating event. Nevertheless, in Section 6 of the SA, a control restricts FG/RMCS activities when tornado activity has been predicted within the next 8 hours within a 50 mile radius.

4.9.6. Flood and High Rainfall

Reference 36 describes probable maximum flooding of the 200-West Area—streams, rivers, surge and seiche flooding, flooding from ice dams, tsunamis, and flooding from dam failures. The worst-case flood was found to be caused by a hypothetical catastrophic failure of the Grand Coulee Dam. In this case, it was concluded that the floodwaters (elevation ~140.2 m (460 ft) would be well below the elevation of the 200-West Area [elevation ~213.4 m (700 ft)]. Thus, flooding was eliminated as an external initiating event. In the case of excessive rainfall, the operations are required to be stopped. Necessary controls are established in Section 6.

4.9.7. Volcanism

Volcanic hazards of the 200-West Area were examined in Ref. 36. In this report, it is stated that there is no evidence of lava flows, ash flows, or mudflows from Cascade Range volcanoes having reached the Pasco Basin during the Quaternary period. The nearest Cascade Range volcano is more than 96.5 km (60 mi) from the Hanford Site. With the exception of mudflows and airborne ejecta, most eruption products remain within 48.3 km (30 mi) of Cascade volcanoes. At increasing distances from the eruptive vent, flows of lava, debris, and mud tend to become more confined to existing drainage channels. Because no streams flow directly from the Cascade Range volcanoes to the Hanford Site, this type of volcanic product is not considered likely at Hanford.

A volcanic ashfall event is considered to be a potential natural phenomenon occurrence at the Hanford Site. The design criterion for ashfall loading on Hanford Safety Class I (SC I) structures, systems, and components is an uncompacted ashfall of 11.4 cm (4.5 in.). This ashfall should cause no undue additional loadings on critical structures.

The low probability of a volcanic event, combined with the minor consequences of an ashfall, are not considered to pose a significant hazard to the proposed operations. The installation and removal procedures contains a requirement to suspend operations in the event of volcanic activity that could lead to an ashfall.

4.9.8. Dust Devils

A dust devil is a localized wind pattern that moves in a circular motion which spawns and decays quickly and travels at relatively low velocities. Dust devils occur frequently in the Hanford Site areas during the daytime in the summer months. Wind speeds are believed to be in the low tens of miles per hour. The major concerns related to dust devils entering the site are (1) the effects on lifting the equipment, (2) the control of contaminants during installation and removal, and (3) the effect on personnel around an open riser from contaminant dispersal. It is difficult to predict the effect of a dust devil moving over the open riser because the dust devil wind speeds are unknown and because of the variety of operations being performed. To prevent adverse effects from dust devils, FG/RMCS activities must be suspended at the discretion of the PIC when there is observable dust devil activity.

4.10. REFERENCES

1. A. D. Swain, "Accident Sequence Evaluation Program Human Reliability Analysis Procedure," US Nuclear Regulatory Commission report NUREG-CR-4772 (February 1987).

2. J. Robinson, "Description of Conductive Flexible Hose for Exhauster," Westinghouse Hanford Company letter to J. Darby (January 31, 1996).

3. "Standard Reliability Data," IEEE Standard 500, Published by the Institute of Electrical and Electronics Engineering, Inc. (1984).

4. J. Robinson, "Exhauster Duct Resistivity Measurements," Westinghouse Hanford Company letter 75230-96-012 to Cetin Unal (June 4, 1996).

5. J. E. Rasmussen, "Approval Requested for New Potential-to-Emit for the Rotary Mode Core-Sampling System Exhauster," Westinghouse Hanford Company letter (enclosure WHC Environmental Compliance Document, WHC-CM-7-5, Rev. 1) to Mr. A. W. Conklin and Mr. Jerry Leitch (December 1995)

6. Air Movement and Control Association, Standard 99-0401-86 (1986).

7. R. N. Johnson "Sparking Potential of Aluminum vs. Aluminum," Pacific Northwest National Laboratory letter to J. Robinson (February 10, 1996).

8. J. Smalley, Westinghouse Hanford Company, "Design Review Meeting for Purge Gas System," Purge Gas Pneumatic Diagram, H-2-690009 (December 1995).

. J. C. Krok and J. E. Shepherd, "Electrical and Frictional Spark Ignition of N_2O-H_2-N_2-Air Mixture," Los Alamos National Laboratory report LANL-WT-800 (June 1993).

10 K. S. Witwer, "Test Report for Ignitability Testing," Westinghouse Hanford Company report WHC-SD-WM-TRP-257 (June 1996).

11. C. Unal, "Burn in the Shielded Receiver," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-099 (January 1996).

12. J. Smalley, Westinghouse Hanford Company personal communication, (November 1995).

13. R. A. Huckfeldt, "NFPA Barriers," Westinghouse Hanford Company internal memorandum 75230-96-006, to D. Hamilton, Characterization Equipment Design Project (February 27, 1996).

14. C. M. Keller, "Push Mode Core Sample Test," Westinghouse Hanford Company Report WHC-SD-WM-TRP-048 (January 23 1991).

15. A. J. Kostelnik, "Rotary Mode Core Sample Truck Material and Component Compatibility with Tank Waste," letter (attachment Westinghouse Hanford Company internal memo, 75230-96-001 R2) to Dennis Hamilton (February 5, 1996).

16. L. F. Ermold, "Actions in Response to Spark Reported During Work on Tank 241-U-109," Westinghouse Hanford Company letter WHC-9650352, (enclosure WHC Occurrence Report, RL-WHC-TANKFARM-1996-0009) to S. Burnam (January 23, 1996).

17. H. Sullivan, et al., "A Safety Assessment for Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 242-SY-101," Los Alamos National Laboratory report LA-UR-92-3196, Rev. 14 (1995).

18. K.S. Witwer, "Envelope Testing for Rotary-mode Core Sampling," Westinghouse Hanford Company reprot WHC-SD-WM-TRP-252 (June 1996).

19. J. F. McCormick, "Test Report For Drill String Seal Pressure Test," WHC-SD-WM-TRP-DRAFT, Rev. 0 (January 1996).

20. C. Shepard and L. Pederson, "Reaction of Aluminum with Gases Released by Wastes in Tank 101-SY," Los Alamos National Laboratory memorandum LANL-WT-1152, to Troy Stokes (April 11, 1994).

21. D. Scheele, R. Shell, J. Sobolik, and L. Burger, "Organic Tank Safety Project: Preliminary Results of Energetics and Thermal Behavior Studies of Model Organic Nitrate and/or Nitrite Mixtures and a Simulated Organic Waste," Pacific Northwest National Laboratory report PNL-10213 (August 1995).

22. E. C. Martin, "Complexant Stability Investigation Task 2-Organic Complexants," Pacific Northwest National Laboratory report PNL-5453 (1985).

23. G. A. Beitel, "Exothermic Potential of Sodium Nitrate Salt Cake," Atlantic Richfield Hanford Company report ARH-LD-163 (1977).

24. V. C. Boyles, "Operating Specifications for Single-Shell Waste Storage Tanks," Westinghouse Hanford Company report OSD-T-151-00013, Rev. D-4 (1994).

25. W. O. Miller, "Retained Gas Sampler Drill String Drop Analysis," Los Alamos National Laboratory Calc Note TSA-6-CN-WT-SA-075 (November 30, 1994).

26. W. O. Miller, "Riser Impact Loads," Los Alamos National Laboratory Calc-Note TSA6-CN-WT-SA-ST-063 (March 1994).

27. P. M. Francis, "Aerosol Study for the Rotary Mode Exhauster," Westinghouse Hanford Company report WHC-SD-WM-ES-225, Rev. 0 (1993).

28. J. D. Voice, "Tank Farm Accelerated Safety Analysis; Tank Ventilation System," Westinghouse Hanford Company report WHC-SD-WM-SARR-018, Rev. 0 (June 29, 1994).

29. "General Safety Standard for (ANSI NBS 114) Installations Using Non-Medical X-ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV," ANSI N43.3 (American National Standards Institute, Inc., New York, 1993).

30. "Section Performance Standard for 1020-1991 Ionizing Radiation Emitting Products," Code of Federal Regulations (CFR), 21 CFR

31. Westinghouse Hanford Company report WHC-SD-WM-HSP-022, Rev. 0A (April 12, 1993).

32. "Hanford Site Tank Farm Facilities Interim Safety Basis," Westinghouse Hanford Company report WHC-SD-WM-ISB-001, Rev. 0 (August 1, 1993).

33. W. L. Cowley, "Evaluation of Hazards From Lightning Strikes to Tank Farm Facilities," Westinghouse Hanford Company report WHC-SD-WM-SARR-027, Rev. 0 (June 29, 1994).

34. D. I. Herborn, et al., "Hanford Waste Vitrification Plant Preliminary Safety Analysis Report," Westinghouse Hanford Company report WHC-EP-0250, Rev. 0 (May 1991).

35. "General Design Criteria," US Department of Energy Order 6430.1A (1989).

36. Kennedy, et al., "Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards," Department of Energy report UCRL-15910 (1990).

remain within 48.3 km (30 mi) of Cascade volcanoes. At increasing distances from the eruptive vent, flows of lava, debris, and mud tend to become more confined to existing drainage channels. Because no streams flow directly from the Cascade Range volcanoes to the Hanford Site, this type of volcanic product is not considered likely at Hanford.

A volcanic ashfall event is considered to be a potential natural phenomenon occurrence at the Hanford Site. The design criterion for ashfall loading on Hanford Safety Class I (SC I) structures, systems, and components is an uncompacted ashfall of 11.4 cm (4.5 in.). This ashfall should cause no undue additional loadings on critical structures.

The low probability of a volcanic event, combined with the minor consequences of an ashfall, are not considered to pose a significant hazard to the proposed operations. The installation and removal procedures contains a requirement to suspend operations in the event of volcanic activity that could lead to an ashfall.

4.9.8. Dust Devils

A dust devil is a localized wind pattern that moves in a circular motion which spawns and decays quickly and travels at relatively low velocities. Dust devils occur frequently in the Hanford Site areas during the daytime in the summer months. Wind speeds are believed to be in the low tens of miles per hour. The major concerns related to dust devils entering the site are (1) the effects on lifting the equipment, (2) the control of contaminants during installation and removal, and (3) the effect on personnel around an open riser from contaminant dispersal. It is difficult to predict the effect of a dust devil moving over the open riser because the dust devil wind speeds are unknown and because of the variety of operations being performed. To prevent adverse effects from dust devils, FG/RMCS activities must be suspended at the discretion of the PIC when there is observable dust devil activity.

4.10. REFERENCES

1. A. D. Swain, "Accident Sequence Evaluation Program Human Reliability Analysis Procedure," US Nuclear Regulatory Commission report NUREG-CR-4772 (February 1987).

2. J. Robinson, "Description of Conductive Flexible Hose for Exhauster," Westinghouse Hanford Company letter to J. Darby (January 31, 1996).

3. "Standard Reliability Data," IEEE Standard 500, Published by the Institute of Electrical and Electronics Engineering, Inc. (1984).

4. J. Robinson, "Exhauster Duct Resistivity Measurements," Westinghouse Hanford Company letter 75230-96-012 to Cetin Unal (June 4, 1996).

5. J. E. Rasmussen, "Approval Requested for New Potential-to-Emit for the Rotary Mode Core-Sampling System Exhauster," Westinghouse Hanford Company letter (enclosure WHC Environmental Compliance Document, WHC-CM-7-5, Rev. 1) to Mr. A. W. Conklin and Mr. Jerry Leitch (December 1995)

6. Air Movement and Control Association, Standard 99-0401-86 (1986).

7. R. N. Johnson "Sparking Potential of Aluminum vs. Aluminum," Pacific Northwest National Laboratory letter to J. Robinson (February 10, 1996).

8. J. Smalley, Westinghouse Hanford Company, "Design Review Meeting for Purge Gas System," Purge Gas Pneumatic Diagram, H-2-690009 (December 1995).

9. J. C. Krok and J. E. Shepherd, "Electrical and Frictional Spark Ignition of N_2O-H_2-N_2-Air Mixture," Los Alamos National Laboratory report LANL-WT-800 (June 1993).

10 K. S. Witwer, "Test Report for Ignitability Testing," Westinghouse Hanford Company report WHC-SD-WM-TRP-257 (June 1996).

11. C. Unal, "Burn in the Shielded Receiver," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-099 (January 1996).

12. J. Smalley, Westinghouse Hanford Company personal communication, (November 1995).

13. R. A. Huckfeldt, "NFPA Barriers," Westinghouse Hanford Company internal memorandum 75230-96-006, to D. Hamilton, Characterization Equipment Design Project (February 27, 1996).

14. C. M. Keller, "Push Mode Core Sample Test," Westinghouse Hanford Company Report WHC-SD-WM-TRP-048 (January 23 1991).

15. A. J. Kostelnik, "Rotary Mode Core Sample Truck Material and Component Compatibility with Tank Waste," letter (attachment Westinghouse Hanford Company internal memo, 75230-96-001 R2) to Dennis Hamilton (February 5, 1996).

16. L. F. Ermold, "Actions in Response to Spark Reported During Work on Tank 241-U-109," Westinghouse Hanford Company letter WHC-9650352, (enclosure

WHC Occurrence Report, RL-WHC-TANKFARM-1996-0009) to S. Burnam (January 23, 1996).

17. H. Sullivan, et al., "A Safety Assessment for Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 242-SY-101," Los Alamos National Laboratory report LA-UR-92-3196, Rev. 14 (1995).

18. K.S. Witwer, "Envelope Testing for Rotary-mode Core Sampling," Westinghouse Hanford Company reprot WHC-SD-WM-TRP-252 (June 1996).

19. J. F. McCormick, "Test Report For Drill String Seal Pressure Test," WHC-SD-WM-TRP-DRAFT, Rev. 0 (January 1996).

20. C. Shepard and L. Pederson, "Reaction of Aluminum with Gases Released by Wastes in Tank 101-SY," Los Alamos National Laboratory memorandum LANL-WT-1152, to Troy Stokes (April 11, 1994).

21. D. Scheele, R. Shell, J. Sobolik, and L. Burger, "Organic Tank Safety Project: Preliminary Results of Energetics and Thermal Behavior Studies of Model Organic Nitrate and/or Nitrite Mixtures and a Simulated Organic Waste," Pacific Northwest National Laboratory report PNL-10213 (August 1995).

22. E. C. Martin, "Complexant Stability Investigation Task 2-Organic Complexants," Pacific Northwest National Laboratory report PNL-5453 (1985).

23. G. A. Beitel, "Exothermic Potential of Sodium Nitrate Salt Cake," Atlantic Richfield Hanford Company report ARH-LD-163 (1977).

24. V. C. Boyles, "Operating Specifications for Single-Shell Waste Storage Tanks," Westinghouse Hanford Company report OSD-T-151-00013, Rev. D-4 (1994).

25. W. O. Miller, "Retained Gas Sampler Drill String Drop Analysis," Los Alamos National Laboratory Calc Note TSA-6-CN-WT-SA-075 (November 30, 1994).

26. W. O. Miller, "Riser Impact Loads," Los Alamos National Laboratory Calc-Note TSA6-CN-WT-SA-ST-063 (March 1994).

27. P. M. Francis, "Aerosol Study for the Rotary Mode Exhauster," Westinghouse Hanford Company report WHC-SD-WM-ES-225, Rev. 0 (1993).

28. J. D. Voice, "Tank Farm Accelerated Safety Analysis; Tank Ventilation System," Westinghouse Hanford Company report WHC-SD-WM-SARR-018, Rev. 0 (June 29, 1994).

29. "General Safety Standard for (ANSI NBS 114) Installations Using Non-Medical X-ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV," ANSI N43.3 (American National Standards Institute, Inc., New York, 1993).

30. "Section Performance Standard for 1020-1991 Ionizing Radiation Emitting Products," Code of Federal Regulations (CFR), 21 CFR

31. Westinghouse Hanford Company report WHC-SD-WM-HSP-022, Rev. 0A (April 12, 1993).

32. "Hanford Site Tank Farm Facilities Interim Safety Basis," Westinghouse Hanford Company report WHC-SD-WM-ISB-001, Rev. 0 (August 1, 1993).

33. W. L. Cowley, "Evaluation of Hazards From Lightning Strikes to Tank Farm Facilities," Westinghouse Hanford Company report WHC-SD-WM-SARR-027, Rev. 0 (June 29, 1994).

34. D. I. Herborn, et al., "Hanford Waste Vitrification Plant Preliminary Safety Analysis Report," Westinghouse Hanford Company report WHC-EP-0250, Rev. 0 (May 1991).

35. "General Design Criteria," US Department of Energy Order 6430.1A (1989).

36. Kennedy, et al., "Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards," Department of Energy report UCRL-15910 (1990).

5.0. CONSEQUENCES OF ACCIDENTS

In this section, the consequences of accidents are discussed for the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Tanks (FG tanks) or those tanks recommended by the contractor to be included on the FG tanks, hence referred to as FG/RMCS operations. Section 5.1 presents the Risk Guidelines (RGs). Section 5.2 contains a summary of bounding accidents identified in Section 4. In Sections 5.3 through 5.5 the bounding consequences of different accidents are quantified. The consequences are then compared with the RGs in Section 5.6.

Long-term radiological and toxicological consequences of material releases into the soil are not quantified in this safety assessment (SA). Accidents that may lead to a containment breach and to a release of material into the soil are identified and discussed in Section 4. The mitigative features of such accidents also are included in the discussion provided in Section 4. Environmental risk associated with the rotary mode core sampling operations in flammable tanks (FG/RMCS) is not further discussed in this section.

5.1. RISK GUIDELINES

This section defines the RGs used for comparing the consequences of the accidents analyzed in this SA. These criteria are divided into two major areas: radiological committed effective dose equivalent (CEDE) and toxic material exposure.

5.1.1. Radiological Risk Criteria

The RGs used in this SA for radiological consequences are obtained from Ref. 1. Reference 1 requires that the radiological RGs contained in Revision 3 of Ref. 2 be used. Revision 4 of Ref. 2 recommends a less conservative set of radiological RGs. The more conservative set proposed in Ref. 1 and in Revision 3 of Ref. 2 were used.

To use the RGs, a frequency and consequence for the particular accident must be analyzed. The best estimates of the frequencies are given in Section 4, and the basis of the frequencies is discussed in Appendixes D, E and L. The present analysis was performed using conservative modeling assumptions, and the conservative consequences have been judged using best estimates for the frequencies. Ref. 1 provides the frequency-dependent, radiological dose limits shown in Table 5-1a. Also, Ref. 1 specifies that if a specific single-point frequency is used, the guidelines are to be applied as curves. However, if a qualitative frequency ranking is used, the corresponding consequence limit (in rem) must be used equal to the lowest value for that frequency range.

The less restrictive alternative guidelines contained in Ref. 2 are shown in Table 5-1b for comparison purposes. Note that the guidelines in Ref. 2 are to be applied as a step-function.

5.1.2. Toxicological Risk Guidelines

Toxicological acceptance criteria have been developed from the guidelines presented in Ref. 2. In the referenced material, the onsite and offsite concentration limits are given in terms of Emergency Response Planning Guidelines (ERPGs) and Permissible Exposure Limit—Time-Weighted Average (PEL-TWA). The toxicological RGs are summarized in Table 5-2.

ERPG-1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing anything other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

TABLE 5-1A
RADIOLOGICAL RISK GUIDELINES (REF. 1, WHC-CM-4-46, REV. 3)

Frequency Category	Frequency Range (yr^{-1})	On-site CEDE (rems)	Off-site CEDE (rems)
Anticipated	10^{-1} to 10^{-2}	1 to 5	NA
Anticipated	1 to 10^{-2}	NA	0.01 to 0.5
Unlikely	10^{-2} to 10^{-4}	5 to 25	0.5 to 4
Extremely Unlikely	10^{-4} to 10^{-6}	25 to 100	4 to 25

TABLE 5-1B
RADIOLOGICAL RISK GUIDELINES (REF. 2, WHC-CM-4-46, REV. 4)

Frequency Category	Frequency Range (yr^{-1})	On-site EDE * (rems)	Off-site EDE (rems)
Anticipated[a]	1.0 to 10^{-2}	5	0.5
Unlikely	10^{-2} to 10^{-4}	25	5
Extremely Unlikely	10^{-4} to 10^{-6}	100	25

* EDE: effective dose equivalent

TABLE 5-2
TOXICOLOGICAL RISK GUIDELINES

Frequency Category	Frequency Range (yr^{-1})	On-site Limit	Off-site Limit
Anticipated	1 to 10^{-2}	≤ ERPG-1	PEL-TWA
Unlikely	10^{-2} to 10^{-4}	≤ ERPG-2	≤ ERPG-1
Extremely Unlikely	10^{-4} to 10^{-6}	≤ ERPG-3	≤ ERPG-2

ERPG-3 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing life-threatening effects.

When specific values for PEL-TWA and ERPGs are not available, alternative concentration guidelines also are included in Ref. 2.

Based on Ref. 2, these guidelines are applied using a step-function within the specified frequency range. In this SA, the following RGs are used:

Ammonia: Ammonia (NH_3) is a corrosive or irritant and it is known to exist in large quantities in the waste gas.

Nitrous Oxide: Nitrous oxide (N_2O) is a central nervous system depressant, and it is known to exist in large quantities in the waste gas.

Waste Material: The human reception of solid/liquid waste material results in systemic toxicity and corrosive effects. Various accidents analyzed in this SA (unfiltered releases, burns, spills, etc.) result in a wide range of waste release quantities. Note that all the releases that result in radiological consequences also yield toxicological consequences as a result of an exposure to the same material.

The results of the vapor space sampling program were reviewed.[3] Major toxic gases that are found in the dome space of the presently defined flammable-gas tanks are ammonia and nitrous oxide. Other gases are found in trace quantities and do not pose a concern. However, it was recognized that the data contained in Ref. 3 are limited, and all tanks of interest are not covered. Consequently, the toxic gas evaluation was made a checklist item (Section 7). Thus, it is required that the potential for toxic gases other than ammonia and nitrous oxide must be re-evaluated before FG/RMCS operations may be initiated in a specific tank.

Also, combustion products were not considered in this SA. Major combustion products that must be considered for their toxic effects are nitrogen oxides (NO_X). As discussed in Ref. 4, large quantities of NO_X may be produced if a large volume of waste gases is burned. However, such a large burn in the single-shell tanks (SSTs) also result in releases of large quantities of waste material (see the dome collapse accidents). Under these circumstances, the contribution of the NO_X releases to the total toxic consequences of a burn is very small and well within the uncertainties of the toxicological consequence calculations.

Table 5-3 provides the PEL and ERPG values for the toxic gases considered in this SA. To determine the acceptance limits for liquid/solid waste material, Westinghouse Hanford Company (WHC) uses different types of composite waste for different tank grouping.[5] The risk associated with waste releases is divided into three categories: particulate, toxic effects and corrosive effects. The chemical species in the composite waste is divided into toxic and corrosive bins. Within each bin, the allowable releases are computed using the "sum of the fractions" methodology. The minimum among the three categories (particulate, toxic, corrosive) is chosen in each frequency range. For further details of the methodology used in determining the maximum acceptable waste releases, the readers are referred to Ref. 5. The

TABLE 5-3
ESTABLISHED RISK GUIDELINES FOR SPECIFIC GASES

Species	PEL-TWA	ERPG-1	ERPG-2	ERPG-3
NH_3	17 mg/m^3 (25 ppm)	17 mg/m^3 (25 ppm)	140 mg/m^3 (200 ppm)	680 mg/m^3 (1000 ppm)
N_2O	90 mg/m^3 (50 ppm)	270 mg/m^3 (150 ppm)	18,000 mg/m^3 (10,000 ppm)	36,000 mg/m^3 (20,000 ppm)

TABLE 5-4
MAXIMUM ACCEPTABLE WASTE MATERIAL RELEASES[5]

	SST LIQUID RELEASES			
	ONSITE		OFFSITE	
Freq. (yr^{-1})	Puff (L)	Continuous (L/s)	Puff (L)	Continuous (L/s)
10^{-2} - 1	3.57×10^{-4}	1.04×10^{-4}	$7.69 \times 10^{+1}$	1.85×10^{-1}
10^{-2} - 10^{-4}	4.55×10^{-3}	1.33×10^{-3}	$7.69 \times 10^{+1}$	1.85×10^{-1}
10^{-4} - 10^{-6}	1.75×10^{-2}	5.00×10^{-3}	$1.01 \times 10^{+3}$	$2.38 \times 10^{+0}$
	SST SOLID RELEASES			
10^{-2} - 1	9.09×10^{-5}	2.56×10^{-5}	$6.67 \times 10^{+0}$	1.59×10^{-2}
10^{-2} - 10^{-4}	1.67×10^{-4}	5.00×10^{-5}	$1.92 \times 10^{+1}$	4.55×10^{-2}
10^{-4} - 10^{-6}	3.45×10^{-3}	1.02×10^{-3}	$3.70 \times 10^{+1}$	9.09×10^{-2}

resulting maximum acceptable releases for SST liquid and solid releases are shown in Table 5-4. Note that the values reported in Table 5-4 represent the release quantities at the source because the atmospheric dispersion coefficients already are accounted for in deriving these magnitudes.

5.2. ACCIDENT CONSEQUENCES

The accidents for the FG/RMCS operations identified in Section 3 are analyzed in Section 4. The radiological and toxicological consequences of these accidents are analyzed in this section. Not all the accidents have unique consequences; the bounding consequences for all the burn accidents are analyzed as a dome collapse. Section 4.4 discusses that the waste burn resulting in a dome collapse is highly unlikely given the controls introduced by this SA. Consequences of a local waste burn are not currently analyzed and assumed to be bounded by a dome collapse. Table 5-5 summarizes how the accidents analyzed in Section 4 are mapped into the consequence analysis contained in this section.

Accidents resulting in environmental contamination are identified in Section 4. However, long-term radiological and toxicological consequences of environmental contamination are not analyzed in this SA.

In Section 5.6. all the consequences are summarized and graphically compared with the RGs.

5.3. CONSEQUENCES OF DOME COLLAPSE ACCIDENTS

In SSTs, burn accidents result in unacceptable consequences because even a small pressurization in the dome may result in dome failure potentially followed by a catastrophic collapse. Because of large radiological and toxicological consequences (especially onsite) of a dome collapse accident, one must demonstrate that such accidents have a frequency of less than 10^{-6}/yr. However, burn accidents are not the only accidents that may result in dome failure.

The design basis earthquake (DBE) has a return period of 7500 yr (frequency > 1×10^{-4}/yr). SSTs are designed to withstand a 0.20-g zero-period acceleration (ZPA). Because they are independent of the RMCS activities, structural consequences of seismic events are not analyzed in this SA.

The frequency of the dome collapse as a result of dome space deflagration is obtained by summing the frequency of the first 3 accident categories shown in Table 5-5. Thus, the unmitigated accident frequency for the dome collapse during FG/RMCS operations is > 1.0E-4/yr/tank.

Taking credit of the controls discussed in Section 4 and listed in Section 6, the frequency of the dome collapse accident (denoted as mitigated frequency) is lowered to less than 2.5 E-7/ yr/tank.

TABLE 5-5
SUMMARY OF CONSEQUENCE ANALYSIS

Accident Category	Bounding Consequence	Frequency	Radiological Consequences	Toxicological Consequences
Above Ground Fires (Sec. 4.1)	Dome Collapse (Sec. 5.3)	MAF = 2.4E-07 UAF = 1.8E-04	Sec. 5.3.1	Sec. 5.3.2
Dome Fires (Sec. 4.2)	Dome Collapse (Sec. 5.3)	MAF = 4.8E-10 UAF = 2.8E-07	Sec. 5.3.1	Sec. 5.3.2
Drill String Fires (Sec. 4.3)	Dome Collapse (Sec. 5.3)	MAF = 1.3E-8 UAF = 6.6E-4	Sec. 5.3.1	Sec. 5.3.2
Waste Fires (Sec. 4.4)	Dome Collapse (Sec. 5.3)	MAF < 1.0E-06 UAF ~ 3.7	Sec. 5.3.1	Sec. 5.3.2
Chemical Reactions (Sec. 4.5)	Environmental Contamination	NA	NA	NA
Containment Breach (Sec. 4.6)	Environmental Contamination	NA	NA	NA
GRE (no burn) (Sec. 4.7)	Toxic Gas Release (Sec. 5.4.1)	Qualitative	Sec. 5.4.1.2	Sec. 5.4.1.1
	Unfiltered Material Release (Sec. 5.4.2)	Qualitative	Sec. 5.4.2.1	Sec. 5.4.3
Spills, etc (Sec. 4.8).	HEPA Blowout (Sec. 5.5)	MAF = 1.6E-5 UAF = 1.6E-5	Sec. 5.5.1	Sec. 5.5.2
	Sampler Drop (Sec. 5.5)	MAF = 8.6E-9 UAF = 2.9E-6	Sec. 5.5.1	Sec. 5.5.2

TABLE 5-5 (cont)
SUMMARY OF CONSEQUENCE ANALYSIS

	Core barrel drop (Sec. 5.5)	MAF = 6.2E-7 UAF = 2.0	Sec. 5.5.1	Sec. 5.5.2
	Drill String Drop (Sec. 5.5)	MAF = 4.4E-6 UAF = 2.0	Sec. 5.5.1	Sec. 5.5.2
External Events (sec. 4.9)	Seismic Induced Dome Collapse (Sec. 5.3)	1.0E-04	Sec. 5.3.1	Sec. 5.3.2

MAF = Mitigated accident frequency
UAF = Unmitigated accident frequency
HEPA= High-efficiency particulate air (filter)

The material releases as a result of dome collapse are discussed in Appendix I. Based on the calculations provided in Appendix I, the conservative amount of prompt respirable material release during a dome collapse in an SST is obtained as 62.5 L. The long-term respirable release from the crater left after the dome collapse is obtained as 12.5 L/wk.

5.3.1. Radiological Consequences

Appendix R provides the on-site and off-site receptor doses for a 1 L release for solid and liquid waste. Because the surface of the SST waste may be quite dry and the solid waste may result in larger doses than the liquid waste, it is assumed that all the short-term and long-term releases correspond to solid waste. Using the unit doses provided in Appendix R, the on-site and off-site radiological doses are obtained as shown in Table 5-6. As shown in Table 5-6, the long term doses are much lower than the prompt doses and are well within the uncertainty of the prompt doses. Also shown in Table 5-6 are the doses corresponding to RGs. Note that assuming that a fraction of the release is liquid lowers the doses.

5.3.2. Toxicological Consequences

The toxicological consequences of waste and toxic gas releases are discussed below.

5.3.2.1. Waste Material

For waste material, the release volume of 62.5 L must be compared with the puff release limits given in Table 5-4. The long term release of 12.5 L/wk (2×10^{-5} L/s) may be compared to continuous release limits given in Table 5-4. The prompt release volume (if assumed to be solid waste) exceeds the offsite RGs even for a very unlikely accident.

TABLE 5-6
BOUNDING RADIOLOGICAL CONSEQUENCES OF
DOME COLLAPSE ACCIDENT

		Receptor Dose (rem)
ONSITE	Prompt	17250
	Long-Term 1 wk	193
OFFSITE	Prompt	9.3
	Long-Term 1 wk	0.1

5.3.2.2. Toxic Gases

The toxic gases of interest (ammonia and nitrous oxide) are flammable. Thus, they will be totally or partially consumed during the burn event and the consequences of toxic gas releases during a burn are bounded by the consequences of a gas-release event (GRE) without a burn (Section 5.4.1.). As discussed previously, the combustion products are not considered.

5.4. GRE WITHOUT A BURN

A large gas release event that pressurizes the dome space is of concern because of the potential toxic gas and unfiltered material releases.

5.4.1. Toxic-Gas Releases.

This section considers the release of toxic gases (ammonia and nitrous oxide) through the open risers, frisbee, and the exhaust and inlet stacks.
As bounding magnitudes, the maximum ammonia fraction in the waste gas is set to 60%, and the maximum nitrous oxide fraction in the waste gas is set to 75% (Appendix C). Only the toxicological consequences of ammonia are discussed in this section because if ammonia releases meet the RGs, the nitrous oxide releases also will meet the RGs. While the maximum nitrous oxide fraction is 125% of the ammonia fraction, the guidelines for nitrous oxide are always more than twice the ammonia guidelines for all the accident frequencies (see Table 5-3).

The peak ammonia concentrations in the dome are provided in frequency bins in Appendix L. In this section, the peak concentration as well as the release rate are needed. For the purpose of this consequence assessment, the total release volume of waste gas is obtained by multiplying the peak concentration by the dome volume at a given frequency bin. The results are shown in Table 5-7. The toxicological guidelines are given in terms of 1-h average values (Section 5.1.2.). For added conservatism, the total release is postulated to occur in less than 15 minutes, and the average release rate is obtained by dividing the volumes shown in Table 5-7 by 15 minutes. The release to the atmosphere is assumed to occur at this release rate with the peak ammonia concentration. This simplification is conservative because the expected gas-release rates are much lower than the magnitudes obtained by this simple approach (see Appendix L). If the actual release is faster than 15 min. (which is very unlikely based on the discussion in Appendix L), the proposed approach still yields the correct time-averaged release rate over a 15-min. period.

The dome peak ammonia and nitrous oxide concentrations then become 1.2%, 6%, and 12% for the anticipated, very unlikely, and extremely unlikely gas-release events defined based on frequency ranges and expected gas release amounts and marked as GRE-1, GRE-2 and GRE-3 in Table 5-7. These three GREs categories will be used in tables given in the rest of this section. The releases are not expected during installation because the installation is not a waste-intrusive activity. However, gas releases could be induced during the operation or removal phase. Postulated gas releases are listed in Table 5-8. Note that release rates given in Table 5-8 is based on 15-minute average releases.

The first three accidents may occur during removal when the riser is open for a period of much less than 8 hours. The conservative 8-hour open riser period relative to mission time is considered in the frequency determination, resulting in a gas-release probability of 8/144 = 5.6E-2. The third accident will not be considered further because the frequency is low. Accidents 4-6 consider gas releases from the frisbee. The riser sleeve is protected with nitrogen purge. This system prevents any gas penetration between the riser sleeve and the DS. Thus, the gas release from the frisbee could occur only if the nitrogen purge fails. Accidents 5 and 6 are beyond extremely unlikely. Accident scenarios 7 to 9 are gas releases through the drill string. This accident can occur when the drill string is disconnected from the drill unit if the seal between the sampler and drill bit fails or if the sampler fails to latch before drilling. Accidents 8 and 9 are beyond extremely unlikely. The last 6 accidents considered only the GRE from the exhauster and inlet stack during operations.

TABLE 5-7
ANTICIPATED AND UNLIKELY GAS-RELEASE EVENTS

Event Probability	Event Category	Q-Prompt Release, (ft^3)	Peak NH_3 Conc. (%)
≥1.0 E-2	GRE-1	≤1000	1.2
≥1.0 E-4	GRE-2	≤ 5000	6
≥1.0 E-6	GRE-3	≤ 10,000	12

TABLE 5-8
SUMMARY OF GAS-RELEASE ACCIDENTS

Accident Condition	Frequency (yr)	Gas Concentration & Release Rate
1-GRE-1 and open riser (removal)	1.1E-3 (0.01x5.6E-2x2)	1.2% NH_3 in the dome, 66 scfm*
2-GRE-2 and open riser (removal)	1.1E-5 (1E-4x5.6E-2x2)	6% NH_3 in the dome, 333 scfm*
3-GRE-3 and open riser (removal)	1.1E-7 (1E-6x5.6E-2x2) Beyond extremely unlikely	12% NH_3 in the dome, 666 scfm*
4-GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails)	3.2E-6 (2x0.01x1.6E-4)	1.2% NH_3 in the dome, 66 scfm*
5-GRE-2 and open frisbee (operation) (nitrogen purge to riser sleeve fails)	3.2E-8 (2x1.0E-4x1.6E-4) beyond extremely unlikely event	6% NH_3 in the dome, 333 scfm*
6-GRE-3 and open frisbee (operation) (nitrogen purge to riser sleeve fails)	3.2E-10 (2x1.0E-6x1.6E-4) beyond extremely unlikely event	12% NH_3 in the dome, 666 scfm*
7-GRE-1 and drill string open at the top with sampler in the drill string	2.6E-5 (2x0.01x1.3E-3)	1.2% NH_3 in the dome, 66 scfm*
8-GRE-2 and drill string open at the top with sampler in the drill string	2.0E-7 (2x1.0E-4x1.3E-3) beyond extremely unlikely event	6% NH_3 in the dome, 333 scfm*
9-GRE-2 and drill string open at the top with sampler in the drill string	2.0E-9 (2x1.0E-6x1.3E-3) beyond extremely unlikely event	12% NH_3 in the dome, 666 scfm*
10-GRE-1 from exhaust and inlet stack (operation)	0.02 (2x0.01)	1.2% NH_3 in the dome, 66 scfm*

TABLE 5-8 (cont)
GAS-RELEASE ACCIDENTS

Accident Condition	Frequency (yr)	Gas Concentration & Release Rate
11-GRE-2 from exhaust and inlet stack (operation)	2.0E-4 (2x1.0E-4)	6% NH_3 in the dome, 333 scfm*
12-GRE-3 from exhaust and inlet stack (operation)	2.0E-6 (2x1.0E-6)	12% NH_3 in the dome, 666 scfm*
13-Continuous releases from exhauster after an GRE-1	0.02 (2x0.01)	1.2% NH_3 in the dome, 250 scfm**
14-Continuous releases from exhauster after an GRE-2	2.0E-4 (2x1.0E-4)	6% NH_3 in the dome, 250 scfm**
15-Continuous releases from exhauster after an GRE-3	2.0E-6 (2x1.0E-6)	12% NH_3 in the dome, 250 scfm**

* Averaged over 15-minute period

** Maximum exhauster flow rate

5.4.1.1. Toxicological Consequences

The toxic-gas concentrations at the on-site and off-site receptor locations are calculated using Eq. (K-2) given in Appendix K. Atmospheric dispersion factors fo ground and stack releases are summarized in Table K-3 of Appendix K. Table 5-9 gives the calculated on-site and off-site ammonia concentrations for ground and stack releases. Numbers given in parentheses are acceptable concentrations for ammonia.

In the first nine accidents given in Table 5.8, the GREs are treated as ground releases because they involve an opening at the top of the tank. Note that there are still inlet and exhaust stacks where approximately 2/3 of the release occurs. It is clear from Table 5-9 that the on-site RGs are not exceeded (accidents 1, 2, 4, 7 in Table 5.9) for accidents involving ground releases.

Accidents 10 to 15 do not involve ground releases. For these accidents, the results of both ground or stack releases are given in Table 5.9. Accidents 11, 12, 13, and 14 result in exceeding RGs if they were considered as ground releases. However, the exhauster has a 15-ft height stack with a 4-in. internal diameter. This SA requires the use of an inlet stack with the same exit diameter and height as the exhaust stack. For gas releases of 66, 330, and 250 scfm, the velocity of released gas in these stacks become 3.8 m/s, 19.2 m/s, and 7.3 m/s, respectively. With these velocities and the consideration of the height of the stacks, the plume effective emission height increases as a result of momentum effects. Dispersion coefficients for these conditions are smaller than those given for ground releases, as shown in Appendix K. Consideration of the stack height reduces the on-site concentrations 6 to 7 times.

TABLE 5-9
AMMONIA CONCENTRATIONS AT ON-SITE AND OFF-SITE RECEPTORS FOR GROUND AND STACK RELEASES FOR ALL GAS RELEASE ACCIDENTS

		Ground Release		Stack Release	
Accident	Freq. (1/yr)	Onsite (ppm)	Offsite (ppm)	Onsite (ppm)	Offsite (ppm)
1-GRE-1 and open riser (removal), 1.2% NH_3, 66 scfm	1.1E-3	13 (200)	0.01 (25)	NA	NA
2-GRE-2 and open riser (removal), 6% NH_3, 633 scfm	1.1E-5	324 (1000)	0.18 (200)	NA	NA
4-GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails), 1.2% NH_3, 66 scfm	3.2E-6	13 (1000)	0.01 (200)	NA	NA
7-GRE-1 and drill string open at the top with sampler in the drill string, 1.2% NH_3, 66 scfm	2.6E-5	13 (1000)	0.01 (200)	NA	NA
10-GRE-1 from exhaust and inlet stack (operation),1.2% NH_3, 66 scfm	0.02	13 (25)	0.01 (25)	2 (25)	0.01 (25)
11-GRE-2 from exhaust and inlet stack (operation), 6% NH_3, 333 scfm	2.0E-4	324 (200)	0.18 (25)	48 (200)	0.18 (25)
12-GRE-3 from exhaust and inlet stack (operation), 12% NH_3, 666 scfm	2.0E-6	1297 (1000)	0.72 (200)	193 (1000)	0.72 (200)
13-Continuous releases from exhauster after a GRE-1, 1.2% NH_3, 250 scfm	0.02	49 (25)	0.03 (25)	7 (25)	0.03 (25)
14-Continuous releases from exhauster after an GRE-2, 6% NH_3, 250 scfm	2.0E-4	244 (200)	0.13 (25)	36 (200)	0.13 (25)
15-Continuous releases from exhauster after an GRE-3, 12% NH_3, 250 scfm	2.0E-6	487 (1000)	0.27 (200)	72 (1000)	0.27 (200)

To be conservative, credit is taken only for the height of the stack. A point source at a 15-ft height is considered. With this assumption, the ammonia concentrations at the on-site and off-site receptor locations meet the RGs as shown in Table 5-9. The consideration of the velocity and diameter of the stack further decreases ammonia concentrations. Furthermore, the flammable-gas monitors will alarm at concentrations much lower than those postulated in these conservative estimates, providing adequate time for workers and nearby individuals to take protective measures. Response procedures for a GRE must be developed, assuming that the release contains a large fraction of ammonia (flammable-gas monitors cannot differentiate between hydrogen and ammonia).

5.4.1.2. Radiological Consequences

The radiological consequences of gas release is a concern when the riser is open. If the release is through HEPA filters, there is no particulate release. Open riser particulate releases are discussed in the next section.

5.4.2. Unfiltered Material Releases

This section discusses the unfiltered waste releases associated with the GREs. Releases from spill accidents are considered in the next section. Unfiltered releases can occur during operation and removal. During installation, a GRE is not expected; thus, only the operation and removal phases involve unfiltered material releases. Accidents for unfiltered releases are listed in Table 5-10. Release amounts are determined in Appendix M.

Appendix M gives the release amounts for unfiltered releases through an open riser. The waste releases from the open riser become 12 g, 60 g, and 120 g for gas release amounts of 1000, 5000, and 10,000 ft^3, respectively. Accidents 1 and 2 in Table 5-8 are considered for unfiltered releases through the open riser. The third accident given in Table 5.8 is beyond extremely unlikely. In the fourth scenario, it is conservatively assumed that waste material is released from an opening between the frisbee and the drill string if the nitrogen purge fails, the frisbee fails and a GRE occurs. Credit was not taken for the failure of the frisbee. The frequency includes the failure probability of a nitrogen purge while drilling. Accidents 5 and 6 are not considered for unfiltered releases because they are beyond extremely unlikely events. The seventh scenario addresses a release through the drill string with a failed chevron seal. It is assumed that the internal surfaces of the drill string are contaminated. If there is a 0.5-mm layer inside the surface of the drill string with a maximum length of 395 in., the total waste could be estimated as 1280 g. Assuming a 10% release fraction (because velocities could be high in the drill string), a release amount of 128 g for both anticipated and unlikely GREs can be estimated. Accidents 8 and 9 (Table 5.8) are not considered for unfiltered releases because they are beyond extremely unlikely events. Accidents 10 to 12 given in Table 5.8 do not involve unfiltered releases because they are through HEPA filters. The last scenario involves releases through the exhauster if the HEPA filters fail. The frequency of this accident is 1.6E-5/yr and it is same for anticipated or unlikely GREs. The

TABLE 5-10
UNFILTERED WASTE RELEASE ACCIDENTS

Accident	Freq. (1/yr)	Release Type
GRE-1 and open riser (removal) (1)*	1.1E-3	12 g material release
GRE-2 and open riser (removal) (2)	1.1E-5	60 g material release
GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails) (4)	3.2E-6	12 g material release
GRE-1 and drill string open at the top with sampler in the drill string (7)	2.6E-5	128 g material release
Continuous releases from exhauster after a HEPA filter fails (NA)	1.6E-5	0.08 g/s

* Numbers in parentheses correspond to accident numbers in Table 5-8.

maximum flow rate is 250 scfm. Based on a dome loading of 950 g, the solid flow rate is 0.08 g/s. These accidents cover the cases 13 to 15 of Table 5.8 with the assumption that the HEPA filter fails.

There is another case in which a GRE during removal with a contaminated drill string occurs. Failure of the decontamination procedures and the seal or the sampler latching is assumed. The frequency of this accident is very small because a contaminated drill string must occur during removal and coincide with a GRE.

A non-GRE unfiltered release occurs if the riser is open and the tank-dome pressure becomes positive. Ventilation system failure combined with open-tank conditions has been identified as one of these conditions. Controls are established to help ensure that this kind of release is minimized. No waste-intrusive activities can be started if the ventilation system is not working properly. However, the ventilation system can fail during the periods when the riser is open. In comparison to other releases driven by GREs, this release is small, and the frequency of this accident is also small.

The controls derived from these analyses are as follows:

- Existence of a decontamination system operation and the decontamination of the sleeve and drill string are required when the radiation level exceeds the allowable limits.
- RMCS operations must be shut down if the dome flammable gas concentration is above 5000 ppm hydrogen equivalent. Based on currently available calibration data, this set point gives protection for ammonia concentrations of ~10,000 ppm if the gas is purely ammonia.

- Risers shall not be opened within four hours after drilling.
- The riser shall be open no more than eight hours.
- Evacuation is necessary if a gas release occurs.

5.4.2.1. Radiological Consequences
Radiological doses at the onsite and offsite receptor locations are summarized in Table 5-11. All the accidents listed in Table 5.11 meet the radiological on-site and off-site RGs.

5.4.3. Toxicological Consequences

The off-site and on-site consequences are measured at the release source. For a GRE and open riser or a GRE and open frisbee the volume release rates are 8.3E-6 L/s for an anticipated GRE and 4.2E-5 L/s for a very unlikely GRE. For an unfiltered release and failed chevron seal, the volume released is 9.0E-5 L/s. HEPA filter failure can cause a release of 0.08 g/s (5E-5 L/s). The waste-release rates are compared with the RGs in Table 5-12.

Toxic waste release rates are based on 15 minute continuous releases. Acceptable release rates at the source are obtained from Table 5-1 and are shown in parentheses in Table 5-12. The consequences meet the on-site and off-site RGs.

TABLE 5-11
RADIATION DOSES AT ON-SITE AND OFF-SITE RECEPTORS FOR GRE ACCIDENTS

Accident Condition	Frequency (yr)	Onsite (rem)	Offsite (rem)
GRE-1 and open riser (removal), 12 g. (1)*	1.1E-3	2.04 (10)	0.001 (2)
GRE-2 and open riser (removal), 60 g. (2)	1.1E-5	10.2 (49)	0.006 (10)
GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails), 12 g. (4)	3.2E-6	2.04 (70)	0.001 (15)
GRE-1 and drill string open at the top with sampler in the drill string, 128 g. (7)	2.6E-5	21.8 (38)	0.012 (10)
Continuous releases from exhauster after a HEPA filter fails, 0.08 g/s. (NA)	1.6E-5	12.4 (40)	0.007 (10)

* Numbers in parentheses correspond to accident numbers in Table 5-8.

5.5. SPILL ACCIDENTS

Spill accidents are summarized in Table 5-13. The frequencies of the second and third accidents in Table 5-13 are small, and these accidents are beyond extremely unlikely events.

5.5.1. Radiological Consequences

The calculated on-site and off-site radiation doses for HEPA filter blowout and waste spill from drill string accidents are given in Table 5-14 with the acceptable dose amounts given in parentheses. HEPA filter blowout does not result in exceeding on-site and off-site RGs. On-site and off-site radiological consequences of spill meet the radiological RGs.

TABLE 5-12
ONSITE AND OFFSITE TOXIC SOLID WASTE RELEASES

Accident	Freq. (1/yr)	Onsite	Offsite
GRE-1 and open riser (removal), 12 g. (1)*	1.1E-3	8.3E-6 L/s (5E-4 L/s)	8.3E-6 L/s (4.55E-2 L/s)
GRE-2 and open riser (removal), 60 g. (2)	1.1E-5	4.2E-5 L/s (1.02E-3 L/s)	4.2E-5 L/s (9.09E-2 L/s)
GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails), 12 g. (4)	3.2E-6	8.3E-6 L/s (1.02E-3 L/s)	8.3E-6 L/s (9.09E-2 L/s)
GRE-1 and drill string open at the top with sampler in the drill string, 128 g. (7)	2.6E-5	9E-5 L/s (1.02E-3 L/s)	9E-5 L/s (9.09E-2 L/s)
Continuous releases from exhauster after a HEPA filter fails, 0.08 g/s. (NA)	1.6E-5	5E-5 L/s (1.02E-3 L/s)	5E-5 L/s (9.09E-2 L/s)

* Numbers in parentheses correspond to accident numbers in Table 5-8.

TABLE 5-13
SUMMARY OF SPILL ACCIDENTS

Accident	Frequency (1/yr)	Release (g)
Radioactive aerosols are released from HEPA filter blowout.	1.6E-5	9
Spill results from dropped sampler in shielded receiver.	8.6E-9 beyond extremely unlikely	0.08
Waste from contaminated drill string interior is released above ground.	6.2E-7 beyond extremely unlikely	0.66
Waste from contaminated drill string exterior is released above ground.	4.4E-6	0.75

5.5.2. Toxicological Consequences

The off-site and on-site consequences are measured at the release source. For the short term release for HEPA failure the volume released is 5.63E-3 L. A spill from drill string yields 4.7E-4 L of material. Release amounts and acceptable release amounts to meet the ERPG values are given in Tables 5.14a. Spill releases meet the off-site RGs. The on-site RGs are exceeded for HEPA filter blowout accidents. However, in deriving allowable limits, the atmospheric dispersion coefficients for ground releases were used.[5]

TABLE 5-14
ONSITE AND OFFSITE RADIOLOGICAL DOSES FOR SPILLS

Accident	Freq. (1/yr)	On-site Dose (rem)	Off-site Dose (rem)
Radioactive aerosols are released from HEPA filter blowout.	1.6E-5	1.53 (43.4)	8.3E-4 (2)
Waste from a contaminated drill string exterior is released aboveground.	4.4E-6	0.13 (64)	7.0E-5 (4)

TABLE 5.14A
ONSITE AND OFFSITE TOXIC SOLID WASTE RELEASES FOR SPILLS

Accident	Freq. (1/yr)	On-site	Off-site
Radioactive aerosols are released from HEPA filter blowout.	1.6E-5	5.63E-3 L (3.45E-3 L)	5.63E-3 L (37 L)
Waste from contaminated drill string exterior is released aboveground.	4.4E-6	4.7E-4 L (3.45E-3 L)	4.7E-4 L (37 L)

HEPA filter blowout would be an elevated release with a factor of 6 reduction in the dispersion coefficient. Thus, the receptor doses will be 1 x 10^{-3} L and within the allowable limits.

5.6. COMPARISON OF THE ACCIDENT CONSEQUENCES WITH THE RGS

Section 5.6 presents the comparison of the consequence calculated in Section 5.5 to the RGs presented in Section 5.1. The comparison is broken into the following sections,

- Section 5.6.1 - Comparison to on-site and off-site radiological dose.
- Section 5.6.2 - Comparison to on-site and off-site toxic gas releases.
- Section 5.6.3 - Comparison to on-site and off-site toxic waste release.

In order to perform the comparison, the frequency of the accidents on a per-year basis must be computed. It is assumed in Section 4 that there will be two FG/RMCS activities per year per tank. The accident frequencies are calculated based on this assumption. The risk computed is on a per-tank basis and is not a site-wide risk, where the site-wide risk is defined as the cumulative risk of FG/RMCS operations over multiple tanks in a given year. The information contained in this SA cannot be easily converted to a site-wide risk because of the following:

- The SA uses bounding tank parameters for a hypothetical worse-case tank;
- The SA uses 95% meteorology data to compute the consequences;

Appendix Q discusses this issue in detail. The discussion in Appendix Q demonstrates that the use of the bounding tank consequences computed in this SA is not adequate to obtain site-wide risk. This approach is expected to grossly overestimate the risk.

On the other hand, this SA should not be interpreted as only being applicable to a single tank in a given year. This SA does not place any restrictions on the number of tanks that can be sampled in a given year, and multiple tanks can be sampled under the present safety basis.

This interpretation is in agreement with the general concept of RGs and the Safety Assessment approach and does not contradict the guidance provided in Ref. 2. However, the guidance provided by Ref. 2 on how to combine the risk from different activities and from different tanks is not very explicit and is subject to interpretation.

5.6.1. Accidents with Radiological Consequences

All accidents (except the dome collapse accidents and other accidents which are beyond extremely unlikely events) resulting in radiological consequences are summarized in Table 5-15. Comparison with the on-site and off-site RGs is shown in Figs. 5-1 and 5-2. The numbers next to the data points correspond to the accident numbers given in Table 5.15. As shown in Fig. 5-1 and 5-2, all the conservative doses fall below the RG using best-estimate frequencies.

5.6.2. Toxic-Gas Releases

All gas-release accidents (except the accidents which are beyond extremely unlikely events) with toxicological consequences are summarized in Table 5.16. The computed ammonia concentrations shown in Table 5.16 are plotted in Figs. 5.3 and 5.4 in comparison with the RGs. As shown in these figures, all conservatively calculated ammonia concentrations at the on-site and off-site receptor locations fall below the RGs using best-estimate frequencies. This conclusion is valid also for nitrous oxide releases because the calculated bounding nitrous oxide concentrations are slightly higher than the ammonia concentrations shown in these figures, but the RGs for nitrous oxide are much larger.

5.6.3. Toxic Liquid/Solid Releases

All of the accidents (except the dome collapse accidents and other accidents which are beyond extremely unlikely events) resulting in material release are listed in Table 5-17. Release rates are given over a 15-minute release period. The first five accidents are continuous releases, and the last two are puff releases. Table 5-17 lists the frequency each of accident and the release rates at the release point.

TABLE 5-15
SUMMARY OF ALL ACCIDENTS RESULTING IN RADIOLOGICAL RELEASES

Accident Condition	Frequency (yr)	Onsite (rem)	Offsite (rem)
1-GRE-1 and open riser (removal), 12 g.	1.1E-3	2.04	0.001
2-GRE-2 and open riser (removal), 60 g.	1.1E-5	10.2	0.006
3-GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails), 12 g.	3.2E-6	2.04	0.001
4-GRE-1 and drill string open at the top with sampler in the drill string, 128 g.	2.6E-5	21.8	0.012
5-Continuous releases from exhauster after a HEPA filter fails, 0.08 g/s.	1.6E-5	12.4	0.007
6-Radioactive aerosols are released from HEPA filter blowout.	1.6E-5	1.53	8.3E-4
7-Waste from the contaminated drill string exterior is released aboveground.	4.4E-6	0.13	7.0E-5

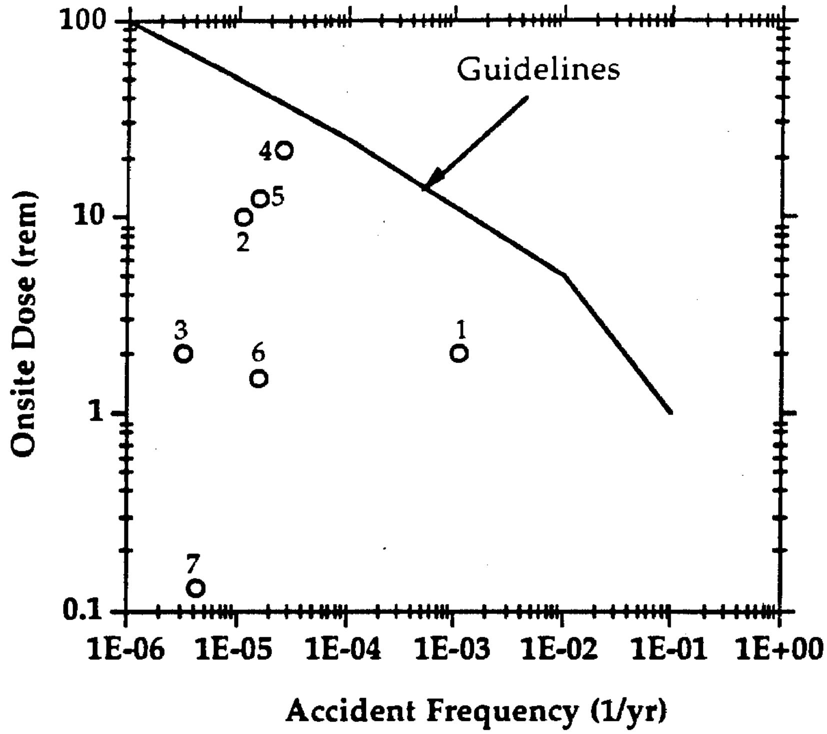


Fig. 5-1. Comparison of calculated radiological doses with the on-site RGs.

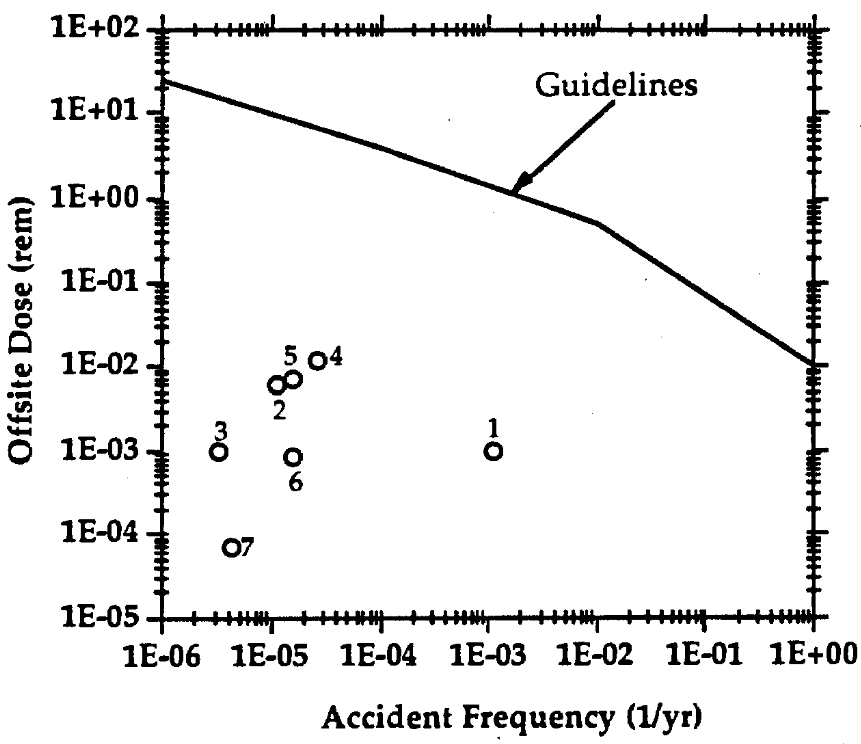


Fig. 5-2. Comparison of calculated radiological doses with the off-site RGs.

TABLE 5-16
SUMMARY OF GAS-RELEASE ACCIDENTS

Accident	Freq. (1/yr)	Onsite (ppm)	Offsite (ppm)
1-GRE-1 and open riser (removal), 1.2% NH_3, 66 scfm	1.1E-3	13	0.01
2-GRE-2 and open riser (removal), 6% NH_3, 633 scfm	1.1E-5	324	0.18
3-GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails), 1.2% NH_3, 66 scfm	3.2E-6	13	0.01
4-GRE-1 and drill string open at the top with sampler in the drill string, 1.2% NH_3, 66 scfm	2.6E-5	13	0.01
5-GRE-1 from exhaust and inlet stack (operation),1.2% NH_3, 66 scfm	0.02	2	0.01
6-GRE-2 from exhaust and inlet stack (operation), 6% NH_3, 333 scfm	2.0E-4	48	0.18
7-GRE-3 from exhaust and inlet stack (operation), 12% NH_3, 666 scfm	2.0E-6	193	0.72
8-Continuous releases from exhauster after a GRE-1, 1.2% NH_3, 250 scfm	0.02	7	0.03
9-Continuous releases from exhauster after an GRE-2, 6% NH_3, 250 scfm	2.0E-4	36	0.13
10-Continuous releases from exhauster after an GRE-3, 12% NH_3, 250 scfm	2.0E-6	72	0.27

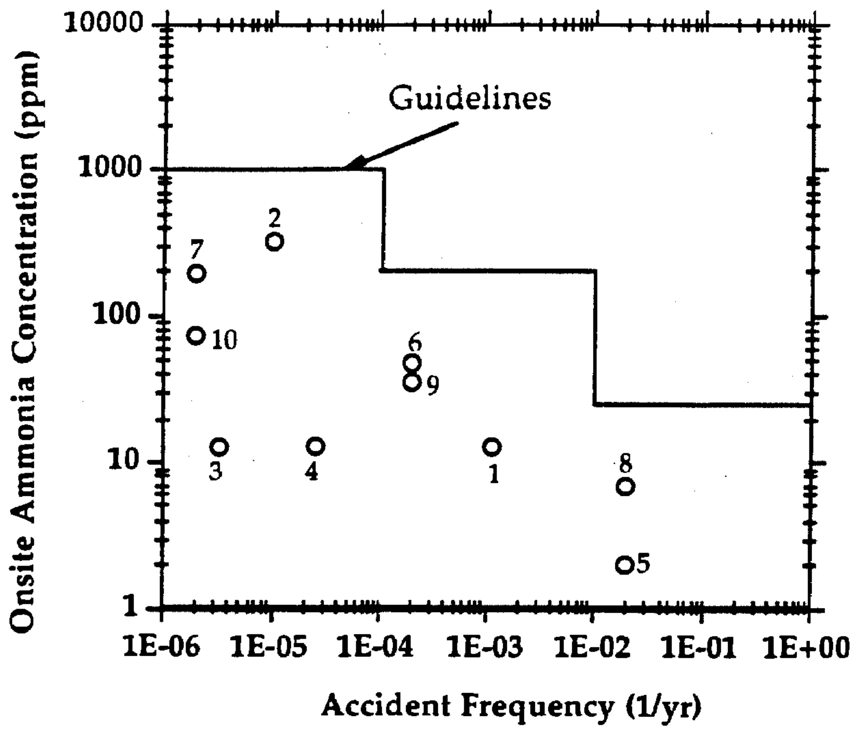


Fig. 5-3. On-site ammonia concentrations for gas release accidents.

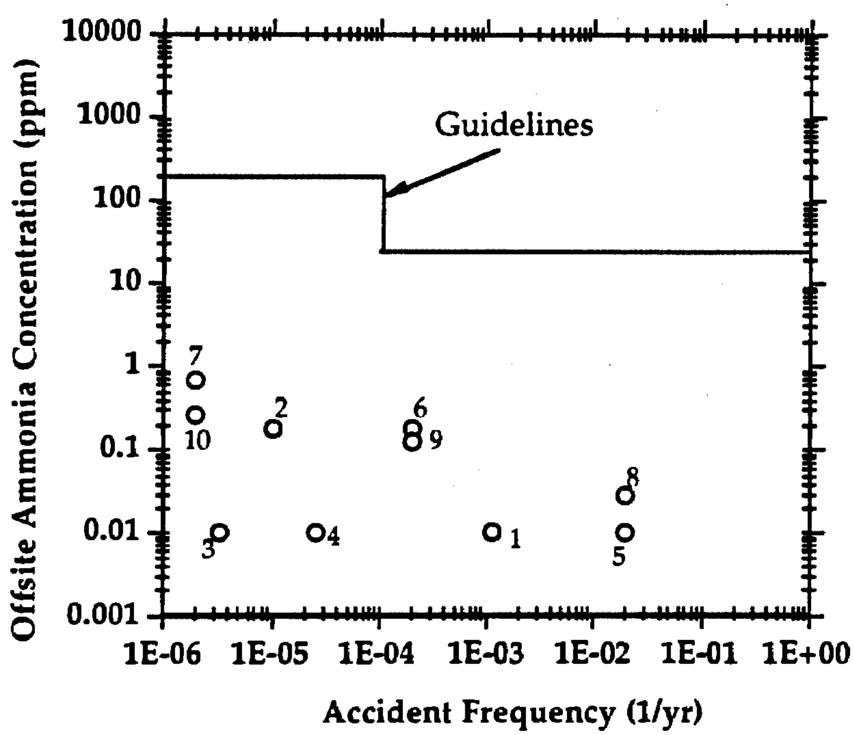


Fig. 5-4. Off-site ammonia concentrations for the GRE accidents

TABLE 5-17
SUMMARY OF TOXIC SOLID WASTE RELEASES

Accident	Freq. (1/yr)	On-site	Off-site
1-GRE-1 and open riser (removal), 12 g.	1.1E-3	8.3E-6 L/s	8.3E-6 L/s
2-GRE-2 and open riser (removal), 60 g.	1.1E-5	4.2E-5 L/s	4.2E-5 L/s
3-GRE-1 and open frisbee (operation) (nitrogen purge to riser sleeve fails), 12 g.	3.2E-6	8.3E-6 L/s	8.3E-6 L/s
4-GRE-1 and drill string open at the top with sampler in the drill string, 128 g.	2.6E-5	9E-5 L/s	9E-5 L/s
5-Continuous releases from exhauster after a HEPA filter fails, 0.08 g/s.	1.6E-5	5E-5 L/s	5E-5 L/s
6-Radioactive aerosols are released from HEPA filter blowout.	1.6E-5	5.63E-3 L	5.63E-3 L
7-Waste from contaminated drill string exterior is released aboveground.	4.4E-6	4.7E-4 L	4.7E-4 L

The computed waste-release rates at the source of releases shown in Table 5-17 are plotted in Figs. 5-5 and 5-6 in comparison with the RGs. The RGs in these figures are given in terms of the release amount or release rate at the release point. As shown in these figures, all the conservative waste release rates at the on-site and off-site receptor locations fall below RGs using best-estimate frequencies, except for Accident 6. Accident 6 is the HEPA failure accident. Total release is estimated as 9 g. The onsite acceptable release amount is 5.5 g. To minimize a significant particulate accumulation at the HEPA filters, a radiation survey control is established. The radiation rate is limited with 100 mrem/h. This rate corresponds to waste amounts much less than 900 g that is assumed to accumulate in the HEPA filters. This control was not credited in obtaining the frequency of 1.6E-5. Furthermore, in deriving allowable limits, the atmospheric dispersion coefficients for ground releases were used.[5] A HEPA filter blowout would be an elevated release with a factor of 6 reduction in the dispersion coefficient. Thus, the receptor doses will be within the allowable limits.

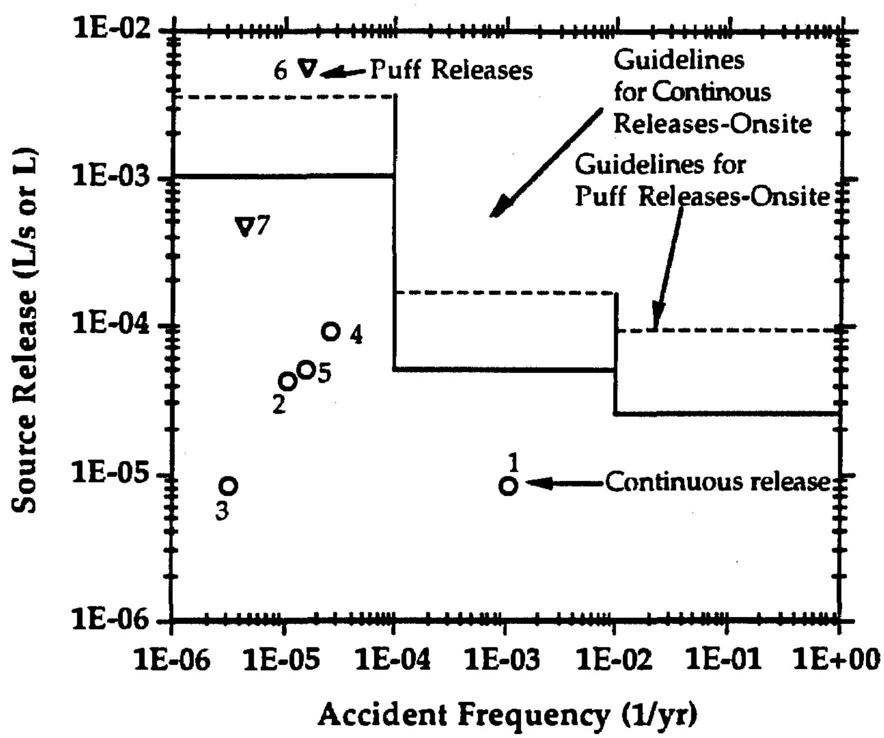


Fig. 5-5. Consequence of toxic waste releases at the on-site receptor location.

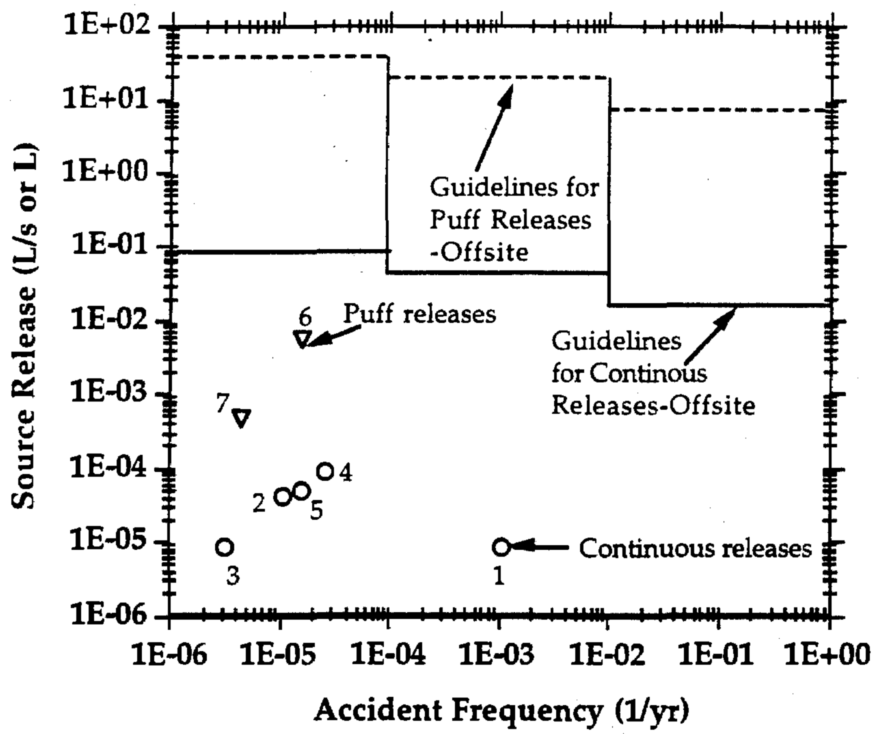


Fig. 5-6. Consequence of toxic waste release at the off-site receptor location.

5.7. REFERENCES

1. A. B. Sidpara, "Risk Acceptance Criteria for Tank Farm Operation," Department of Energy/Richland Operations, letter, 95-TOP-063 to the President of Westinghouse Hanford Company (June 14, 1995).

2. Westinghouse Hanford Company, "Safety Analysis Manual," Westinghouse Hanford Company report WHC-CM-4-46 Rev. 4 (September 30, 1995).

3. J. L. Huckaby, H. Babad, and D. R. Bratzel, "Headspace Gas and Vapor Characterization Summary for the 43 Vapor Program Suspect Tanks," Westinghouse Hanford Company report WHC-SD-WM-ER-514, Rev. 1A (September 1995).

4. W. L. Kubic, "Production of Nitrogen Oxides During Burn Accidents in Tank 241-SY-101," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-GR-040 (September 1995).

5. Westinghouse Hanford Company, "Toxic Chemical Considerations for Tank Farm Releases," Westinghouse Hanford Company report WHC-SD-WM-SARR-011 Rev. 1 (October 1995).

6.0. CONTROLS

In this section, the comprehensive list of all credited design features, and procedural and administrative controls imposed on the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations, are described.

6.1. ADMINISTRATIVE CONTROLS

This section provides the controls to be used for all phases of FG/RMCS activities in: (1) pre-installation and installation activities; (2) drilling and sample retrieval; and (3) removal and decontamination. The controls have been grouped for each phase of the FG/RMCS activities for clearer and easier procedures development, and have been developed based on the results, assumptions, and initial conditions of this SA, in conjunction with existing WHC controls. Those WHC standard controls important to the activities have been repeated in this SA for clarity; however, the set of controls listed in this SA is intended only to supplement the WHC standard controls, not replace them.

Westinghouse Hanford Company (WHC) standard controls include a series of WHC documents that define the safety envelope for the tank farm, waste transfer activities, and waste storage activities. The primary document is the WHC Health and Safety Plan[1], although other documents include the Safety Assessment for Push- and Rotary-Mode Core Sampling in Ferrocyanide Tank,[2] Safety Analysis for the Push Mode and Rotary Mode Core Sampling,[3] and the Interim Operational Safety Requirements for Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks.[4] During the development of the procedures for each of the activities, the current operational safety requirements (OSRs), interim operational Safety requirements (IOSRs), and operational safety documents (OSDs) must be considered (refer IOSR[4] for restart requirement). The safety envelope established by the analyses shall not be changed unless approved by the Department of Energy (DOE). The controls provided in this section can be modified if the appropriate organization grants approval.

Most of the controls presented in this section are based on the analyses conducted for this safety assessment (SA). These controls have been designed to ensure that the analysis assumptions and initial conditions are maintained throughout each phase of the activities. In several cases, the controls have been developed to add an additional safety margin, consistent with a philosophy of defense-in-depth. Therefore, the controls should be an integral part of the procedure development process to maintain the level of safety demonstrated in this SA.

Administrative controls are the requirements that shall be followed to ensure that the activity stays within the bounds of the SA. As such, this set of administrative controls shall be used during the development of the procedures for each activity.

Sections 6.5 through 6.9 provide the specific controls in tabular format to be used for the activities covered by this SA. Of these activities, FG/RMCS operations are the most complex. Therefore, more controls have been instituted for the operational phase than for other processes. Because of the complexity of the FG/RMCS operation, these controls have been divided into three levels. Each control level requires a different level of approval for modification and for restarting operations after abnormal shut downs.

FG/RMCS operation controls are designated as either Level 1, Level 2, or Level 3. This graded approach reflects the importance of a particular control, the level of approval required for modification, and the level of approval required to restart operation if a particular limit is exceeded.

Level 1 controls are the most important, they are under the most stringent management supervision and are equivalent to OSRs (see Section 6.2.). Level 1 controls ensure that the most important bounds, established in the SA, are maintained at all times, as demonstrated by the appropriate analyses for both potential prompt effects and post-operation effects. Changes to the Level 1 controls, if required, will be developed by Characterization/RMCS support personnel, and approved by the Plant Review Committee (PRC), WHC management, and DOE/RL. The WHC Design Authority is responsible for approval of all aspects of equipment design.

Level 2 controls are the next level in importance. The PRC must approve modifications to Level 2 control parameters and notify WHC Management and DOE/RL of the modifications and the technical bases for the modifications. Changes to those Level 2 controls that are included in the IOSR's require DOE approval.

Level 3 controls are the lowest level in importance. Changes to the Level 3 controls will be approved by the PRC. WHC Management and DOE/RL will be notified of the changes and their technical bases.

The PRC may charter a separate technical review group to perform the review and approval responsibilities of the PRC.

All changes to any of the controls or equipment credited in this safety assessment, and any special tests, must be screened for unreviewed safety questions, in accordance with DOE Order 5480.21, and in accordance with WHC policies and procedures.

An automatic shutdown as defined in the following administrative control tables is not considered a violation of the control. Restart of any FG/RMCS activity shall be commensurate with its designated level, and with DOE and contractor procedures.

6.2. LEVEL DESIGNATION PROCESS

The designation of the control levels was performed using the following methodology Mitigated and unmitigated accident frequencies and consequences were estimated for each individual accident scenario discussed in Section 4 by considering the application of the controls (mitigated) or without the controls (unmitigated).

In general, controls were designated Level 1 when the control prevented the mitigated consequence of an accident scenario from exceeding the offsite Risk Guidelines.

Level 2 was assigned to controls when the accident was considered to result in consequences that exceed the onsite Risk Guidelines, based on unmitigated accident frequencies.

A control was designated Level 3 if the unmitigated accident frequency was lower than 1.0E-6, or if it enhanced the defense-in-depth arguments even when the accident consequences are within the Risk Guidelines.

Certain controls appeared in multiple accident scenarios. In these cases, the most conservative level was designated for that control.

6.3 FG/RMCS SAFETY DESIGN FEATURES

Principal safety criteria have been established to ensure safe operations during rotary-mode core sampling activities. Design features within the FG/RMCS equipment and procedures have been established to comply with these safety criteria.

The safety equipment list with design criteria classifications, as approved by the WHC Design Authority and plant management, is provided in Reference 5. Reference 6 lists the qualitative safety design features to prevent the identified hazards. Table 6-1, which identifies those credited design features used in this SA, is based on new design features added to the FG/RMCS trucks, and Ref. 5 and 6.

Table 6-1 identifies design features with significance to safety credited for mitigation of "offsite" or "onsite" consequences. Combinations of design features with significance to safety and administrative controls were used to meet "offsite" and "onsite" Risk Guidelines (RG). Appendix E describes how the design features and administrative controls are combined to meet the guidelines. No modifications to the design features identified in Section 6 are required to meet the RGs. Therefore, classification of a design feature as "offsite" would not require the modification of a design feature to increase its reliability beyond that credited in Appendix E. For example, redundant sensors, beyond that specified in Section 6, would not be necessary for a detector system identified as "offsite".

6.3.1 Worker Health and Safety Requirements

This safety assessment addresses the risks to onsite individuals at 100 m and to the offsite public, and provides for safety equipment and administrative controls to reduce such risks to within risk guidelines. Included are the risks from radioactive materials, toxic gases, and toxic chemicals, as described in Section 5. The RGs are defined for individuals to 100 m from the source of releases. This SA does not specify any new controls necessary to protect workers who are located closer than 100 m the RMCS activity. The current controls, that protect workers within 100 m, are defined in the contractors Hanford Radiological Control Manual and the Tank Farm Health and Safety Plan (HASP). Those current controls which were credited in this SA are listed in Section 6.

There is a potential for worker exposure to high concentrations of toxic gases during tank intrusive work around open tank risers or from emissions from the ventilation exhauster, including ammonia, nitrous oxide, and various organic species. Concentrations of these gases may be in excess of OSHA-allowed values in the tank vapor space during the rotary sampling work. Because the tank vapor space will be exhausted into the ambient air above the tank a pathway for worker exposure is recognized to exist. Assessment of the hazards from these materials, and protection of the workers is provided by the contractors HASP (Reference 1). Significant elements of this plan include monitoring of the work area for organic vapors, ammonia and other chemical species whenever there is a potential for elevated employee exposure levels. In addition, personnel monitoring is performed on those tasks which are judged to have the highest potential for exposure. Finally administrative barricades have been erected around areas with known vapor releases, and monitoring or protective equipment is required whenever employees work within these areas.

Tank Farms are considered to be a RCRA Treatment, Store and Disposal (TSD) facility, and all work in Tank Farms must comply with the HASP. The contractors Industrial Hygiene staff has responsibility for implementation of the HASP, including monitoring and personnel sampling. Trained industrial hygiene technicians perform monitoring of each task. If any tank vapor levels are detected that present a possibility of employee over exposure, the IH technicians will take appropriate actions, including the use of personal protective equipment or suspending the activity, to ensure that no employee overexposures occur.

TABLE 6-1
FG/RMCS CREDITED DESIGN SAFETY FEATURES

General Features	
Material compatibility (Onsite) Significant to Safety	Materials used in FG/RMCS activities and the drill string components are compatible with the waste stored in single-shell tanks to prevent chemical action or material failures resulting from expected or accidental contact with the wastes.[7,8]
Spark-resistant tools (NA)	Spark-resistant tools are used at all times around open risers or the sampled riser to mitigate mechanical sparking.
Grounding and bonding (NA)	The FG/RMCS equipment is grounded and bonded to mitigate electrical sparking and mitigate the buildup of static electricity.
Radiological controls (NA)	The area around the riser is radiologically monitored, and the exhauster HEPA filter housing is monitored to prevent exposure of personnel to hazardous radiological conditions as set by WHC ALARA controls.
Riser Adapter Features	
Riser sleeve (Offsite) Significant to Safety	A conductive sleeve is inserted into the riser to be sampled to mitigate frictional sparking. In addition, the sleeve is provided with a manually controlled nitrogen purge system to prevent flammable gas accumulation in the riser sleeve.
Drill string spray washer (NA)	A hot-water spray washer is provided on the riser adapter to reduce the contamination of drill rods as they are removed from the tank. Check valves and a positive displacement pump are provided on the system to restrict back flow.
Frisbee/DS interface lubricant (NA)	The frisbee/DS interface is lubricated with a non-spark inducing, waste-compatible material to decrease the friction between the rubber seal and the drill string, and thereby mitigate damage to the seal.
Pneumatic foot clamp (Offsite) Significant to Safety	The pneumatic foot clamp is designed to fail closed to prevent the drill string from falling into the tank when the drill truck or platform hoist are not connected.
Locking wrench (Offsite) Significant to Safety	The locking wrench is a mechanism used concurrently with the foot clamp to ensure the support of the drill string during installation, sampling operations, and removal.
Drill String Features	
Drill bit configuration and material (Offsite) Significant to Safety	The drill bit is made of a waste-compatible material, and must be qualified commensurate with the requirements provided in Appendices F, G and T of this SA.
Drill centering spike (NA)	The first rotary-core sampler shall be equipped with a centering spike on initial use to prevent random bit motion when first entering the waste.

Chevron seal between drill bit and sampler (NA)	The chevron seal between the drill bit and sampler provides a barrier between tank waste and the drill string. This seal allows one-way flow of nitrogen purge from the drill string into the tank, but does not allow waste or waste gas to flow back into the drill string.
Core sampler and drill string components (Offsite) Significant to Safety	The core sampler and drill string components must meet the requirements specified in Appendix T to prevent sparking. The section of the core barrel having the serrated edges (grooves) and the quadralatch fingers and body must be made of stainless steel to reduce the likelihood of spark (see Appendix T).
Sniffing ports (NA)	Sniffing ports are provided to allow measurement of flammable gas from a contained environment.
Change-out assembly (NA)	The change-out assembly is provided with a ball valve to isolate and maintain pressure within the drill string during sampler exchange.
Cable spray washer (NA)	The hot-water cable spray washer connects to the drill string to wash cables and samplers that are contaminated.
Drilling Features	
Purge flow limitation (Offsite) Significant to Safety	In FG/RMCS operations, the drill string is purged with a minimum of 30 scfm of nitrogen to prevent drill bit overheating and to remove cutting-products from the drill bit. Purge flow is initiated just before drilling begins. With a loss of nitrogen purge, drilling is automatically terminated with no delay to maintain drill bit temperature within the defined limits.
Rotational speed limitation (Offsite) Significant to Safety	In FG/RMCS operations, the maximum rotational speed of the drill string is 55 rpm to maintain the drill bit temperature within the defined range. Drilling is automatically terminated with no delay if the speed exceeds 55 rpm.
Down force limitation (Offsite) Significant to Safety	In FG/RMCS operations, a maximum down force of 750 lbf shall be imposed on the drill string to maintain drill bit temperature within the defined range. When the rotational speed is greater than 2 rpm, the set point is selected at 750 lbf upon which shutdown will be initiated. Drilling is automatically terminated with no delay if the down force exceeds 750 lb.
Drill string penetration rate (Offsite) Significant to Safety	In FG/RMCS operations, a minimum penetration rate of 0.75 in./min is limited to < 60 seconds to maintain drill bit temperature within the defined range. Drilling automatically terminates when the penetration rate is <0.75 in./min. for a cumulative time of 60 seconds in any 3 min. period.
Hydraulic bottom detector (Offsite) Significant to Safety	The hydraulic bottom detector detects the increased resistance during the last sample to prevent increasing the downward force and penetrating the tank bottom by reversing ram motion upward. Two operators are needed to enable the hydraulic interlock system to ensure activation redundancy. The hydraulic interlock system has a pressure-relief valve to control overpressure and check valves to prevent inappropriate flow reversal.

Walk Down Function (Offsite) Significant to Safety	The walk down function automatically limits down force by controlling lower ram pressure.
Hydrostatic head (NA)	Hydrostatic head pressure is maintained and monitored during sample retrieval to prevent drill string flooding.
Sampling Truck Features	
Truck position (Offsite) Significant to Safety	All truck ignition sources are greater than 3-ft. from the frisbee or protected with a barrier to separate potential sources and flammable gases leaking from the frisbee.
Stabilizing jacks (NA)	The sampling truck is provided with stabilizing jack locking collars to prevent truck movement in case of hydraulic failure.
Quill rod adapter (Offsite) Significant to Safety	The quill rod adapter shall be fabricated of a waste-compatible, spark-resistant material.
Grapple Hoist Assembly Features	
Grapple hoist assembly (Offsite) Significant to Safety	The grapple hoist assembly is designed to meet NEC requirements as defined in this SA to allow operation in a flammable gas environment.
Grapple (sample actuator) (Offsite) Significant to Safety	The mechanical design of the grapple (sample actuator) mitigates electrical and mechanical sparking.
Grapple insertion (NA)	The design of the grapple hoist assembly limits grapple insertion and removal rates to $\leq$ 1 ft/s to minimize frictional sparking.
Grapple hoist cable tension (Offsite) Significant to Safety	The grapple hoist assembly measures cable tension during sampling to prevent grapple hoist damage. The electrical motor automatically shuts down when the load is >250 lb.
Shielded Receiver Assembly Features	
Shielded receiver assembly (Offsite) Significant to Safety	The shielded receiver assembly is designed to meet NEC as defined in this SA to allow operation in a flammable gas environment.
SR tube (NA)	Shielding materials are used in the SR to protect against sampler radiation.
SR view port (NA)	The SR view port provides a means to inspect the sampler during retrieval to control the spread of contamination.
SR hoist cable tension (Offsite) Significant to Safety	The SR hoist assembly measures cable tension during sample retrieval to prevent damage to the SR hoist assembly. The cable has a structural capacity of 2000 lbf in tension.
SR hoist motor (NA)	The SR hoist motor

Remote latch unit (Offsite) Significant to Safety	The mechanical design of the remote latch unit mitigates electrical and mechanical sparking.
RLU insertion (NA)	The design of the SR assembly limits RLU insertion and removal rates to ≤ 1 ft/s to minimize frictional sparking.
RLU position indicator (NA)	The position of the RLU is monitored to ascertain whether the core sampler is completely raised into the SR, or inserted into the drill string.
Exhauster Features	
Exhauster Operation (Offsite) Significant to Safety	The exhauster continues to operate, as described in Appendix L, but terminates drilling upon detection of flammable gases or dome pressure rise exceeding the specified limits to protect personnel and equipment during a potential gas-release event.
Exhauster intrinsic safety (Offsite) Significant to Safety	All electrical equipment within the exhauster flow stream, including the exhauster fan and instrumentation, is qualified to operate in a NEC Class-1, Division-I, Group B environment to allow operation in a flammable gas environment.
Exhauster PLC (Offsite) Significant to Safety	An exhauster programmable logic controller processes out-of-tolerance alarm signals to activate the alarm strobe and indicator lights, and sends a signal to the shut-down logic to initiate drill engine shutdown for all operating parameters listed in the administrative control table.
Exhauster duct (Offsite) Significant to Safety	The exhauster duct is made of a conductive material and is grounded to mitigate static sparking. In addition, the duct is attached to the exhauster to prevent damage from wind.
Exhauster heater (Offsite) Significant to Safety	The heat exchanger is designed for operation in a flammable gas environment.
Exhauster fan and motor assembly (Offsite) Significant to Safety	The exhauster fan and motor assembly as defined in this SA is qualified for operation in a flammable gas environment.
Inlet breather stack (Offsite) Significant to Safety	The tank inlet breather stack shall be at least 15-ft tall with a nominal 4-in. i.d. to reduce toxicological consequences and to protect non-qualified equipment on the tank dome during GRE.
Tank pressure detection (Offsite) Significant to Safety	The exhauster is equipped with a tank pressure detection system to prevent low tank pressure.
Flammable Gas Detection	
Flammable gas detector (Offsite) Significant to Safety	The flammable gas detection system, with redundant sensing systems, is provided to meet the functional requirements and performance acceptance criteria as defined in Appendices C and U to terminate FG/RMCS operations in the event of a GRE. Tank pressure is also measured to provide GRE detection and diversity.
Mobile X-ray System Feature	

X-ray containment (NA)	The mobile X-ray system has a sealed, conductive-tube enclosure and redundant sleeve to separate waste and waste-generated flammable gases from the electrical components of the system.
Nitrogen System Safety Features	
DS nitrogen purge supply (Offsite) Significant to Safety	The DS nitrogen purge supply is provided to prevent drill bit overheating. Automatic termination of drilling operations on low purge flow is provided to prevent drill bit overheating.
Nitrogen hydrostatic head supply (NA)	Maintaining the hydrostatic equilibrium in the drill column with hydrostatic head nitrogen is controlled by a flow controller to ensure that excessive amounts of nitrogen are not injected into the waste.
Riser sleeve nitrogen purge supply (NA)	The riser sleeve nitrogen purge flow is provided to prevent flammable gas accumulation in the annulus between the riser sleeve and drill string. Automatic termination of drilling operations occurs on loss of flow.
Unique connections (NA)	Unique connections are provided for both the DS and riser/sleeve annulus nitrogen purge systems, as well as the hydrostatic head systems for the DS and SR, to prevent incorrect connections.
Instrumentation, Control, and Interlock Features	
Truck PLC (Offsite) Significant to Safety	The truck programmable logic controller processes out-of-tolerance alarm signals to activate the alarm strobe, horn, and indicator lights and to send a signal to the shut-down logic to initiate drill engine shutdown for all operating parameters listed in the administrative control table.
Audible and visual annunciation (NA)	Audible and visual annunciation is provided to alert the operator to out-of-tolerance alarm conditions as listed in the administrative control table.
Shut-down interlock (Offsite) Significant to Safety	The shut-down interlock accepts signals from the PLC to shut down the drill rig engine ignition.

6.4. FG/RMCS CONTROLS

The control tables in this section are discussed in terms of the applicable phases, the descriptions of the columns and several definitions that are pertinent to accurately interpreting the controls.

6.4.1. FG/RMCS Controls Phases

All of the controls developed for FG/RMCS activities have been categorized into one of the following 5 phases:

- All Phases—these controls will apply to all phases of FG/RMCS operations. See Section 6.6, Table 2.

- Pre-installation Phase—controls in this phase are focused at the activities necessary to prepare the site, acquire and set up equipment, and perform grounding and bonding activities. See Section 6.7, Table 3.
- Installation Phase—these controls are directly related to all activities associated with opening and preparing the riser, and inserting the drill string. See Section 6.8, Table 4.
- Operations Phase—this phase contains all of the controls related to sampling operations and sampler handling. See Section 6.9, Table 5.
- Removal Phase—this final phase includes the decontamination of the drill string, breaking down the equipment and restoring the site. See Section 6.10, Table 6.

6.4.2. Control Table Columns

Each of the tables has the following columns:

- System or condition—defines the situation or equipment for which the control is being developed.
- Safe operating condition—defines the levels or conditions under which safe operation occurs.
- Surveillance or monitoring method—defines the surveillance or monitoring method used to check the operation condition.
- Administrative controls—defines the controls for the given system or equipment in terms of operation or performance.
- Level—defines the Level 1, 2 or 3, as described in Sections 6.1 and 6.2.
- Basis for Control—defines the reason behind or necessity for the control.
- Safe Shutdown Definition—defines the conditions and actions necessary if the control requirements are not met.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.5. ALL PHASES	/					
6.5.1. Use of FG/RMCS Controls						
6.5.1.1. Control Applicability	Approved checklist	Checklist evaluation	This Safety Assessment and its controls shall be applicable to single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL. This SA does not cover the RMCS operations in tanks involving floating organic layers or organic remnant layers and ferrocyanide tanks as specified in Appendix G. Each tank shall be evaluated against the checklist in Section 7, and the evaluation results shall be reviewed and approved by the PRC before initiating any FG/RMCS operations.	1	SA assumptions in regard to tank specific parameters such as gas and waste composition, gas release probability etc. may become non-conservative by a new analysis or data for a specific tank considered to be sampled by RMCS prior operations. See section 7 and Appendix G.	No FG/RMCS operations can proceed without checklist approval. If FG/RMCS operations are initiated without checklist approval, immediately terminate activities and notify plant management.
6.5.1.2. Existing procedures and controls	Use controls identified in this document for specified phases of FG/RMCS operations.	Procedural evaluation	The PRC shall verify that all FG/RMCS controls specified in this SA are implemented in the operating procedures. Non-RMCS-related activities on the flammable gas tank being sampled shall be performed under existing Contractor controls and procedures, unless superseded by FG/RMCS controls.	3	SA analyses requires changes in current procedures. New procedures are needed to maximize safety to personnel, equipment and the environment. Provides defense in depth to all aspects of safety.	NA
6.5.2. Flammable Gas Detection System						
6.5.2.1. Flammable gas detection system calibration	Use of calibrated detection system	Periodic calibration	New SMC sensors shall be initially calibrated in a laboratory environment using hydrogen and ammonia. A functional SMC calibration test shall be performed in the field at initial setup and then every day the flammable gas detection	1	The use of a redundant and adequate flammable gas detector is a key assumption to provide safe shutdown of FG/RMCS	No FG/RMCS activities shall proceed without the use of a calibrated flammable gas detection system.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/		A functional SMC calibration test shall be performed in the field at initial setup and then every day the flammable gas detection system is used. The Whittaker sensor shall be calibrated every three months. The functional calibration test shall consist of setting the zero with pure air or nitrogen and calibration with nominal 6000 ppm hydrogen for both sensors. The functional calibration test procedure at a nominal 6000 ppm hydrogen shall test the shutoff electronics as well as the sensor reading for both sensors.		detector is a key assumption to provide safe shutdown of FG/RMCS operations during a GRE. This reduces the likelihood of spark in flammable gas atmosphere and also provides protection for toxic gas exposures. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.2.1.	calibrated flammable gas detection system.
6.5.2.2 Flammable gas detection system operation	Limit setpoint of flammable gas detection system at ≤ 25% LFL.	Flammable gas detection system connected between riser and exhauster housing with system readout and alarmed setpoints One out of two redundant logic	A redundant, calibrated flammable gas detection system shall be operational before FG/RMCS waste intrusive operations begin, and operate consistent with exhauster operation defined in Section 4.1.3. The flammable gas detection system shall be trip setpoint limited at: • > 5000 ppm hydrogen concentration equivalent; and • > 100 ppm/s rate of equivalent hydrogen concentration increase over a 10-s period. Send a shutdown signal to the truck PLC. One out of two redundant logic. SMC sensors shall be replaced at least once each month with new sensors.	1	System detects flammable gas accumulation sufficient for deflagration or detonation in tank. Detects GRE and provides protection for fire and toxic hazards. Reduces the likelihood of spark in flammable gas atmosphere. Provides protection for exposure to toxic gas releases. This mitigates unacceptable offsite consequences resulting from a dome collapse. Section 4 and	Upon detection, the exhauster will continue to operate. If drilling, the drill rig engine will automatically trip. All personnel within a 100-m radius from the edge of the tank will evacuate and don protective equipment before returning for further equipment stabilization. FG/RMCS activities can resume in compliance with appropriate controls in Section 4.1.1.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
					Appendix B.	
6.5.2.3. Tank gas pressure detection system	Detect rate of tank pressure increase.	Gas pressure detection system in dome or riser One out of two redundant logic	A redundant gas pressure detection system shall detect an increase in tank pressure of > 2 in. w.g. in any 5 minute period. Send a shutdown signal to the truck PLC. One out of two redundant logic.	1	Prevent burn in and out of dome by detecting gas release rates >1000 ft^3/min. Provides protection for fire and toxic hazards. Reduces the likelihood of spark in flammable gas atmosphere. Provides protection for exposure to toxic gas releases. This mitigates unacceptable offsite consequences resulting from a dome collapse. Sec. 4.1.1, 4.2.1, 4.2.4, and Appendix B	Upon detection, the exhauster will continue to operate. If drilling, the drill rig engine will automatically trip. All personnel within a 100-m radius from the edge of the tank will evacuate and don protective equipment before returning for further equipment stabilization. FG/RMCS activities can proceed in compliance with appropriate controls in Section 6.4.
6.5.3. Spark-free environment						
6.5.3.1. Spark-free environment	Use spark-resistant tools, materials, and FG/RMCS components at all times within a radius of 36 in. of open riser or sampled riser	Procedural evaluation	An administrative control shall be developed and implemented that imposes an environment that significantly reduces the likelihood of sparking by: • The use of spark-resistant tools, materials, and FG/RMCS components at all times within a radius of 36 in. of the riser being sampled or any open riser. • Nonsmoking environment on top of the tank.	3	Prevent ignition sources in proximity with flammable gas environments. Prevent fire and its propagation above the tank dome. See Sections 4.3.3, 4.2.2, and 4.2.3.	No FG/RMCS activities can be initiated or proceed until a spark-free environment is established.
6.5.4. Material compatibility						
6.5.4.1. Material	Use waste compatible	Procedural	An administrative control shall be	2	Prevent gas	No FG/RMCS

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
compatibility	materials and lubricants	evaluation	developed and implemented that requires, when in contact with the DS or tank waste, the use of: • waste-compatible materials, and • pipe compounds, lubricants, seals and tapes that do not contain spark-inducing or waste-incompatible materials.		generation caused by material incompatibilities. Protects against local exothermic chemical reactions that could produce large quantities of flammable gas and heat and cause a waste fire if propagates. Prevents equipment damage. Sections 4.3.1 and 4.4.2.	activities can be proceed until the use of waste compatible materials is implemented.
6.5.5. Exhauster emissions			Contractor Controls		See Section 4.1.1	
6.5.6. Simultaneous activities						
6.5.6.1. FG/RMCS vehicle operations on tank	Limits on vehicle operations during open riser conditions or waste-intrusive activities	Procedural evaluation	An administrative control shall be developed and implemented that evaluates flammable gas concentrations in the FG/RMCS tank during open riser conditions or waste-intrusive activities before any vehicle operations.	3	Minimize the potential for vehicle operations igniting flammable gas concentrations. See Section 4.1.7.	Upon detection, vehicle operations will be immediately terminated and not resumed until flammable gas limits are met.
6.5.6.2. Simultaneous activities on FG/RMCS tank	Limits on simultaneous non-FG/RMCS activities on sampled tank	Procedural evaluation	An administrative control shall be developed and implemented that prevents non-FG/RMCS activities on the tank during waste-intrusive operations. Simultaneous dome-intrusive activities can be performed provided: • the equipment is qualified for operation in a Class I, Division 1, Group B environment, and • operation is based on its own safety assessment. • operation does not physically interact with the drill string, and	1	Tank dome is considered to be Class I, Div. 1, Group B environment because RMCS can induce a GRE. Sparks in the dome or volumes having a connecting path to the tank dome must be controlled. Control prevents ignition of flammable gas by non-FG/RMCS-related ignition sources.	No non-FG/RMCS activities can proceed during period defined by control, or until any simultaneous tank activities comply with the control.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/		is not waste-intrusive.		This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.2.7 and Appendix B.	
6.5.6.3. Inter-connected tanks	Limits on simultaneous non-FG/RMCS activities on interconnected tanks	Procedural evaluation	An administrative control shall be developed and implemented that prevents non-FG/RMCS activities on interconnected tanks when waste-intrusive activities are in progress. If necessary, an action plan shall be prepared for PRC review and approval to proceed with noncompliant activities.	3	Tank dome is considered to be Class I Div. 1 Group B environment because RMCS can induce a GRE. Sparks in the dome or volumes having a connecting path to the tank dome must be controlled. Control mitigates gas release or fire from interconnected tank resulting in burn in FG/RMCS tank. See Section 4.2.7 and Appendix B.	No non-FG/RMCS activities can proceed during period defined by control , or until all simultaneous activities on interconnected tanks comply with the control.
6.5.7.Refueling Activities						
6.5.7.1. Flammable gas concentrations	Limits on refueling with flammable gas concentrations≥25% LFL	Procedural evaluation	No refueling operations shall be performed inside the tank farm when FG/RMCS tank flammable gas concentrations are ≥25% LFL.	3	Limit flammable gas concentrations in proximity with ignition sources. Operations when the tank dome have flammable gas concentration above 25% LFL is prohibited to prevent dome fires. Control reduces the likelihood of fire accident in the dome.	All FG/RMCS activities will be terminated until flammable gas concentrations are within limits specified in Section 6.9.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
					See Section 4.1.7.	
6.5.7.2. Equipment refueling	Limits on equipment refueling operations	Procedural evaluation and implementation	An administrative control shall be developed and implemented for equipment refueling operations that: • prevents refueling operations around open risers, • controls refueling operations, and • defines management of fuel spills and leaks.	3	Limit ignitable material in proximity with flammable gas environment during refueling operations. Prevent fuel fire and fire propagation to the tank. See Sections 4.1.6 and 4.1.7.	No FG/RMCS activities can proceed until refueling activities comply with the control.
6.5.8.Drill String Support						
6.5.8.1. Locking wrench	Redundant, external mechanical support for drill string	Procedural implementation PIC verification	An administrative control shall be developed to ensure the concurrent use of a locking wrench with foot clamp engagement during DS installation, sampling operations and DS removal. The locking wrench shall be installed before the quill rod is disconnected.	3	Redundant mechanism prevents drill string drop with foot clamp failure. See Section 4.2.3.	No FG/RMCS activities can proceed until the locking wrench is concurrently employed with foot clamp use.
6.5.9.External events						
6.5.9.1. Meteorological verification	Monitor external events	Procedural evaluation	Before and periodically during FG/RMCS operations external event status shall be verified with meteorological station or appropriate authorities Contractor shall identify an acceptable meteorological station and acceptable verification authorities.	3	Monitoring mitigates the effects of external events on FG/RMCS activities. See Section 4.9.	When external events exceed given controls, terminate activities, secure auxiliary equipment, and place sampling truck in stabilized mode as required by approved Tank Farm Operating Procedures.
6.5.9.2. Range fires	No range fires within 5 mile radius	Procedural evaluation	At the discretion of the PIC, no FG/RMCS activities shall be performed if a range fire is within a 5 mile radius.	3	Minimize spark sources. Reduces likelihood of fire propagation into dome.	As required by General External Event control.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/				Prevents equipment damage. See Section 4.9.3.	
6.5.9.3. Thunder-storm & lightning, high winds, dust devils and tornadoes	No thunderstorm activity or lightning strikes within 50 mile radius No sustained wind velocities > 25 mph	Procedural evaluation	At the discretion of the PIC, no FG/RMCS activities shall be performed when: • thunderstorm activity or lightning strikes are reported within a 50 mile radius. • Sustained wind velocities are > 25 mph. • Dust devil activity that can disrupt operations • tornado activity has been predicted within the next 8 hours within a 50 mile radius.	3	Prevent personnel injury, equipment damage, and reduce potential for electrostatic sparking. See Section 4.1.2 and 4.9.	As required by General External Event control.
6.5.9.4. High rain fall or flooding, seismic activity, and volcanic activity/ashfall	Reduce potential for personnel injury and equipment damage.	Procedural evaluation	An administrative control shall be developed and implemented that assesses the limits of safe FG/RMCS activities with: • excessive rain fall • extreme temperature conditions • seismic activity • volcanic activity or ashfall accumulation	3	Prevent personnel injury and equipment damage. See Section 4.9.4, 4.9.6. and 4.9.7	As required by General External Event control.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.6.PRE-INSTALLATION PHASE						
6.6.1.Waste Reactivity Evaluation						
6.6.1.1. Waste reactivity	FG/RMCS operations on tanks specified in Appendix G of this SA	Procedural implementation	FG/RMCS operations shall be performed only in tanks listed in Table G-3 of Appendix G in this SA.	1	Prevents propagating exothermic chemical reaction that could produce large quantities of flammable and toxic gas and heat. Waste and flammable gas ignition consequently a possible dome collapse is prevented. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Appendix G	No FG/RMCS activities can proceed in tanks not listed.
6.6.2.Tank and riser conditions						
6.6.2.1. Gas leak paths	Identify and repair leaking risers prior to waste-intrusive activities	Visual inspection Procedural evaluation	An administrative control shall be developed and implemented for a formal tank walkdown prior to waste-intrusive activities that: • assesses the general condition of risers, • identifies observable leaks • as a minimum, documents identified leaks ≥ 1 in. effective diameter, • as a minimum, seals or add deflectors to identified leaks with a leak diameter ≥ 1 in. effective diameter.	1	Above ground fires that could propagate into the dome are managed by controlling position of the non-qualified equipment. Since sparks from non-qualified equipment can not be eliminated, a safe distance criteria is developed in App. B. This criteria requires that possible leak	No FG/RMCS activities can proceed until procedural controls are implemented.

Just drilled tank

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/				diameter is to be known and controlled. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.1.2.1 and Appendix B.	
6.6.2.2 Open riser exclusion zone	Exclusion zone with radius of 36-riser-diameters around open risers during waste-intrusive activities	Procedural evaluation and verification	An administrative control shall be developed and implemented for an exclusion zone with a radius of 36-riser-diameters around any open riser during waste-intrusive FG/RMCS activities.	1	Minimizes ignition sources in proximity with flammable gas. Minimizes gas leakage in proximity with ignition sources or unqualified equipment. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.1.2.1 and Appendix B.	No FG/RMCS activities can proceed until procedural controls are implemented.
6.6.3.Grounding and bonding						
6.6.3.1. Equipment attached to tank	Ensure equipment grounding	Resistance measurement Procedural evaluation and verification	An administrative control shall be developed and implemented for grounding and bonding all FG/RMCS equipment attached to the riser or inserted into the tank, including the drill string such that: • Electrical power grounding shall comply with the requirements of NFPA 70, Article 250. • Lightning protection shall be consistent with the principles	3	Prevent static electricity discharge and lightning strike initiated sparks. See Sections 4.1.1.1, 4.2.5, 4.3.10, 4.91.	No FG/RMCS activities can proceed until grounding and bonding activities are completed and verified.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/		stated in "Evaluation of Hazards From Lightning Strikes to Tank Farm Facilities", W. L. Cowley, WH-SD-WM-SARR-027, Rev 0 (June 29,1994).			
6.6.3.2 Equipment not attached to tank	Ensure equipment grounding	Resistance measurement Procedural evaluation and verification	Equipment not attached to the riser or inserted into the tank shall be grounded commensurate with Contractor grounding and bonding controls, using independent verification before FG/RMCS activities.	3	Prevent static electricity discharge and lightning strike initiated sparks. See Section 4.1.1.	No FG/RMCS activities can proceed until grounding and bonding activities are completed and verified.
6.6.4 Energized equipment						
6.6.4.1. Energized equipment in the dome	All energized equipment exposed to the tank dome (as defined in approved contractor safety documentation) or dome of connecting tanks shall be rated for operations in Class I, Division 1, Group B environment or Class I, Division 2, Group B environment with automatic shut down for flammable gas concentrations ≥25%LFL.	Procedural evaluation of verification and certification	During waste-intrusive operations, all energized equipment exposed to the tank dome vapor space (as defined in approved contractor safety documentation) or dome vapor space of connecting tanks shall be rated for operations in Class I, Division 1, Group B environment or Class I, Division 2, Group B environment with automatic shut down for flammable gas concentrations ≥25%LFL. All existing energized equipment not meeting the above control shall be de-energized.	1	Prevents ignition sources in proximity with flammable gases. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.0, 4.1.1.3, 4.3.4 and Appendix B.	No FG/RMCS activities can proceed until equipment in the tank dome or dome of connecting tanks complies with control.
6.6.4.2 Energized equipment in open riser exclusion zones	Qualifications of energized equipment in open riser exclusion zones.	Procedural evaluation of verification and certification	During waste-intrusive operations, all energized equipment in open riser exclusion zones as defined in section 6.6.2.2 shall be rated for operations in Class I, Division 1, Group B environment, or rated for Class I, Division 2, Group B environment with automatic shut down for flammable gas concentrations ≥25%LFL. All energized equipment in riser exclusion zones not meeting the above control shall be de-energized.	1	Prevents ignition sources in proximity with flammable gases. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.1.2.1.	No FG/RMCS activities can proceed until equipment in the riser exclusion zones complies with control.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.6.5. Equipment positioning and Setup						
6.6.5.1. Tank loading	Prevent loading exceeding tank structural capabilities.	Procedural evaluation Engineering review for equipment positioning on tank top	Loading on each tank shall comply with IOSR requirements for simultaneous static and dynamic loading for each specific FG/RMCS tank.	1	Limits on tank loading can prevent collapse. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.6.1 and Appendix N.	No equipment positioning or set up can proceed until tank load capabilities are verified.
6.6.5.2. Vehicle operations on tank	Prevent vehicle impacts.	Procedural evaluation	An administrative control shall be developed and implemented for controlling the safe operation of vehicles on top of the tank during waste-intrusive activities.	3	Prevent ignition sources caused by vehicle impacts. See Section 4.1.7.	With procedural noncompliance, corrective actions must be implemented before resuming any FG/RMCS activities.
6.6.5.3. Truck ramp and jacks	Safe use of ramps and hydraulic jacks.	Procedural evaluation	An administrative control shall be developed and implemented for the safe use of the ramp supporting the sampling truck and the truck's hydraulic jacks.	3	Prevent tank riser damage See Section 4.6.1.	With procedural noncompliance, corrective actions must be implemented before resuming any FG/RMCS activities.
6.6.5.4. Truck position	No truck-induced ignition sources near potential gas leak source	Procedural evaluation	An administrative control shall be developed and implemented that, prior to waste-intrusive operations: • prevents positioning the sampling truck over an open riser, and • seals any risers under the truck, and • raises the truck a minimum of 36 inches between any potential ignition source on the truck and the top of any riser or pit over which the truck is positioned.	1	Truck when parked over an unused riser must be protected from flammable gas releases. This requires to control the distance between the leak source and truck. Reduces above tank fire frequencies by mitigating human error and minimizing ignition sources	No FG/RMCS activities can proceed until procedural controls are implemented.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
					within area surrounding leak sources. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.1.2.1.	
6.6.5.5. Lift operations	Prevent sparks induced from equipment lifting over the tank.	Procedural evaluation	An administrative control shall be developed and implemented that, during waste-intrusive activities: • controls safe lifting operations over the tank, and • restricts lift operations over the exhauster during installation, sampling or restart activities.	3	Minimizes potential for above tank fires caused by frictional spark induced by load impacts on tank and exhauster. See Section 4.1.1.4 and 4.1.2.	No lifting of FG/RMCS equipment, during waste-intrusive activities, over the tank can proceed without the procedure. With procedural noncompliance, corrective actions must be implemented before proceeding with any FG/RMCS activities.
6.6.6. Exhauster setup						
6.6.6.1. Exhauster installation	Prior to waste-intrusive activities, ensure accurate exhauster positioning, set-up and maintenance per procedures	Procedural evaluation	An administrative control shall be developed and implemented that, prior to waste-intrusive activities, controls the positioning, setup and maintenance of the exhauster system.	3	Optimum exhauster performance mitigates unfiltered releases. See Section 5.4.2.	No waste-intrusive FG/RMCS activities can proceed without procedure. With procedural noncompliance, corrective actions must be implemented before proceeding with any FG/RMCS activities.
6.6.6.2. Exhauster	Prevent duct-induced	Procedural	An administrative control shall	3	Grounding	No FG/RMCS

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
duct	static ignition sources	evaluation and verification	be developed and implemented that controls the following: • The exhauster duct shall be mounted in compliance with Contractor procedures. • The exhauster duct shall be inspected for leaks after the exhauster is installed, with independent verification.		verification controls sparking caused by static electricity, lightning, etc. Prevents exposure of flammable gas to non-qualified equipment around flexible hose. See Section 4.1.1, 4.1.2.	activities can proceed without procedural compliance.
6.6.6.3. Duct exclusion zone	No unqualified equipment < 18 in. from exhauster duct	Procedural evaluation and verification	An administrative control shall be developed and implemented that locates unqualified equipment greater than 18 in. away from exhauster duct, or provides deflectors for equipment located within 18 in., using independent verification.	3	Prevent undetected hose leak in contact with unqualified equipment resulting in fire. See Section 4.1.2.	No FG/RMCS activities can proceed until exhauster duct exclusion zone is established.
6.6.6.4. Exhauster fan	Prevent ignition source from exhauster fan.	Procedural evaluation	The exhauster fan shall meet the requirements of this SA for operation in flammable gas environment commensurate with Std 99-0401-86, Air Movement and Control Association, and NFPA 91.	3	Prevent a fan-induced ignition source in a potentially flammable environment. See Section 4.1.1.4.	No FG/RMCS activities can proceed until ignition sources are eliminated from the exhauster's potentially flammable environment.
6.6.7. Tank Breather Inlet HEPA Filter						
6.6.7.1. Portable Inlet Stack	Controlled releases from stack during GRE	Procedural evaluation and verification	An administrative control shall be developed and implemented that, prior to waste-intrusive activities, ensures that inlet breather filter effluent (in the event of tank pressurization) is directed vertically to a height of at least 15 ft above ground level.	1	Directing the breather inlet HEPA effluent 15 ft vertically: • allows atmospheric dispersion coefficients to decrease so that toxicological acceptance guidelines at the onsite boundary can be met.	No waste-intrusive FG/RMCS activities can proceed until inlet HEPA effluent is directed 15 ft vertically.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/				• prevents electrically unqualified equipment in proximity with flammable gas. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.1.2.1.	

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.7.INSTALLATION PHASE						
6.7.1.Riser preparation						
6.7.1.1. Gas concentrations while breaching tank containment	Detect flammable gas concentrations	Flammable and toxic gas monitoring procedures	An administrative control shall be developed and implemented for monitoring the riser for flammable and toxic gas concentrations every time before opening a riser.	3	Detects flammable gas concentrations sufficient for deflagration before installing riser equipment. See Section 4.1, 4.2, and 4.3 involving accidents during installation phase.	No FG/RMCS activities can proceed without procedural compliance.
6.7.1.2. Riser exposure	Limit personnel exposure	Radiation monitoring procedures	Direct exposure to open riser shall be limited to values specified by approved Tank Farm Operating Procedures.	3	Minimize personnel direct exposure from open riser conditions. See Section 4.8.8.4.	No FG/RMCS activities can proceed until personnel protection is appropriately ensured.
6.7.1.3. Riser equipment	Prevent tool drops to waste through open riser.	Procedural evaluation	Activities and use of tools around open risers shall be strictly controlled, especially during installation and removal of the riser adapter, frisbee and washer and foot clamp assemblies, in compliance with approved Tank Farm Operating Procedures.	3	Limited open riser time reduces the potential for aerosol, particulate and gas releases. Frequency of gas release accidents considers a 8-hour open riser period. See Section 4.2.3 and 5.4.1.	No FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.7.1.4. Sleeve insertion	Minimize ignition sources from sleeve insertion	Procedural evaluation	An administrative control shall be developed and implemented for installing the riser conductive sleeve. • The sleeve insertion and removal rate shall be limited to ≤ 1 foot/sec.	3	Equipment drops are potentially spark inducing. Control further reduces the likelihood of spark caused by drops. See Sections 4.2.3, 4.2.4, and 4.4.3.	No FG/RMCS activities can proceed until procedural corrective actions are implemented.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.7.1.5. Frisbee installation	Minimize flammable gas leakage from frisbee	Procedural evaluation Visual inspection	An administrative control shall be developed and implemented for inspecting frisbee to verify that: • the frisbee inner diameter is smaller than the drill rod outer diameter, and • the frisbee is in good physical condition before DS insertion.	3	Control minimizes frictional sparking potential between riser and sleeve. See Section 4.1.2.1.	No DS insertion or operations can be initiated unless functional frisbee is in place.
6.7.1.6. Frisbee/DS interface lubrication	Improved contact between frisbee and DS Mitigate frisbee damage.	Procedural evaluation and verification	The frisbee/DS interface shall be lubricated with a waste-compatible, spark-resistant lubricant before DS insertion.	3	Correct frisbee/DS interface reduces gas leak potential during operations. Lubricant eases drill rod insertion and removal, and mitigates seal damage, therefore gas/particulate releases. See Section 4.2.5.	No DS insertion can be initiated unless frisbee is lubricated.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.8. OPERATIONS PHASE						
6.8.1. Drill Bit						
6.8.1.1. Drill bit qualification	Use of qualified FG/RMCS drill bit	Procedural implementation.	Only drill bits qualified by BOM and envelope testing, as specified in Appendix T, shall be used for FG/RMCS sampling operations.	1	FG/RMCS operational parameters, including downforce, RPM, purge flow rate and penetration rate were derived and verified using the drill bit specified in Appendix T. Frictional spark issues were verified for the specified bit based on BOM test results.	FG/RMCS sampling activities can proceed only with a qualified drill bit.
6.8.2. Core Sampler						
6.8.2.1. Core sampler qualification	Use of qualified core sampler	Procedural implementation.	Only core samplers qualified by BOM and envelope testing, as specified in Appendix T, shall be used for FG/RMCS sampling operations.	1	DS fire and frictional spark potential for the core sampler specified in Appendix T are negated by BOM test results.	FG/RMCS sampling activities can proceed only with a qualified core sampler.
6.8.2.2. Leakage	Reduce contamination from sampler leakage	Procedural evaluation Visual inspection	An administrative control shall be developed and implemented for: • visually inspecting the sampler for leakage during retrieval, and • properly handling a leaking sampler.	3	Leaking samplers result in equipment contamination, and the potential for gas generation and accumulation in uncontrolled spaces. See Section 4.1.2.2 and 4.1.3.	No FG/RMCS activities can proceed until leakage is contained.
6.8.3. Drill string						
6.8.3.1. Drill bit, core barrel and drill rods	Baselined performance of rotary drilling equipment	Procedural evaluation QA/QC over	The FG/RMCS drill bit, core barrel and drill rods shall be of the configuration and material	1	Results from envelope testing and ignition testing	No waste-intrusive FG/RMCS activities can

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/	selection and use of materials	tested by the Bureau of Mines and performance evaluated in this SA.		are only valid for equipment of the design tested. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.4.4.	proceed until incorrect drilling equipment is replaced or tested and evaluated for performance.
6.8.3.2 DS open to atmosphere	Detect flammable gas accumulation.	Flammable gas meter Procedural evaluation	An administrative control shall be developed and implemented for: • sniffing the contained DS before the quill rod is disconnected, and • isolating the DS immediately (maximum of 60 minutes) after the drill string is disconnected from the quill rod. • Sniffing the DS before breaking containment if left isolated for > 60 minutes.	3	Sniffing detects gas accumulation in the DS and reduces potential for a fire. Immediate change-out assembly installation mitigates flammable gas interactions. See Section 4.1.2.2 and 4.3.3.	No sample retrieval operations can proceed without DS sniffing commensurate with control.
6.8.3.3 Gas accumulation	Purge drill string	Procedural evaluation	An administrative control shall be developed and implemented for sniffing and purging the DS sufficiently to evacuate flammable gas accumulations before FG/RMCS activities if: • sampler is left in DS without nitrogen flow or hydrostatic pressure for $\geq$ 60 minutes; or • DS hydrostatic head is lost with no sampler in place.	3	Purging eliminates gas accumulation in the DS and reduces potential for a fire. See Section 4.3.1.	No FG/RMCS waste-intrusive activities can proceed until requisite purging activities have been completed.
6.8.3.4 Waste flooding	Minimize flooded waste in DS.	SR visual inspection of sampler or loss of hydrostatic head during change-out activities	The DS shall be flushed and purged with indications of waste flooding in the DS, based on approved Tank Farm Plant Operating Procedures, to the extent practicable.	3	Waste flooding in the DS can result in gas generation and accumulation. See Section 4.1.4.	No waste-intrusive FG/RMCS activities can proceed until control is implemented, and the source of flooding is verified.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.8.4 Shielded Receiver						
6.8.4.1. Sampler retrieval	Ensure sampler completely in SR	Visual inspection of sampler	An administrative control shall be developed and implemented for verifying that the sampler is completely within the SR when held by the RLU before disconnecting the SR from the DS, the X-ray or the cask.	3	Prevents spills and waste discharges from samplers, which mitigates unanticipated waste releases to the environment. See Sections 4.1.4 and 4.8.4.	If sampler is not completely in SR, no FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.4.2. Waste accumulation	Detect waste accumulation >100 mrem/hr.	Radiological monitoring procedures	The external SR contact dose rate shall not exceed 100 mrem/hr, without sampler in SR.	3	Monitoring reduces potential personnel exposure and excessive waste accumulation in the SR which can generate gas concentrations sufficient for ignition. See Section 4.1.2.2 and Appendix R.	No FG/RMCS activities can proceed until waste accumulation levels are decreased below the specified limit.
6.8.4.3. Waste contamination	Minimize waste-generated gas accumulation	Procedural evaluation	An administrative control shall be developed and implemented for decontaminating the SR if it becomes contaminated with waste levels > 100 mrem/hr.	3	Decontaminating the SR mitigates the effects of waste-generated gas accumulation, and reduces personnel exposure. See Section 4.1.2.2.	No FG/RMCS activities can proceed without procedural compliance for SR decontamination.
6.8.5 RLU/Grapple						
6.8.5.1. Travel rate	Travel rate< 1 ft/s	Sampling truck instrumentation Procedural evaluation	The travel rate for the grapple and the RLU shall not exceed 1 foot/sec.	3	Controlled travel rate mitigates potential for frictional sparking. See Section 4.3.2 and 4.3.6.	With excessive travel rates, no FG/RMCS activities can proceed until procedural corrective actions are implemented.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.8.5.2 Grapple Load	Grapple load ≤ 250 lb	Sampling truck instrumentation Load Cell	The electrical motor driving the grapple hoist shall automatically shutdown when the load reading is >250 lb. The grapple hoist cable shall be inspected once every 6 months. The grapple hoist load cell shall be calibrated once every 6 months.	1	Controlled loads prevent grapple drop consequences and potential for fire. See Sections 4.3.2 and 4.3.6.	No FG/RMCS activities can proceed until procedure is implemented.
6.8.6 X-ray						
6.8.6.1. Sampler insertion	Minimize waste accumulation in X-ray	Visual inspection Procedural evaluation	An administrative control shall be developed and implemented preventing a known leaking sampler, or sampler contaminated in excess of Contractor controls, to be placed into the mobile X-ray system.	3	Mitigates waste-generated gas accumulation. See Section 4.1.2.2	No FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.6.2. X-ray sample liner	Minimize waste or flammable gas entering X-ray	Procedural evaluation	A redundant barrier shall protect the X-ray system from flammable gas penetrating into the system, and from sampler contamination.	3	Prevents flammable gas in proximity with X-ray ignition source. See Section 4.1.3.	No FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.7. Exhauster						
6.8.7.1. Duct inspections	Prevent duct leaks and static-induced sparking.	Procedural evaluation Visual inspection	The exhauster duct shall be visually inspected for leaks and adequately supported for environmental loads before FG/RMCS operations, and after any situation the operators believe the duct may have been damaged.	3	Inspecting verifies hose functional capabilities. Reduces likelihood of above ground fire that could propagate into the dome. See Section 4.1.2.	No FG/RMCS activities can proceed until duct has been inspected.
6.8.7.2. Operations	Operate exhauster 1 hr before purge established, during rotary drilling, and 16 hours following purge termination.	Procedural evaluation	An administrative control shall be developed and implemented that mandates that the exhauster be fully operational: • 1 hour before the nitrogen purge flow to the DS is established at 30 scfm, and the flammable gas concentration < 1000 ppm	1	Flammable gas concentrations are mixed, dispersed and reduced with exhauster preparation. Accumulation of aerosols, particulates and flammable gases	No DS nitrogen purging or waste-intrusive activities can proceed unless the exhauster is operational. With noncompliance to procedures, no FG/RMCS

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/		• during all rotary drilling operations • cumulative 16 hours following termination of nitrogen purge flow to the DS. When rotary drilling operations are resumed within any 16 hour waiting period, a new 16 hour period will be initiated following termination of DS nitrogen purge flow of 30 scfm. The PIC shall be authorized to prematurely terminate exhauster operation for external events that threaten personnel or equipment.		following waste intrusive activities must be minimized. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Sections 4.1.1 and 5.4.2.	activities can proceed until procedural corrective actions are implemented.
6.8.7.3. Riser aerosols	Mitigate aerosol, particulates and gas releases	Radiation monitoring procedures	An administrative control shall be developed and implemented that: • prevents opening a riser within 4 hour following termination of rotary drilling, and • limits the riser open period to less than 8 hours per activity.	2	Limited open riser time reduces the potential for aerosol, particulate and gas releases. See Section 5.4.1.	For periods greater than 8 hours, no FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.7.4. Exhauster-induced tank pressure	Tank pressure • <atmospheric pressure, and • ≥ -3 in. w.g.	Procedural evaluation	Exhauster operation shall not draw a tank pressure less than value specified in approved IOSR.	1	Mitigate excessive tank negative pressure, potential for dome collapse. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.6.1.	No FG/RMCS activities can proceed until tank pressures are in the specified limits.
6.8.7.5. HEPA radiological monitoring	HEPA filter housing loading < 100 mrem/hr contact dose rate on filter housing	Radiological monitoring procedures	An administrative control shall be developed and implemented for manually monitoring the HEPA filter housing loading daily during operations for radioactivity.	3	Control prevents accumulation of radioactive waste particulate on HEPA filters reduces the likelihood of	If the radiological levels are exceeded, then no waste-intrusive FG/RMCS activities can proceed until the

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/		• HEPA filter housing radiological loading shall be limited to < 100 mrem/hr contact dose rate.		unfiltered releases. See Section 4.8.8.1 and Appendix R.	HEPA filters are changed.
6.8.7.6. Operational-induced exhauster shut down	Exhauster flow during operation • <250 scfm, and • >150 scfm	Exhauster detection system	The exhauster shall automatically shutdown and send a shutdown signal to the truck PLC: • immediately with > 5.9 inches of water differential pressure across the HEPA filter bank, or • after 5 minutes for ≥250 scfm high flow, or • immediately with ≤150 scfm low flow. An administrative control shall be developed and implemented for timely exhauster restart: following an operational shut down.	3	Exhauster operation in out-of-tolerance condition can impair overall exhauster performance and could result in unfiltered radioactive waste releases, toxic gas release, exposure of radioactive waste to workers. To prevent tank overpressurization due to purge gas. To prevent unacceptable vacuum in the dome To provide acceptable emission of radioactive waste particulates.	Upon detection, the exhauster will shut down within 5 min. when flow exceeds 250 scfm. If drilling, the drill rig engine will automatically trip. No FG/RMCS activities can proceed until the cause of shut down is identified and corrected.
6.8.8 DS Nitrogen purge system						
6.8.8.1. Bypass leakage verification	Ensure sufficient nitrogen purge flow during rotary drilling	Procedural evaluation and verification	The nitrogen purge system for the DS shall be tested for bypass leakage every 6 months, with independent verification and indication of failures. System leak rates must be within the uncertainty range of the instrumentation system, or less than 2% of the required flow.	1	Bypass leakage testing ensures that the purge flow is adequately provided to drill bit for cooling during drilling. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.4.1.	No nitrogen purge flow activities can proceed unless testing has been completed, and flow levels increased as appropriate.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.8.9. Riser/sleeve Purge Flow						
6.8.9.1. Bypass leakage verification	Ensure adequate purge in sleeve to DS annulus	Procedural evaluation	The nitrogen purge system for the sleeve to DS annulus shall be tested for bypass leakage every 6 months, with independent verification and indication of failures.	3	Bypass leakage testing ascertains nitrogen flow in annulus. See Section 4.2.4.	No nitrogen purge flow activities can proceed unless testing has been completed, and flow levels increased as appropriate.
6.8.10. Hydrostatic Head						
6.8.10.1. Bypass leakage verification	Mitigate waste flooding	Procedural evaluation and verification	The hydrostatic head systems for the DS and the SR will be tested for bypass leakage every 6 months, with independent verification and indication of failures. System leak rates must be within the uncertainty range of the instrumentation system, or less than 2% of the required flow.	3	Ensure hydrostatic head capabilities before sample retrieval. Prevents inadvertent waste and flammable gas accumulation in the drill string during retrieval of core samplers. See Section 4.3.1.	No hydrostatic head activities can proceed unless testing has been completed.
6.8.11. Instrumentation and controls						
6.8.11.1. Truck I&C	Ensure accurate I&C measurements	Procedural evaluation and verification	All truck shutdown indication system elements shall be calibrated every 6 months with independent verification and tested with indication of all failures. This control does not include the sensors in the flammable gas detection system.	1	Periodic calibration ensures accuracy. Control provides assurances for critical measurements, proving protections for waste, dome ,drill string fires, to be adequate during RMCS operations. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.0.	With noncompliance, no FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.11.2 Exhauster I&C	Ensure accurate I&C measurements	Procedural evaluation and	All exhauster shutdown indication system elements shall	3	Periodic calibration ensures accuracy.	With noncompliance, no

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/	verification	be calibrated every 6 months with independent verification and tested with indication of all failures. This control does not include the sensors in the flammable gas detection system.		Control provides assurances for critical measurements, proving protections for waste, dome ,drill string fires, to be adequate during RMCS operations. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Section 4.0.	FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.12 Rotary Drilling Operations						
6.8.12.1. Installation and removal of drill rod, spray washer and change-out assembly	Restrict ignition sources around open risers	Procedural evaluation	Activities and use of tools around open risers shall be strictly controlled during installation and removal of the drill rod, spray washer and change-out assembly.	3	Limits potential for inducing spark in flammable environment. See Section 4.3.3.	With noncompliance, no FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.12.2. Last sampler	Terminate drill 3 in. From bottom	Procedural evaluation	Based on evaluation of the depth to the tank bottom, drill string length shall be calculated to terminate drilling $\geq$ 3 inches above the tank bottom.	3	Reduces the likelihood of the bottom liner penetration. See Section 4.6.2. Appendix N	With noncompliance, no FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.13 Rotary Drilling Operational Parameters						
6.8.13.1. Down force	DS down force $\leq$ 750 lbf	Force detector and walkdown function used for all samples except the last The force detector and the hydraulic bottom detector used for the last sample	The drill string shall not be operated with a down force > 750 lbf. • The drill rig engine shall automatically shut down with down force > 750 lbf. • Automatic shutdown signal is assumed to occur within 2 seconds for out-of-tolerance	1	Drill bit overheating and waste ignition is prevented, while factoring the potential effects of DS failure. Control prevents a local exothermic chemical reactions	With noncompliance, the DS will shut down. Nitrogen purge and exhauster systems will remain operational within specified limits. No FG/RMCS

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/	Procedural evaluation and verification	conditions. • The force detector shall be used for all samples, automatically armed. The walkdown function used for all samples except the last, shall be enabled using independent verification. The hydraulic bottom detector used for the last sample, shall be enabled using independent verification.		as well as an ignition of flammable gas in the waste, consequently a possible dome collapse due to frictional sparks. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Sections 4.4.1, 4.4.4, and 4.6.3.	activities can proceed until procedural corrective actions are implemented.
6.8.13.2. Down Force with DS length > 45 ft.	DS down force ≤ 650 lbf	Walkdown function used for all samples except the last The hydraulic bottom detector used for the last sample Procedural evaluation and verification	An administrative control shall be developed and implemented that manually maintains the down force < 650 lbf with DS length >45 ft.	3	Prevent drill string failure. See Section 4.2.1.	With noncompliance, the DS will be manually shut down. Nitrogen purge and exhauster systems will remain operational within specified limits. No FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.13.3. RPM	DS rotational speed ≤ 55 rpm	RPM detection system Procedural evaluation One out of two redundant logic	The drill string shall not be operated with rotational speed > 55 rpm. • The drill rig engine shall automatically shut down with DS rotational speed > 55 rpm. • Automatic shutdown signal is assumed to occur within 2 seconds for out-of-tolerance conditions.	1	Drill bit overheating and waste ignition is prevented, while factoring the potential effects of DS failure. Control prevents local exothermic chemical reactions as well as an ignition of flammable gas in	With noncompliance, the DS will shut down. Nitrogen purge and exhauster systems will remain operational within specified limits. No FG/RMCS activities can proceed until procedural

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/				the waste, consequently a possible dome collapse due to frictional sparks. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Sections 4.4.1., 4.4.4, and 4.6.3	corrective actions are implemented.
6.8.13.4. RPM with DS length > 45 ft	DS rotational speed ≤ 40 rpm	RPM detection system Procedural evaluation	An administrative control shall be developed and implemented that manually maintains the rotational speed < 40 rpm with DS length >45 ft.	3	Prevent drill string failure. See Section 4.2.1.	With noncompliance, the DS will be manually shut down. Nitrogen purge and exhauster systems will remain operational within specified limits. No FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.13.5. Nitrogen purge flow	DS nitrogen purge ≥ 30 scfm	Purge flow detection system Procedural evaluation	The DS shall be purged with nitrogen at ≥ 30 scfm. • The drill rig engine shall automatically shut down with nitrogen flow less than 30 scfm, using two out of three redundant logic. • Automatic shutdown signal is assumed to occur within 2 seconds for out-of-tolerance conditions. • Nitrogen purge gas temperature entering the tank shall be > 10°F and < 140°F.	1	Drill bit overheating and waste ignition is prevented. Control prevents a local exothermic chemical reactions as well as an ignition of flammable gas in the waste, consequently a possible dome collapse due to frictional sparks. This mitigates	With noncompliance, the DS will shut down. Nitrogen purge and exhauster systems will remain operational within specified limits. No FG/RMCS activities can proceed until procedural corrective actions are implemented.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/				unacceptable offsite consequences resulting from a dome collapse. See Sections 4.4.1 and 4.4.4.	
6.8.13.6. Riser/sleeve purge operations	Sleeve to DS annulus purge ≥ 2 scfm	Designated measurement system Procedural evaluation and verification	The sleeve to DS annulus shall be purged with nitrogen at ≥ 2 scfm during rotary drilling operations. • Nitrogen flow in the sleeve to DS annulus shall be verified before rotary drilling operations, using independent verification. • Nitrogen purge ≤ 40 psid shall be alarmed and will automatically shut down the drill rig with one out of two redundant logic.	3	Prevents accumulation of flammable gas in the riser and consequently a dome fire caused by the frictional spark between the rotating drill string and sleeve. See Section 4.2.4.	No FG/RMCS activities can proceed until nitrogen purge flows are adequately established.
6.8.13.7. Slow penetration rate	Prevent extended waste heatup and ignition	Penetration detection system Procedural evaluation 1 out of 1 control logic with operator backup.	The DS shall not be operated with a penetration rate < 0.75 in./min for ≥ 60 seconds. • The DS shall automatically trip when the penetration rate is <0.75 in./min. for a cumulative time of 60 seconds in any 3 min. period. The drill bit shall be replaced if drilling is shutdown four times consecutively as a result of low penetration rate, and if the cumulative penetration is <0.3 in. for the last three attempts.	1	Waste burn induced by slow penetration is negated. Control prevents a local exothermic chemical reactions as well as an ignition of flammable gas in the waste, consequently a possible dome collapse due to frictional sparks. Control also prevents drilling against materials not covered by envelope testing. Prevents the ignition of flammable gas due to hot spots	With noncompliance, no FG/RMCS activities can proceed until procedural corrective actions are implemented.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/				(exceeding autoignition temperature). Provides protection against severe drill bit tooth wear and protects the Carbon Steel Blank from exposure to metals. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Sections 4.4.1 and 4.4.4.	
6.8.14.Shut down and Restart Conditions						
6.8.14.1. Drill Rig shut down	Prevent drill bit overheating	Alarmed setpoints	The drill rig shall automatically shut down with out-of-tolerance values for down force, RPM, nitrogen purge or penetration rate, operational exhauster shutdown, or upon detection of a GRE. A minimum 10-minute wait period shall be imposed following automatic drill rig shut down before any waste-intrusive activities can be resumed.	1	Wait period allows cool down of drill bit and localized waste temperatures due to out-of-tolerance down force, RPM or purge flow values. Control ensures that the initial local waste temperature is in thermal equilibrium with the tank waste and provides assurances for drill bit/waste temperature not to be exceed above allowable limits. This mitigates unacceptable offsite consequences resulting from a dome collapse.	No FG/RMCS activities can proceed until wait period is satisfied.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
					See Section 4.4.1.	
6.8.14.2. GRE shut down	Protect personnel	Alarmed setpoints	A GRE is defined to occur when: • > 5000 ppm hydrogen concentration equivalent, or • > 100 ppm/s rate of equivalent hydrogen concentration increase over a 10-s period, or • > 2 in. w.g. increase in a 5 minute period above the tank background pressure. Upon detection of a GRE, the exhauster will continue to operate, and drill rig operation will be terminated	1	Automatic shut down during GRE prevents exposure to flammable gas concentrations sufficient for ignition. Reduces the possible spark sources in the dome, waste and around drill string. Provides protection for toxic gas exposures. This mitigates unacceptable offsite consequences resulting from a dome collapse. See Appendix B.	All personnel within a 100-m radius from the edge of the tank will evacuate and don protective equipment before returning for further equipment stabilization.
6.8.14.3. GRE restart	Minimize unanticipated ignition sources following GRE.	Procedural evaluation and verification	An administrative control shall be developed and implemented for restart following GRE.	3	Flammable gas removal following a GRE is enhanced by exhauster operation and the use of pressure measurement systems qualified to operate in a Class I, Division 1, Group B environment. Appendix B.	FG/RMCS activities cannot resume until restart requirements are implemented and flammable gas concentration limits are met.
6.8.14.4. Power loss restart	Prevent unanticipated ignition sources following power loss.	Procedural evaluation	An administrative control shall be developed and implemented for restart following power loss to include: • The DS shall be sniffed and purged following shut down caused by power loss,	3	Loss of hydrostatic flow from a power loss can allow waste flooding and gas release into DS and SR. See Section 4.1.4.	FG/RMCS activities cannot proceed until restart requirements are implemented.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
	/		sufficiently to evacuate flammable gas accumulations. • Hydrostatic head shall be reestablished. • The exhauster shall be restarted following a power loss event.			
6.8.15. Water addition						
6.8.15.1. Quantity	Minimize water addition	Procedural evaluation	Per activity, water addition shall be limited to < 250 gallons in compliance with approved Tank Farm Operating Procedures. Increased water addition quantities shall require PRC approval.	3	Contractor control See Section 4.5.2 and Appendix O.	No FG/RMCS activities can proceed until procedural corrective actions are implemented.
6.8.15.2. Temperature	P... ent unanticipated temperature-induced, waste-related chemical reactions	Temperature measurement	The temperature of added water shall be limited to < 200°F in compliance with approved Tank Farm Operating Procedures.	3	Contractor control See Section 4.5.2 and Appendix O.	No FG/RMCS activities can proceed until water temperature is within specified limits.

System or Condition	SCO	Surveillance/ Monitoring	Administrative Controls	Level	Basis for Control	Safe Shut Down Condition
6.9. REMOVAL PHASE						
6.9.1. DS Removal						
6.9.1.1. DS removal	Reduce gas production and ALARA personnel exposures	Procedural evaluation	DS shall be removed to above the waste surface level only with the last sampler, a dummy sampler or water in place, in compliance with approved Tank Farm Plant Operating Procedures	3	Minimize gas release potential. See Section 4.1.2.1.	Removal and decontamination activities cannot proceed until procedural control is implemented.
6.9.2. Decontamination						
6.9.2.1. Decontamination system	Complete DS decontamination	Procedural evaluation	Decontamination systems shall be verified operational before DS removal in compliance with approved Contractor procedures.	3	Verification ensure decontamination capabilities. See Section 5.4.2.	No decontamination activities can proceed until system operability is verified.
6.9.2.2. Riser exposure	Minimize radioactive releases	Radiation monitoring procedures	• Personnel direct exposure from open riser shall be limited to values specified by approved Tank Farm Operating Procedures. • Riser open period shall not exceed 8 cumulative hours per activity.	3	Minimize personnel direct exposure from open riser conditions. See Section 4.8.8.4, 4.8.8.5 and 5.41.	No FG/RMCS activities can proceed until personnel protection is appropriately ensured.
6.9.2.3. Drill rod removal	Minimize radioactive releases	Radiological monitoring procedures Procedural evaluation and verification	Drill rods shall be monitored and controlled as they are removed commensurate with approved Tank Farm Plant Operating Procedures.	3	Limit unfiltered, uncontained releases to environment, as required by Contractor controls. See Section 4.8.5, 4.8.6, 4.8.7 and 5.4.2.	With noncompliance, no decontamination activities can proceed until procedural corrective measures are implemented.

6. REFERENCES

1. "Tank Farm Health and Safety Plan," Westinghouse Hanford Company report WHC-SD-WM-HSP-002, Rev. 0A (September 28, 1993).

2. "Safety Assessment for Push- and Rotary-Mode Core Sampling in Ferrocyanide Tanks," Westinghouse Hanford Company report WHC-SD-WM-SAD-013, Rev 3-A (November, 1993).

3. "Safety Analysis for the Push Mode and Rotary Mode Core Sampling," Westinghouse Hanford Company report WHC-SD-WM-SARR-031, Rev. 2 (July, 1995).

4. J. E. Corbett, "Rotary-mode Core Sampling Safety Equipment List, WHC-SD-WM-SEL-032, Rev. 0 (February 16, 1994).

5. J. E. Corbett, "Rotary-mode Core Sampling Safety Equipment List, WHC-SD-WM-SEL-032, Rev. 0 (February 16, 1994).

6. R. L. Koontz, "Hazards Identification and Evaluation for Waste Tank Core-Sampling Equipment," Westinghouse Hanford Company Report, SD-WM-SAR-007, (June 1985).

7. "Rotary Mode Core Sample Truck Material and Component Compatibility with Tank Waste," Westinghouse Hanford Company Internal Memo 75230-96-001 R2 (February 5, 1996).

8. L. H. Sullivan et al., "A Safety Assessment for Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-101-SY: Hanford Site, Richland, Washington," Los Alamos National Laboratory report LA-UR-92-3196 (October, 1992).

7.0. CHECKLIST ITEMS

This safety assessment (SA) assessed safety aspects of the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations.

This SA was developed using bounding assumptions. However, these assumptions are not verified against each one of the existing or potential flammable gas tanks (see Section 1 of this SA). The following assumptions must be verified before this SA can be used for RMCS operations in any FGT.

CHECKLIST ITEMS

TANK SPECIFIC HAZARDS/OTHER WATCHLISTS
If a given tank has a specific hazard or accident initiator that is not analyzed in Sections 3 and 4 of this SA, the analysis must be supplemented to cover the tank specific conditions. For instance, this SA does not address ferrocyniade issues even though some of the FGTs may also be on the ferrocyianite watchlist. This checklist item is especially important for tanks that are on multiple watchlists (in addition to flammable gas watchlist).
FLAMMABLE GAS COMPOSITION
This SA assumes that 25% of the LFL is greater than 5000 ppm hydrogen based on the analysis provided in Appendix C. The only flammable gas species considered are hydrogen and ammonia with small amounts of methane. If new information (information that is not cited in Appendix C) reveals that, for a given tank, there are other flammable gas species and/or the assumed value of the LFL is not conservative, the analysis in Appendix C must be revised to incorporate the new data.

CHECKLIST ITEMS (cont)

TOXIC GAS COMPOSITION
For toxic effects, the gas composition in a given GRE is assumed to be 60% ammonia or 75% nitrous oxide. If any evidence before the FG/RMCS operation exists to indicate that these values (especially the ammonia fraction) may be exceeded in one of the SSTs as a result of new analysis or data, or if they are not conservative, the consequence analysis must be re-evaluated. This can be achieved by simply scaling the new data with the 60% fraction used in the consequence analysis. The consequence analysis is the linear function of gas composition; thus, simple multiplication would be used to consider different gas concentrations. Also, the results of vapor space sampling program were reviewed. Major toxic gases that are found in the dome space of the presently defined flammable-gas tanks are ammonia and nitrous oxide. Other gases are found in trace quantities and do not pose a concern. However, it was recognized that the existing data are limited and all tanks of interest are not covered. Thus, if new data reveal that toxic gases in excess of the hazardous limits are detected in a given tank, the consequence analysis must be reevaluated. The reevaluation may be done by simply scaling the toxic gas fraction and the guidelines against the ammonia fraction and the associated RGs.
WASTE TEMPERATURE
The best available tank temperature data must show that the peak waste temperature (considering uncertainties) must be less than 90°C. If the peak waste temperature is ≥ 90° C, the envelope testing results discussed in Appendix F must be re-evaluated.
WASTE ENERGETICS
Table G-3 of Appendix G lists the frequency of waste fire accidents for the 100-series SSTs. The analysis given in Appendix G is based on waste composition data through December 1995. New data taken after December 1995 or revisions to the old database may alter the results of the analysis given in Appendix G. Therefore, in using new or revised data, it first must be verified that the conclusions of the analysis in Appendix G are not changed.

CHECKLIST ITEMS (cont)

LIKELIHOOD OF GAS RELEASE EVENTS

The GRE probability includes statistical distributions for gas-release amounts and rates that are based on limited data and expert judgment. If additional data or analyses exist for a specific tank to indicate that the GRE probabilities used in this SA are not conservative, the accident frequencies need to be re-evaluated for that tank.

In general, before the FG/RMCS operation starts on a given tank, the best available tank specific data for gas inventory and gas release evidence must be evaluated to confirm that the statistical model for gas-release amounts and rates used in the SA are still conservative. In general, if one or more of the following conditions are observed for a given tank, the GRE probability model given in Appendix L must be re-evaluated.

- Periodic level drops and level swells in excess of ± 3 in.
- Level drop ≥ 3 in. during or after an intrusive event
- Dome concentration measurements ≥ 25% of the LFL before, during or after a waste intrusive event.
- A well defined nonconvective layer (parabolic temperature profile) below a supernate or convective layer (flat temperature profile) that would be indicative of potential rollovers.
- Retained gas inventory estimates (via level swell, fill history, etc) is greater than 20% of the available dome space volume.

If the reevaluation indicates that the existing GRE model given in Appendix L is not conservative for a given tank, a revision to the SA will be necessary.

APPENDIX A

HAZARD IDENTIFICATION

This appendix describes the process used to identify and qualitatively assess the potential operational events, external events, and natural phenomena that can cause the release of hazardous material during the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations. This process, called hazard identification, is equivalent to the hazard analysis (HA) or hazard evaluation process in a safety analysis (SA) report. The final product of this hazard identification process is a list of Design Basis Accidents that will be examined in more detail in the Accident Analysis section of the SA.

The guidance used to perform the hazard identification (or HA) is DOE-STD-3009).[1] DOE-STD-3009 provides the following guidance on the requirements for a complete hazards analysis.

A complete hazards analysis should include the following requirements (STD-3009, pg. 31);

1. Consider the complete spectrum of accidents that may occur as a result of facility operations;

2. Analyze potential consequences to the public and worker;

3. Estimate the likelihood of occurrence;

4. Identify and assess associated preventive and mitigative features;

5. Identify safety-significant structures, systems, and components; and

6. Identify a select subset of accidents to be formally defined in accident analysis.

In the hazard identification (hazard analysis) performed for FG/RMCS drilling, four of the six requirements above were met in full, namely, (1) a complete consideration of the spectrum of accidents; (2) analysis of the potential consequences; (3) estimation of likelihood; and (6) identification of a select subset of accidents for accident analysis (the end product for this hazard identification).

However, two of the requirements; (4) the identification of preventive and mitigative features; and (5) identification of safety-significant structures, systems and components, were only partially met. For the FG/RMCS activity, hardware design and procedures were being developed during the hazard identification (hazard analysis) process. Therefore, at that time, preventive and mitigative procedures were not fully identified. By not identifying the preventive and mitigative features, the identification of safety-significant structures, systems, and components could not be performed. However, identification of preventive and mitigative systems is performed in the design change/control implementation section of the SA (Section 6).

A safety equipment list will be developed prior to the beginning of FG/RMCS operations.

The hazard identification performed for rotary-core mode drilling is presented in Sections A.1 through A.4. Section A.1 describes the role of hazard identification in the SA process and the methods chosen to perform hazard identification. Section A.2 briefly describes the FG/RMCS activity and presents the organization of the process for analysis. Section A.3 presents the results of the hazard identification and the list of design basis accidents (DBAs). Finally, Section A.4 presents accident progression results that were derived as an extension of the hazard identification process.

A.1. ROLE OF HAZARD IDENTIFICATION AND METHODS

The hazard identification process is one step in the overall safety analysis for rotary-core drilling. The role that hazard identification plays in safety analysis is discussed in Section A.1.1. The methods chosen to perform hazard identification are briefly described in Section A.1.2.

A.1.1. Role Of Hazard Identification In Safety Analysis Process

Hazard identification is the first step in the SA process. The goals of hazard identification for this SA are a subset of the HA requirements presented earlier, namely:

- Consideration of the complete spectrum of potential accidents;
- Qualitatively assess the consequences to the worker and the public;
- Qualitatively estimate the frequency (or likelihood) of occurrence;
- Identification of a select set of representative and unique accidents (DBAs) for further evaluation.

The main focus of the hazard identification process is on the completeness of the spectrum of accidents, and assigning a qualitative measure of consequence and frequency. An attempt is made to be exhaustive in identifying all possible initiators that can lead to adverse consequences in the process. By attempting to assess all initiators, a basis for examining some select accidents in more detail can be made (i.e., justification is provided for why some accidents are looked at and others are not).

The representative and unique accidents (or DBAs) identified in the hazard identification process will be examined in more detail in the Accident Analysis portion of the SA. A part of this analysis is a more in-depth examination of the preventive and mitigative features. The final product of the SA will be a validation of the controls/design used in rotary-core drilling (presented in Chapter 6).

The hazard identification process is not an attempt to define what is acceptable risk or provide a quantified assessment of consequence or frequency. For this reason, the measure of risk used in the hazard identification process is a "relative" measure of risk used only for accident selection.

A.1.2. The Hazard-Identification Methodology

The FG/RMCS hazard identification process was performed by a multi-disciplinary team consisting of Los Alamos and Westinghouse personnel, using a combination of two standard techniques, the hazards and operability (HAZOP) technique and "what if"/checklist techniques. We will not elaborate on details of these techniques; they are described in detail in *Hazard Evaluation Procedures*, published by the American Institute of Chemical Engineers (AIChE).[2] These techniques produce tabulated data that identify the following for each accident.

- Hazard - "A source of danger (i.e., material, energy source, or operation) with the potential to cause illness, injury, or death to personnel or damage to an operation or to the environment." (Ref. 1) A hazard is not the accident initiator, cause or deviation. Rather, it is a property, typically radiological or toxicological, inherent to the danger.

- Cause/Deviation–A description of the initiating event and accident progression.

- Preventive/Mitigative Features–A description of the controls or components that could either prevent the accident or mitigate its consequences.

- Frequency Estimate–Accident frequency assignment to a bin (frequency range). Other than for seismic accidents, each frequency assignment is for a single tank assuming 2 drilling activities per year for a complete core sample.

- Consequence Estimate–An assignment to an accident consequence bin.

- Measure of relative risk–A risk index used for accident selection.

- Recommendations–Generic information that indicates what further analysis is needed.

Standard occupational hazards covered by Occupational Safety and Health Administration (OSHA) regulations are not included in this HA.

The RMCS system is an operation utilizing mobile equipment. The guidelines and criteria defined in DOE Std. 3009 were used in this hazards assessment, but are considered conservative because FG/RMCS operations are not considered a "facility" as defined in the standard, and do not have the operational lifetime of a facility.

Following accident frequency and consequence assignment, each value is assigned to bins as defined in Tables A-1 and A-2, respectively.

TABLE A-1
LIKELIHOOD CLASSIFICATION TABLE

Classification	Relative Likelihood	Description
I (> 10^{-2}/yr)	Anticipated	Incidents that may occur several times during the lifetime of the facility, e.g., incidents that commonly occur.
II (10^{-2} to 10^{-4}/yr)	Unlikely	Accidents that are not anticipated to occur during the lifetime of the facility, frequency between once in 100 years and once in 10,000 operating years.
III (10^{-4} to 10^{-6}/yr)	Extremely Unlikely	Accidents that will probably not occur during the life cycle of the facility. Frequency between once in 10,000 years and once in a million years.
IV (< 10^{-6}/yr)	Beyond Extremely Unlikely	All other accidents. Frequency of less than once in a million years.

TABLE A-2
CONSEQUENCE SEVERITY TABLE

	Public	On-Site Worker	Facility Worker	Environment
High (A)	Off-site EGs[a] exceeded • > 25 rem off-site • > ERPG-2/h	• > 100 rem • > ERPG[b]-3/h	Prompt fatality • 250 rem • > ERPG-3/h	Significant off-site contamination
Mod (B)	Challenge to Off-site EGs • 1- 25 rem • > ERPG-1/h	• 10-100 rem • > ERPG-2/1h	Serious injury • 100-250 rem • >ERPG-2/h	Significant on-site contamination
Low (C)	Minor challenge to off-site EGs • 0.1- 1.0 rem • < ERPG-1/h	• 1-10 rem • > ERPG-1/h	Minor injury • 1-100 rem • > ERPG-1/h	Significant facility contamination
No Impact (D)	Less than low	Less than low	Less than low	Less than low

NOTE: ERPG values are defined over a one hour period

[a] EG = Evaluation Guideline

[b] ERPG = Emergency Response Planning Guidelines

After frequency and consequence bins are assigned, a relative measure of risk is determined for each accident scenario. This measure of risk is based on the risk ranking table presented in TABLE A-3. This table, used for accident selection only, is not used to identify high or unacceptable levels of risk.

TABLE A-3
RISK-RANKING MATRIX

	Likelihood			
Consequence	**I**	**II**	**III**	**IV**
A	1	1	2	3
B	1	2	3	4
C	2	3	4	4
D	3	4	4	4

Rank	**Accident Disposition**
1	Major candidate for selection
2	Serious candidate for selection
3	Marginal candidate for selection
4	Not a candidate for selection

A.2. PROCESS FLOW SHEETS

The GF/RMCS is described in detail in Section 2 of the main report. During the hazard identification process the following activities were examined

- Startup of operations,
- Rotary-core drilling mode,
- Bump-drilling mode,
- Change of mode between push and rotary mode, and
- Shutdown of operations.

A simplified flow sheet showing an understanding of the tasks involved in the FG/RMCS activities at the time the hazards identification was initiated is presented in Fig. A-1. Subsequent changes in the FG/RMCS process were evaluated and included in the accident analysis, but are not reflected in Fig A-1. For example, evaluation of hazards determined that the consequences of bump drilling mode were unacceptable. Therefore, bump drilling mode was eliminated from the operation. All changes were evaluated in the accident analyses, consequently, it was unnecessary to redo the hazards identification.

Each activity was broken into numbered study nodes that represent the smallest individual task examined in the hazard identification process. In the results section, accidents can be traced to the study node from which they were initiated by means of the number scheme assigned to each study node.

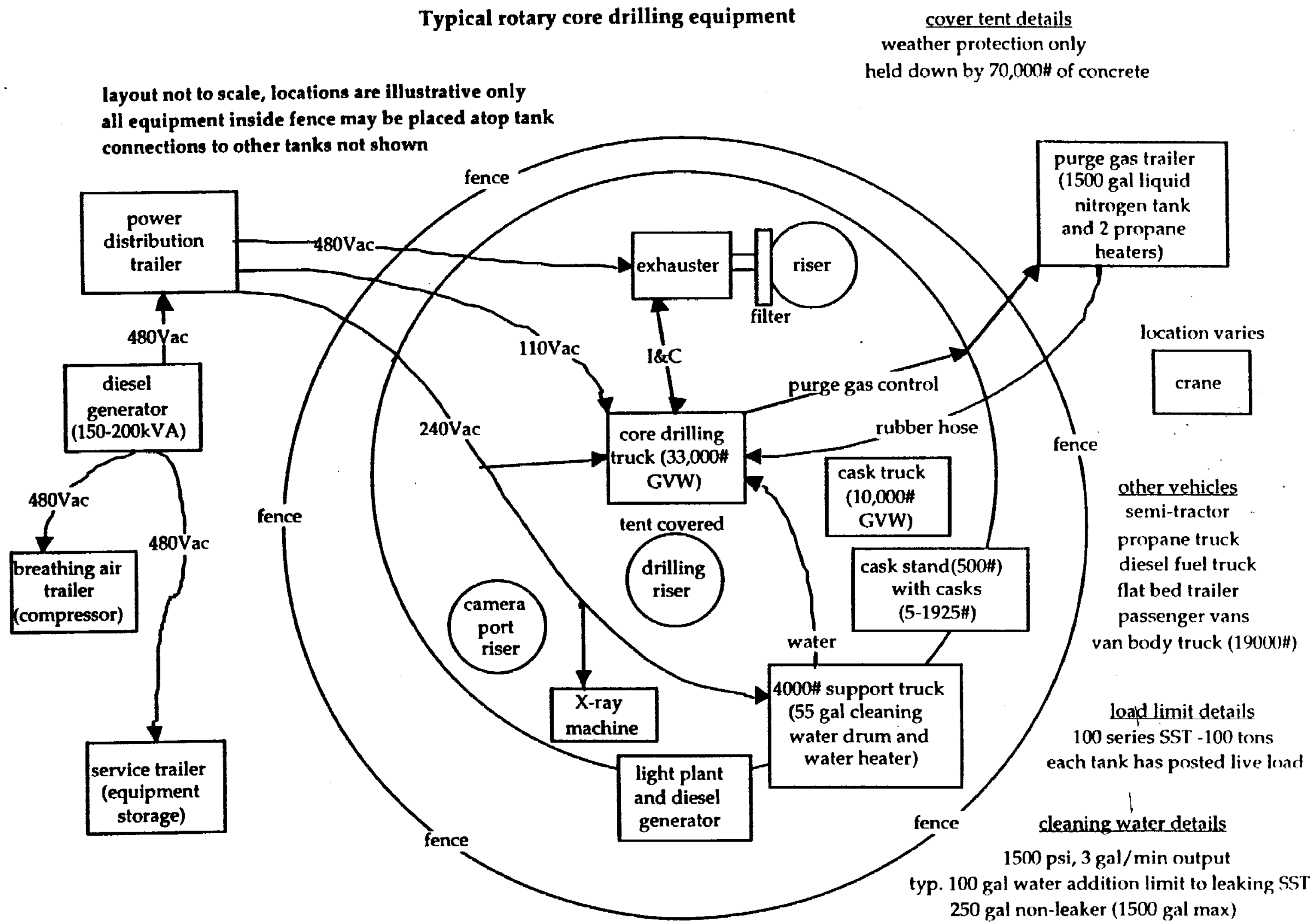

Typical rotary core drilling equipment
cover tent details
weather protection only
held down by 70,000# of concrete
layout not to scale, locations are illustrative only
all equipment inside fence may be placed atop tank
connections to other tanks not shown
fence
power distribution trailer
480Vac
110Vac
240Vac
exhauster
filter
riser
I&C
purge gas trailer (1500 gal liquid nitrogen tank and 2 propane heaters)
purge gas control
rubber hose
location varies
crane
diesel generator (150-200kVA)
480Vac
480Vac
480Vac
breathing air trailer (compressor)
service trailer (equipment storage)
core drilling truck (33,000# GVW)
tent covered
drilling riser
cask truck (10,000# GVW)
cask stand(500#) with casks (5-1925#)
camera port riser
X-ray machine
water
4000# support truck (55 gal cleaning water drum and water heater)
light plant and diesel generator
fence
fence
fence
fence
other vehicles
semi-tractor
propane truck
diesel fuel truck
flat bed trailer
passenger vans
van body truck (19000#)
load limit details
100 series SST -100 tons
each tank has posted live load
cleaning water details
1500 psi, 3 gal/min output
typ. 100 gal water addition limit to leaking SST
250 gal non-leaker (1500 gal max)

Fig. A-1

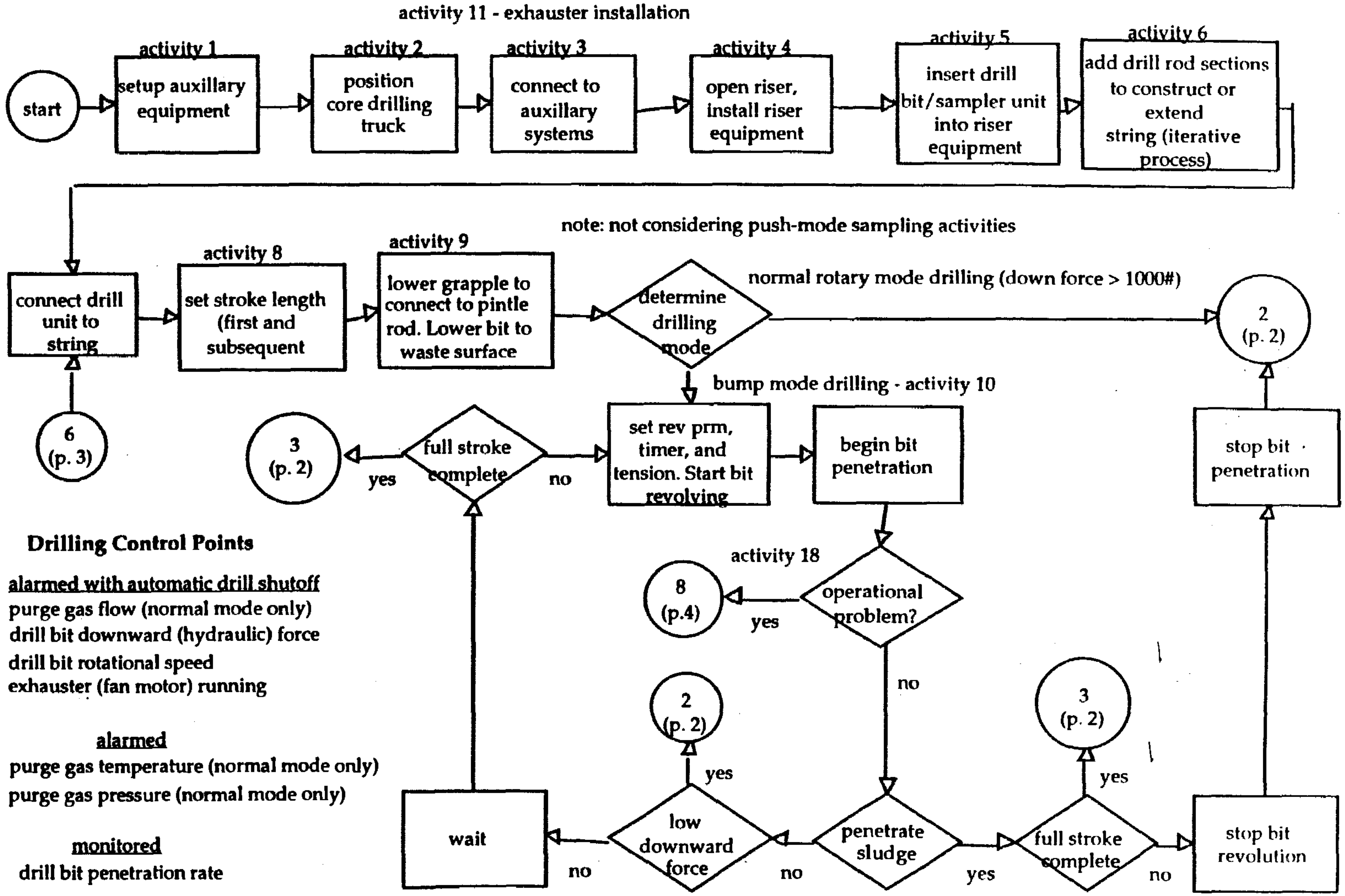


Figure A-1 (Page 1)

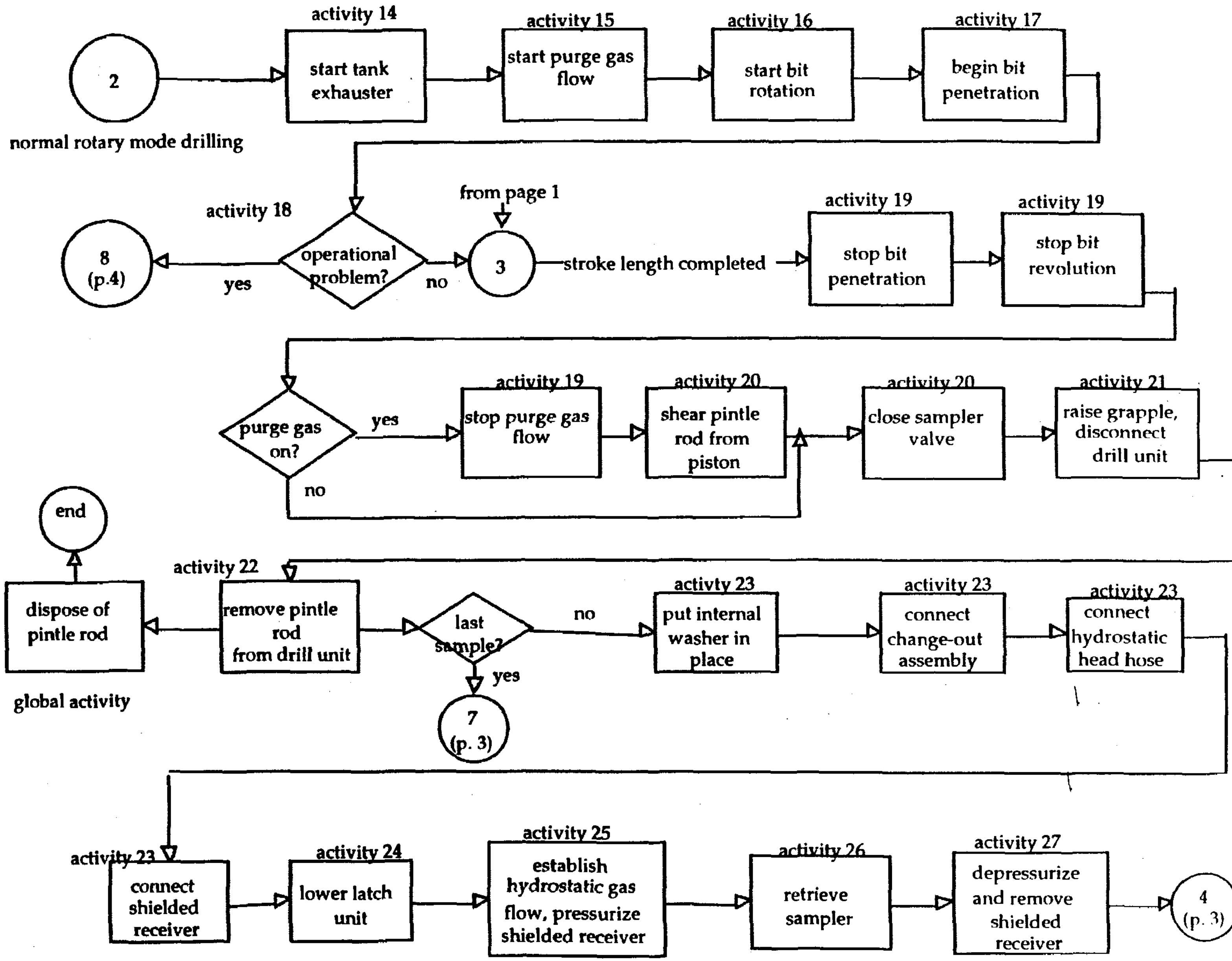


Figure A-1 (Page 2)

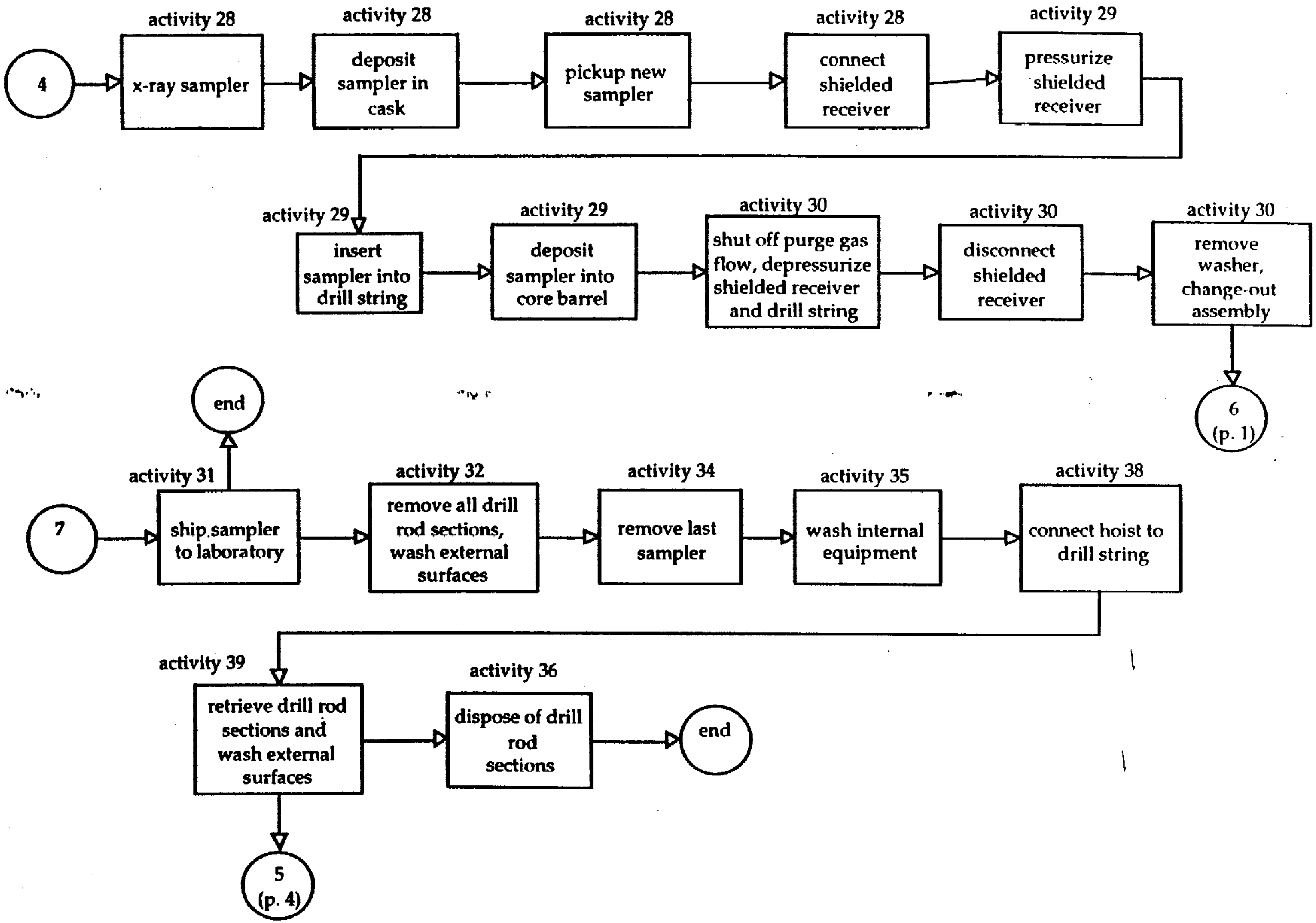
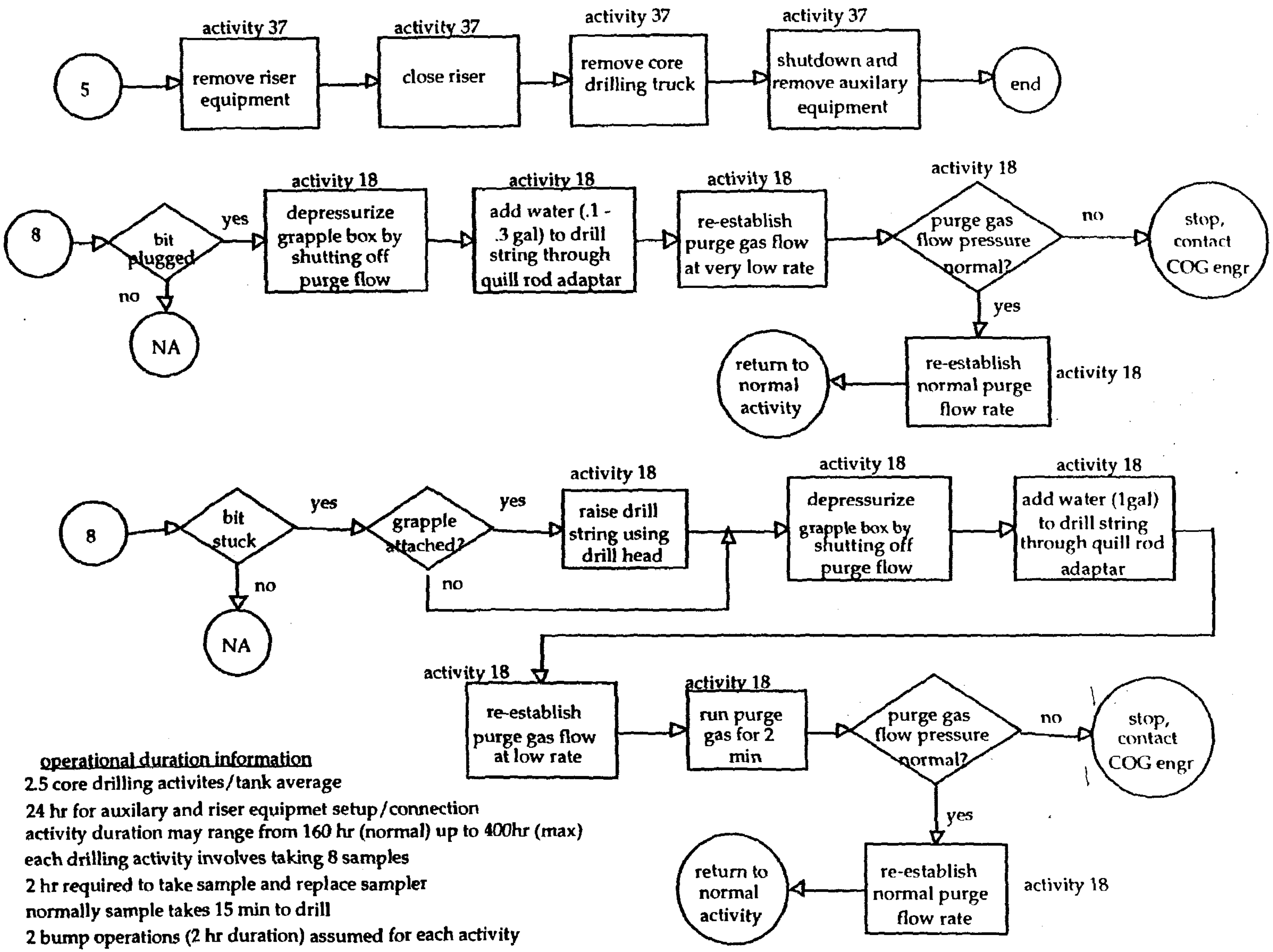


Figure A-1 (Page 3)



<u>operational duration information</u>

2.5 core drilling activites/tank average
24 hr for auxilary and riser equipmet setup/connection
activity duration may range from 160 hr (normal) up to 400hr (max)
each drilling activity involves taking 8 samples
2 hr required to take sample and replace sampler
normally sample takes 15 min to drill
2 bump operations (2 hr duration) assumed for each activity

Figure A-1 (Page 4)

A.3. RESULTS

The hazard identification process produced a database of approximately 180 accident scenarios. These accidents were sorted to obtain design-basis accidents that are examined in more detail in the Accident Analysis section of the SA (see Section 4.0 of the SA). A summary of the DBAs is presented in Section A.3.1. The complete accident database is presented in Section A.3.2.

A.3.1. Summary of Results (Identification of DBAs)

The types of accidents selected for additional analysis can be grouped into two broad categories: representative accidents and unique accidents. Representative accidents are those of a similar type, often having the same initiators or similar accident progression. Seismic events, explosions, or tank dome fires are all examples of representative accidents. Unique accidents are typically low-frequency, high-consequence accidents or those not defined as representative accidents. An example of a unique accident is an explosion resulting from the mixing of incompatible materials.

The process of selecting FG/RMCS DBAs involved sorting the database of accidents by accident keyword (this was done to examine groups of similar accidents by consequence, frequency, and relative measure of risk). These sorted results were reviewed, and engineering judgment was used to select representative accidents and to identify any unique accidents.

For the FG/RMCS activity a list of ten representative accidents were identified. No unique accidents were identified that were not already covered in the list of representative accidents. The list of DBAs is presented in TABLE A-4.

A.3.2. Accident Database

The accident database was produced during team meetings held at the Hanford Site. The team consisted of safety personnel, FG/RMCS design engineers, and drilling operators. The team approach and methodology are presented in more detail in *Hazard Evaluation Procedures*.[2] A condensed version of the accident database is presented in TABLE A-5. Columns only include data relevant to the accident analysis.

TABLE A-4
DESIGN-BASIS ACCIDENTS

#	Name	Description
I.	*Aboveground Fire*	Aboveground fires include all fires initiated by a flammable gas mixture above the tank, ignited by either (a) vehicle impact, (b) undetected ignition source (e.g., electrical, static), (c) truck fire, or (d) random spark.
II.	*Dome-space fire*	Dome fires include all fires in which the dome gas space is ignited directly by either (a) vehicle impact, (b) drill-string breakage exposing electrical equipment, or (c) mechanical spark generation from objects (e.g., drill string) impacting metal.
III.	*Drill-string fire*	Drill-string fires include all fires started inside the drill string. This accident typically involves either a human error or mechanical failure that allows waste inside the drill string, creating flammable-gas concentrations above the lower flammability limit (LFL). The fire is then started by an electrical equipment or a mechanically generated spark.
IV.	*Waste fire*	Waste fires include all fires that start in the portions of the tank waste that are combustible, including fires caused by a tank-dome collapse. These fires are primarily caused by drill bit over-temperature. The most likely initiators include excessive drill string rpm, wrong drill bit, loss of nitrogen purge, excessive downward drilling force, and intentional or unanticipated drilling outside the bit parameter envelope.
V.	*Gas release*	This accident type includes all gas releases, either filtered or unfiltered, in which the containment is breached or gas is vented through the exhauster. These gas releases are not accompanied by fire.
VI.	*Chemical reactions in the waste*	This accident category includes chemical reactions caused by incompatible material additions, energy addition/subtraction or water additions to the tank waste.
VII.	*Containment breach*	This group of accidents includes all mechanisms (other than fire) that result in containment breaches such as dome collapse or breach, tank-bottom penetration, or riser penetration. This group includes (a) seismic events, (b) static overload of the dome, and (c) impact to the dome (e.g., dropping a heavy object).
VIII.	*Spills, releases and radiation exposure*	Spills aboveground are caused mainly by human error and have low impact to the public and on-site workers. These spills are an as low as reasonably achievable (ALARA) concern for the workers in the vicinity. Spills as a result of ejection or detonation are also considered in this section. High-efficiency particulate air (HEPA) filter failure releases and aerosol releases are included bounded and by this accident.
IX.	*External event*	Accidents due to range fire, seismic, flooding, tornadoes and high winds, lightening, and volcanoes are included in this category.

TABLE A-5. Rotary Mode Core Drilling HA Accident Database

Table A-5. Rotary Core Mode Drilling HA Accident Database

Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Public-Risk	Onsite-Risk	W-Risk	E-Risk
Global.3	Gas Release	Chemical reaction with tank waste	Intentional or unintentional introduction of incompatible materials into tank because of human error or inadequate design control.	Design review process	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	1) A study on the list of incompatible materials should be assembled (e.g. a list including aluminum) 2) A minimum amount of incompatible material needed for a significant reaction.	D	D	C	D	II	4	4	3	4
Global.4	Waste Fire	Chemical reaction with tank waste with run-away exothermic reaction	Intentional or unintentional introduction of incompatible materials into tank because of human error or inadequate design control.	Design review process	Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	1) A study on the list of incompatible materials should be assembled (e.g. a list including aluminum) 2) A minimum amount of incompatible material needed for a significant reaction.	D	B	B	B	III	4	3	3	3
Global.5	Gas Release	Toxic Gas above tank	Toxic gases released due to random bound gas release with non-detection of toxic gas above tank	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	1) Walk down tank farm and de-energize equipment as necessary. 2) Verify condition of riser seals. 3) Document farm equipment and provide riser map	D	D	C	D	II	4	4	3	4
1.1	Dome Collapse	Tank Waste	Dome static load exceeded, dome collapse with aerosol release of waste	Admin. control OSD-T-51-0013 sets limits on tank loading	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	B	A	A	B	II	2	1	1	2
1.2	Dome Collapse	Tank Waste	Load dropped on top of tank during lift, dome collapse follows.	Admin. control gives procedures for critical crane lifts	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequence	review dome loading analyses	B	A	A	B	III	3	2	2	3
1.3	Gas Release	Tank Waste	Load dropped on top of tank during lift, tank containment breach	Admin. control gives procedures for critical crane lifts	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	D	D	C	D	II	4	4	3	4
1.4	Dome collapse waste fire	Tank Waste	Load dropped on top of tank during lift, tank dome collapse followed by waste fire	Admin. control gives procedures for critical crane lifts	Assumed consequence is a dome collapse followed by a waste fire. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	A	A	A	A	IV	3	3	3	3
1.5	Gas Release	Tank Waste	Vehicle Impacts Riser or Other part of Tank containment, containment breached		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	add administrative control on vehicle speed	D	D	C	D	II	4	4	3	4
1.6	Above Ground Fire	Tank Waste	Vehicle Impacts Riser or Other part of Tank containment, spark ignites above ground fire		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	add administrative control on vehicle speed	D	C	C	C	IV	4	4	4	4
1.7	Dome Fire	Tank Waste	Vehicle impacts and breaches Riser or Other part of Tank containment, vehicle fuel tank breached, spark ignites dome space fire.		Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequence	add administrative control on vehicle speed	B	A	A	B	III	3	2	2	3
1.8	Gas Release	Tank Waste	1 of 3 drill truck jacks fail to support truck, dome containment breached	jack collars hold jack positions	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	D	D	C	D	II	4	4	3	4

Table A-5. Rotary Core Mode Drilling HA Accident Database

Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Public-Risk	Onsite-Risk	W-Risk	E-Risk
1.9	Gas Release	Tank Waste	1 of 3 drill truck jacks mis-positioned due to human error, truck falls and dome containment breached		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	D	D	C	D	II	4	4	3	4
1.11	Gas Release	Tank Waste	1 of 3 drill truck jacks struck by vehicle, truck falls and dome containment breached		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	D	D	C	D	III	4	4	4	4
2.1	Gas Release	Tank Waste	Drill truck impacts Riser or Other part of Tank containment, containment breached		NA - included in scenario 1.5	add administrative control on vehicle speed	D	D	C	D	II	4	4	3	4
2.3	Dome Fire	Tank Waste	Vehicle impacts and breaches Riser or Other part of Tank containment, vehicle fuel tank breached, spark ignites dome space fire		NA - included in scenario 1.7	add administrative control on vehicle speed	B	A	A	B	III	3	2	2	3
2.9	Above Ground Fire	Tank Waste	Vehicle impacts Riser or Other part of Tank containment, vehicle fuel tank breached, spark ignites above ground fire		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	add administrative control on vehicle speed	D	C	C	C	III	4	4	4	4
2.4	Dome Collapse	Tank Waste	Core drilling truck driven off ramps into open pit, dome collapse follows	ramps have edges and stop at ramp end	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	B	A	A	B	II	2	1	1	2
2.5	Gas Release	Tank Waste	Core drilling truck driven off ramps into open pit, dome containment breached	ramps have edges and stop at ramp end	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	D	B	B	B	II	4	2	2	2
2.6	Above Ground Fire	Tank Waste	Core drilling truck driven off ramps into open pit followed by truck fuel fire	ramps have edges and stop at ramp end	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence		D	C	C	C	II	4	3	3	3
2.7	Dome collapse waste fire	Tank Waste	Core drilling truck driven off ramps into open pit, dome collapse followed by a waste fire	ramps have edges and stop at ramp end	Assumed consequence is a dome collapse followed by a waste fire. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	A	A	A	A	III	2	2	2	2
2.8	Above Ground Fire	Tank Waste	Core drilling truck driven on burm, truck overturns, burns and fire propagates back into tank farm		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	Determine whether procedural controls prevent trucks from being driven on burms	D	C	C	C	II	4	3	3	3
3.1	Above Ground Fire	Tank Waste	Non-detection of flammable gas above tank with ignition	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	1) Walk down tank farm and de-energize equipment as necessary prior to connecting to auxiliary equipment 2) Verify condition of riser seals. 3) Review gas detection calibration procedures	D	C	C	C	III	4	4	4	4
4.1	Above Ground Fire	Tank Waste	Non-detection of flammable gas above over open riser followed by ignition	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	1)review gas detector calibration procedures 2) require 20' minimum radius distance to energized equipment if riser open or 3) require class 1 Div. 1, Group B equipment within 20' radius when riser open	D	C	C	C	III	4	4	4	4

Table A-5. Rotary Core Mode Drilling HA Accident Database

Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Public-Risk	Onsite-Risk	W-Risk	E-Risk
4.2	Gas Release	Tank Waste	Non-detection of toxic gas above over open riser	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	determine gas detector calibration details	D	D	C	D	II	4	4	3	4
4.3	Above Ground Fire	Tank Waste	Hardware dropped into open riser strikes riser side and causes a spark and ignition of gas above riser	lanyards connected to (some) hardware	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	verify all loose equipment near open riser, including tools, connected to lanyards	D	C	C	C	III	4	4	4	4
4.7	Dome Fire	Tank Waste	Hardware dropped into open riser causes a spark and ignition of dome space gas	lanyards connected to (some) hardware	Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequence	verify all loose equipment near open riser, including tools, connected to lanyards	B	A	A	B	III	3	2	2	3
4.8	Above Ground Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates flammable gases followed by ignition of above-tank gas		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	C	C	C	III	4	4	4	4
4.4	Dome Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates flammable gases followed by ignition of dome space gas		Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequence	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	B	A	A	B	III	3	2	2	3
4.5	Gas Release	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates toxic gases		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	D	C	D	II	4	4	3	4
4.6	Waste Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction results in waste ignition		Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	B	B	B	III	4	3	3	3
5.1	Waste Fire	Tank Waste	Frisbee seal damage combined with operator error causes drill string drop and strike of tank waste surface, exothermic reaction results in waste burn	Seal is lubricated to prevent damage. Seal is inspected before installation	Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences		D	B	B	B	III	4	3	3	3
5.2	Gas Release	Tank Waste	Frisbee seal damaged - loss of containment	Seal is lubricated to prevent damage. Seal is inspected before installation	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences		D	D	C	D	I	3	3	2	3
6.1	Dome Fire	Tank Waste	Operator error (hoist not attached) or foot clamp failure causing drill string drop and strike of waste surface, spark generated and dome space gas ignites	Clamp failure mode is closed with loss of pressure, but operator action required to close clamp	Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequence	Recommend using hoist for set number of rods attached. Add to procedure.	B	A	A	B	III	3	2	2	3
6.2	Drill String Fire	Waste in drill string	Waste in drill string results in generation or release of flammable gases into drill string, ignition follows. Several initiators: 1) No installation of O-ring. 2) O-ring seal failure. 3) loss of purge gas flow. 4) loss of hydrostatic head gas pressure		Representative consequence is a minimal on-site radioactive material release. See "drill string fire" event tree for complete spectrum of consequence	Inspect drill string looking for O-ring. Operator currently does not use an O-ring during push mode operation.	D	D	C	D	II	4	4	3	4

Table A-5. Rotary Core Mode Drilling HA Accident Database

Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Public-Risk	Onsite-Risk	W-Risk	E-Risk
6.3	Subterranean spill	Tank Waste	Addition of extra drill rod sections or excessive length added because of tank depth measurement uncertainties results in tank bottom breach	1) calc note to determine the number of rod sections needed. Only the required number are taken. 2) ram pressure interlock will prevent tank bottom penetration. 3) bit material can't penetrate tank bottom 4) drill string will buckle prior to penetration	Initiation of or increased rate of tank contents leakage	verify actual riser heights match drawing values. Determine whether or how tank bottom buckling condition determined	D	D	D	C	I	3	3	3	2
6.4	Dome Fire	Tank Waste	Drill string strikes metal object during installation causing dome space ignition		Assumed consequenc is a fire-induced dome collapse. See "dome space fire" event tree for complete spectra of consequence	Ensure near riser tank dome volume viewed with a camera prior to drill string installation	B	A	A	B	III	3	2	2	3
6.6	Gas Release		Drill string strikes metal object during installation causing drill string to buckle and to cause frisbee seal failure		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	Ensure near riser tank dome volume viewed with a camera prior to drill string installation	D	D	C	D	II	4	4	3	4
7.1	Gas Release	Tank Waste	Drill platform strikes drill string during rotation. Containment is breached		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	verify rotation operations are monitored	D	D	C	D	I	3	3	2	3
9.1	Drill String Fire	Waste in drill string	Hoist failure or failure to connect results in grapple drop and impact of sampler. Ignition in drill string follows spark generation	String is inerted with nitrogen. String should not contain flammable gas.	Representative consequence is a minimal on-site radioactive material release. See "drill string fire" event tree for complete spectrum of consequence	verify hoist and lifting cable are inspected prior to use	D	D	C	D	II	4	4	3	4
11.1	Above Ground Fire	Tank Waste	Non-detection of flammable gas above over open riser followed by ignition	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	1)determine gas detector calibration details 2) require 20' minimum radius distance to energized equipment if riser open or 3) require class 1 Div. 1, Group B equipment within 20' radius when riser open	D	C	C	C	III	4	4	4	4
11.2	Gas Release	Tank Waste	Non-detection of toxic gas above over open riser	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	determine gas detector calibration details	D	D	C	D	II	4	4	3	4
11.3	Dome Fire	Tank Waste	Hardware dropped into open riser causes a spark and ignition of dome space gas	lanyards connected to (some) hardware	NA - Included in scenario 4.7	verify all loose equipment near open riser, including tools, connected to lanyards	B	A	A	B	III	3	2	2	3
11.7	Above Ground Fire	Tank Waste	Hardware dropped into open riser strikes riser side and causes a spark and ignition of gas above riser	lanyards connected to (some) hardware	NA - Included in scenario 4.3	verify all loose equipment near open riser, including tools, connected to lanyards	D	C	C	C	III	4	4	4	4
11.4	Dome Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates flammable gases followed by ignition of above-tank or dome space gas		NA - Included in scenario 4.4 and 4.6	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	B	A	A	B	IV	4	3	3	4
11.5	Gas Release	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates toxic gases		NA - Included in scenario 4.5	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	D	C	D	II	4	4	3	4
11.6	Waste Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction results in waste ignition		NA - Included in scenario 4.6	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	C	C	C	III	4	4	4	4

Table A-5. Rotary Core Mode Drilling HA Accident Database

Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Public-Risk	Onsite-Risk	W-Risk	E-Risk
14.1	Dome Collapse	Tank waste	Tank collapse caused by excessive vacuum on tank. Low pressure caused by plugged inlets and failure of DP photohelic monitors	Photohelic pressure monitors on exhauster. Limits set on fan speed. Probability of tank sealing to the point of excess vacuum considered unlikely.	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	B	A	A	B	III	3	2	2	3
14.2	Gas Release	Tank waste	Unfiltered release through leakage paths caused by excessive tank pressure as a result of high exhauster flow	Photohelic pressure monitors on exhauster. Limits set on fan speed. Probability of tank sealing to the point of excess pressure considered unlikely.	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	verify how leakage paths determined. specify separation to energized equipment	D	D	C	D	I	3	3	2	3
14.3	Gas Release	Tank waste	low exhauster flow causes normal drill string purge gas to over-pressurize drill string and result in unfiltered release	Photohelic pressure monitors on exhauster. Limits set on fan speed. Probability of tank sealing to the point of excess pressure considered unlikely.	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	determine whether low exhauster flow results in purge gas shut off	D	D	C	D	IV	4	4	4	4
14.4	Dome Collapse	Tank waste	Tank collapse caused by excessive vacuum on tank. Low pressure caused by high flow and failure of DP photohelic monitors	Photohelic pressure monitors on exhauster. Limits set on fan speed. Probability of tank sealing to the point of excess pressure considered unlikely.	NA - included in scenario 14.1	see scenario 14.1	B	A	A	B	III	3	2	2	3
14.5	Above Ground Fire	Tank Waste	Exhauster component initiates exhaust gas fire	1) Exhauster heater classified Class1, Div. 2, Group B	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	Replace exhaust pressure photohelics, humidity and temperature probe, HEPA delta P photohelic probe, fan, and CAMS with Class 1, Div. 2, Group B equipment. An alternative approach may be to re-energize these devices if high H2 concentration measured or	D	C	C	C	II	4	3	3	3
14.5 (cont.)				note, we assume flammable gas release from another tank in farm disperses prior to reaching operational exhauster		installation of a flame arrestor in series with the exhaust. If required to sample for other flammable gasses, recommend classify all equipment to Class 1, Div. 2, Group B									
14.6	Gas Release	Tank Waste	Random or activity-initiated gas release from waste generates high levels of toxic gases		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	require toxic gas sensors and personnel evacuation if large gas release believed eminent or if one occurs	D	D	C	D	III	4	4	4	4
14.7	Above Ground Fire	Tank Waste	Electrostatic charge on exhauster hose initiates above ground fire		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	Replace existing exhauster hose with conductive hose or with hose having a spirally wound grounded conductor	D	C	C	C	III	[illegible]	[illegible]	4	4
14.8	Above Ground Fire	Tank Waste	Flexible exhauster hose tear, tear not discovered, purge gas flow forces flammable gas out tear, fire results on top of tank.	Hose is manually inspected during installation.	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence		D	C	C	C	IV	4	4	4	4
14.9	Above Ground Fire	Tank Waste	Seal pot failure results in fire in condensate line	Seal pot is isolated except to open drain line and manual pump down.			D	C	C	C	IV	4	4	4	4
14.11	Above Ground Fire		Heat trace tape for condensate line or condensate pot causes ignition		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequence	The pump and heat trace on condensate lines need to be checked for qualification	D	C	C	C	III	4	4	4	4

Table A-5 Rotary Core Mode Drilling HA Accident Database

Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Public-Risk	Onsite-Risk	W-Risk	E-Risk
15.1	Waste Fire	Tank Waste	Low nitrogen purge gas flow causes bit over temperature which results in a waste fire	Two of three redundant flow meters must agree for unit to operate	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	require 10 drill string volume purges each time purge is interrupted Determine reliability of purge system	D	B	B	B	III	4	3	3	3
15.2	None	Tank Waste	Low nitrogen purge gas temperature because of failed controller or failed heater	Temperature controller stops operation of nitrogen truck at temp below 40 F	qualitatively assigned - speculative	none	D	D	D	D	III	4	4	4	4
15.3	Waste Fire	Tank Waste	High nitrogen temperature because of failed controller or runaway heater results in high bit temperature and subsequent waste fire	Temperature controller stops operation of nitrogen truck at temp above 100 F	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	investigate reliability of temperature controller	D	B	B	B	III	4	3	3	3
15.4	Waste Fire	Tank Waste	nitrogen heat exchanger failure results in propane flowing into drill string	Heat exchanger is an ASME pressure vessel	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	determine number of barriers between propane and nitrogen	D	B	B	B	III	4	3	3	3
15.4	Waste Fire	Tank Waste	Vendor supplies gas other than nitrogen in purge gas truck tank, gas is flammable, gas contact with bit during drilling initiates a waste fire	Vendor QA program to ensure no other gas is substituted.	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	review vendor QA procedures	D	B	B	B	II	4	2	2	2
15.5	Waste Fire	Tank Waste	Broken N2 line downstream of flow meters causing bit over temperature and subsequent waste fire	Oxygen monitor on truck may sense low oxygen and sound alarm	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	determine whether a purge line back to the tank is a possible gas bypass path	D	B	B	B	III	4	3	3	3
Global	Gas Release		diesel fume build under core drilling truck tent	Oxygen monitor on truck may sense low oxygen and sound alarm	ALARA issue		D	D	C	D	II	4	4	3	4
16.1	Waste Fire	Tank Waste	High drill bit RPM causes high bit temperature and subsequent waste burn	Redundant magnetic speed monitor with alarm followed by automatic rotation shutdown	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	determine reliability of high RPM detection system to shut down drilling	D	B	B	B	II	4	2	2	2
16.2	Waste Fire	Tank Waste	Reverse drill bit rotation causes excessive bit temperature and waste burn	Reverse direction is locked out on 2 of 4 drill trucks	Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	add lock out feature to 2 remaining trucks	D	B	B	B	II	4	2	2	2
16.4	Waste Fire	Tank waste	Wrong bit or no bit installed (push mode setup), normal rotary core drilling causes high bit temperature and subsequent waste fire	bits are visually different and must add bit when rotary mode operation expected	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences		D	B	B	B	II	4	2	2	2
16.5	Dome Fire		Drill bit catches fast in waste and is unable to rotate, drill sting breakage results, exposed wiring or non-qualified equipment ignition sources, ignition in dome space follows.		Assumed consequenc is a fire-induced dome collapse. See "dome space fire" event tree for complete spectra of consequence	replace motor-driven RLU with mechanically-operated one	B	A	A	B	II	2	1	1	2
16.6	Waste Fire	Tank Waste	Combination of excessive torque loading and downward force causes bit to overheat, resulting in waste fire		Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	limit bit torque to sufficiently low value so that thermal energy input to bit low enough to be conducted away from bit by waste	D	B	B	B	I	3	1	1	1
16.7	Waste Fire	Tank Waste	Loss of purge gas flow causes bit to overheat resulting in waste fire	none - bit temperature measurement not possible given existing technology	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	determine reliability of purge loss detection and drill shutdown systems	D	B	B	B	III	4	3	3	3

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Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Public-Risk	Onsite-Risk	W-Risk	E-Risk
18.8	Waste Fire	Tank Waste	inadequate testing envelope or improper heat-up modeling results in bit overheating during normal (or unanticipated) drilling causing bit to overheat resulting in waste fire		Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	review and verify present heat-u modeling analyses	D	B	B	B	I	3	1	1	1
18.9	Waste Fire	Tank Waste	High drill torque load causes drill bit break which initiates a spark or over temperature resulting in a waste fire		Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	consider adding drill bit torque limit interlock	D	B	B	B	II	4	2	2	2
18.10	Waste Fire	Tank Waste	current operational envelope violated by substitution of incorrect bit, high bit temperature results from normal drilling. Waste fire results	administrative procedures, visual differences between qualified and non-qualified bits	Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	review bit operational modeling and testing parameters including aerosol generation and ignition in different gaseous atmospheres	D	B	B	B	II	4	2	2	2
18.11	Dome Fire	Tank Waste	Drill bit impacts item in waste, drill sting breakage results, exposed wiring or non-qualified equipment ignition sources. Ignition in dome space follows.		Assumed consequenc is a fire-induced dome collapse. See "dome space fire" event tree for complete spectra of consequence	replace motor-driven RLU with mechanically-operated one	B	A	A	B	II	2	1	1	2
18.16	Waste Fire	Tank Waste	Drill bit impacts item in waste, spark generated which ignites waste gaseous phase, fire propagates to waste.		Representative consequenc is a waste-fire induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences		D	B	B	B	II	4	2	2	2
18.17	Gas Release		incorrect operational envelope results in drilling in a mode which generates excessive dust, exhauster filter plugs, slight dome space over-pressurization results in unfiltered release through leakage paths		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	determine drilling aerosol generation rates	D	D	C	D	III	4	4	4	4
18.12	Dome Fire	Tank Waste	incorrect operational envelop results in drilling in a mode which generates excessive dust, possible dust ignition and dome collapse.	unlikely, propagation most likely to occur for situations where initial ignition results in a spread of additional flammable dust or fibrous material	Assumed consequenc is a fire-induced dome collapse. See "dome space fire" event tree for complete spectra of consequence	review bit operational modeling and testing parameters including aerosol generation and ignition in different gaseous atmospheres	B	A	A	B	IV	4	3	3	4
18.7	Gas Release		addition of an excessive amount of water during attempts to clean or loosen drill bit results in ammonia release from waste	55 gallon limit on water supply, OSD allowable limit is 100 gallons for leaking tanks, 250 gallons for non-leaking tanks. Up to 1500 gallons can be added to either with Nuclear Safety approval	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	require toxic gas sensors and personnel evacuation if large gas release believed eminent or if one occurs	D	D	C	D	III	4	4	4	4
18.8	Gas Release		drill string contaminated, addition of an excessive amount of water during attempts to clean or loose drill bit results in ammonia generation and release	55 gallon limit on water supply, OSD allowable limit is 100 gallons for leaking tanks, 250 gallons for non-leaking tanks. Up to 1500 gallons can be added to either with Nuclear Safety approval	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	require toxic gas sensors and personnel evacuation if large gas release believed eminent or if one occurs	D	D	C	D	III	4	4	4	4
18.9	Gas Release		Normal drilling melts sufficient waste to result in a steam release		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences		D	D	C	D	II	4	4	3	4
18.15	Gas Release		excessive purge gas flow initiates gas release through leakage paths		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	investigate high purge gas flow detection and controls	D	D	C	D	I	3	3	2	3

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10.3	Drill String Fire	Waste Tank	Loss of seal during bump mode (no N2 used) -waste enters drill string. Flammable concentration exceeded in drill string, ignition occurs		Representative consequence is a minimal on-site radioactive material release. See "drill string fire" event tree for complete spectrum of consequences	Use purge gas on 1st sample to inert sting	D	D	C	D	III	4	4	4	4
30.3	Subterranean spill	Waste Tank	Bit hits and breaches tank bottom	1) bit runs cooler when drilling metal (more heat removed)	Initiation of or increased rate of tank contents leakage	determine reliability of bottom force detection and drill direction reversal systems	D	D	D	C	I	3	3	3	2
30.4	Drill String Fire	Waste Tank	Failure to move drill string above waste surface on last sample prior to removing sampler - result is drill string full of waste, Flammable concentration exceeded in drill string, ignition occurs		Representative consequence is a minimal on-site radioactive material release. See "drill string fire" event tree for complete spectrum of consequences		D	D	C	D	III	4	4	4	4
30.4 (cont)															
30.5	Subterranean spill	Waste Tank	High down force punctures tank bottom	1) Limited down force 2) hydraulic bottom detector 3) frangible bit 4) operator observation 5) drill string may buckle prior to tank penetration 6) only carbide bit is expected to penetrate bottom	Initiation of or increased rate of tank contents leakage	determine reliability of bottom force detection and drill direction reversal systems	D	D	D	C	II	4	4	4	3
32.1	Gas Release	Waste Tank	Addition of large volumes of water to tank initiates gas release	55 gallon limit on water supply, OSD allowable limit is 100 gallons for leaking tanks, 250 gallons for non-leaking tanks. Up to 1500 gallons can be added to either with Nuclear Safety approval	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences	require toxic gas sensors and personnel evacuation if large gas release believed eminen or if one occurs	D	D	C	D	III	4	4	4	4
32.2	Dome Fire	Tank Waste	Operator error (hoist not attached) or foot clamp failure causing drill string drop and strike of waste surface, spark generated and dome space gas ignites	Clamp failure mode is closed with loss of pressure, but operator action required to close clamp	Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequences	Recommend using hoist for set number of rods attached. Add to procedure.	B	A	A	B	III	3	2	2	3
32.3	Dome Collapse	Tank Waste	Human error - jib hoist used to lift drill string - truck pulled off jacks, falls, impacts dome. Dome collapse results	Administrative requirements call for using the drill-motor in reverse to lift drill string until sting bit is above waste	dome collapse without a fire		A	B	B	A	III	2	3	3	2
32.4	Gas Release	Tank Waste	Human error - jib hoist used to lift drill string - truck pulled off jacks, falls, impacts dome. Dome containment breached		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences		D	D	C	D	II	4	4	4	4
34.1	Gas Release	Tank Waste	Swab of bore by drill string during removal causes a low pressure puff release of gas to tank dome		Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "gas release event" event tree for complete spectrum of consequences		D	D	C	D	III	4	4	4	4
35.1	Above ground spill	Tank Waste	Error causing waste in drill string (i.e.. seal failure) followed by plugging of leak - result is 5 ft of waste spilled to ground	Requirements to sniff string and use a rad. detector on outside of drill string	ALARA issue		D	D	D	D	III	4	4	4	4

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37.1	Dome Collapse	Tank Waste	Dome static load exceeded, dome collapse with aerosol release of waste	Admin. control OSD-T-51-0013 sets limits on tank loading	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	A	B	B	A	II	1	2	2	1
37.2	Dome Collapse	Tank Waste	Load dropped on top of tank during lift, dome collapse follows.	Admin. control gives procedures for critical crane lifts	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequence	review dome loading analyses	D	B	B	B	III	4	3	3	3
37.3	Gas Release	Tank Waste	Load dropped on top of tank during lift, tank containment breach	Admin. control gives procedures for critical crane lifts	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	D	D	C	D	II	4	4	3	4
37.4	Dome collapse waste fire	Tank Waste	Load dropped on top of tank during lift, tank dome collapse followed by waste fire	Admin control gives procedures for critical crane lifts	Assumed consequence is a dome collapse followed by a waste fire. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	A	A	A	A	IV	3	3	3	3
37.5	Gas Release	Tank Waste	Vehicle Impacts Riser or Other part of Tank containment, containment breached		NA - included in scenario 1.5	add administrative control on vehicle speed	D	D	C	D	II	4	4	3	4
37.6	Above Ground Fire	Tank Waste	Vehicle Impacts Riser or Other part of Tank containment, spark ignites above ground fire		NA - included in scenario 1.6	add administrative control on vehicle speed	D	C	C	C	IV	4	4	4	4
37.8	Dome Fire	Tank Waste	Vehicle impacts and breaches Riser or Other part of Tank containment, vehicle fuel tank breached, spark ignites dome space fire.		NA - included in scenario 1.7	add administrative control on vehicle speed	B	A	A	B	III	3	2	2	3
37.10	Gas Release	Tank Waste	Drill truck impacts Riser or Other part of Tank containment, containment breached		NA - included in scenario 1.5	add administrative control on vehicle speed	D	D	C	D	II	4	4	3	4
37.12	Above Ground Fire	Tank Waste	Vehicle Impacts Riser or Other part of Tank containment, vehicle fuel tank breached, spark ignites above ground fire		NA - included in scenario 2.9	add administrative control on vehicle speed	D	C	C	C	III	4	4	4	4
37.13	Dome Collapse	Tank Waste	Core drilling truck driven off ramps into open pit, dome collapse follows	ramps have edges and stop at ramp end	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequence	review dome loading analyses	D	B	B	B	I	4	2	2	2
37.14	Gas Release	Tank Waste	Core drilling truck driven off ramps into open pit, dome containment breached	ramps have edges and stop at ramp end	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	D	D	C	D	II	4	4	3	4
37.15	Above Ground Fire	Tank Waste	Core drilling truck driven off ramps into open pit, truck fuel fire results	ramps have edges and stop at ramp end	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences		D	C	C	C	II	4	3	3	3
37.16	Dome collapse waste fire	Tank Waste	Core drilling truck driven off ramps into open pit, dome collapse followed by waste fire	ramps have edges and stop at ramp end	Assumed consequence is a dome collapse followed by a waste fire. See "tank loading" event tree for complete spectrum of consequences	review dome loading analyses	A	A	A	A	III	2	2	2	2
37.18	Above Ground Fire	Tank Waste	Core drilling truck driven on burm, truck overturns, burns and fire propagates back into tank farm		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences	Determine whether procedural controls prevent trucks from being driven on burms	D	C	C	C	II	4	3	3	3
37.19	Above Ground Fire	Tank Waste	Non-detection of flammable gas above over open riser followed by ignition	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences	1)review gas detector calibration procedures 2) require 30' (or other) minimum radius distance to energized equipment if riser open or 3) require class 1 Div. 1, Group B equipment within 30' (or other) radius when riser open	D	C	C	C	III	4	4	4	4

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37.20	Gas Release	Tank Waste	Non-detection of toxic gas above over open riser	1) High winds in area are prominent. 2) WHC-SD-WM-HSP-002 controls gas detection	Representative consequence is an extended low concentration toxic gas (no solid) personnel exposure. See "tank loading" event tree for complete spectrum of consequences	determine gas detector calibration details	D	D	C	D	II	4	4	3	4
37.21	Above Ground Fire	Tank Waste	Hardware dropped into open riser causes a spark and ignition of gas above riser	lanyards connected to (some) hardware	NA - included in scenario 4.3	verify all loose equipment near open riser, including tools, connected to lanyards	D	C	C	C	III	4	4	4	4
37.22	Dome Fire	Tank Waste	Hardware dropped into open riser causes a spark and ignition of dome space gas	lanyards connected to (some) hardware	NA - included in scenario 4 7	verify all loose equipment near open riser, including tools, connected to lanyards	B	A	A	B	III	3	2	2	3
37.23	Above Ground Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates flammable gases followed by ignition of above-tank gas		NA - included in scenario 4.8	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	C	C	C	III	4	4	4	4
37.24	Dome Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates flammable gases followed by ignition of dome space gas		NA - included in scenario 4.4	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	B	A	A	B	III	3	2	2	3
37.25	Gas Release	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction generates toxic gases		NA - included in scenario 4.5	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	D	C	D	II	4	4	3	4
37.26	Waste Fire	Tank Waste	Reactive material dropped into open riser, uncontrollable chemical reaction results in waste ignition		NA - included in scenario 4.6	1) perform general waste material compatibility study, including minimum mass required for uncontrolled reaction 2) do not allow reactive materials to enter tank farm	D	B	B	B	III	4	3	3	3
external events and natural phenomena	Above Ground Fire	Tank Waste	Fuel spill during operation resulting in fire	Fuel spill limited to 5 gallons	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences	Put spill pan beneath truck	D	C	C	C	II	4	3	3	3
external events and natural phenomena	Waste Fire	Tank Waste	Fuel spill near pump pit with pump pit drain open results in exothermic reaction in waste		Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences	Put spill pan beneath truck. Do not allow fuel tank filling while riser open	D	B	B	B	III	4	3	3	3
external events and natural phenomena	Above Ground Fire	Tank Waste	Ignition within equipment within 30 ft of riser causes fire		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences	Prevent other operations while rotary core drilling is being performed or prevent equipment operation within 30 ft of riser (assuming riser dia = 1 ft and adding 50% safety factor) Verify 20 ft separation distance correct	D	C	C	C	II	4	3	3	3
external events and natural phenomena	Waste Fire	Tank Waste	Drilling is performed in the wrong tank. Tank could be high heat or have non-qualified equipment, waste fire results	QC verifies tank location	Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences		D	B	B	B	II	4	2	2	2
external events and natural phenomena	Waste Fire	Tank Waste	The wrong truck is used in the drilling process (i.e. crew uses rotary mode on a push mode truck operation outside operational parameters and waste burn result		Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences		D	B	B	B	II	4	2	2	2
external events and natural phenomena	Above Ground Fire	Tank Waste	The exhauster is connected to the wrong riser - tank is not exhausted. Tank could have a gas release above ground and subsequent fire		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences		D	C	C	C	II	4	3	3	3

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external events and natural phenomena	Dome Fire	Tank Waste	Activity in interconnected tank in farm causes fire that propagates to tank being sampled		Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequences	Prevent other operations while rotary core drilling is being performed	B	A	A	B	II	2	1	1	2
Changing operational modes	Waste Fire	Tank Waste	Wrong bit used when going from push mode to rotary mode - bit over-temperature results in waste fire		Representative consequence is a waste-fire-induced filter blowout release. See "waste fire" event tree for complete spectrum of consequences		D	B	B	B	III	4	3	3	3
Changing operational modes	Drill String Fire	Tank Waste	Wrong sampler inserted when going from rotary mode to push mode, drill string filled with waste, increased rate of flammable gas generation results, flammable concentration exceeded in drill string, ignition occurs		Representative consequence is a minimal on-site radioactive material release. See "drill string fire" event tree for complete spectrum of consequences		D	D	C	D	III	4	4	4	4
external events and natural phenomena	Above Ground Fire		diesel fuel released from truck during diesel generator tank refilling activities, fuel flows into tank farm and ignites		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences		D	C	C	C	II	4	3	3	3
external events and natural phenomena	volcano		volcanic eruption results in buildup of ash and dust		extended loss of site power and interruption of tank farm activities		D	D	D	D	I	3	3	3	3
external events and natural phenomena	Drill String Fire		volcanic eruption results in buildup of ash and dust, gas builds up in drill string prior to recovery, fire initiates at restart of activities		Representative consequence is a minimal on-site radioactive material release. See "drill string fire" event tree for complete spectrum of consequences		D	D	C	D	III	4	4	4	4
external events and natural phenomena	Dome Collapse		volcanic eruption results in buildup of ash and dust, tank dome loading limit exceeded		dome collapse without a fire	review dome loading analyses	A	B	B	A	IV	3	4	4	3
external events and natural phenomena	Dome Collapse		.25g (middle range) seismic event		dome collapse(s) without fire due to structural failure		A	B	B	A	IV	3	4	4	3
external events and natural phenomena	Dome Fire		.25g (middle range) seismic event results in fire(s) in tank dome space		NA - assume bounded by releases from structural failures		A	B	B	A	IV	3	4	4	3
external events and natural phenomena	Dome Collapse		.45g (middle range) seismic event		dome collapse without fire of a few (4) tanks due to structural failure		A	B	B	A	III	2	3	3	2
external events and natural phenomena	Dome Fire		.45g (middle range) seismic event results in fires in tank dome spaces of a few (4) tanks		NA - assume bounded by releases from structural failures		A	B	B	A	IV	3	4	4	3
external events and natural phenomena	Dome Collapse		.55g (middle range) seismic event		dome collapse without fire of a few (12) tanks due to structural failure		A	B	B	A	III	2	3	3	2
external events and natural phenomena	Dome Fire		.55g (middle range) seismic event results in fires in tank dome spaces of a few (12) tanks		NA - assume bounded by releases from structural failures		A	B	B	A	IV	3	4	4	3

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external events and natural phenomena	Dome Collapse		.70g (middle range) seismic event		dome collapse without fire of a many (45) tanks due to structural failure		A	A	A	B	III	2	2	2	3
external events and natural phenomena	Dome Fire		.70g (middle range) seismic event results in fire in tank dome spaces of a many (45) tanks		NA - assume bounded by releases from structural failures		A	B	B	A	IV	3	4	4	3
external events and natural phenomena	Dome Collapse		1.0 g (middle range) seismic event		dome collapse without fire of the majority (122) of the tanks due to structural failure		A	A	A	A	IV	3	3	3	3
external events and natural phenomena	Dome Fire		1.0 g (middle range) seismic event results in fire in tank dome spaces of the majority (122) of the tanks		NA - assume bounded by releases from structural failures		A	B	B	A	IV	3	4	4	3
external events and natural phenomena	Dome Collapse		extreme winds during equipment installation or removal activities results in drop of equipment onto dome	15 mph wind limit on operations	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequence	review dome loading analyses	A	B	B	A	IV	3	4	4	3
external events and natural phenomena	Dome Collapse		extreme winds during drilling activities results in drilling tuck upset due to jack or ramp failure	15 mph wind limit on operations	Representative consequence is a dome collapse. See "tank loading" event tree for complete spectrum of consequence	determine how truck positioned to secure condition during periods of possible high winds	A	B	B	A	III	2	3	3	2
external events and natural phenomena	Above Ground Fire		moderate or extreme winds cause truck tent to become electrostatically charged, flammable gases present when activities commence, tent brushes truck igniting gases	main tent body is canvas, only windows are plastic. 15mph wind limit on operations	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences	investigate electrostatic charging potential of tent windows	D	C	C	C	III	4	4	4	4
external events and natural phenomena	Above Ground Fire		lightning strike results in above ground fire		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences		D	C	C	C	IV	4	4	4	4
external events and natural phenomena	Dome Fire		lightning strike on an inadequately grounded tank results in tank dome space fire		Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequences		B	A	A	B	IV	4	3	3	4
external events and natural phenomena	Dome Fire		airplane crash into tank results in dome collapse		Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequences		B	A	A	B	IV	4	3	3	4
external events and natural phenomena	Dome Fire		insertion of non-conductive material into dome space results in static discharge and subsequent dome space fire		Assumed consequence is a fire-induced dome collapse. See "dome space fire" event tree for complete spectrum of consequences		B	A	A	B	IV	4	3	3	4
external events and natural phenomena	Above Ground Fire		propane fuel released from truck during nitrogen truck tank refilling activities ignites range fire which spreads into tank farm	ground cover removed or controlled	Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences		D	C	C	C	II	4	3	3	3
external events and natural phenomena	Above Ground Fire		flammable gas builds up during loss of electrical power period, flammable gas builds up during extended shutdown, fire ignites in exhauster equipment upon re-start		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences	review restart procedures to ensure H2 concentration measured prior to re-energizing electrical equipment	D	C	C	C	IV	4	4	4	4

Table A-5. Rotary Core Mode Drilling HA Accident Database

Scenario ID	Keyword	Hazard	Accident Description (Cause or Deviation)	Preventive/Mitigative Features	Consequences	Recommendations	Public	Onsite	Worker	Environment	Frequency	Pub-Risk	Onsite-Risk	W-Risk	E-Risk
external events and natural phenomena	Above Ground Fire		flammable gas builds up during loss of electrical power period, flammable gas builds up during extended shutdown, fire ignites in drill truck equipment upon re-start		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences	review restart procedures to ensure H2 concentration measured prior to re-energizing electrical equipment	D	C	C	C	IV	4	4	4	4
external events and natural phenomena	Above Ground Fire		external brush fire causes sparks that carry to tank farm, equipment fire results		Representative consequences is a HEPA filter holdup release. See "above ground fire" event tree for complete spectrum of consequences		D	C	C	C	II	4	3	3	3
Global	Gas Release		contaminated equipment stored in non-compatible material (aluminum) containers, chemical reaction generates		Assumed consequence is a short, low concentration toxic gas (no solid) personnel exposure.	do not store contaminated equipment in aluminum containers	D	D	C	D	I	3	3	2	3
Global	Above Ground Fire		contaminated equipment stored in non-compatible material (aluminum) containers, chemical processes generate sufficient heat to cause waste self-ignition		ALARA issue	do not store contaminated equipment in aluminum containers	D	D	D	D	II	4	4	4	4

A.4. ACCIDENT PROGRESSION OF REPRESENTATIVE ACCIDENTS

Even though each accident postulated during the hazard identification process was described as having a unique progression and therefore assigned a single consequence, the actual progression could take several paths and result in different consequences. For example, the HA team postulated that if a fire were to start above a tank at ground level, several accident end-states could be possible. The fire could be confined to the aboveground area and do no damage, could be confined to aboveground but damage HEPA filters containing hazardous material (the HA database consequence assignment), could spread to the tank waste, or could spread to the tank dome space causing a dome fire that may have several possible consequences. In order to show actual accident progression for a limited number of DBAs, event trees were constructed. These trees are presented in Section 4.1.

Even though each event-tree accident end-state can be assigned to a consequence bin, each tree (and therefore each representative accident) was assigned to a representative accident consequence bin. The consequence bin assignment justification is included in Section 4.2. As mentioned earlier, when the HA database was constructed, it was not feasible to include all possible consequences for each accident initiator. Therefore, the team assigned each accident (or initiator) a "representative" consequence corresponding to the outcome considered most likely.

A.4.1. Event Trees

Six of the nine DBAs selected for accident analysis required the construction of event trees. These six are

1. Aboveground fire
2. Dome-space fire
3. Drill-string fire
4. Waste fire
5. Gas release
6. Containment breach (tank loading)

The event trees for each DBA are presented below, along with descriptions of the top events and end-states.

A.4.2. Aboveground Fire

The ev nt tree for an aboveground fire is shown in Fig. A-2. A description of the top eve ts and end-states is presented in TABLE A - 6.

TABLE A - 6
ABOVEGROUND FIRE EVENT TREE DESCRIPTIONS

Top Event	Description
Aboveground fire occurs.	Fire is either initiated at or spreads to an above-tank area.
Flammable-gas concentrates in dome space.	Fuel, oxidizers, and inerting agents exist in sufficient proportions to allow deflagration in the tank dome space.
Fire propagates to tank dome space.	The fire spreads from the above-tank area into the tank dome space volume.
Tank dome space fire occurs.	A fire (deflagration reaction) is initiated in the dome space volume.
Fire propagates to waste.	The (dome space) fire results in waste combustion.
Deflagration to detonation occurs in dome space.	Proper confinement conditions and ratios of fuel, oxidizers, and inerting agents exist to allow a deflagration-to-detonation transition in the dome space.
HEPAs are burned.	Exhauster HEPA filters are ignited by the aboveground fire.
Dome collapses.	A significant portion of the tank dome fails structurally.
End-State	**Description**
No release	(Aboveground) Fire does not cause any radioactive or toxic material release.
HEPA release	Burning results in release of the exhauster HEPA material burden.
Pressure-induced filter blowout	Exhauster HEPA hold-up material is released.
Fire-induced dome collapse	Tank dome deflagration-induced collapse results in an aerosol and toxic gas release.
Detonation-induced dome collapse	Tank dome detonation-induced collapse results in a pressurized aerosol and toxic gas release.
Waste-fire-induced filter blowout	Initial exhauster HEPA burden release followed by release of waste radioactive and toxic combustion products.
Fire-induced dome collapse with waste fire	Initial tank-dome, deflagration-induced-collapse aerosol release is followed by waste radioactive and toxic combustion products release.
Detonation-induced dome collapse with waste fire	Initial tank-dome, detonation-induced-collapse pressurized aerosol is released followed by waste radioactive and toxic combustion products release.

A.4.3. Dome Space Fire

The event tree for a dome-space fire is shown in Fig. A-3. A description of the top events and end-states is presented in TABLE A - 7.

TABLE A - 7
DOME-FIRE EVENT TREE DESCRIPTIONS

Top Event	Description
Tank dome-space fire occurs.	A fire (deflagration reaction) is initiated in the dome-space volume.
Fire propagates to waste.	The (dome-space) fire results in waste combustion.
Deflagration to detonation occurs in dome space.	Proper confinement conditions and ratios of fuel, oxidizers, and inerting agents exist to allow a deflagration-to-detonation transition in the dome space.
Dome collapses.	A significant portion of the tank dome fails structurally.
End-State	**Description**
Pressure-induced filter blowout	Exhauster HEPA hold-up material released.
Fire-induced dome collapse	Tank-dome, deflagration-induced collapse results in an aerosol and toxic-gas release.
Detonation-induced dome collapse	Tank-dome, detonation-induced collapse results in a pressurized aerosol and toxic-gas release.
Waste-fire-induced filter blowout	Initial exhauster HEPA burden release followed by release of waste combustion products.
Fire-induced dome collapse with waste fire	Initial tank-dome, deflagration-induced collapse aerosol release followed by waste radioactive and toxic combustion products release.
Detonation-induced dome collapse with waste fire	Initial tank-dome detonation-induced collapse pressurized-aerosol release is followed by waste radioactive and toxic combustion products release.

A.4.4. Drill String Fire

The event tree for a drill string fire is shown in Fig. A-4. A description of the top events and end-states is presented in TABLE A - 8.

TABLE A - 8
DRILL-STRING FIRE EVENT TREE DESCRIPTIONS

Top Event	Description
Drill string fire occurs.	A fire (deflagration reaction) is initiated in the drill string volume.
Detonation in drill string occurs.	Proper confinement conditions and ratios of fuel, oxidizers, and inerting agents exist to allow a deflagration-to-detonation transition in the drill string.
Fire propagates to waste-gas phase.	The drill string fire propagates to a gaseous waste volume.
Waste fire occurs.	The waste-gas phase fire spreads to result in waste combustion.
Combustibles in dome space occur.	Materials (fuel and oxidizers) that may become involved in a deflagration or detonation reaction materials are present in the dome space.
Deflagration to detonation in dome space occurs.	Proper confinement conditions and ratios of fuel, oxidizers, and inerting agents exist to allow a deflagration-to-detonation transition in the dome space.
Tank dome space fire occurs.	A fire (deflagration reaction) is initiated in the dome-space volume.
Dome collapse occurs.	A significant portion of the tank dome fails structurally.
End-State	**Description**
Minimal radioactive release (small containment breach)	Release of radioactive material is present in sampler and drill-string volume.
Gas release	Waste toxic gas is released.
Waste-fire-induced filter blowout	Initial exhauster HEPA burden is released followed by release of waste combustion products.
Pressure-induced filter blowout	Exhauster HEPA hold-up material is released.
Fire-induced dome collapse	Tank-dome, deflagration-induced collapse results in an aerosol, and toxic gas is released.
Detonation-induced dome collapse	Tank-dome, detonation-induced collapse results in a pressurized aerosol and toxic gas release.
Waste-fire-induced filter blowout	Initial exhauster HEPA burden release is followed by release of waste combustion products.

A.4.5. Waste Fire

The event tree for a tank waste fire is shown in Fig. A-5. A description of the top events and end-states is presented in TABLE A - 9.

TABLE A - 9
WASTE FIRE EVENT TREE DESCRIPTIONS

Top Event	Description
Waste fire occurs.	Fire is initiated in the tank waste, portions of which may be combustible.
Combustibles in dome space occur.	Materials (fuel and oxidizers) that may become involved in a deflagration or detonation reaction are present in the dome space.
Deflagration to detonation occurs in dome space.	Proper confinement conditions and ratios of fuel, oxidizers, and inerting agents exist to allow a deflagration-to-detonation transition in the dome space.
Tank-dome space fire occurs.	A fire (deflagration reaction) is initiated in the dome space volume.
Dome collapse occurs.	A significant portion of the tank dome fails structurally.
End-State	**Description**
Waste-fire-induced filter blowout	Initial exhauster HEPA burden release is followed by release of waste combustion products.
Pressure-induced filter blowout	Exhauster HEPA hold-up material is released.
Fire-induced dome collapse	Tank-dome deflagration-induced collapse results in an aerosol and toxic-gas release.
Detonation-induced dome collapse	Tank-dome, detonation-induced collapse results in a pressurized aerosol and toxic-gas release.

A.4.6. Gas Release

The event tree for a gas release is shown in Fig. A-6. A description of the top events and end-states is presented in TABLE A - 10.

TABLE A - 10
GAS RELEASE EVENT TREE DESCRIPTIONS

Top Event	Description
Gas release from waste occurs.	Random release of gases normally bound in the waste volume
Significant dome pressure occurs.	Dome pressurization is sufficient to result in large volume bypass of HEPA-filtered release path.
Significant unfiltered paths occur.	Large unfiltered leakage paths exist.
Personnel are in tank vicinity.	Personnel (workers) at risk from gas exposure.
Personnel are in breathing suits.	Personnel (workers) in self-contained breathing apparatuses.
Rapid area evacuation is carried out.	Personnel (workers) leave quickly and therefore limit their exposure.
End-State	**Description**
No exposure	Personnel (workers) do not receive toxic gas exposure.
Short, small-volume, low-concentration toxic gas release	Personnel are exposed to short-term, low-concentration toxic gases.
Extended, small-volume, low-concentration toxic-gas release	Personnel are exposed to long-term, low-concentration toxic gases.
Short, large-volume, low-concentration toxic-gas release	Personnel are exposed to short-term, low-concentration toxic gases.
Extended, large-volume, low-concentration toxic-gas release	Personnel are exposed to long-term, low-concentration toxic gases.
Short, small-volume, low-concentration toxic-gas and solids release	Personnel are exposed to short-term, low-concentration toxic gas and solids.
Extended, small-volume, low-concentration toxic-gas and solids release	Personnel are exposed to long-term, low-concentration toxic gas and solids.
Short, large-volume, low-concentration toxic-gas and solids release	Personnel are exposed to short-term, low-concentration toxic gas and solids.
Extended, large-volume, low-concentration toxic-gas and solids release	Personnel are exposed to long-term, low-concentration toxic gas and solids.

A.4.7. Containment Breach (Tank Loading)

The event tree for tank loading (containment breach) is shown in Fig. A-7. A description of the top events and end-states is presented in TABLE A - 11.

TABLE A - 11
TANK LOADING (CONTAINMENT BREACH) EVENT TREE DESCRIPTIONS

Top Event	Description
External load on tank dome	Equipment load placed over tank dome.
Load < design load limit	Load placed atop tank dome exceeds tank-dome structural design limits.
General dome collapse	A significant portion of the tank dome fails structurally.
Localized dome collapse	The portion of the tank dome below the load fails structurally.
Tank-dome space vented	General or localized tank-dome structural failure results in a venting of the tank-dome gases.
Flammable-gas concentration in dome space	Fuel, oxidizers, and inerting agents exist in sufficient proportions to allow deflagration in the tank-dome space.
Tank-dome-space fire occurs	A fire (deflagration reaction) is initiated in the dome-space volume.
Deflagration to detonation in dome space	Proper confinement conditions and ratios of fuel, oxidizers, and inerting agents exist to allow a deflagration-to-detonation transition in the dome space.
Waste fire	The tank load or a dome space fire initiates waste combustion.
Dome collapse	A significant portion of the tank dome fails structurally.

TABLE A - 11 (cont.)
TANK LOADING (CONTAINMENT BREACH) EVENT TREE DESCRIPTIONS

End-State	Description
No release	No radioactive or toxic material exposure.
Dome breach, extended, large-volume, low-concentration, toxic-gas release	Personnel are exposed ~~to~~ long-term, low-concentration toxic gases.
Dome breach, extended, small-volume, low-concentration, toxic-gas release	Personnel are exposed to long-term, low-concentration toxic gases.
Dome breach with waste fire	A waste fire is initiated following a dome breach; waste combustion products are released.
Dome breach with dome fire	A dome-space fire is initiated following a dome breach.
Fire-induced dome collapse	Tank-dome, deflagration-induced collapse results in an aerosol and toxic gas release.
Dome breach with dome and waste fire	A dome-space fire and a waste fire are initiated following a dome breach.
Fire-induced dome collapse with waste fire	Tank-dome, deflagration-induced collapse results in aerosol, toxic-gas, and waste-combustion product releases.
Detonation-induced dome collapse	Tank-dome, detonation-induced collapse results in a pressurized-aerosol and toxic-gas release.
Detonation-induced dome collapse with waste fire	Tank-dome, detonation-induced collapse results in a pressurized-aerosol and toxic-gas as well as a waste-combustion products release.
Dome collapse	Tank-dome collapse results in an aerosol and toxic-gas release.
Dome collapse with waste fire	A waste fire is initiated following a dome collapse; waste-combustion products are released.
Dome collapse with dome fire	A dome-space fire is initiated following a dome collapse.
Dome collapse with dome and waste fire	A dome-space fire and a waste fire are initiated following a dome breach.
Dome collapse with detonation	Pressurized aerosol and toxic gas are released.
Dome collapse with detonation and waste fire	Pressurized aerosol, toxic gas, and waste-combustion products are released.

A.4.8. Justification of Consequence Assignments

The consequence assignments in the hazard identification process were made using the following steps:

1. For each accident in the database, the end-state was either postulated or assigned to the appropriate accident-progression event tree.

2. As was noted earlier for each accident-progression event tree, a representative accident end-state was selected for each event tree. Engineering judgment was used to pick the appropriate end-state, and it is noted that for each event tree, the range of end-state consequences varies greatly. However, an attempt was made to find the most likely end-state, given that no calculation of frequency was attempted.

3. A few members of the Hazards Identification team met and examined previous consequence analysis for the Hanford waste tanks. The team used engineering judgment to assign consequence bin assignments to each accident end-state.

4. A table of accident end-states (which is also the same as the keywords assigned to each accident) was constructed. The table relates the accident end-state to the appropriate letter identifier for each accident-consequence bin as applied to each accident receptor.

A.4.9. Assignment of Accident End-States to Consequence Bins

The accident end-states (which also correspond to accident keywords) are assigned to consequence bins using the previously discussed data and assumptions. TABLE A - 12 shows the accident consequence assignments used in the HA database; TABLE A-2 provides the quantitative doses associated with the consequence bin letter identifiers.

TABLE A - 12
CONSEQUENCE ASSIGNMENTS FOR HAZARD IDENTIFICATION DATABASE

Accident End-State	Public	On-site Worker	Facility Worker	Environment
Dome collapse	B	A	A	B
Dome collapse w/ fire	B	A	A	B
Dome collapse w/ waste fire	A	A	A	A
Filter blowout (SST passive ventilation)	D	C	C	C
Aboveground fire	D	C	C	C
Drill-string fire	D	D	C	D
Waste fire	D	C	C	C
Subterranean spill	D	D	D	C
Gas release (filtered)	D	D	C	D
Aboveground spill	D	D	D	D
Auxiliary equipment fire	D	D	D	D

Figure A.2 Above Ground Fire Event Tree

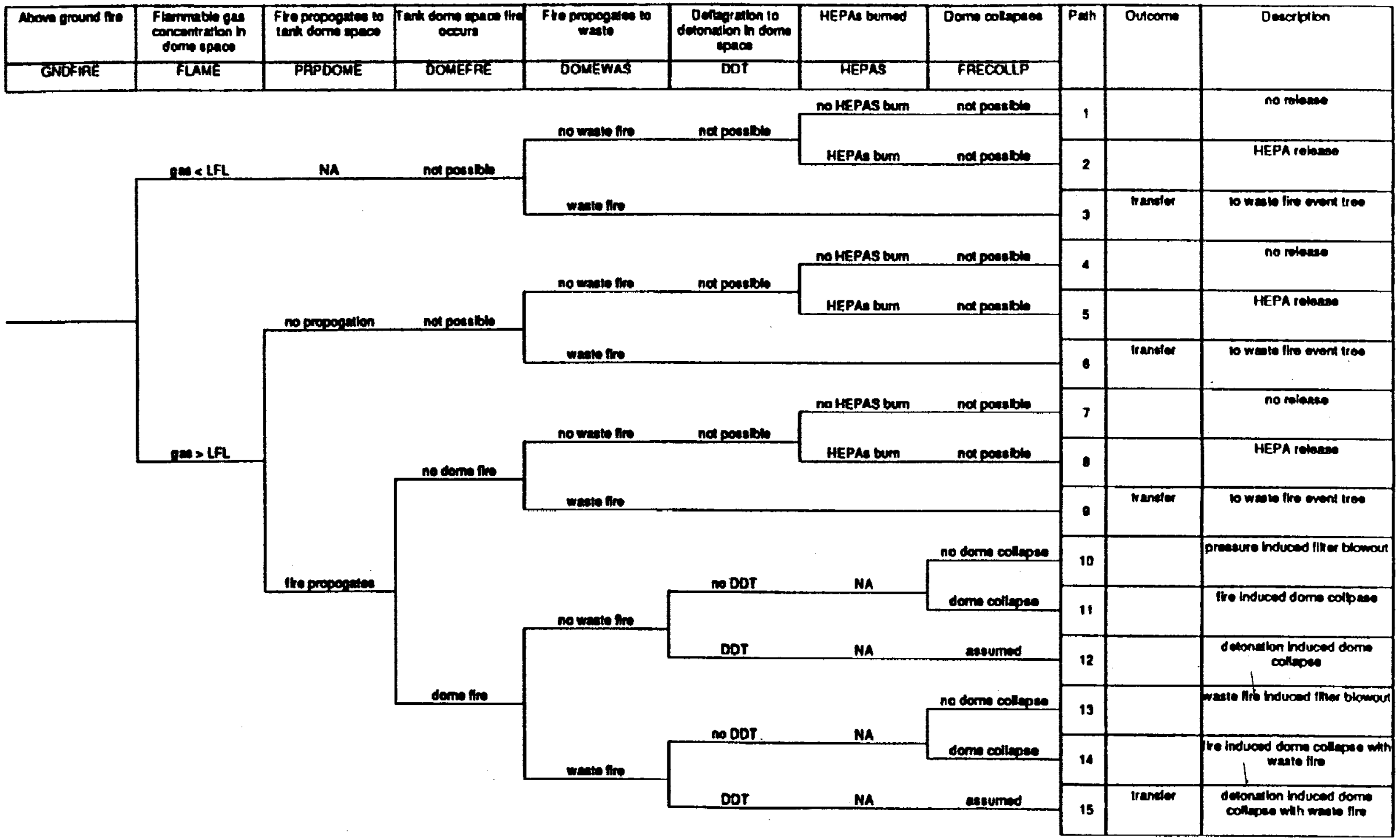


Figure A.3 Dome Space Fire Event Tree

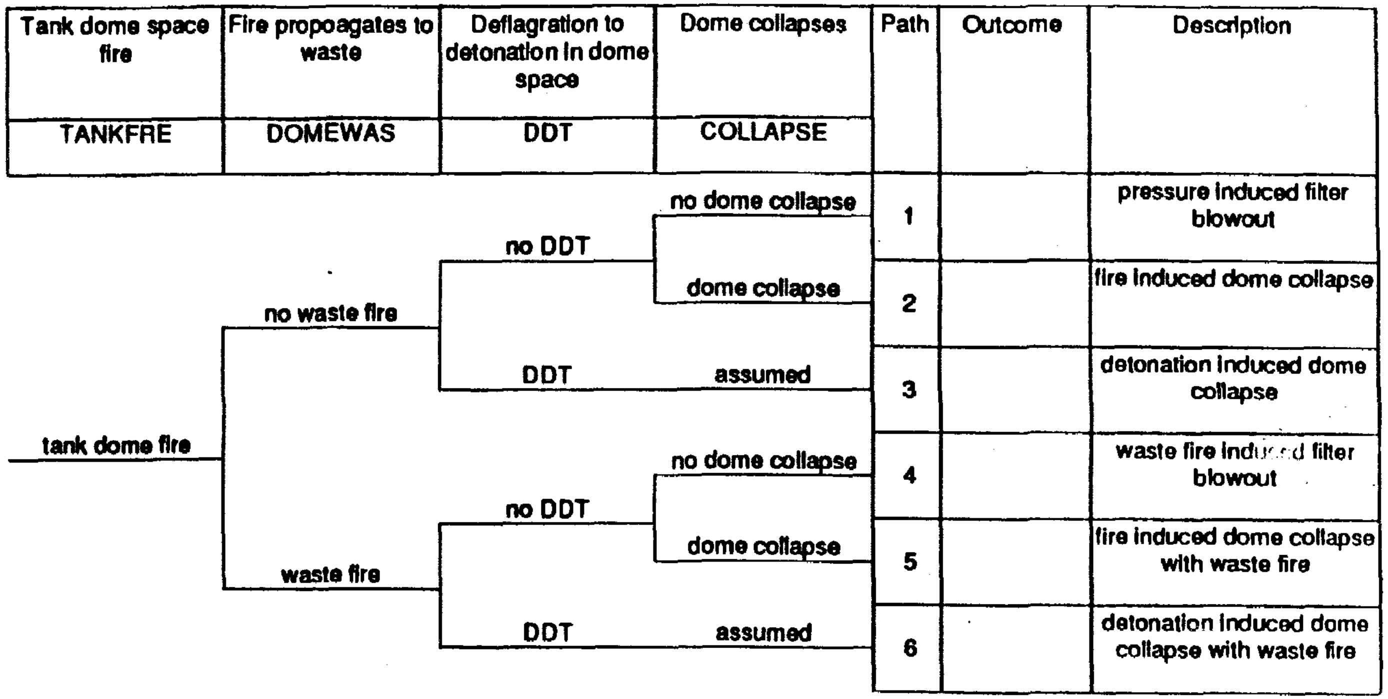


Figure A.4 Drill String Fire Event Tree

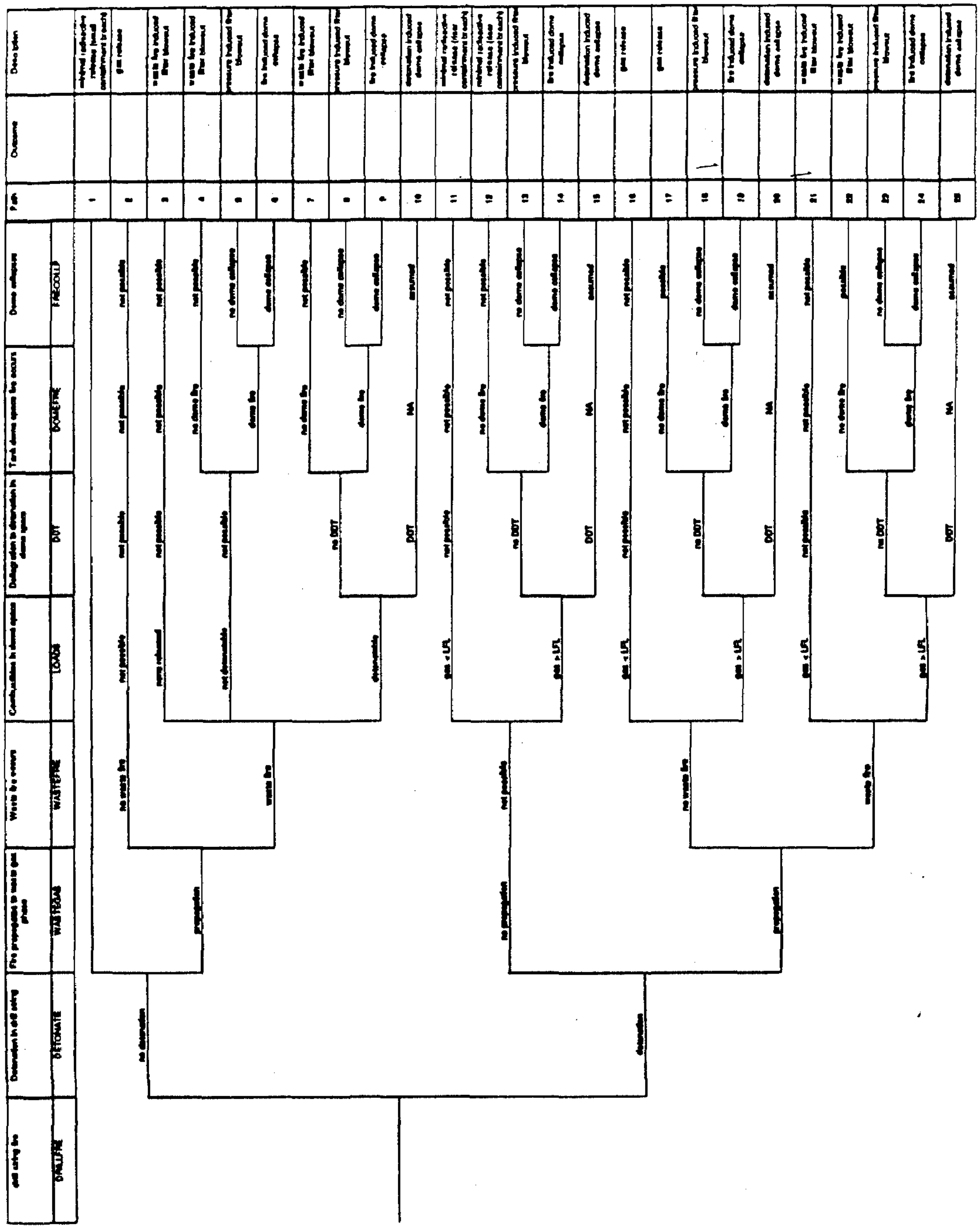


Figure A.5 Waste Fire Event Tree

Waste fire	Combustibles in dome space	deflagration to detonation in dome space	Tank dome space fire occurs	Dome collapses	Path	Outcome	Description
WASFIRE	LOADS	DDT	DOMEFRE	FRECOLLP			
	none released	not possible	not possible	not possible	1		waste fire induced filter blowout
	not detonatable	not possible	no dome fire	not possible	2		waste fire induced filter blowout
			dome fire	no dome collapse	3		pressure induced filter blowout
				dome collapse	4		fire induced dome collapse
	detonatable	no DDT	no dome fire	not possible	5		waste fire induced filter blowout
			dome fire	no dome collapse	6		pressure induced filter blowout
				dome collapse	7		fire induced dome collapse
		DDT	NA	assumed	8		detonation induced dome collapse

Figure A.6 Gas Release Event Tree

Gas Release from waste GASREL	Significant dome pressure increase DOMEPRESS	Significant unfiltered paths to atmosphere PATHS	Personnel in tank vicinity PERSON	Personnel in breathing apparatus SUITS	Rapid area evacuation LEAVE	Path	Outcome	Description
				yes	NA	1		no exposure
		no paths	assumed	no	yes	2		short, small volume, low concentration toxic gas release
	no increase				no	3		extended, small volume, low concentration toxic gas release
				yes	NA	4		no exposure
		paths exist	assumed	no	yes	5		short, large volume, low concentration toxic gas release
					no	6		extended, large volume, low concentration toxic gas release
				yes	NA	7		no exposure
		no paths	assumed	no	yes	8		short, small volume, low concentration toxic gas and solids exposure
	increase				no	9		extended, small volume, low concentration toxic gas and solids exposure
				yes	NA	10		no exposure
		paths exist	assumed	no	yes	11		short, large volume, low concentration toxic gas and solids exposure
					no	12		extended, large volume, low concentration toxic gas and solids exposure

Figure A.7 Tank Loading Event Tree

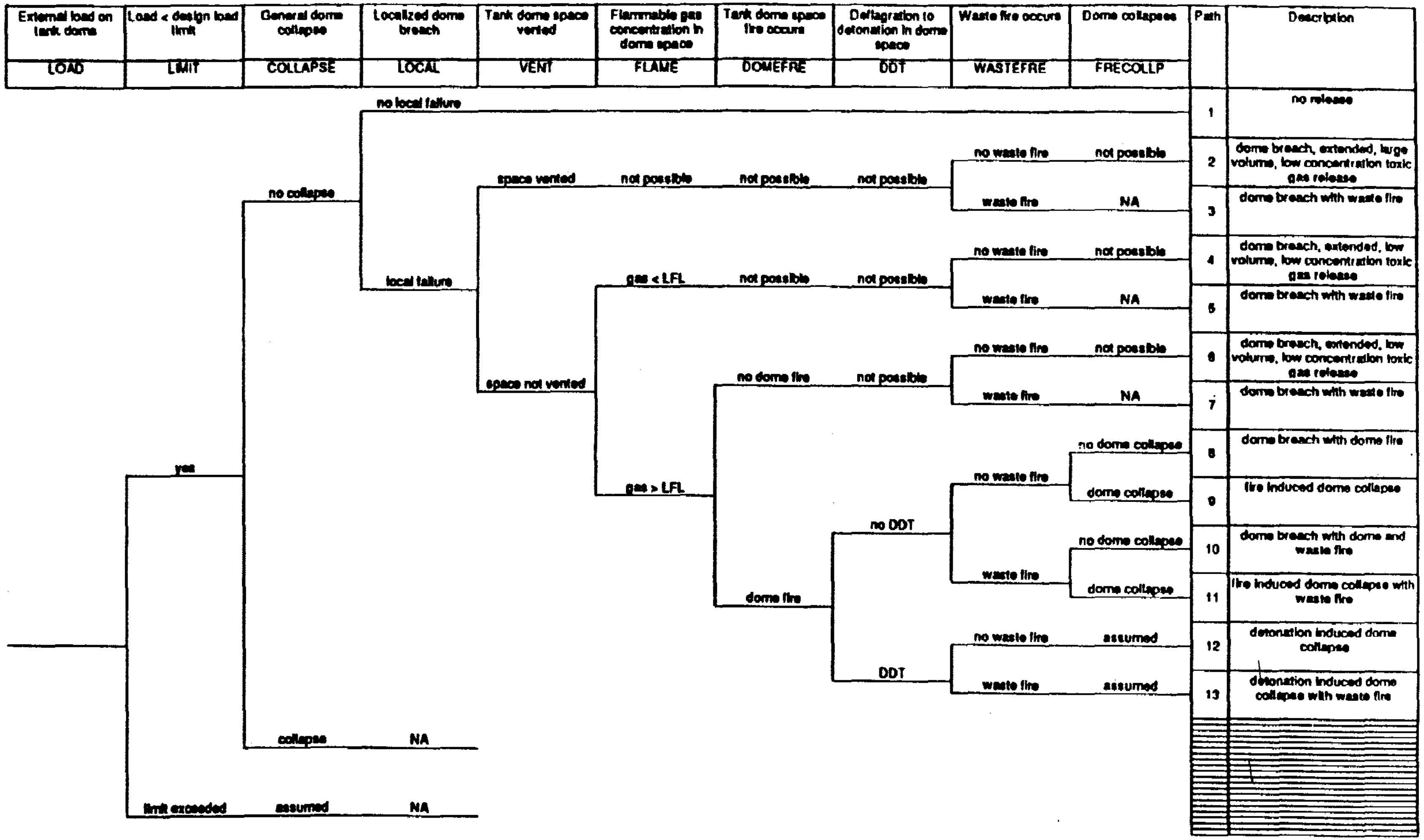
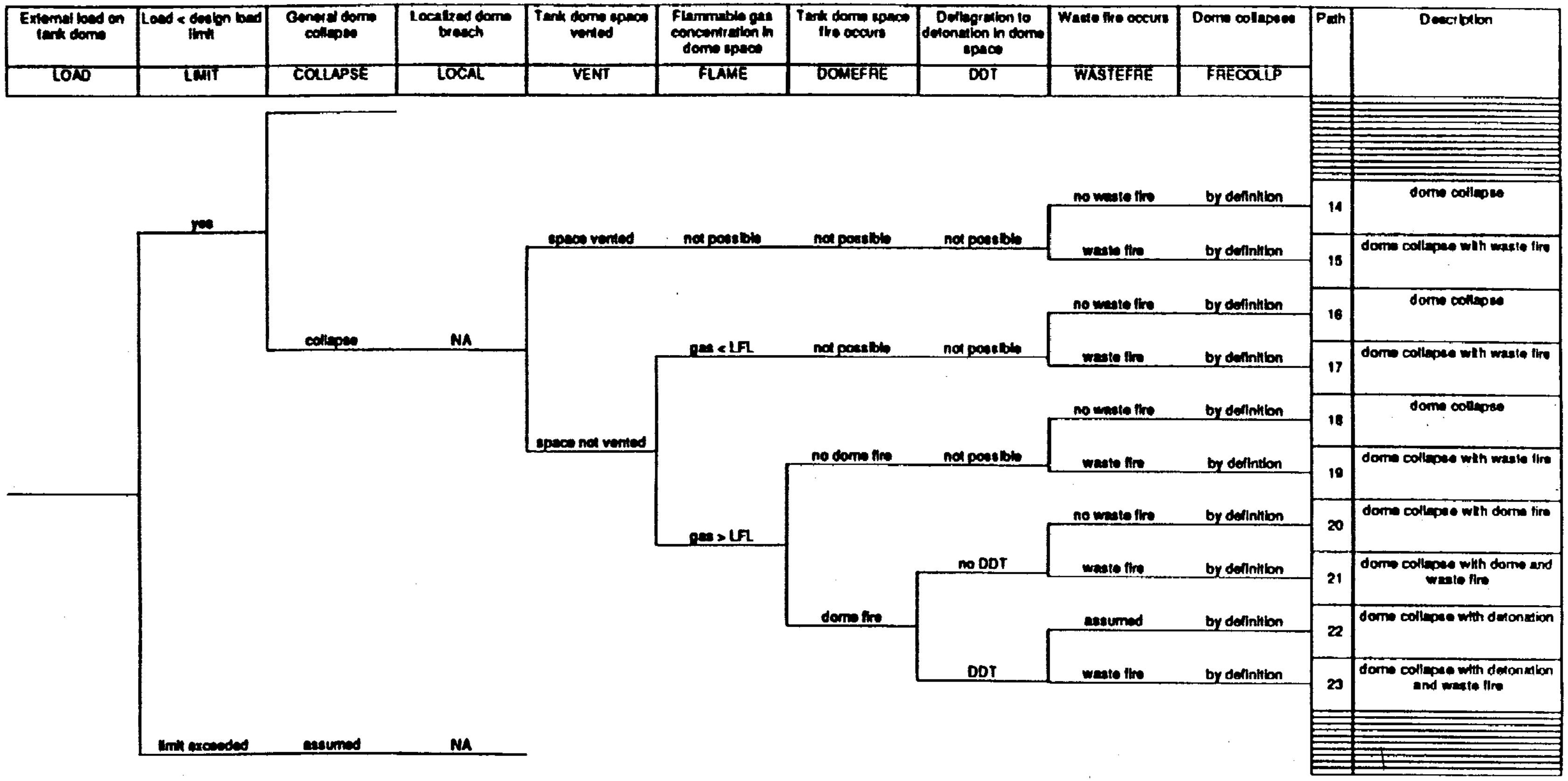


Figure A.7 Tank Loading Event Tree



A.5. REFERENCES

1 . DOE Standard Preparation Guide for U. S. Department of Energy Nonreactor Nuclear Facility Safety Analysis reports DOE-STD-3009-94 (July 1994).

2 . Center for Process Safety of the American Institute of Chemical Engineers, *Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples* (New York, New York, 1992).

APPENDIX B

EQUIPMENT RATING AND AUTOMATIC SHUT-DOWN REQUIREMENTS

B.1. OBJECTIVE

This appendix provides the basis for the requirements imposed on equipment capable of generating sparks in a flammable-gas (FG) environment. Also included in this appendix are the trip set points necessary to shut down the equipment that is not designed to operate in an FG environment.

B.2. BACKGROUND

The gas-retention and release mechanisms in the waste tanks are not fully understood. The understanding is even poorer for the single-shell tanks (SSTs). Although semi-quantitative estimates are available for SST gas-release mechanisms,[1] in the absence of detailed data, it is difficult to argue that such analyses provide bounding estimates. The gas composition and maximum allowable gas-release estimates provided in Appendix C show that, in some of the SSTs, small releases may result in a flammability hazard. Our current understanding of the gas-release phenomena in the SSTs is limited and does not allow us to develop reliable administrative controls to limit or control the gas releases during the proposed intrusive activities. Consequently, the major emphasis in this safety assessment (SA) is on managing the spark sources when flammable gases (FGs) are present. Furthermore, a burn even with a small amount of FGs in the tank dome space is likely to result in dome failure (Appendix C), which may result in unacceptable radiological and toxicological consequences (see Section 5 of this SA) if the failure is catastrophic.

As with gas releases, gas-storage mechanisms are poorly understood. Waste gases may be stored in the waste in the form of elongated/dentritic bubbles that may be connected through the pores. Demonstrating that an ignition in the waste will not propagate also is difficult without a detailed knowledge of pore sizes, heat dissipation mechanisms, and the moisture content in the pores. The pressure resulting from a burn in the waste, the subsequent damage to the tank, and the amount of material release is difficult to bound. Consequently, this SA is aimed at preventing ignition inside the waste as opposed to demonstrating that propagation is impossible.

Under these conditions, as a general rule, design restrictions are imposed so that no single failure should lead to sparking conditions. A minimum of double-engineering protection against a sparking condition is required. These requirements are developed assuming that the likelihood of FG presence during the activity is high.

B.3. SAFETY RATING REQUIREMENTS

During the proposed intrusive activities, the following regions must be carefully protected from possible spark sources:

- Tank dome space,
- Regions below the waste surface (waste volume),
- Confined regions with possible flow paths to waste or waste gas in-leakage and accumulation,
- Pump pits (if not sealed from the dome),
- A specified region outside an open riser or a leak path,
- Tanks adjacent and connected to the subject tank, and
- Other equipment connected to the dome space.

B.3.1. Electrical Equipment

Before beginning the discussion of safety requirements for the electric equipment, it is important to note that the intent of this section is not to develop a National Fire Protection Association (NFPA) classification for the tank farms. NFPA classification requirements are used merely as guidance in achieving the desired very low frequencies for the burn accidents.

During FG/RMCS operations, all electrical equipment located in these regions must be rated to operate in a Class-I, Division-1 (Div.-1) Group-B environment according to NFPA classification. Recognizing the fact that the FGs will not continuously exist in these regions, Class-I, Div.-2, Group-B-rated equipment also may be operated in these regions, provided that they are equipped with a reliable automatic shut-down system. It requires an unlikely sequence of multiple failures and malfunctions for Class-I, Div.-1, Group-B-rated equipment to cause a spark.

Class-I, Div.-2, Group-B equipment is capable of sparking upon single failure. Consequently, such equipment must be protected by a reliable shut-down circuit. Furthermore, the background concentrations of FGs must be measured and shown to be less than 25% of the lower flammability limit (LFL) before energizing this equipment. In order to cause a spark, a sequence of double independent failures are necessary (the shut-down circuit must fail, and the Class-I, Div.-2, Group-B equipment must also fail simultaneously). If Class-I, Div.-2, Group-B equipment is used in the above regions, the reliability of the shut-down circuit must be evaluated and must be shown that it will perform with a desired reliability.

All equipment that must continue to operate upon detection of FGs must be designed to Class-I, Div.-1, Group-B requirements. Examples of such equipment are the ventilation fan needed to discharge the FGs and FG monitoring equipment.

Regions immediately adjacent to the Class-I, Div.-1, Group-B regions discussed above are automatically classified as Class-I, Div.-2, Group-B spaces, and the equipment must meet the requirements of this classification.

B.3.2. Mechanical Systems

All moving mechanical systems capable of generating frictional forces must be assumed to be sparking, unless bounding analyses or experiments show otherwise. Without specific experiments, it is very difficult to demonstrate that such mechanical systems will not generate sparks capable of igniting the flammable mixtures of interest. Consequently, such mechanical systems also must have double protection against either sparking or being exposed to a flammable atmosphere. The necessary protective measures could be a combination of the following systems:

- Spark-resistant and electrically conductive material(s) (to protect against static electricity buildup) must be used in the regions specified above.
- Mechanical devices must be protected by a seal that prevents waste or FG in-leakage.
- The region around the mechanical device must be protected by an adequate purge. The adequacy of the purge system must be demonstrated by analysis.
- Upon loss of purge flow, the system must be quickly deenergized.
- Upon detection of FGs, the system must be quickly deenergized before the gas mixture reaches the LFL.

As a minimum, two of the above methods must be used to protect the mechanical systems capable of sparking. Depending on the reliability required by accident analysis, more than two systems may be necessary.

B.3.3. Equipment over the Tank Dome

Using an algebraic momentum jet model,[2] FG concentration as a fraction of the source concentration may be obtained from the following equation:[2,3]

$$\frac{C_c}{C_o} = \frac{(\lambda^2+1)}{\lambda^2}\frac{0.25}{\left[1.414\alpha\frac{(s-s_o)}{D}+0.5\right]} \quad \text{for } s \geq s_o, \qquad \textbf{(B-1)}$$

where C_c is the centerline concentration, C_o is the source concentration, s_o is the jet length in the establishment zone ($s_o = 6.2 \times D$), s is the distance to the source, D is the source diameter, λ is the spreading parameter ($\lambda = 1.16$ taken from Ref. 2) and α is the empirical entrainment parameter.

Setting the source concentration to 8% and using an entrainment parameter $\alpha = 0.057$, the jet centerline concentration drops to 2.4% at a distance of 18 diameters. Using a Gaussian concentration profile,[2] the concentration at the axial distance of 18 D drops to <0.6% at a radial distance of 2.2 x D from the jet centerline.[3] The centerline concentration drops to 1.2% at a distance of 36 x D away from the source.[3]

As discussed in Appendix C, 2.4% H_2 corresponds to the LFL of gas mixtures that are very rich (70%) in ammonia and <30% in hydrogen. For these gas mixtures, prompt gas releases >283 m^3 (10,000 ft^3) are required to exceed the 8% H_2 concentration at the source. If we postulate pure hydrogen releases, only 113 m^3 (4000 ft^3) of prompt release may result in 8% H_2 in the source. However, the LFL of hydrogen is 4%. A hydrogen concentration of 4% at 18 diameters away from the source corresponds to 13.3% H_2 at the source, which requires a prompt release >190 m^3 (6700 ft^3). These calculations are based on a minimum dome volume of 1400 m^3 (50,000 ft^3). Therefore, it is believed that an 8% H_2 concentration at the source combined with 2.4% H_2 because the LFL provides a conservative bound. Based on the model discussed in Appendix L, the frequency of exceeding 8% H_2in the dome would be ~10^{-3} per intrusion.

Entrainment Parameter. The use of $\alpha = 0.057$ is conservative because this value is the lowest magnitude given in Ref. 2. Using the linear mixing law model and the momentum jet solution provided in Schlichting,[4] α is obtained as 0.087. As shown in Eq. (B-1), larger α results in enhanced dilution within a given distance. Furthermore, this analysis does not account for atmospheric turbulence that would further enhance the entrainment.

Probability of Exceeding 2.4% H_2. If we assume a random spark source in the hemispherical region around an open riser, the probability of exceeding 2.4% H_2at the spark location is computed in Ref. 3 and shown in Fig. B-1. As shown in this figure, the probability of exceeding 2.4% H_2 drops below 10^{-3} at distances ≥16 x D.

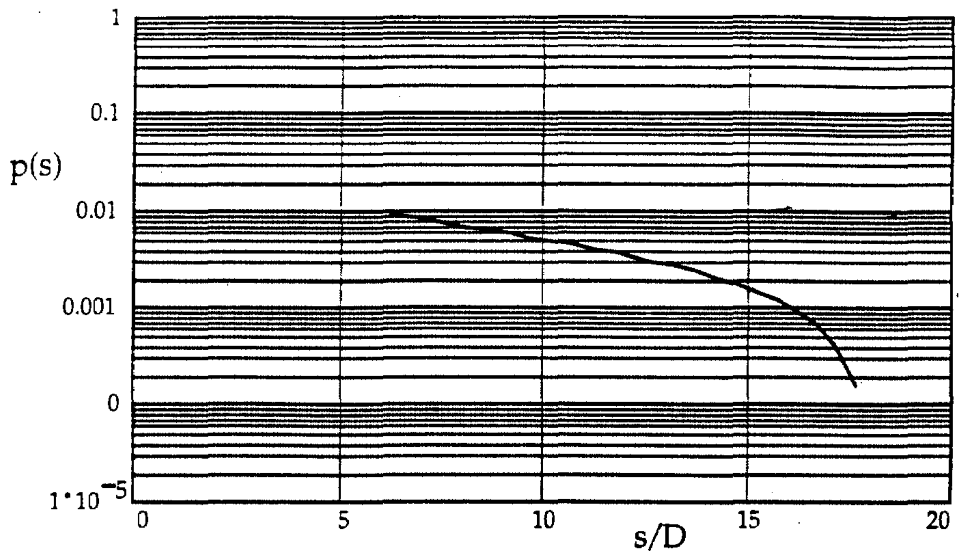


Fig. B-1. Probability of exceeding 2.4% H_2.

The jet direction is determined by the direction of the open area, initial momentum, buoyancy, and wind direction. In general, the open riser will result in a vertical jet unless the direction is affected by the wind. Thus, the above probabilities may be reduced further by not placing the equipment directly above an open riser and in the prevailing wind direction. The jet coming out of an opening typically is buoyant because

- The dome space is warmer than the ambient, and
- The waste gases are lighter than air if they are predominantly flammable (hydrogen, ammonia, and methane).

Thus, to reduce the probability of the equipment being exposed to a flammable atmosphere, the equipment should be placed near ground level and in the opposite direction to the prevailing wind direction. Furthermore, any opening directly aimed at the equipment location must be sealed, or the equipment must be protected from direct jet impingement.

Based on these conservative calculations, up to a distance of 18 diameters away from the source, the equipment must be rated for operation in a Class-I, Div.-1, Group-B environment. Equipment rated for Class-I, Div.-2, Group-B may also be used, provided it is automatically deenergized upon detection of FGs in the riser.

At distances from 18 x D to 36 x D, the equipment must be rated for operations in Class-I, Div.-2, Group-B environments and must be deenergized manually upon detection of FGs in the dome space.

If the above classification conditions cannot be met, the open riser must be equipped with a flame arrester to prevent flame propagation into the dome, provided that the consequences of an external fire are shown to be acc :ptable.

B.4. AUTOMATIC SHUT-DOWN REQUIREMENTS

If an automatic shutdown of equipment upon detection of FGs is relied upon, the shut-down system

- must be reliable,
- must respond to rapid transient surges, and
- must be located near the equipment that will be shut down.

The reliability of the protective systems (shut-down systems) is discussed in Appendix D of this SA.

To protect against spatial maldistribution of gases in the dome space, the gas samples must be taken from the region where the target equipment is located. During operations with an active ventilation system, the sampling in the vent lines is adequate, provided that the trip points are conservatively set.

The FG concentrations in the tank dome space are typically very low during the steady-state periods. Only during a gas-release event (GRE) does the FG concentration start to increase. If the gas release rates are high, the FG concentrations may increase very rapidly. Slow detectors may not be able to perform their shut-down function adequately during fast GREs. In this SA, two detection mechanisms are considered,

- Trip on high hydrogen concentration or on a high rate of hydrogen increase, and
- Trip on high dome pressure.

B.4.1. Hydrogen Trip

The adequacy of a hydrogen detector time constant is assessed using the Whittaker cell analysis. The standard hydrogen monitoring systems (SHMS) that are used in the tank farms contain Whittaker hydrogen detection cells. These cells measure 90% of a step change in <2 min.[5] If we assume a first-order relaxation model that is adequate for diffusion-based devices, the time constant of the cell is obtained as 52 s (Ref. 6). Also using a first-order relaxation model and a constant rate of increase in hydrogen concentration expressed as

$$X_a(t) = \frac{(X_s - X_o)}{T} t + X_o \quad , \qquad \text{(B-2)}$$

where X_a is the actual hydrogen concentration, X_o is the background (initial) concentration, X_s is the target concentration, T is the time necessary for the actual concentration to reach the target concentration, and t is the time. For a linear increase in the actual hydrogen concentration, the measured hydrogen concentration (X) may be obtained as[5]

$$X(t) = \begin{cases} (X_s - X_o)\frac{\tau}{T}\left(e^{-(t-t_d)/\tau} + \frac{(t-t_d)}{\tau} - 1\right) + X_o & t \geq t_d \\ X_o & t < t_d \end{cases} \quad , \qquad \text{(B-3)}$$

where t_d is the delay time (time that it takes to transport the dome gases to the instrument). Figure B-2 shows the necessary trip set points to deenergize the equipment before the dome concentration reaches 2.4% H_2. The following assumptions are used in obtaining the results shown in Fig. B-2:

- Initial background concentration (X_o) is 1000 ppm,
- After the trip is initiated, it takes 10 s to deenergize the circuits of interest totally,
- The monitor provides one data point per ~5 s, and a minimum of 10 s worth of data is needed for a rate trip,
- X_s is set to 2.4%,
- Dome volume is equal to 1416 m^3 (50,000 ft^3), and
- 90% of the waste gas is hydrogen.

Based on Fig. B-2, by setting the trip point at 5000 ppm H_2, the equipment can be deenergized on time if the release rate into the dome is ≤0.47 m^3/s (1000 ft^3/min).

If a rate trip set at 100 ppm/s is used, such a trip will provide protection for release rates between 0.14 and 1 m^3/s (300 and 2200 ft^3/min). Thus, in the range between 0.14 and 0.71 m^3/s (300 and 1500 ft^3/min), both the concentration trip and the rate trip will deenergize the equipment before reaching the target concentrations. A rate trip of 100/s corresponds to a concentration increase of 1000 ppm over the 10 s averaging time. Setting the rate trip to lower values may result in premature and unnecessary shutdown when there are small fluctuations in the instrument readings.

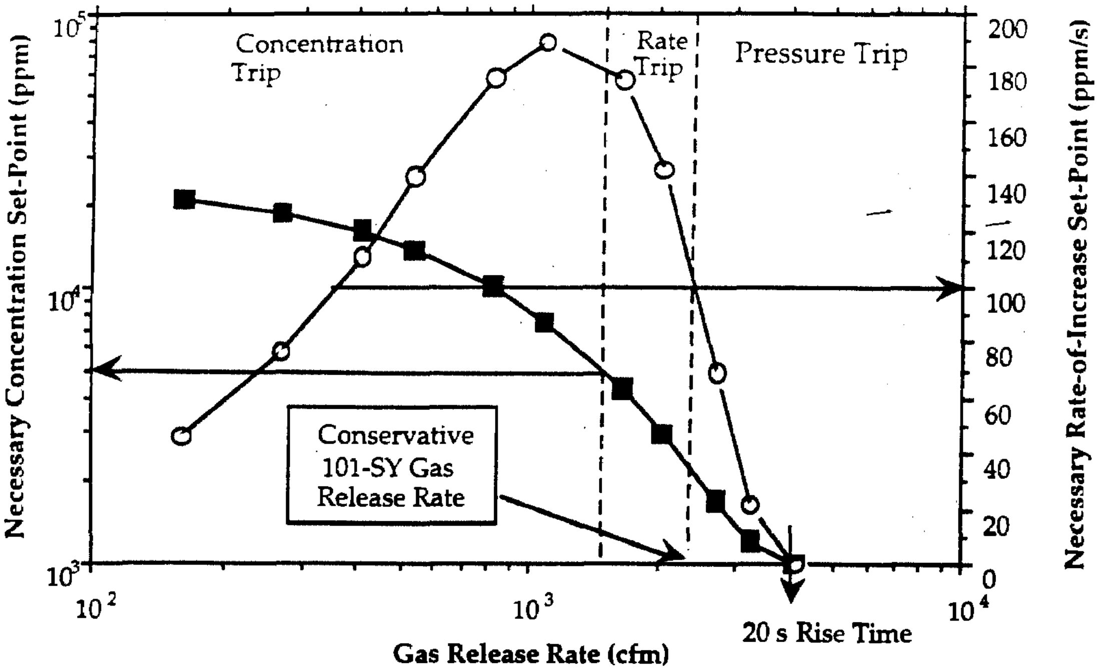


Fig. B-2. Necessary trip points to shut down the equipment before the concentration reaches 2.4% H_2 during constant rate of concentration increase.

A trip based on hydrogen concentration is not adequate in protecting against gas-release rates ≥1 m^3/s (2200 ft^3/min). Note that 1 m^3/s (2200 ft^3/min) is the conservative gas-release rate obtained for 101-SY releases during the first 200 s of a rollover. Based on the analysis provided in Ref. 1, the best-estimate release rates for the most likely fast-release scenario in SSTs is 0.006 m^3/s (12 ft^3/min).

B.4.2. Pressure Trip

No specific analysis is performed for the pressure traces during a large gas release. The experience in 101-SY demonstrated that for release rates as low as 0.19 m^3/s(400 ft^3/min), the dome space experiences pressure pulse of 50.8 mm (2 in.) w.g. or greater. The pressure pulse is a function of the dome volume, relief area, and the pressure drop through the relief area. The relief area for Tank 101-SY is 0.145 m^2 (226 ft^2).

A pressure pulse of 50.8 mm (2 in.) w.g. would correspond to a 0.5% increase in the dome pressure. If we use a dome volume of 1416 m^3 (50,000 ft^3), which is the ideal gas law and adiabatic compression, a 5.1-m^3 (180-ft^3) sudden release into the dome is sufficient to generate a 2-in. w.g. pressure pulse. Thus, large release rates ≥0.47 m^3/s (1000 ft^3/min), a pressure switch set at 50.8 mm (2 in. w.g.) above the background pressure will detect the gas release and deenergize the equipment.

B.4.3. Automatic Shut-Down Trips

For deenergizing the equipment that does not meet Class-I, Div.-1, Group-B requirements, the automatic shut-down trip may be set by using the hydrogen detectors and a dome pressure gauge. The hydrogen detector switch must be set to ≤5000 ppm, and the pressure gauge trip must be set to 50.8 mm (2 in. w.g.) w.g. above the background pressure. The trip for the rate of increase must be set to 100 ppm/s (averaged over 10 s).

If FGMs are used instead of a hydrogen detector, upon availability of the calibration curves, the FGM should be set to provide an equivalent trip to 5000 ppm H_2 and a 100 ppm/s rate of increase in the hydrogen. Also, it must be confirmed that the response time of the FGM is bounded by the assumptions listed above.

B.5. REFERENCES

1. R. T. Allemann, "A Discussion of Some Mechanisms for Sudden Gas Release from Single-Shell Waste Tanks," Pacific Northwest Laboratory letter report PNL-WTS-101095 (October 1995).

2. B. Gebhart, D. S. Hilder, and M. Kelleher, "The Diffusion of Turbulent Buoyant Jets," *Advances in Heat Transfer* **16** (Academic Press, Inc., 1984).

3. K. O. Pasamehmetoglu, "Flammable Gas Concentration Outside an Open Riser," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-GR-044 (December 1995).

4. H. Schlichting, *Boundary Layer Theory*, 7th Edition (McGraw-Hill, New York, 1979).

5. T. C. Schneider, "Wittaker Electro-Chemical Cell H_2 Monitoring System Accuracy," Westinghouse Hanford Company memorandum to G. F. Vargo (January 8, 1993).

6. K.O. Pasamehmetoglu, "Automatic Shutdown Requirements," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-GR-045 (November 1995).

APPENDIX C

BOUNDING GAS COMPOSITION, LEAN FLAMMABILITY LIMIT, AND ALLOWABLE GAS RELEASE AND BURN VOLUMES

C.1. OBJECTIVE

This appendix provides a bounding estimate for the gas composition of the waste gas that might be released during intrusive operations in single-shell tanks (SSTs) that are on the Flammable Gas Watch List (FGWL). This appendix also evaluates the bounding value for the lower flammability limit (LFL) for the estimated gas compositions. A brief summary of the maximum allowable gas-release volumes into the dome space and the maximum allowable burn volume in the waste are discussed in this appendix. Finally, the current estimates for the gas inventory in the tanks are summarized and compared to the maximum allowable releases.

C.2. SST DOME VOLUMES

The SST types typically are characterized by their waste storage capacity. The three types of interest and the associated tanks are summarized in Table C-1.

Figure C-1 shows a schematic of the different types of SSTs in which the characteristic dimensions taken from Ref. 1 are given in Table C-1. The dome vapor space volumes are obtained assuming an ellipsoidal dome, as shown in Fig. C-1, where H is the dome apex height, W is the height of the cylindrical tank, R is the tank radius, and L is the waste level. Using the approximate waste levels obtained from Refs. 2 and 3, the dome volumes (V) are calculated[4] and reported in Table C-2. Also, the maximum drop height (Z) used during a dome collapse accident and the waste volume (V_W) are shown in Table C-2

C.3. GAS COMPOSITION

There is no direct measurement for the waste gas composition for any of the tanks. The waste gas composition must be inferred from dome space concentration data. Unfortunately, there are very limited data regarding concentration in the dome space of the SSTs. The SSTs that are on the FGWL currently are being instrumented with a standard hydrogen monitoring system (SHMS) for continuous hydrogen measurements. As a means of baselining the SHMS, vapor grab samples from the FGWL SSTs were taken during the summer of 1995, and the samples were analyzed using mass spectroscopy. The resulting data are reported in Ref. 5. Only the noncondensable gases are identified in the grab samples.

TABLE C-1
CAPACITY AND CHARACTERISTIC DIMENSIONS OF THE SSTS OF INTEREST

TYPE	CAPACITY (gal.)	TANKS	R (ft)	W (ft)	H (ft)
1	1,000,000	A-101, AX-101, AX-103, SX-101, SX-102, SX-103, SX-104, SX-105, SX-106, and SX-109	37.5	32.5	12.0
2	758,000	S-102, S-111, and S-112	37.5	22.5	14.0
3	530,000	T-110, U-103, U-105, U-107, U-108, and U-109	37.5	19.2	9.5

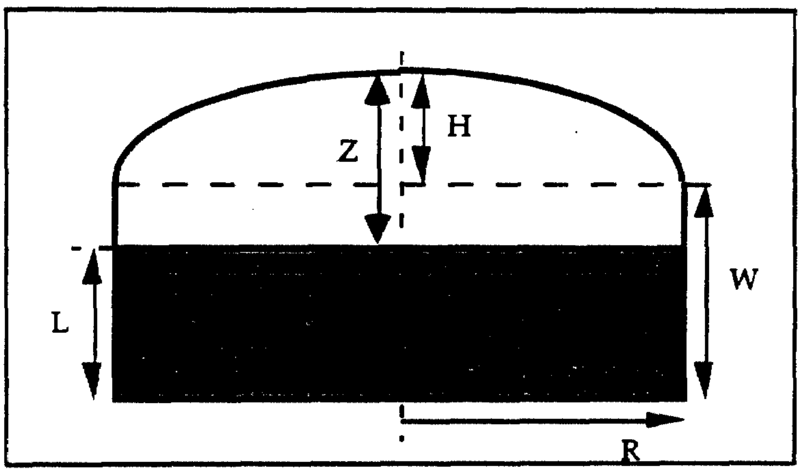


Fig. C-1. Schematic of an SST. **(Dish bottom is not represented in this figure.)**

TABLE C-2
DOME VOLUMES AND IMPORTANT DIMENSIONS

TANK	L (in.)	V (ft^3)	V_W (ft^3)	Z (ft)
A-101	345	51,910	127,010	15.8
AX-101	278	76,570	102,350	21.3
AX-103	42	163,460	15,640	41.0
SX-101	172	115,600	63,320	30.2
SX-102	205	103,450	75,470	27.4
SX-103	245	88,720	90,200	24.1
SX-104	237	91,570	87,250	24.8
SX-105	257	84,310	94,620	23.1
SX-106	207	102,710	76,210	27.3
SX-109	95	143,950	34,980	36.6
S-102	205	65,160	75,470	19.4
S-111	205	65,160	75,470	19.4
S-112	197	68,110	72,530	20.1
T-110	148	57,600	54,490	16.3
U-103	167	50,600	61,480	14.8
U-105	150	56,860	55,220	16.2
U-107	168	50,240	61,850	14.7
U-108	165	51,340	60,750	14.9
U-109	145	58,700	53,380	16.6

C.3.1. Noncondensable Gas Composition

The sample analysis provided dome concentrations for hydrogen, methane, and nitrous oxide. The available data are converted to waste-gas composition, assuming that these three species make up the noncondensable portion of the waste gas. The following model is used in converting the measured concentrations into a waste-gas composition estimate:[6]

$$X_{nc,hydrogen} + X_{nc,methane} + X_{nc,nitrous} = 1 \quad , \tag{C-1}$$

$$\frac{X_{nc,hydrogen}}{X_{nc,nitrous}} = \text{constant} \quad \text{and} \quad \frac{X_{nc,methane}}{X_{nc,hydrogen}} = \text{constant} \quad \text{or} \quad \frac{X_{nc,methane}}{X_{nc,nitrous}} = \text{constant}. \tag{C-2}$$

This model is based on the assumption that the species ratios obtained from the dome space measurements are the same for the gas bubbles that exist in the waste. Thus, it is assumed that

- The mass transfer (including the molecular diffusion out of the waste) from the waste surface is negligible, and
- The species ratios are established by equilibrium in the waste prior to initiation of GRE.

The noncondensable species of interest are not very soluble in the waste. Consequently, the mass-transfer effects are expected to be negligible. Likewise, provided that all the species are generated at constant proportions independent of the location, the surface diffusion effects also are expected to be small. As discussed later the amount of methane in all the tanks analyzed is small. Thus, the uncertainties associated with the above assumptions for methane releases are not expected to influence the final conclusions. Continuous monitoring data for nitrous oxide and hydrogen concentrations during and between large gas-release events are available for Tank 101-SY. The data show that during steady-state releases, the nitrous oxide concentration is slightly above the hydrogen concentration (nitrous-oxide-to-hydrogen ratio is >1). During gas-release events (GREs), the hydrogen-to-nitrous-oxide ratio is slightly less than 1 (see Ref. 7). Moderate solubility of nitrous oxide, the response time, the accuracy of different instruments used for monitoring hydrogen and nitrous oxide, and variations in the waste temperature near the surface may be responsible for small differences. As long as the results of the present model are interpreted conservatively, such small differences are not expected to influence the conclusions.

In determining the bounding gas composition in which the fuel is maximized, $X_{nc,hydrogen}/X_{nc,nitrous}$ and $X_{nc,methane}/X_{nc,hydrogen}$ ratios are used. In cases where the nitrous oxide is maximized for toxicological release analysis, $X_{nc,hydrogen}/X_{nc,nitrous}$ and $X_{nc,methane}/X_{nc,nitrous}$ ratios are used.

In summary, for each grab sample obtained from a given tank, the ratios shown in Eq. (C-2) are computed. The mean values and the standard deviations for these ratios are obtained using all the grab samples' data from a given tank. To obtain the bounding gas composition with the maximum fuel content, $X_{nc,hydrogen}/X_{nc,nitrous}$ and $X_{nc,methane}/X_{nc,hydrogen}$ ratios are obtained as the mean plus 2 standard deviations (for tanks where there are greater than two samples). For tanks with only two samples, the maximum computed ratio is used.

The same methodology is followed in obtaining the gas composition with maximum nitrous oxide content. For this case, mean plus 2 standard deviations are used for $X_{nc,nitrous}/X_{nc,hydrogen}$ and $X_{nc,nitrous}/X_{nc,methane}$ ratios for tanks with more than two grab samples. The maximum of the two samples is used for tanks with only two grab samples.

In the grab samples, the minimum detection limit appears to be 1 to 2 ppm. Thus, analyzing samples with very low waste gas concentrations results in a bias toward the minor species. Consequently, only those samples that contain hydrogen concentrations that are ≥30 ppm are analyzed. The results are shown in Table C-3.

As shown in Table C-3, in general, the tanks in the A, AX, S and SX Farms appear to be rich in fuel (hydrogen and methane), with the exceptions of AX-103 and S-102, which show ~40% N_2O in the release gas. The maximum hydrogen concentration is estimated as 89.2% for Tank SX-106. The maximum methane concentration is estimated for Tank AX-103 as 7.2%. However, the grab sample data for this tank yielded low concentrations in the dome space and are believed to be biased toward minor species (methane). The maximum methane concentration measured in the dome of AX-103 is 3%. Furthermore, the waste level in this tank is only 1.07 m, and the flammable-gas (FG) release in this tank with a large dome volume is not expected to be a major problem.

The tanks in the U Farm appear to be richer in nitrous oxide. The upper-bound estimate for the nitrous oxide is obtained as 75.4% in Tank U-105. This value will be used to compute the toxicological consequences of nitrous oxide releases.

Justifying the use of tank-specific gas compositions based on these analyses is difficult. The difficulty is primarily in extrapolating steady-state gas concentration measurements to predict the gas concentration during a prompt release event and stems from the modeling assumption discussed above. Conservatively, the gas ratios used in obtaining the values in Table C-3 are evaluated at 2 standard deviations in which either fuel or nitrous oxide is maximized and the existence of nitrogen (that is known to be generated in the waste) is ignored. However, the concentrations shown in Table C-3 are obtained using a very limited database. Furthermore, the SSTs within a given farm are connected through overflow lines, and most SSTs are passively ventilated. Consequently, it is possible that the dome gases in connected tanks intermix, and the grab sample data may not necessarily represent the waste gas that is released from a specific waste tank. Thus, we must be cautious in using the computed gas compositions on a tank-by-tank basis.

To determine the bounding case, the concept of equivalent fuel[6] is used for the compositions shown in Table C-3. Table C-3 lists the equivalent fuel in terms of hydrogen concentration in the noncondensable waste gas. The equivalent fuel[6] is obtained as

$$EF = R_m \times X_{methane} + X_{hydrogen} \quad , \qquad \text{(C-3)}$$

where R_m is the ratio of combustion energy of methane (798 kJ/mole) to the combustion energy of hydrogen (241 kJ/mole). Thus, R_m is obtained as 3.32.

TABLE C-3
HYDROGEN, NITROUS OXIDE, AND METHANE FRACTION IN THE NONCONDENSABLE RELEASE GAS

	MAXIMUM FUEL				MAXIMUM N_2O
TANK	$X_{hydrogen}$ (%)	$X_{methane}$ (%)	$X_{nitrous}$ (%)	EF (%H_2)	$X_{nitrous}$ (%)
A-101	86.7	1.3	12.0	90.9	15.4
AX-101	88.1	4.5	7.4	103.0	11.3
AX-103	55.1	7.2	37.7	79.1	49.6
SX-101					
SX-102	81.4	4.6	14.0	96.8	15.4
SX-103	79.7	3.8	16.4	92.4	18.1
SX-104					
SX-105	81.8	3.0	15.2	91.9	15.2
SX-106	89.2	3.7	7.1	101.7	33.3
SX-109					
S-102	59.1	0.9	40.0	62.2	42.5
S-111	82.8	2.2	15.0	90.0	17.8
S-112					
T-110					
U-103	51.9	1.5	46.6	57.0	61.2
U-105	40.9	1.6	57.5	46.2	75.4
U-107	53.3	2.1	44.6	60.4	62.6
U-108	59.2	2.1	38.7	66.2	57.2
U-109	55.0	1.4	43.6	59.7	58.7

(Hatched cells:) The data from these samples are not used because the concentrations are either too low or are reported as less-than values.

Based on this analysis, the composition obtained for Tank AX-101 results in the maximum equivalent fuel being 103% H_2 and appears to be the limiting composition for the flammability analysis at the conditions prior to GRE.

C.3.2. Condensable Gases

The gas monitoring done in the tank farms in general show that almost all tanks contain and release ammonia. Unfortunately, there are limited ammonia data available to quantify the amount of ammonia in the tanks of interest. Because the waste in SSTs is typically older than the waste in the double-shell tanks (DSTs) for which ammonia content estimates are available, the amount of dissolved ammonia in the SST waste is expected to be higher than the amount of ammonia in the DST waste. There are two DSTs for which there are sufficient data to estimate the ammonia content in the waste gas during a release event. For Tank 101-SY, the maximum ammonia fraction in the release gas, including the mass transfer from a freshly exposed surface during a rollover, is obtained as 15%.[7] For Tank 103-SY, the bounding ammonia fraction in the release gas is given as 17%.[8]

For Tank A-101, the amount of dissolved ammonia is estimated by comparing the total organic carbon, radiolytic loads, sodium nitrite inventory, and the age of the waste to Tank 101-SY waste using bounding assumptions.[9] Based on these calculations, the mean plus 2 standard deviations ammonia fraction in the release gas is estimated as ~40%.[9] Currently, similar analyses are not available for other tanks.

There are limited amounts of ammonia data available in Ref. 10. Typically, one value for a few of the tanks on the FGWL is reported, along with the corresponding value of nitrous oxide and hydrogen. Nitrous oxide and hydrogen values are within the range reported in Ref. 1. The gas concentration measurements reported in Ref. 10 are given in Table C-4 for those tanks that are on the FGWL. Data for each tank on Table C-3 are not available.

TABLE C-4
GAS CONCENTRATION DATA REPORTED IN REF. 10

TANK	NH_3 (ppm)	H_2 (ppm)	N_2O (ppm)	$X_{ammonia}$ (%)
A-101	754	758	218	46.5
S-102	412	669	509	26.8
S-111	122	391	48	20.5

TABLE C-5
GAS CONCENTRATION DATA REPORTED IN REF. 10

TANK	NH_3 (ppm)	H_2 (ppm)	N_2O (ppm)	$X_{ammonia}$ (%)
SX-103	77	<23	<23	72.8
SX-106	179	98	14	62.0
U-103	730	555	878	40.7
U-105	325	<49	154	61.4
U-107	453	500	701	32.5

One can obtain a conservative estimate of ammonia fraction in the release gas through

$$\frac{X_{ammonia}}{1-X_{ammonia}} = X_{nc,i}\frac{X_{ammonia}}{X_i} \quad , \qquad \text{(C-4)}$$

where $X_{nc,i}$ is the hydrogen or nitrous oxide fraction in the noncondensable gas that may be obtained from Table C-3 and $X_{ammonia}/X_i$ is the ratio obtained from data shown in Table C-4. The resulting ammonia fraction ($X_{ammonia}$) is shown in the last column in Table C-4.

In obtaining the results for $X_{ammonia}$, either the hydrogen or the nitrous oxide data from Tables C-3 and C-4 are used. In general, the hydrogen data are used, except for Tank U-105, for which the nitrous oxide data are used because the hydrogen data are given as "less-than" value. For Tank S-103, both the hydrogen and nitrous oxide numbers are given as less-than value, and the hydrogen data are used for this tank neglecting the < sign. The results for Tank S-103 have the highest uncertainty. First, the analysis reported in Table C-3 is based on two data points only. Secondly, the low concentrations in ammonia and hydrogen result in a large uncertainty in the ratio. Especially, the low ammonia concentration measured suggests that the mass-transfer contribution to the total ammonia release is probably very large (see discussion for Tank 101-SY below).

It is evident that there is much uncertainty in the ammonia results reported in Table C-4, primarily because the analysis is based on a single data point. However, the application of these results in consequence analysis for prompt and large gas releases is conservative because of the following:

- Nitrogen in the gas composition is neglected. Nitrogen is known to exist in the waste gas. Especially, nitrogen fraction is expected to be high in waste gas that is rich in ammonia and nitrous oxide.

- Undoubtedly, some water vapor also will exist in the form of condensable gas. The water vapor content of the waste gas is conservatively set at zero.

- Extensive data from Tank 101-SY indicate that a large fraction of ammonia during the steady-state periods is released by mass transfer of the surface. During steady-state periods, dome space ammonia-to-hydrogen ratio typically ranges between 2 and 3 in Tank 101-SY.[7] During the steady-state period, the background hydrogen concentration typically would be ~20 ppm, but the ammonia concentration would be between 50 and 60 ppm. In this respect, the data for Tank S-103 appear similar to the Tank 101-SY data. However, during episodic large GREs, the ammonia-to-hydrogen ratio drops to 0.3 to 0.5 (Ref. 7). This behavior is explained by the high solubility of ammonia in the waste. During steady-state releases, the mass transfer of the surface significantly contributes to ammonia releases.

Also, slowly released bubbles are expected to come to thermodynamic equilibrium at the waste surface, where the pressure is atmospheric. During large episodic releases, mass-transfer contribution is small, and the bubbles are rapidly released from the lower layers where the ammonia fraction is small because of high hydrostatic pressure. Thus, applying the ammonia-to-hydrogen ratios obtained from background data is believed to be very conservative in predicting the large prompt releases that may be triggered from the deep layers during an intrusion.

Considering all these conservative assumptions, it is expected that the ammonia fraction during a prompt release to be much less than the 60% computed for Tanks SX-106 and U-105. For instance, Ref. 9 uses a simple model based on the energy of formation of nitrogen and other species to obtain the best-estimate ammonia fraction in the release gas as 20% for Tank A-101, but the above methodology yields ~47%. However, given the other uncertainties, the ammonia fraction is set conservatively to 60% the for bounding analysis. Once the ammonia concentration is known, the overall waste-gas composition is estimated as

$$X_i = (1 - X_{ammonia})X_{nc,i} \quad , \tag{C-5}$$

where X_i (i is hydrogen, nitrous oxide, or methane) is the species fraction in the release gas and $X_{i,nc}$ is the species fraction in the noncondensable portion of the release obtained from Table C-3.

The ammonia fraction in the release gas is important in determining the safety envelope for the proposed activities. The presence and amount of ammonia affects the safety analyses in the following major areas:

- Ammonia is a more energetic fuel than hydrogen. Thus, the existence of ammonia increases the fuel energy of the waste gas. The effect of ammonia on the equivalent fuel is discussed in Section 3.2.1 of this appendix.
- Ammonia affects the LFL of the mixture. When expressed in terms of hydrogen concentration, the LFL decreases with increasing ammonia content. The effect of ammonia on the LFL is discussed in Section 3.3 of this appendix.
- Ammonia appears to combust very energetically in a pure nitrous oxide environment.[11,12]
- Ammonia is corrosive, and the consequences of the ammonia releases must be kept below the acceptance guidelines (see Section 5 of this SA).

C.3.2.1. **Effect of Ammonia on the Equivalent Fuel.** Including ammonia, the equivalent fuel is obtained as

$$EF(X_{hydrogen}) = R_m \times X_{methane} + R_a \times X_{ammonia} + X_{hydrogen} \quad , \qquad \text{(C-6)}$$

where R_m is 3.32 (discussed above) and R_a is the ratio of combustion energy of ammonia (317 kJ/mole) to the combustion energy of hydrogen (241 kJ/mole). Thus, R_a is obtained as 1.32.

Using 60% NH_3 and the noncondensable gas composition given in Table C-3 for Tank AX-101, the equivalent fuel becomes equal to 120% H_2, compared to 103% H_2 obtained without any ammonia.

C.3.3. Lower Flammability Limits

The LFL of hydrogen, ammonia, methane, and nitrous oxide mixtures is discussed in Refs. 13 and 14. Based on Refs. 13 and 14, Le Chatelier's linear mixing law[15] appears to be adequate, and the effect of nitrous oxide on the LFL is minimal for the mixtures of interest. The linear mixing law can be expressed in terms of hydrogen concentration as follows:

$$LFL\left(\frac{1}{LFL_{o,hydrogen}} + \frac{X_{ammonia}/X_{hydrogen}}{LFL_{o,ammonia}} + \frac{X_{methane}/X_{hydrogen}}{LFL_{o,methane}}\right) = 1 \qquad \text{(C-7)}$$

where the LFL of the hydrogen, methane, and ammonia ($LFL_{o,i}$) are bounded by 4, 5, and 15%, respectively.[13,14] The LFL for each gas composition shown in Table C-3 is computed as a function of the ammonia fraction in Ref. 6. If we add 60% NH_3 to the AX-101 composition shown in Table C-3, the LFL is obtained as 2.7% H_2.

C.4. MAXIMUM ALLOWABLE RELEASES INTO THE DOME

In this section, the maximum allowable gas releases into the dome space considering the flammability issues and toxicological consequences are discussed first. Also, the maximum allowable burn volume in the waste is quantified. Finally, current estimates for the retained-gas inventory in the tanks of interest are summarized at the end of this section.

Using the LFL values computed for each tank, the maximum allowable release based on the flammability hazard is defined as the gas-release volume necessary to reach 25% of the LFL when the waste gas is homogeneously mixed in the dome space.

For the bounding tank with a 1415.8-m^3 (50,000-ft^3) dome volume, the maximum allowable release corresponding to 6000 ppm H_2 in the dome space would be 8.5 m^3

(300 ft^3) H_2. Currently, all intrusive activities are stopped when 6000 ppm H_2 is detected in the dome space (see Appendix B). Using the gas composition obtained for 101-AX (with 60% NH_3), the release volume corresponding to 6000 ppm H_2becomes 24 m^3 (850 ft^3).

Using an adiabatic burn model, we can show that, if burned, a gas-release volume of 96 m^3 (3400 ft^3) corresponding to 2.4% H_2 in the dome space would result in a peak pressure >240 kPa (35 psia). The maximum peak pressure that could be experienced by SSTs without dome failure is <82 kPa (<12 psig).[16] Thus, even small volumes of gas burned in the dome space may result in catastrophic dome failure. Note that the gas release volume of 96 m^3 is not 100% hydrogen. It was assumed that there is 60% ammonia in the released gas. Remaining 40% includes 88.1% hydrogen (Tank AX-101) as indicated in Table C-3. Thus, the hydrogen concentration becomes 35% in the released gas. This results in 2.4% hydrogen concentration in the dome.

The above values for the maximum allowable limit are obtained considering flammability issues only. Ammonia and nitrous oxide also must be considered for toxicological consequences. The Emergency Response Planning Guideline-1 (ERPG-1) values for ammonia and nitrous oxide are 25 and 150 ppm, respectively. ERPG-1 values are used to determine the dose limit for an on-site receptor located 100 m (328 ft) from the tank for likely releases (see Section 5 of this SA for the Risk Acceptance Guidelines). The maximum allowable release then is determined as the maximum waste-gas volume that results in ≤ERPG-1 when discharged out of the dome and received 100 m (328 ft) from the source.

The atmospheric dispersion factor using 95% weather conditions at the Hanford Site for a 100-m receptor is ~3.44×10^{-2} s/m^3, which is obtained from Ref. 17. For a 0.12-m^3/s (250-ft^3/min) discharge rate, the maximum source concentration may be obtained as 6000 ppm NH_3 and 36,000 ppm N_2O. If we assume 60% NH_3 in the waste gas and a dome volume of 1415.8 m^3 (50,000 ft^3), the maximum allowable release may be obtained as 14.2 m^3 (500 ft^3) to meet the ammonia guidelines. Waste gas releases of up to 68 m^3 (2400 ft^3) will meet the nitrous oxide guidelines, assuming a maximum of 75% N_2O in the waste gas and a 0.12-m^3/s (250-ft^3/min) discharge rate. These numbers are directly proportional to the discharge rates.

C.5. MAXIMUM ALLOWABLE BURN VOLUME IN THE WASTE

In this safety assessment (SA), it is assumed that if the gases are ignited in the waste, the combustion will propagate through the gas phase. If a large enough gas volume is burned, the resulting pressure may be high enough to cause structural damage to the tank and/or dome.

In the previous sections, the concern was the release of flammable and toxic gases into the dome space. For dome burn accidents, the gas composition with the maximum fuel is used as the bounding composition because the dome contains sufficient oxidizer. Likewise, for bounding toxicological analysis, the maximum toxic gas fraction is used. For a burn inside the waste, the worst-case composition would be a stoichiometric mixture of fuel and nitrous oxide. For gases to burn inside the waste, there must be sufficient oxidizer. The only known oxidizer in the waste gas is nitrous oxide. Although the results in Table C-3 have uncertainties associated with them, they show that most of the tanks may be oxidizer limited. Among the tanks for which the gas composition data are analyzed, the nitrous oxide concentration is <20% except for the tanks in the U Farm, Tanks AX-103, SX-106, and S-102. Within the uncertainty of the data, the tanks in the U Farm could certainly have a stoichiometric composition of fuel and oxidizer. In the subsequent analysis, a stoichiometric mixture of hydrogen and nitrous oxide is used. Adding methane and ammonia into the mixture would increase the energy per mole. However, theoretically, complete combustion of 1 mole CH_4 requires 4 moles N_2O, and 1 mole NH_3 requires 1.5 moles N_2O. Thus, methane and ammonia, while more energetic, require more oxidizer than the hydrogen. Thus, for a constant gas volume, adding ammonia and methane to the stoichiometric mixture of hydrogen and nitrous oxide has a small impact on the total combustion energy.

Starting at atmospheric pressure, the adiabatic constant-volume combustion of 1 mole H_2 with 1 mole N_2O results in a peak pressure of 11.2 atm. If the combustion products are allowed to expand isentropically while compressing the dome gases, the equilibrium pressure may be obtained by solving the following simultaneous equations:

$$V_f + V_{cf} = V + V_c \quad , \qquad \text{(C-8)}$$

$$\frac{P_a}{P_f} = \left(\frac{V_f}{V}\right)^{k_a} \quad , \qquad \text{(C-9)}$$

and

$$\frac{P_c}{P_f} = \left(\frac{V_{cf}}{V_c}\right)^{k_c} \quad , \qquad \text{(C-10)}$$

where P_a is the initial dome pressure (1 atm), P_c is the waste gas burn pressure (11.2 atm), P_f is the final equilibrium pressure, V is the initial dome volume, V_c is the volume of the waste gas (combustion products), V_f is the final dome volume after compression, V_{cf} is the final waste gas (combustion products) volume after expansion, and k is the specific heat ratio. For both the dome gases and the combustion products, $k_a = k_c = 1.4$ is used in these calculations. If we set the structural limit to 1.8 atm (Ref. 16), the maximum allowable gas volume may be obtained as 184 m^3 (6500 ft^3) for V = 1416 m^3 (50,000 ft^3).

This approach is conservative because it assumes that there is no pressure relief (no outflow from the dome) during the pressurization phase. Furthermore, it is very unlikely that the burn will easily propagate in the waste. The total energy generated by the combustion of 283 m^3 (10,000 ft^3) stoichiometric waste gas is 4.1 x 10^6 kJ (4.1 x 10^6 Btu). The latent heat of 1.8 m^3 (64 ft^3) of water will be sufficient to absorb all of this energy. Thus, if the water volume in the waste is only 0.3% of the gas volume and if the gas and water are homogeneously distributed, the combustion cannot propagate. If a large gas volume exists, a 184-m^3 (6500-ft^3) gas volume would correspond to a spherical bubble 7.1 m (23 ft) in diameter. Alternatively, a dendritic bubble 2.54 cm (1 in.) in average diameter would have to be 3.6 x 10^5 m (1.2 x 10^6 ft) long.

Based on these arguments, a gas burn in the waste that could result in dome failure is very unlikely. However, it should not be dismissed completely because of the various unknowns in the gas-retention mechanisms and the waste properties in the SSTs.

C.6. Estimates of Tank Gas Inventory

As part of the screening program for potential FG retaining tanks, Westinghouse Hanford Company (WHC) has a continuing effort to estimate the tank gas inventory using the barometric pressure and level variation data.[18] The results for all the tanks of interest are not currently available. The gas inventories of some of the tanks that are not currently on the FGWL are given in Ref. 18.

C.7. CONCLUSIONS

In this appendix, the available gas-composition data obtained from the grab samples are analyzed. However, the grab samples only provide limited data. Conservatively assuming that the waste gas does not contain any nitrogen, the grab sample data are converted to noncondensable waste gas composition. The upper-bound values for the composition with maximum fuel and maximum nitrous oxide are obtained. In terms of fuel, the bounding tank is shown to be AX-101. Tank U-105 appears to show the highest nitrous oxide content. Tanks A-101, AX-101, SX-102, SX-105, SX-106, and S-111 indicate >80% H_2 in the waste gas. The highest hydrogen content is estimated for SX-106 as nearly 90%.

Even though the available data are analyzed conservatively, we must exercise caution in using the current findings. The concentrations are obtained using a very limited database. Furthermore, the SSTs within a given farm are connected through overflow lines, and most SSTs are passively ventilated. Consequently, it is possible that the dome gases in connected tanks intermix, and the grab sample data may not necessarily represent the waste gas that is released from a specific waste tank. Furthermore, data for all the tanks of interest are not available.

Using a conservative interpretation of the limited ammonia data provided in Ref. 10, the LFL is set equal to 2.4% H_2, corresponding to an ammonia-to-hydrogen ratio of 2.5. For toxicological consequence analysis, the bounding ammonia fraction in the release gas is set conservatively equal to 60%.

Based on these findings, it is concluded that

- The potential gas releases during the proposed intrusive activities are poorly understood and cannot be controlled to meet these limits.
- Continuous hydrogen or FG monitoring is necessary as part of the spark management strategy.
- Continuous or frequent ammonia monitoring also is necessary, both for flammability and toxicological consequence considerations.
- A deflagration in the dome space is a more likely dome collapse mechanism than a deflagration of the gas trapped in the waste.
- Ammonia concentrations must be monitored, and operations must be stopped when the ammonia concentration in the dome exceeds 5000 ppm.

C.8. REFERENCES

1. Westinghouse Hanford Company, "Hanford Site Tank Farm Facilities Interim Safety Basis, Volume 2: Design Description," Westinghouse Hanford Company report WHC-SD-WM-ISB-001, Rev. 0, Vol. 2 (August 1993).

2. H. R. Brager, "Summary of Information on Flammable Gas Watch List Tanks," Westinghouse Hanford Company report WHC-EP-0711, (January 1994).

3. P. Whitney, "Screening of the Hanford Tanks for Trapped Gas," Pacific Northwest Laboratory report PNL-10821 (October 1995).

4. K. O. Pasamehmetoglu, "Single-Shell Tank Dome Volume Calculations," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-086 (November 1995).

5. R. G. Brown, "Status of Single-Shell Tank SHMS," Westinghouse Hanford Company internal memorandum 74A10-95-068 to G. D. Johnson (October 2, 1995).

6. K. O. Pasamehmetoglu, "Gas Composition Estimates for Single-Shell Tanks," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-GR-048 (December 1995).

7. L. H. Sullivan et al., "A Safety Assessment for the Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," Los Alamos National Laboratory report LA-UR-92-3196, Rev. 14 (March 31, 1995).

8. R. J. Van Vleet, "Basis for Closure of USQ for Tank 103-SY," presented to Tank Waste Chemical reactions Sub-Panel (October 11, 1995).

9. W. L. Kubic, "Summary, Review, and Analysis of Data for Tank 241-A-101," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-DA-001 (December 1995).

10. J. L. Huckaby, H. Babad, and D. R. Bratzel, "Headspace Gas and Vapor Characterization Summary for the 43 Vapor Program Suspect Tanks," Westinghouse Hanford Company report WHC-SD-WM-ER-514, Rev. 1A (September 1995).

11. M. Hertzberg and I. A. Zlochower, "Explosibility of Nitrous Oxide: the Effect of H-Atom Bearing Impurities," Twenty-Fifth International Symposium on Combustion, University of California, Irvine, July 31–August 5, 1994.

12. E. Jones and J. C. Kerr, "Inflammability Limits of Ammonia, Nitrous Oxide and Air," *J.S.C.I* 68, 31–34 (January 1949).

13. K. O. Pasamehmetoglu, "Composition and Lean Flammability Limit for the Release Gases in Tank 241-SY-101," Los Alamos National Laboratory report LA-UR-94-4229 (December 1994).

14. K. O. Pasamehmetoglu, "LFL for 101-SY Release Gas," Los Alamos National Laboratory Calc-Note N6-CN-WT-SA-GR-010 (March 1994).

15. W. Jost, *Explosion and Combustion Processes in Gases* (McGraw Hill, New York, New York, 1946), p. 134.

16. L. J. Julyk, "Static Internal Pressure Capacity of Hanford Single-Shell Waste Tanks," Westinghouse Hanford Company report WHC-SD-WM-TI-623 (July 1995).

17. Westinghouse Hanford Company, "Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Accelerated Safety Analysis Consequence Assessment," Westinghouse Hanford Company report WHC-SD-WM-SARR, Rev. 1 (October 1995).

18. K. M. Hodgson et al., "Evaluation of Hanford Tanks for Trapped Gas," Westinghouse Hanford Company report WHC-SD-WM-ER-526 Rev. 0 (December 1995).

APPENDIX D

RELIABILITY OF SYSTEMS

D.1. INTRODUCTION

This appendix documents the results of an assessment of the reliability of various systems that support the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations. The systems that were evaluated are those considered in the accident sequences discussed in Section 4 and documented in Appendix E of this safety assessment.

The reliability of the systems were estimated using fault tree analysis, and event tree analysis in a few cases. The system fault trees are not detailed fault trees; however, they do provide a reasonable model for estimating system reliabilities. The level of detail included in the fault trees was limited by the availability of detailed up-to-date system design and operating information.

The system models were developed using the following sources of information:

1. Existing Westinghouse Hanford Company (WHC) safety studies,[1-4]
2. System schematics and operating procedures provided by WHC,
3. Verbal information from WHC cognizant engineers and technicians,
4. Published sources of data for component reliabilities, and
5. Engineering judgment.

It should be noted that automatic trip of drill string is defined as automatic trip of the drill rig engine. The following systems were modeled:

- Nitrogen purge gas cooling for drill bit and associated automatic trip of drill string on low nitrogen flow;
- Nitrogen hydrostatic supply to drill string;
- Nitrogen hydrostatic supply to shielded receiver;
- Automatic trip of drill string on excessive force;
- Automatic trip of walkdown function;
- Automatic trip of hydraulic bottom detector;

- Automatic trip of drill string on high rpm;
- Pneumatic footclamp for holding drill string;
- Automatic trip of drill string on:

  Flammable-gas concentration,

  Flammable-gas concentration rate of rise, and

  Dome pressure;
- Sampler rotary valve operation;
- Sampler chevron seal function; and
- Manual sniff of drill string for flammable gas.

To estimate component failure exposure times, the following time periods were used:

- Two drilling activities on a tank per year;
- 144 hours for an activity from arrival at tank for core sampling until leaving tank after core sampling complete;
- 40 hours to take all samples; 2 samples taken per 8-hour shift;
- 20 minutes drilling time required for each of 11 samples; and
- 6 months between calibration check of instrumentation.

D.2. SUMMARY AND RESULTS

The details of the systems reliability analysis are provided in Refs. 5 and 6. The results are summarized in Table D-1.

Based on these results, human error is concluded to be an important contributor to system failure.

During the development of the system models it was noted that the following qualitative aspects of hardware faidlures. The reliability of the PLC is important because it is a single failure element for both

- automatically tripping the drill, and
- providing annunciation to the operators for manual response to stop drilling or to trip the drill.

The reliability of the rpm-detection system is important because it must

- Trip the drill on high RPM,
- Detect drill string rotation above 2 rpm to enable the automatic trip on low nitrogen purge gas flow, high down force, low penetration rate, and high RPM.

Both the PLC and the rpm detection systems are sufficiently reliable so that failures in these systems do not excessively contribute to the quantified system failure values.

TABLE D-1
RESULTS OF SYSTEM RELIABILITY QUANTIFICATION

Initiating Event Frequency (1/activity)	Probability of Subsequent Failures	Overall Frequency (1/activity)	Contributing Failures (Failure of Following Events Dominates Probability of Subsequent Failures)
Excessive force used while taking any sample except last sample, 0.05 per sample, 0.55 total for 11 samples	Failure to detect excessive force and stop drill 7.9E-5 (Event: force)	4.3E-5	Common mode calibration error, pressure transmitters, operator arm walkdown function, solenoid-operated valve (SOV) 12
Excessive force used while taking last sample 0.05	Failure to detect excessive force and stop drill 7.9E-5	4.0E-6	Common mode calibration error, Pressure transmitters, operator arm, bottom detector, SOV 11
		4.7E-5 total for excessive force with failure to stop drill (sum of two previous values)	

TABLE D-1 (cont)
RESULTS OF SYSTEM RELIABILITY QUANTIFICATION

Initiating Event Frequency (1/activity)	Probability of Subsequent Failures	Overall Frequency (1/activity)	Contributing Failures (Failure of Following Events Dominates Probability of Subsequent Failures)
High H_2 level in exhauster 1.0	Failure to detect hydrogen 7.6E-4 Failure to detect hydrogen and trip the drill string 1.3E-3 + 3.0E-4*	7.6E-4 1.6E-3	2 exhauster programmable logic controllers (PLCs) (common mode), instrumentation and control (I&C) calibration 2 exhauster PLCs (common mode), truck PLC, I&C calibration
High H_2 rate of rise in exhauster 1.0	Failure to detect hydrogen 7.6E-4 Failure to detect hydrogen and trip the drill string 1.3E-3 + 3.0E-4*	7.6E-4 1.6E-3	2 exhauster PLCs (common mode), I&C calibration 2 exhauster PLCs (common mode), truck PLC, I&C calibration
High dome pressure caused by H_2 release 1.0	Failure to detect hydrogen. 7.7E-4 Failure to detect hydrogen and trip the drill string. 1.4E-4 + 3.0E-4* (Event: hydrl)	7.7E-4 1.7E-3	2 exhauster PLCs (common mode), I&C calibration 2 exhauster PLCs (common mode), truck PLC, I&C calibration

TABLE D-1 (cont)
RESULTS OF SYSTEM RELIABILITY QUANTIFICATION

Initiating Event Frequency (1/activity)	Probability of Subsequent Failures	Overall Frequency (1/activity)	Contributing Failures (Failure of Following Events Dominates Probability of Subsequent Failures)
H_2 from waste 1.0	Failure of drill string N_2 hydrostatic system. 6.4E-3	6.4E-3	Operator connect drill string hydro, operator arm drill string hydrostatic system
H_2 from waste 1.0	Failure of shielded receiver N_2 hydrostatic system. 6.4E-3	6.4E-3	Operator connect shielded receiver hydrostatic system, operator arm shielded receiver hydrostatic system *(NOTE: The contributing failure associated with connecting the SR hydrostatic system is overly conservative because the system is hard-piped.)*
H_2 from waste 1.0	Failure of both drill string N_2 hydrostatic system and shielded receiver N_2 hydrostatic systems. 6.9E-4 (Event: hydro)	6.9E-4	Operator connect drill string hydrostatic system and connect shielded receiver hydrostatic system (common mode), operator arm drill string hydrostatic system and shielded receiver hydrostatic system(common mode) *(NOTE: The contributing failure associated with connecting the SR hydrostatic system is overly conservative because the system is hard-piped.)*
Hold drill string above waste with footclamp 1.0	Footclamp drops drill string onto waste surface. 3.0E-5 (Event: foot)	3.0E-5	Operator opens foot clamp. Lock wrench left out.

TABLE D-1 (cont)
RESULTS OF SYSTEM RELIABILITY QUANTIFICATION

Initiating Event Frequency (1/activity)	Probability of Subsequent Failures	Overall Frequency (1/activity)	Contributing Failures (Failure of Following Events Dominates Probability of Subsequent Failures)
Excessive rpm during drilling 0.011	Failure to trip drill string on excessive rpm. 6.2E-4 (Event: rpm)	6.8E-6	truck PLC, I&C calibration
Perform drilling operation 1.0	Total loss of N_2 cooling and failure to stop drill. 3.3E-6	3.3E-6	N_2 cooling holes in drill bit plug, truck PLC
Perform drilling operation 1.0	Partial blockage of N_2 cooling holes in drill bit does not lead to total low N_2 flow 5E-4 original calculation; operating envelope will ensure no overheating can occur unless N_2 low-flow trip also challenged and fails	Operating envelope controls will prevent this.	No blockage of some, but not all, of the N_2 cooling holes in the drill bit, no low N_2 flow as a result of partial blockage, no local overheating of portions of drill bit
Perform drilling operation 1.0	Loss of drill bit N_2 cooling from N_2 bypass leakage 1.6E-5	1.6E-5	No N_2 bypass flow, no high N_2 flow as result of bypass, operator detects N_2 bypass flow

TABLE D-1 (cont)
RESULTS OF SYSTEM RELIABILITY QUANTIFICATION

Initiating Event Frequency (1/activity)	Probability of Subsequent Failures	Overall Frequency (1/activity)	Contributing Failures (Failure of Following Events Dominates Probability of Subsequent Failures)
Perform drilling operation 1.0	High N_2 temperature results in loss of drill bit cooling, Low likelihood based on WHC information that N_2 reaches ambient waste temperature	very small	No high N_2 temperature, no overheating of drill bit from high N_2 temperature, operator trips drill on annunciation of high N_2 temperature, temperature transducer
		1.9E-5 total for overheating drill bit caused by inadequate N_2 cooling (sum of four previous values) (Event: cool)	
Take a sample 11.0	Failure of rotary valve in sampler to completely close. 0.1 (Event: rot)	1.1	No waste blockage during valve closure
Perform drilling operation 1.0	Failure of sampler chevron seal. (Event: seal)	3.3E-2	Installation of chevron seal
H_2 from Waste 1.0	Failure of H_2 sniff in drill string. 4.6E-3 (3.0E-3 operator, 1.6E-3 hardware) (Event: sniff)	4.6E-3	Operator fails to perform sniff, sniff sensor fails low

TABLE D-1 (cont)
RESULTS OF SYSTEM RELIABILITY QUANTIFICATION

Initiating Event Frequency (1/activity)	Probability of Subsequent Failures	Overall Frequency (1/activity)	Contributing Failures (Failure of Following Events Dominates Probability of Subsequent Failures)
Excessive filter ΔP 1.0	Fail to trip exhauster on filter ΔP. 2.6E-3 (Event: gate 32)	2.6E-3	Failure to sense high ΔP across filter, calibration I&C error
Contact rock in waste 0.1	Failure of penetration rate and failure of N_2 cooling to drill bit systems. 3.3E-6 (Event: prrate)	3.3E-7	N_2 cooling holes to drill bit plug, PLC

* 3.0E-4 accounts for requirement to enable the exhauster interlock.

D.3. REFERENCES

1. W. L. Cowley and D. D. Stepnewski, "Evaluation of Hazards to Tank Farm Facilities from Lightning Strikes," Westinghouse Hanford Company report WHC-SD-WM-SARR-027 Rev 0 (June 29, 1994).

2. D. J. Braun, "Risk Assessment for Nitrogen Purge System for Rotary Mode Sampling Truck," Westinghouse Hanford Company report WHC-SD-WM-RA-066 Rev. 0 (September 1992).

3. Westinghouse Hanford Company, "Fault Tree Systems Analysis," Westinghouse Hanford Company report WHC-IP-0690 6.4, Rev 0 (June 30, 1992).

4. J. E. Kelly, "High Downward Force on Rotary Drill," Westinghouse Hanford Company Internal Memorandum 29220-93-030 (July 7, 1993).

5. J. Darby and M. Butner, "Reliability of Systems for Rotary Mode Core Sampling," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-HAZ-004, Rev. 1 (February 1996).

6. J. Darby, "Additional Calculations for Push Mode Event Trees," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-HAZ-009, Rev.0 (June 4, 1996).

APPENDIX E

ACCIDENT SEQUENCES

E.1. INTRODUCTION

Quantification results from event trees are discussed in this appendix for the installation, operation, and removal of rotary-mode core sampling (RMCS) equipment in single-shell tanks (SSTs) on the Flammable Gas Watch List (FGWL) or those tanks recommended by the contractor to be included on the FGWL, hence referred to as FG/RMCS operations. These event trees, developed using the SANET (Ref. 1) code, document the accident sequences discussed in Section 4 of this report. Reference 2 includes the event trees, the detailed accident discussions, and quantification details.

E.2. BACKGROUND INFORMATION

This section discusses the bases for the human-error rate assignments used throughout the accident quantification as well as mission time values used to quantify failure rates and frequencies.

E.2.1. Assumptions Underlying .003 Human Error Probability as Given in NUREG-CR-4772 (Ref. 3)

1. Task failure is not immediately annunciated either if a task is not performed or if an error is made during the task.
2. A post-task test is either not required or it does not immediately annunciate error.
3. Neither a shift nor a daily check is made to verify the status of the system associated with a task.
4. Independent task verification is ensured by requiring that either a second person verify whether a task is performed correctly after a task is completed or whether the original task performer verifies a task correctly performed at a different time and location.
5. Verification procedures are written correctly and verification procedure is followed correctly.
6. Verification fails to discover a task error with a probability of 0.1.

In those activities to which we have assigned a .003 human error failure rate, we implicitly assume that the associated activity is controlled by a correctly written procedure and that the activity has independent verification using a check-off sheet.

If the second-person verification is not performed, this probability increases to .03. Assignment of this human failure probability still requires the associated task to be controlled by procedure.

E.2.2. Assignment of the .05 Failure Probability for Judgment-Based Tasks

The Systematic Human Reliability Procedure (SHARP) gives a failure probability range of .5 to 5E-03 for judgment-based actions (Ref. 4). For actions considered to be judgment-based (dependent on a mental representation of a system), we assigned a probability of .05, the mid-point of the SHARP range.

E.2.3. Mission Time Assumptions

An activity is defined as the process of collecting a set of core samples corresponding to an entire tank depth. One hundred forty-four hours are required to complete an entire activity. Within this 144-h period, 40 h (approximately 2 samples collected per shift) are required to retrieve the 11 samples [based on an average single-shell tank (SST) waste depth]. Total drilling time is approximately 4 h (20 min. per sample). Instrumentation and controls (I&C) are checked, and if necessary, calibrated every six months.

E.2.4. Dependence of Event-tree Events.

Because of the lack of complexity inherent in the rotary-core mode drilling activities, it was possible for us to construct event trees having independent top events. Therefore, accident frequencies can be determined by multiplying path frequencies and probabilities. Important dependencies were handled by broadening the event definition so that the associated fault tree considers them.

E.3. ACCIDENT SEQUENCES

Table E.1 summarizes the quantification of the accident sequences based on assigning a high value to all phenomena except for the likelihood of having flammable gas at a flammable concentration contacting equipment randomly located near risers. This open-riser probability is documented in Ref. 5. The Table E.1 values in parentheses are the accident frequencies that result if only passive (non-control) system hardware is available to respond to accident initiators. These frequencies are called "unmitigated accident frequencies." Both active control hardware and administrative controls are credited in the other listed accident frequencies, which are called "mitigated frequencies".

TABLE E-1
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS

Accident	Frequency (1/Activity)	Dominant Failures	Controls Credited for Mitigative Frequency Quantification
Lightning strike causes dome fire. (Note 1)	4.1E-6 (8.2E-6)	Random lightning strike hits risers or other equipment on top of tank that connects to tank interior	Do not drill during stormy weather.
Hot spots caused by drill bit contacting rocks in waste. (Note 2)	3.3E-7 (0.1)	Hot drill bit contacts rock in waste resulting in flammable gas ignition due to a hot spot exceeding autoignition temperature of the mixture. Penetration rate and nitrogen purge systems fail.	Trip drill string on slow penetration rate (no time for operator trip if penetration rate trip fails). Auto trip of drill string on low N_2 purge gas flow.
Spark from failure of exhauster heater leads to dome fire. (Note 1)	0 (0)	None	Replace electric heater with hot-water heat exchanger in exhauster to provide moisture removal for high-efficiency particulate air (HEPA) filters
Spark from Assembly/disassembly of drill string sections: drill string in dome (Notes 1 and 2) drill string in waste (Note s 2 and 4)	7.6E-5 total (1.65E-2) 3.8E-5 (8.25E-3) 3.8E-5 (8.25E-3)	Fails to perform sniff for flammable gas in drill string. Sampler chevron seal fails.	Sniff enclosed volume for flammable gas in drill string. Presence of sampler with chevron seal in drill string prevents flammable gas movement into drill string.
Drop of equipment from crane onto exhauster leads to dome fire (Note 1) .	3.4E-7 (6.8E-6)	Drops equipment from crane onto exhauster.	Control of equipment lifts over exhauster.
Failure of exhauster fan causes spark leading to dome fire. (Note s 1 and 5)	2.3E-5 (2.3E-5)	Fan bearings seize, shaft fails, and impeller impacts fan housing causing spark.	Fan impeller and housing are Al, which has low potential for sparking.
Leaking riser penetration releases flammable gas to unqualified electrical equipment leading to dome fire (Note 1) (Note: For this accident we calculated the probability that flammable gas in excess of 2.4% reaches equipment randomly placed on the tank top.)	6.5E-3 (1.0)	Randomly located, unqualified equipment is located too close to riser/pit that is not sealed.	Limit leakage from all unused risers/pits to less than 1 in. equivalent diameter. Platform on truck is present to mitigate release from drill-string rubber seal. Following tank walkdown, 50% of risers are assumed to leak.

TABLE E-1 (cont)
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS

Accident	Frequency (1/Activity)	Dominant Failures	Controls Credited for Mitigative Frequency Quantification
Truck placed over an unused penetration results in an above ground fire leading a dome fire	1.5E-4 (1.0)	Operators fail to seal unused penetration Failure to locate truck ignition sources a minimum of 36" away from risers or pit over which the truck is positioned	Limit leakage from penetration so flammable gas will not reach unqualified equipment on the drill truck Truck is located greater than 36" away from risers or pit over which the truck is positioned.
Intentional opening of penetration during drilling results in an above ground fire	1.5E-3 (0.5)	Equipment located too close to open penetration	Locate unqualified equipment > 36 D from open penetration Inlet stack 15 ft tall installed on HEPA inlet riser.
Flammable gas is in drill string/shielded receiver during sampler handling leading to dome fire. (Notes 2 and 4)	9.7E-7 (1.4E-3)	N_2 hydrostatic system to both drill string and to shielded receiver fail. Remote latch unit (RLU) drops sampler.	Leak test N_2 hydrostatic systems for both drill string and for shielded receiver. Unique connections for N_2 hydrostatic systems for both drill string and shielded receiver. Operators verify N_2 hydrostatic supply to both drill string and shielded receiver during activation of hydrostatic mode of N_2 supply. Controls over operation of RLU.
Flammable gas in shielded receiver with shielded receiver isolated from drill string results in aboveground fire. (Notes 2 and 6)	1.4E-5 (not a dome fire accident) (1.5E-4)	Waste prevented previous closure of sampler rotary valve leading to gas release as sample is retrieved and depressurized. Sniff for flammable gas fails to detect flammable gas. RLU drops sampler.	Controls over the operation of RLU are provided.

TABLE E-1 (cont)
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS

Accident	Frequency (1/Activity)	Dominant Failures	Controls Credited for Mitigative Frequency Quantification
Flammable gas in X-ray machine leads to aboveground fire. (Notes 2 and 6)	8.3E-10 (not a dome fire accident) (8.3E-9)	Waste prevented previous closure of sampler rotary valve leading to gas release as sample is retrieved and depressurized. Previous sniff for flammable gas in shielded receiver failed to detect flammable gas. RLU drops sampler. Plastic receiver breaks. Isolation barrier volume fails.	Design includes sealed plastic sampler receiver surrounded by isolation barrier. Controls over operation of RLU are used.
Flammable gas in cask leads to above ground fire. (Notes 2 and 6)	1.4E-5 (not a dome fire accident) (1.4E-4)	Waste prevented previous closure of sampler rotary valve leading to gas release as sample is retrieved and depressurized. Operator fails to perform sniff for flammable gas or sniff not successful. RLU drops sampler.	Controls over operation of RLU are used.
Flammable gas in riser/sleeve during drilling leads to dome fire. (Notes 1 and 2)	1.1E-5 (1.0)	N_2 to riser sleeve fails and with subsequent failure to shut down drill on loss of N_2 (slow release not seen in dome). Drill fails to shut down on detection of flammable gas (rapid release seen in dome), and failure of riser sleeve N_2 supply and shut down of drill on loss of N_2.	Design includes drill string automatic trip when high flammable gas level, high rate of change of flammable gas level, or high dome pressure. Provide for drill string trip on loss of N_2 to riser sleeve. Provide for leak check of N_2 supply to riser sleeve. Provide for unique connector for N_2 supply to riser sleeve. Provide for verification of N_2 supply to sleeve during actuation of system.
Drop of tool into open riser leads to dome burn. (Note 1)	5E-5 (1.0E-4)	Drop of tool into open riser.	Use of spark-resistant tools within 36 D of open risers.

TABLE E-1 (cont)
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS

Accident	Frequency (1/Activity)	Dominant Failures	Controls Credited for Mitigative Frequency Quantification
Drill string break in dome leads to dome fire. (Notes 1 and 2)	1.7E-5 (1.0E-2)	Drill string fails to shut down on detection of flammable gas. Drill string break caused by buckling or overtorque from jamming in waste on obstructions.	Design includes drill string automatic trip, given high flammable gas; auto trip exhauster on: high flammable gas level, high rate of change of flammable gas level, or high dome pressure.
Loss of drill bit cooling leads to waste fire. (Note 3)	1.9E-5 (1.0)	N_2 bypass flow occurs w/subsequent failure to stop drilling. Drill string N_2 cooling holes plug w/subsequent failure to stop drilling.	Design includes auto-trip of drill string on low N_2 purge gas flow. Annunciation of high N_2 purge gas temperature is provided. Test N_2 purge system for bypass leakage is done. Test results show that N_2 leakage from drill string with section O rings not installed is acceptable. Test results show that partial plugging of some of the drill bit nitrogen cooling holes leading to localized overheating without calling for trip on low nitrogen flow is not of concern. Analysis shows that drill string tear without break is very unlikely. WHC analysis shows that overheating of nitrogen source gas is not of concern because in passage through hoses and into drill string, the nitrogen will not exceed waste ambient temperature.
Excessive drilling rpm leads to waste fire. (Note 3)	6.8E-6 (1.1E-2)	The rpm setting is too high. Trip of drill string on high rpm fails.	Control over speed setting is provided. Design includes auto-trip of drill string on excessive rpm.

TABLE E-1 (cont)
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS

Accident	Frequency (1/Activity)	Dominant Failures	Controls Credited for Mitigative Frequency Quantification
Excessive downward force on drill leads to waste fire. (Note 3)	4.7E-5 (0.6)	Excessive downward force is used. Drill string fails to trip on excessive force. Walkdown detector fails to function.	Provide control over downward force used. Design includes: auto-trip drill string on excessive force; force detector and walkdown detector for all samples except last; force detector and bottom detector for last sample.
Slow drilling penetration rate causes waste fire. (Note 3)	3.7E-5 (0.1)	Penetration rate detection fails and operator fails to manually stop drill.	Provide 1 of 1 system for detection of drilling penetration rate. Five minutes are available for operator to recognize slow penetration and stop drilling.
Collision of vehicle with riser leads to dome fire. (Note 1)	2.5E-7 (0.01)	Vehicle hits riser. Riser ruptures fuel tank on vehicle.	Provide controls over operation of vehicles on top of tank.
Blowout of HEPA exhaust filter.	7.8E-6 (not a dome fire) (7.8E-6)	Excessive differential pressure occurs across HEPA filter.	The exhauster HEPA is verified to be sufficiently free from loading at the start of drilling so that subsequent drilling will not result in plugging. The exhauster is shut down given high HEPA differential pressure.
Drop of drill string	3.0E-5 (1.0)	Failure to install lockwrench. Operator opens foot clamp.	Lock wrench is used. Operator training is given.
Drop of drill string results in breach of tank bottom liner.	1.5E-5 (not a dome fire) (0.5)	Failure to install lockwrench. Operator opens foot clamp.	Lock wrench is used. Operator training is given.
Spill from dropped sampler in shielded receiver. (Similar accidents are spills from drops of sampler in X-ray machine or in cask, but they are of lower frequency.)	4.3E-9 (not a dome fire) (0.11)	RLU drops sampler. Sampler rotary valve fails given drop of sampler. Ball valve in shielded receiver inadvertently left open.	Controls over operation of RLU are used. Use control to close ball valve in shielded receiver.

TABLE E-1 (cont)
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS

Accident	Frequency (1/Activity)	Dominant Failures	Controls Credited for Mitigative Frequency Quantification
Waste from contaminated drill string interior is released aboveground.	3.1E-7 (not a dome fire) (1.0)	N_2 hydrostatic systems fail to both drill string and shielded receiver. Operators fail to detect contamination during removal of drill string sections.	Use leak test N_2 hydrostatic systems for both drill string and for shielded receiver. Use unique connections for N_2 hydrostatic systems for both drill string and shielded receiver. Verify N_2 hydrostatic supply to both drill string and shielded receiver during activation of hydrostatic mode of N_2 supply. Monitor for radioactive contamination during removal of drill-string sections.
Waste from contaminated drill string exterior is released aboveground.	2.2E-6 (not a dome fire) (1.0)	Ineffective wash of drill-string exterior surface before removal of drill string is ineffective. Operators fail to detect contamination during removal of drill string sections.	Provide water wash of drill-string exterior surface before removal of drill string. Monitor for radioactive contamination during removal of drill string sections.
Drill string break causes drill string fire (Note 4)	6.3E-9 (3.3E-4)	N_2 bypass flow occurs with sub. failure to stop drilling. Sampler chevron seal fails.	Test N_2 purge system for bypass leakage is done. Test results show that N_2 leakage from drill string with section O-rings not installed is acceptable. Presence of sampler with chevron seal in drill string to prevent flammable gas movement into drill string.
Drop Grapple in Drill String	3.0E-11 (6.6E-4)	Sampler seal fails. N_2 hydro to DS fails. Grapple is dropped.	Sampler seal is used. DS N_2 hydro is used. Load cell and current control for hoist motor.

Notes:

1. Probability of GRE to dome space will lower the frequency of this accident sequence.

2. BOM spark tests may lower the frequency of this accident sequence.
3. Probability of waste burn will lower the frequency of this accident sequence.
4. Probability of gas source to drill string with drill string in waste is estimated as 1.0.
5. WHC documentation on aluminum-on-aluminum spark potential will lower the frequency of this accident sequence.
6. Source of gas is from depressurization of sample.

Some accident frequencies will be lowered as a result of consideration of the gas-release-event (GRE) frequency, the waste-burn probability, and of the Bureau of M[illegible] (BOM) testing results. Section E.4.0 discusses the quantitative effect of thes[illegible] equency-reduction phenomena.

E.4. ACCIDENT SEQUENCE QUANTIFICATION CONSIDERING PHENOMENOLOGICAL FACTORS

This section considers the impacts of the phenomena frequencies or probabilities upon the accident-sequence quantification considered previously by this appendix.

As shown in Appendix L of this report the probability that tank dome space lower flammability limit (LFL) is exceeded as a result of a GRE when a random spark-initiating event occurs is 1.4E-5 based on the mean time that LFL is exceeded. This value is incorporated into the Table E.2 frequencies for all accidents in which the spark source is essentially random in time. This situation is true for all except one accident. For this accident, the "truck over an unused penetration" accident, we assume the spark source is always present and use 7.0E-5 as the probability that a burn occurs. As shown in Appendix L, 7.0E-5 is the probability that LFL is exceeded concurrent with positive tank pressure.

The waste-burn probability quantification and BOM testing are not completed, so we are not yet able to use them to lower our previous accident frequencies.

The frequencies presented in Table E-2 are frequency/yr for rotary-mode drilling into a single tank, assuming 2 drilling activities per yr. They are not accident frequencies for an individual tank farm or for the entire Hanford site. Mitigated frequencies precede the unmitigated frequencies listed in parentheses.

TABLE E-2
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS INCLUDING PHENOMENOLOGICAL FACTORS

Accident	Frequency/yr
Lightning strike causes dome fire. (Note 1)	1.1E-10 (2.3E-10)
Spark from drill bit contacting rock in waste. (Note 2)	6.6E-7 (0.2)
Spark from failure of exhauster heater leads to dome fire. (Note 1)	0 (0)
Spark from assembly/disassembly of drill string sections:	7.6E-5 total (1.65E-2 total)
Drill string in dome (Notes 1 and 2)	1.1E-9 (2.3E-7)
Drill string in waste (Notes 2 and 4)	7.6E-5 (1.65E-2)

TABLE E-2 (cont)
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS INCLUDING PHENOMENOLOGICAL FACTORS

Accident	Frequency/yr
Drop of equipment from crane onto exhauster leads to dome fire. (Note 1)	9.5E-12 (1.9E-10)
Failure of exhauster fan causes spark, leads to dome fire. (Notes 1 and 5)	6.4E-10 (6.4E-10)
Tear in exhauster duct releases flammable gas to unqualified electrical equipment leading to dome fire. (Note 1)	1.4E-9 (5.6E-8)
Leaking riser penetration releases flammable gas to unqualified electrical equipment leading to dome fire. (Note 1) (Note: For this accident we calculated the probability that flammable gas in excess of LFL reaches equipment randomly placed on the tank top).	1.8E-7 (2.8E-5)
Flammable gas is in drill string/shielded receiver during sampler handling leading to dome fire. (Notes 2 and 4)	1.9E-6 (2.8E-3)
Flammable gas in shielded receiver with shielded receiver isolated from drill string results in aboveground fire. (Notes 2 and 6)	2.8E-5 (not a dome fire) (3.0E-4)
Flammable gas in X-ray machine leads to above ground fire. (Notes 2 and 6)	1.6E-9 (not a dome fire) (1.6E-8)
Flammable gas in cask leads to above ground fire. (Notes 2 and 6)	2.8E-5 (not a dome fire) (2.8E-4)
Flammable gas in riser during drilling leads to dome fire. (Notes 1 and 2)	3.1E-10 (2.8E-5)
Drop of tool into open riser leads to dome burn. (Note 1)	1.4E-9 (2.8E-9)
Drill string break in dome leads to dome fire. (Note 1)	4.8E-10 (2.8E-7)
Drill string break in dome leads to DS fire. (Note 4)	1.3E-8 (6.6E-4)
Loss of drill bit cooling leads to waste fire. (Note 3)	3.8E-5 (2.0)
Excessive drilling rpm leads to waste fire. (Note 3)	1.4E-5 (2.2E-2)
Excessive downward force on drill leads to waste fire. (Note 3)	9.4E-5 (1.2)
Slow drilling penetration rate causes waste fire. (Note 3)	7.4E-5 (0.2)
Collision of vehicle with riser leads to dome fire. (Note 1)	7.0E-12 (7.0E-12)
Blowout of HEPA exhaust filter.	1.6E-5 (not a dome fire) (1.6E-5)
Drop of drill string results in breach of tank bottom liner.	3.0E-5 (not a dome fire) (1.0)
Spill from dropped sampler in shielded receiver. (Similar accidents are spills from drops of sampler in X-ray machine or in cask, but they are of lower frequency.)	8.6E-9 (not a dome fire) (0.22)

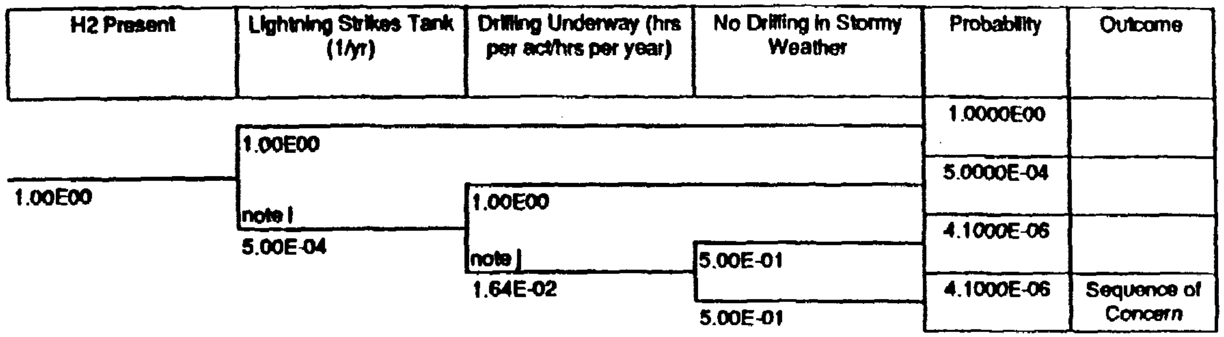
TABLE E-2 (cont)
SUMMARY OF ACCIDENT QUANTIFICATION RESULTS INCLUDING PHENOMENOLOGICAL FACTORS

Accident	Frequency/yr
Waste from contaminated drill string interior is released aboveground.	6.2E-7 (not a dome fire) (2.0)
Waste from contaminated drill string exterior is released aboveground.	4.4E-6 (not a dome fire) (2.0)
Truck over unused riser	2.1E-8 (1.4E-4)
Penetration intentionally open	4.2E-8 (1.4E-5)
Drop of drill string	6.0E-5 (2.0)
Drop of Grapple in drill string	6.0E-11 (1.3E-3)

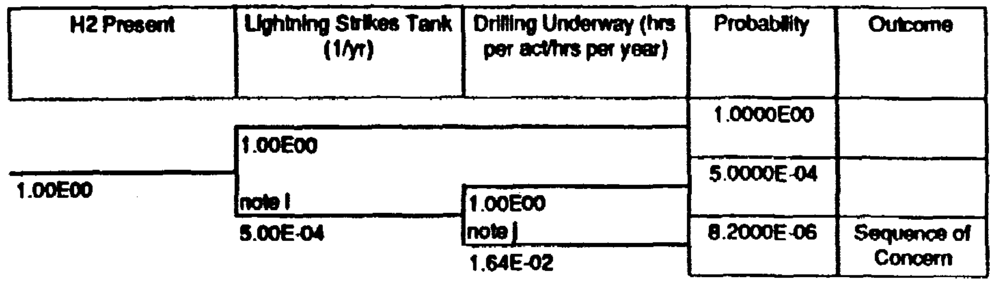
Notes:

1. Frequency lowered using GRE LFL probability.
2. BOM spark tests may lower the frequency of this accident sequence.
3. Probability of waste burn will lower the frequency of this accident sequence.
4. Probability of gas source to drill string with drill string in waste is estimated as 1.0.
5. WHC documentation on aluminum-on-aluminum spark potential will lower the frequency of this accident sequence.
6. Source of gas is from depressurization of sample.

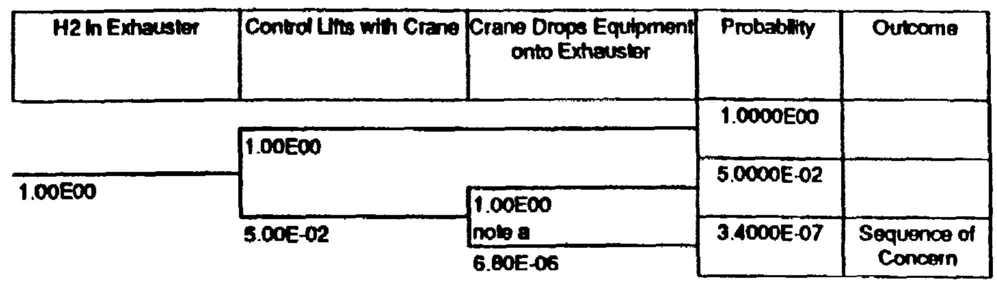
Lightning Strikes Tank (Section 4.1.1.2)



Lightning Strikes Tank (Section 4.1.1.2) Unmitigated Event Tree



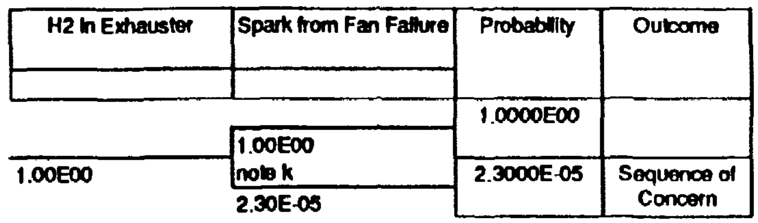
Drop onto Exhauster (Section 4.1.1.4)



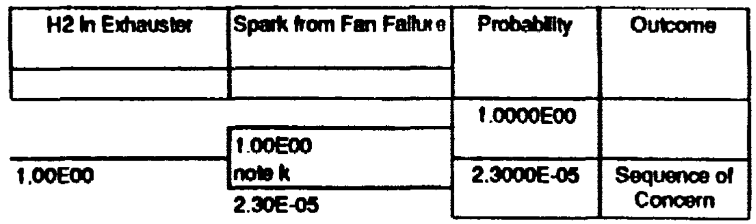
Drop onto Exhauster (Section 4.1.1.4) Unmitigated Event Tree

H2 In Exhauster	Crane Drops Equipment onto Exhauster	Probability	Outcome
		1.0000E00	
1.00E00	1.00E00 note a	6.8000E-06	Sequence of Concern
	6.80E-06		

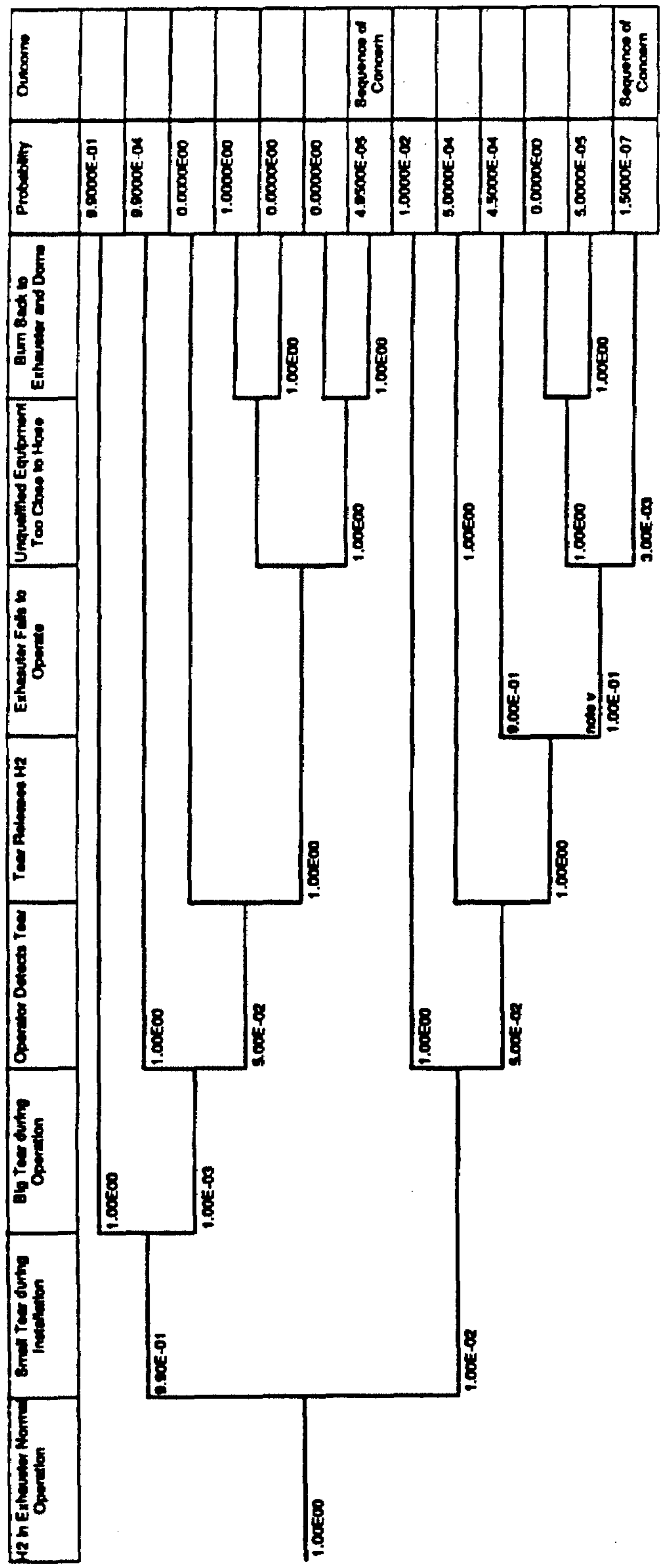
Spark from Exhauster Fan (Section 4.1.1.4)



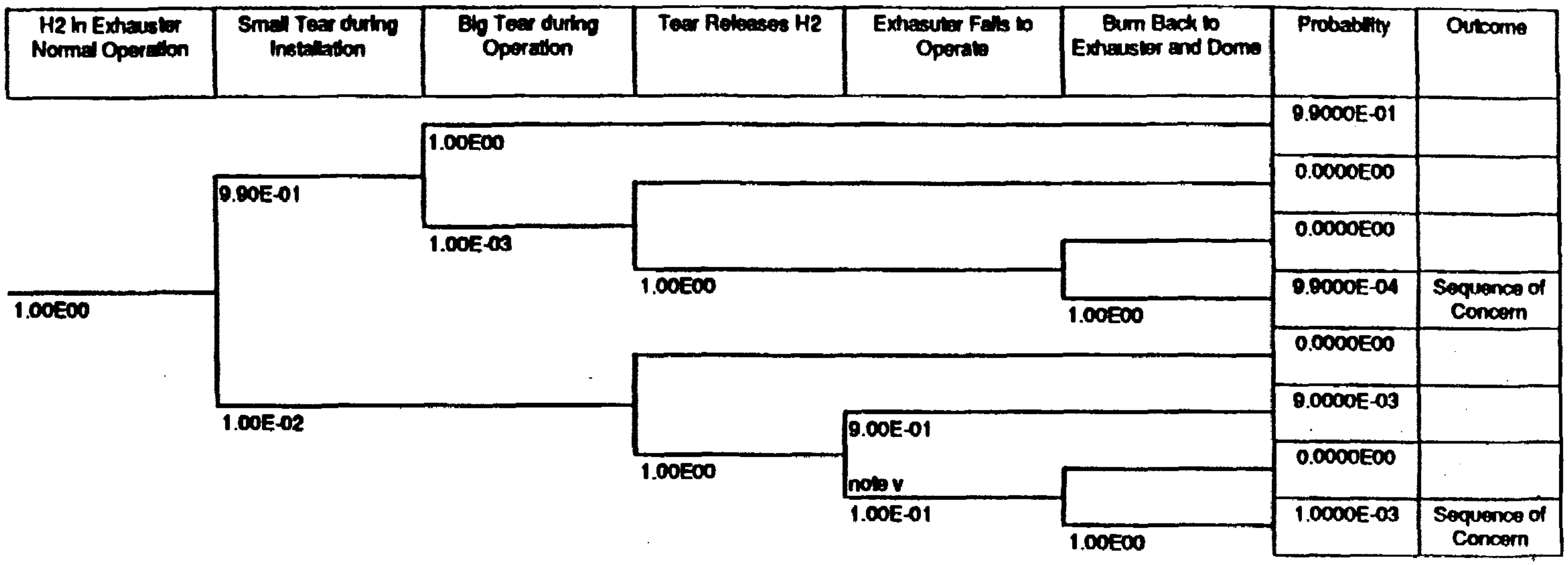
Spark from Exhauster Fan (Section 4.1.1.4) Unmitigated Event Tree



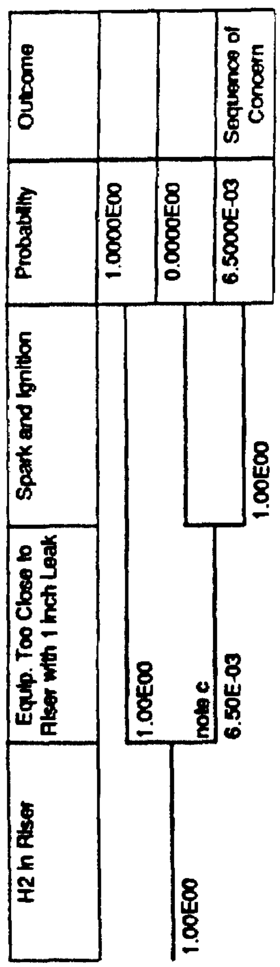
Exhauster Hose Tear (Section 4.1.2)

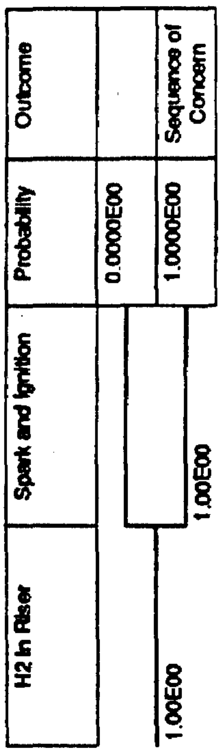


Exhauster Hose Tear (Section 4.1.2) Unmitigated Event Tree



Leaking Penetration (Section 4.1.3





Leaking Penetration (Section 4.1.3) Unmitigated Event Tree

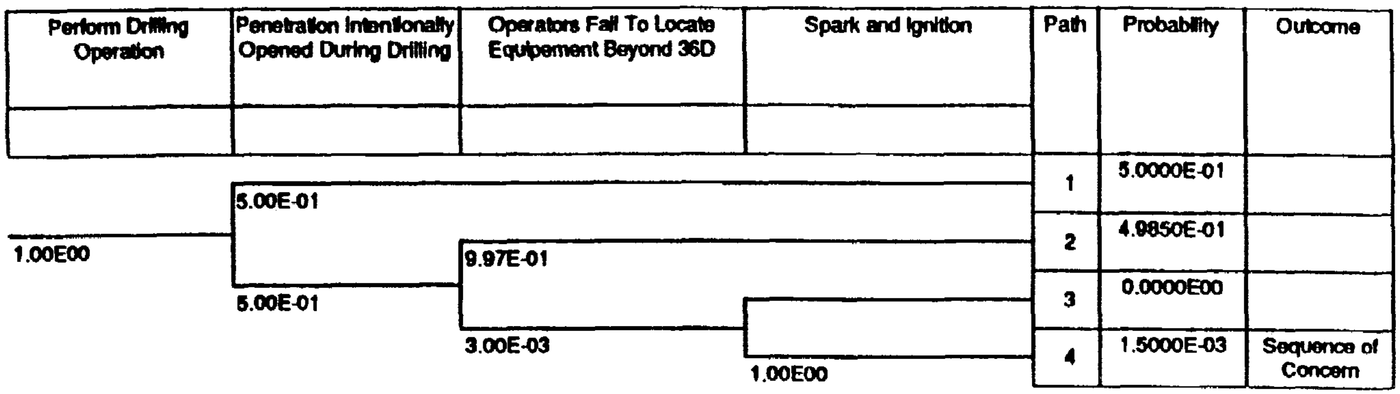
Drill String Truck Parked Over Unused Tank Penetration (Section 4.1.3)

Truck Parked Over Unused Penetration	Operators Fail to Seal Riser/Pit	All Truck Ignition Sources Not > 36 Inches From Riser/Pit	Spark and Ignition	Path	Probability	Outcome
1.00E00	9.97E-01			1	9.9700E-01	
	3.00E-03	9.50E-01		2	2.8500E-03	
		5.00E-02		3	0.0000E00	
			1.00E00	4	1.5000E-04	Sequence of Concern

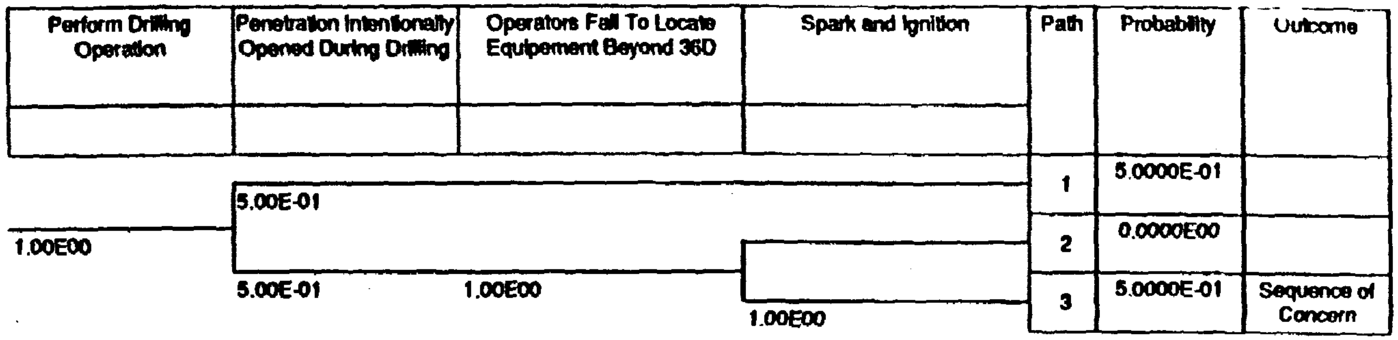
Drill String Truck Parked Over Unused Tank Penetration (Section 4.1.3) Unmitigated Event Tree

Truck Parked Over Unused Penetration	Operators Fail to Seal Riser/Pit	All Truck Ignition Sources Not > 36 Inches From Riser/Pit	Spark and Ignition	Path	Probability	Outcome
				1	0.0000E00	
1.00E00	1.00E00	1.00E00	1.00E00	2	1.0000E00	Sequence of Concern

Intentional Penetration Opening During Drilling (Section 4.1.3)



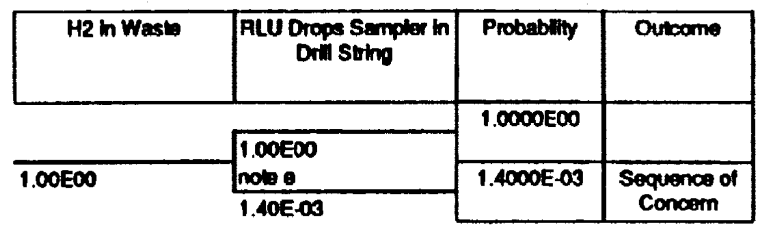
Intentional Penetration Opening During Drilling (Section 4.1.3) Unmitigated Event Tree



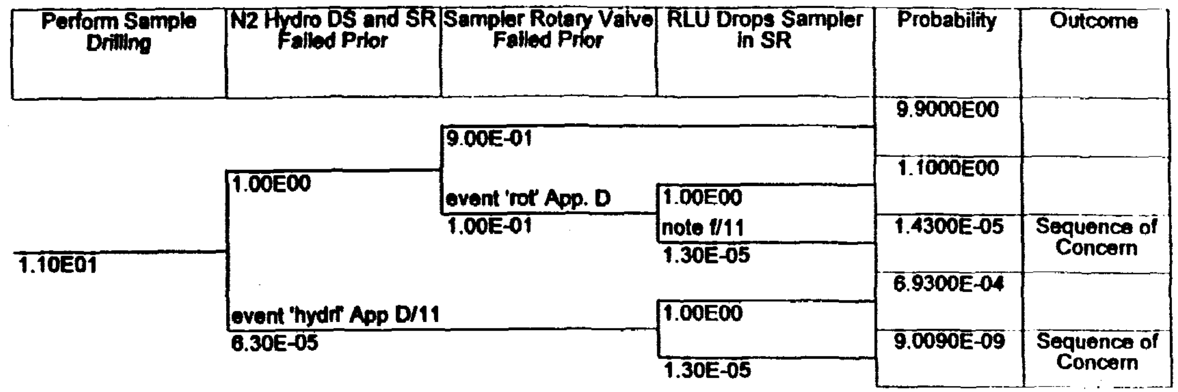
H2 Sample Handling in Drill String (Section 4.1.4)

H2 in Waste	N2 Hydro to Drill and Shield Receiver	RLU Drops Sampler in Drill String	Probability	Outcome
1.00E00	1.00E00		1.0000E00	
	event 'hydro' App. D 6.90E-04	1.00E00	6.9000E-04	
		note e 1.40E-03	9.6600E-07	Sequence of Concern

H2 Sample Handling in Drill String (Section 4.1.4) Unmitigated Event Tree



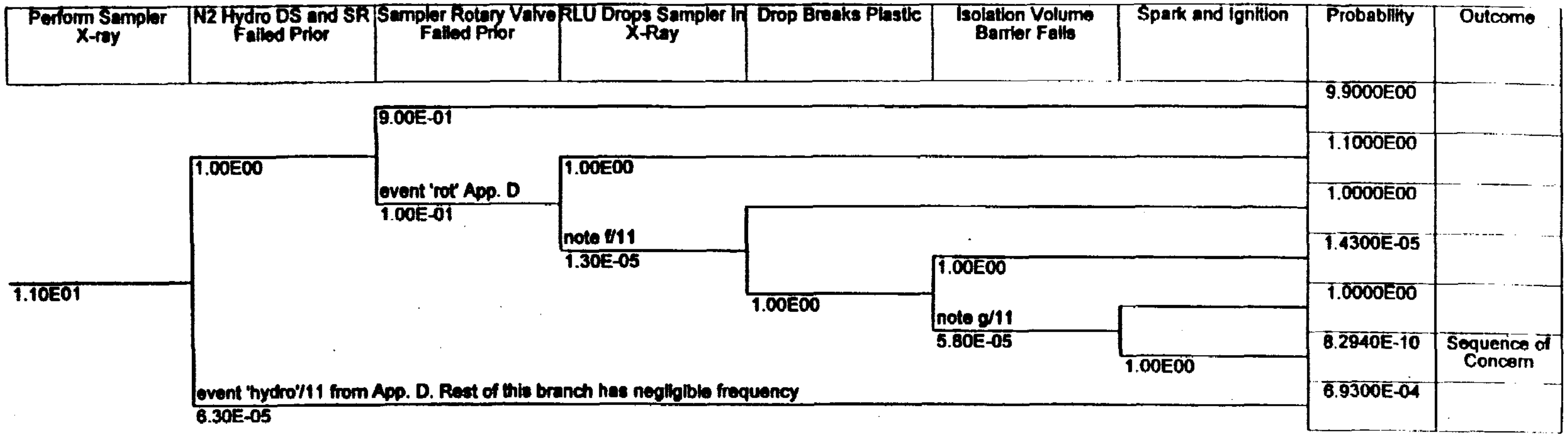
H2 Sample Handling in Isolated Shielded Receiver (Section 4.1.4)



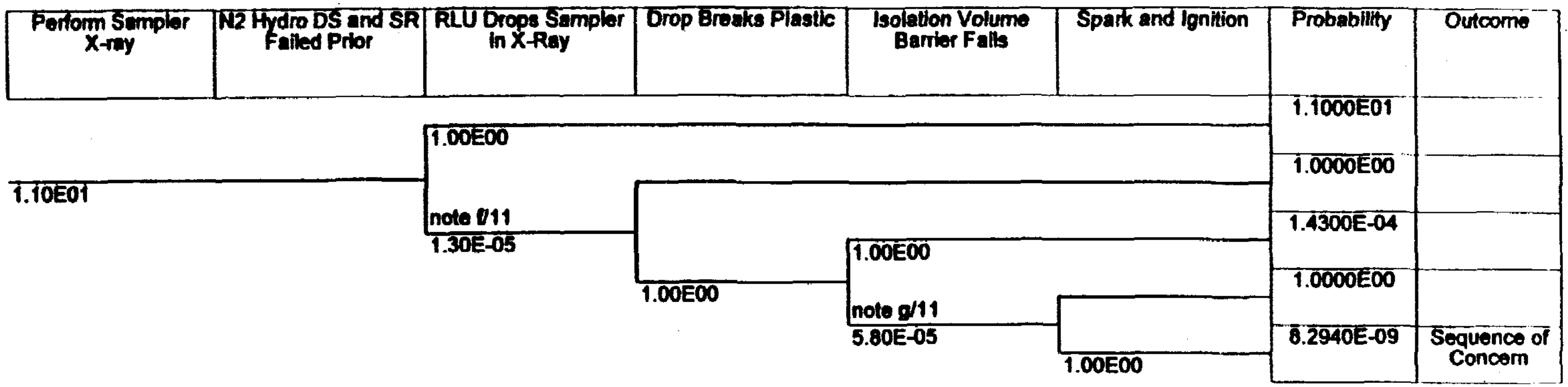
H2 Sample Handling in Isolated Shielded Receiver (Section 4.1.4) Unmitigated Event Tree

Perform Sample Drilling	RLU Drops Sampler in SR	Probability	Outcome
		1.1000E01	
1.10E01	1.00E00 note f/11 1.35E-05	1.4850E-04	Sequence of Concern

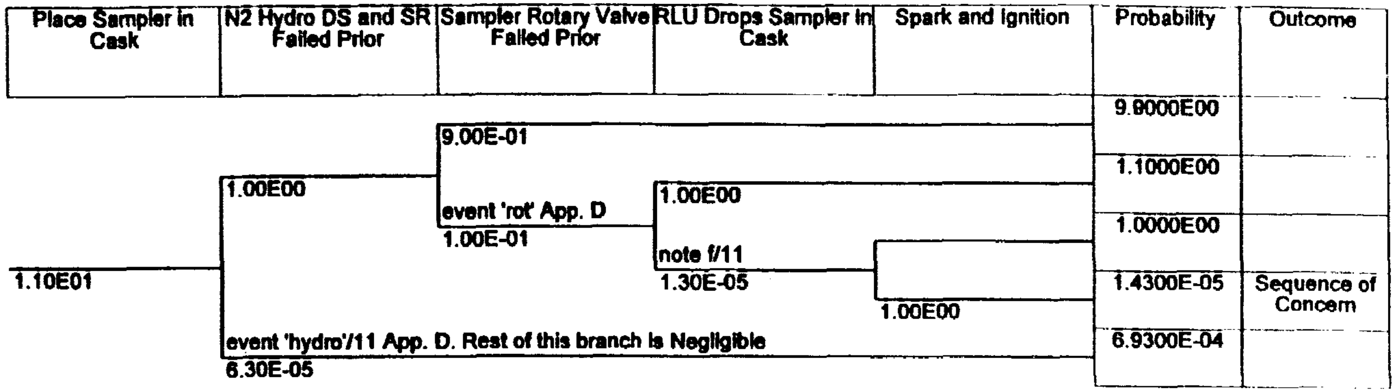
H2 in X- Ray Machine (Section 4.1.5)



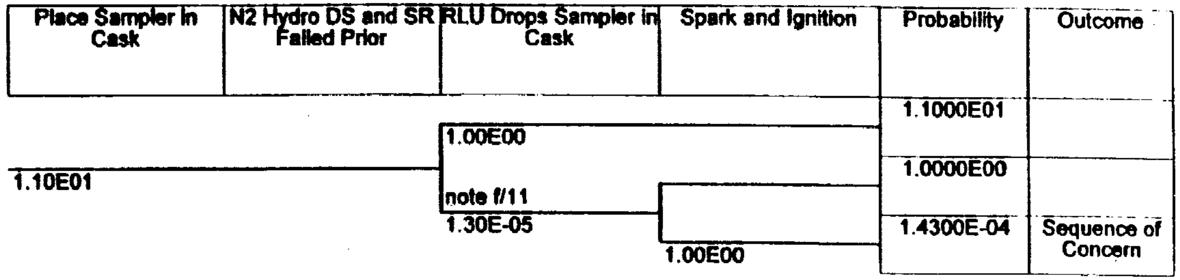
H2 In X- Ray Machine (Section 4.1.5) Unmitigated Event Tree



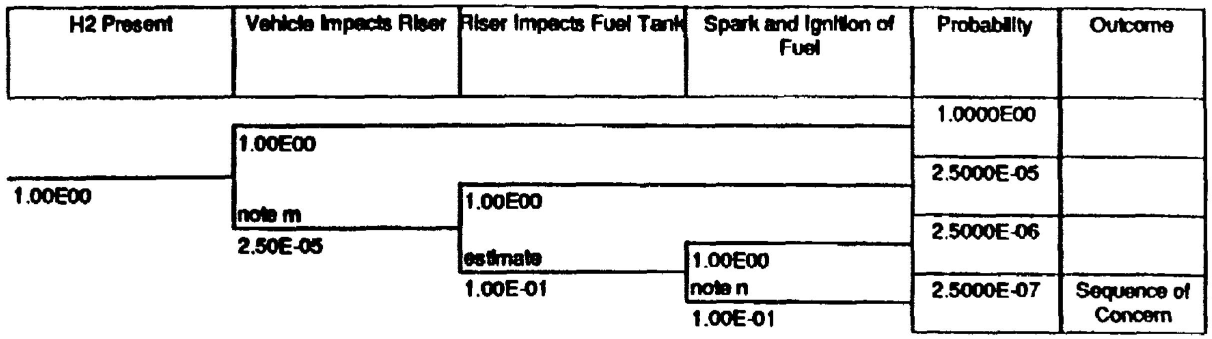
H2 in Cask (Section 4.1.5)



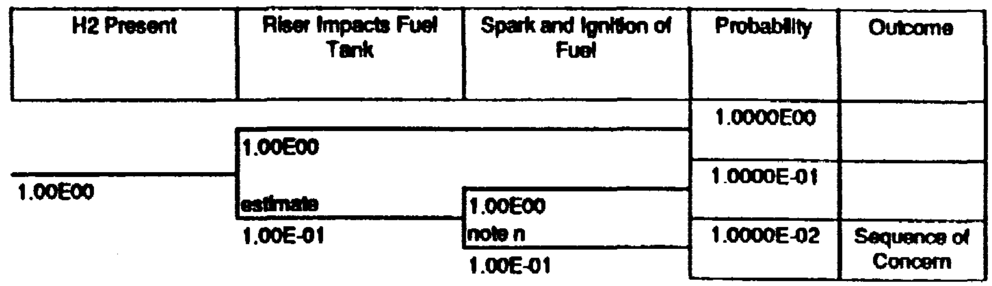
H2 In Cask (Section 4.1.5) Unmitigated Event Tree



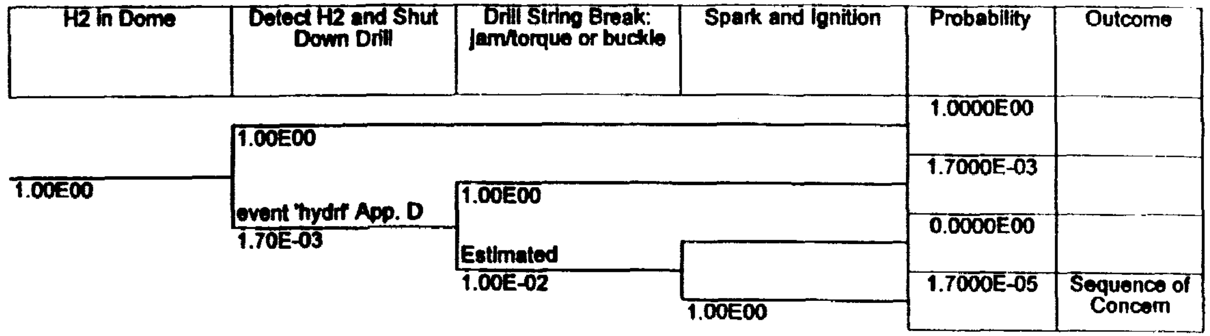
Vehicle Collides with Tank Riser (Section 4.1.9)



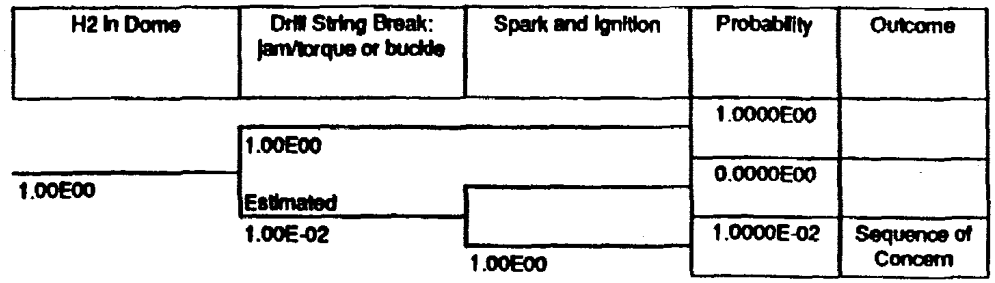
Vehicle Collides with Tank Riser (Section 4.1.9) Unmitigated Event Tree



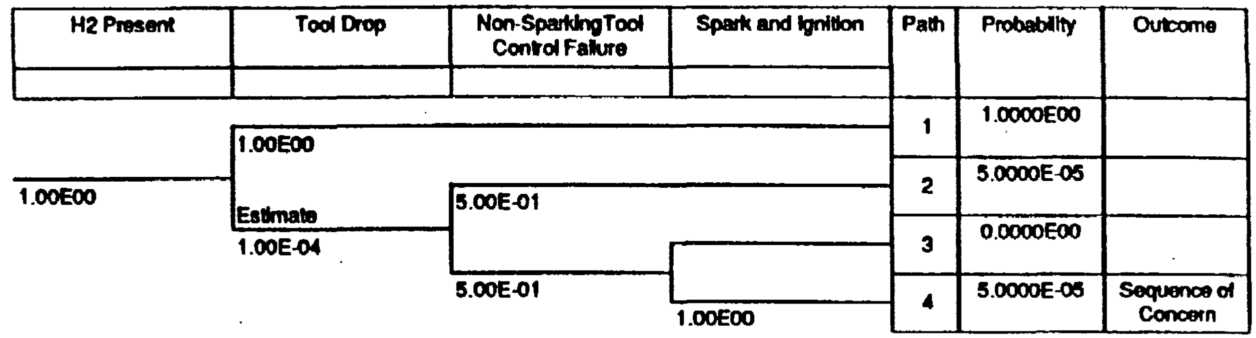
Drill String Break in Dome (Section 4.2.1)



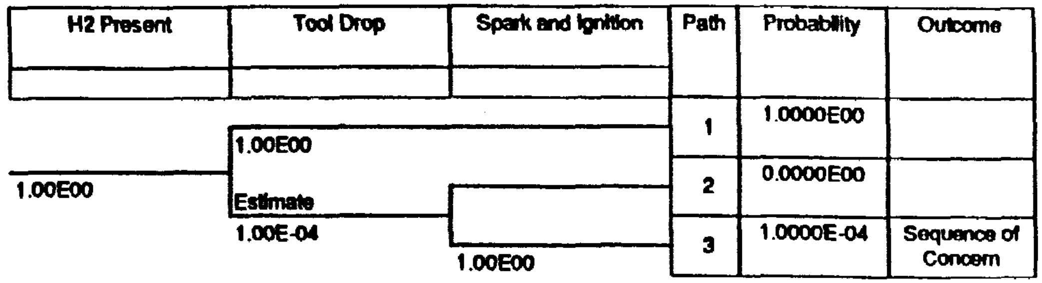
Drill String Break In Dome (Section 4.2.1) Unmitigated Event Tree



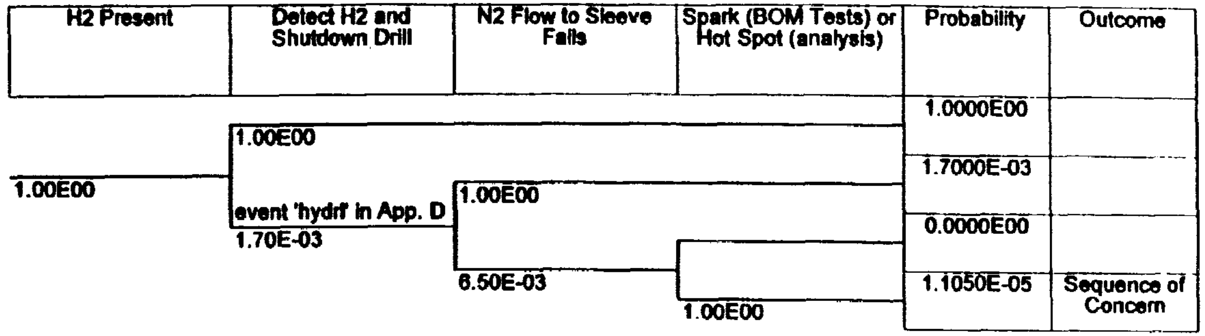
Tool Drop Into Open Riser (Section 4.2.3)



Tool Drop Into Open Riser (Section 4.2.3) Unmitigated Event Tree



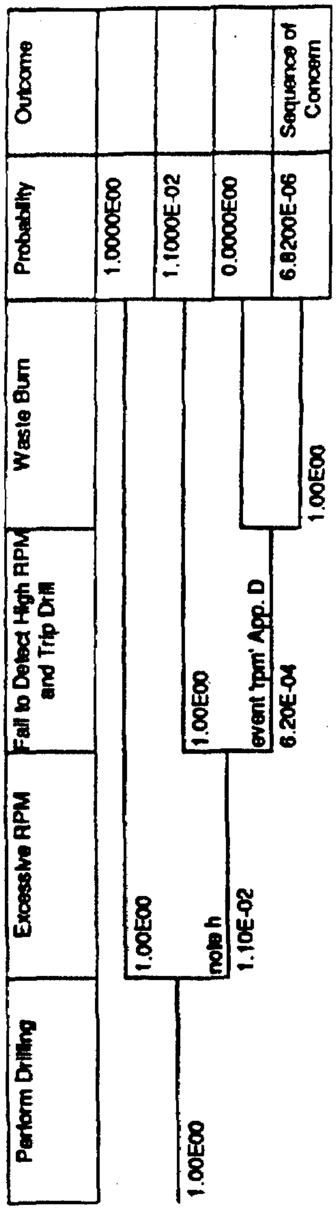
Ignition in Drill String Riser Sleeve (Section 4.2.4)



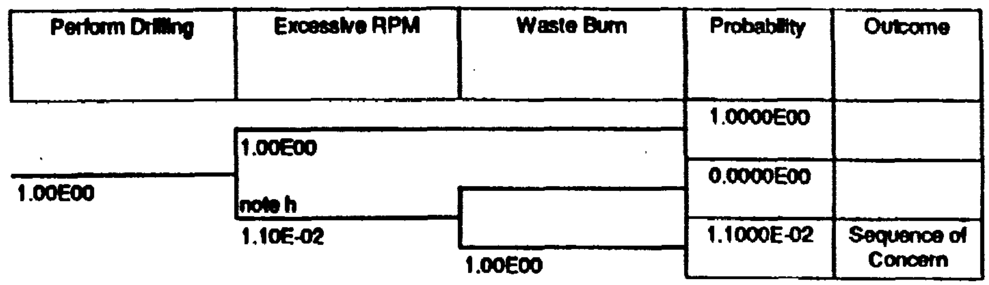
Ignition In Drill String Riser Sleeve (Section 4.2.4) Unmitigated Event Tree

H2 Present	Detect H2 and Shutdown Drill	N2 Flow to Sleeve Fails	Spark (BOM Tests) or Hot Spot (analysis)	Probability	Outcome
				0.0000E00	
1.00E00	1.00E00	1.00E00	1.00E00	1.0000E00	Sequence of Concern

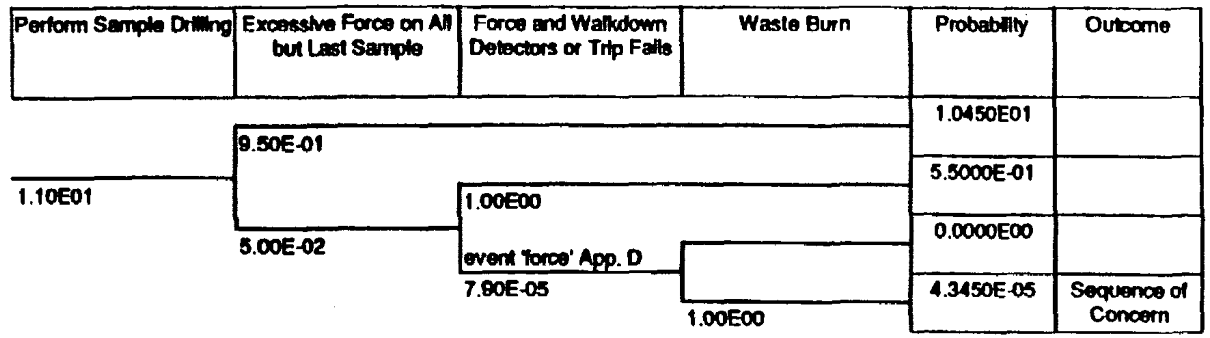
Overheat Waste: Excessive RPM (Sections 4.2.6 and 4.4)



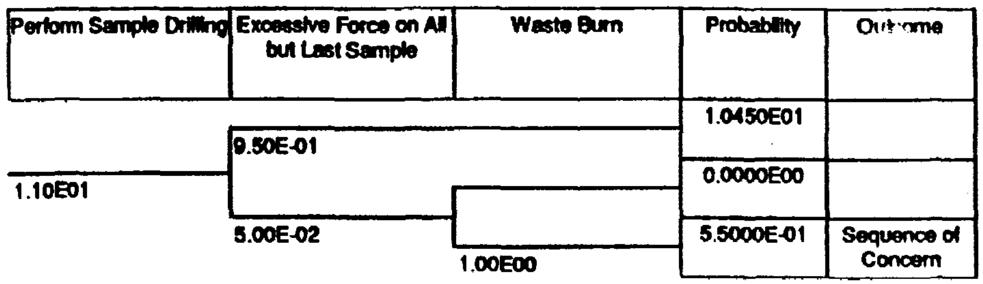
Overheat Waste: Excessive RPM (Sections 4.2.6 and 4.4) Unmitigated Event Tree



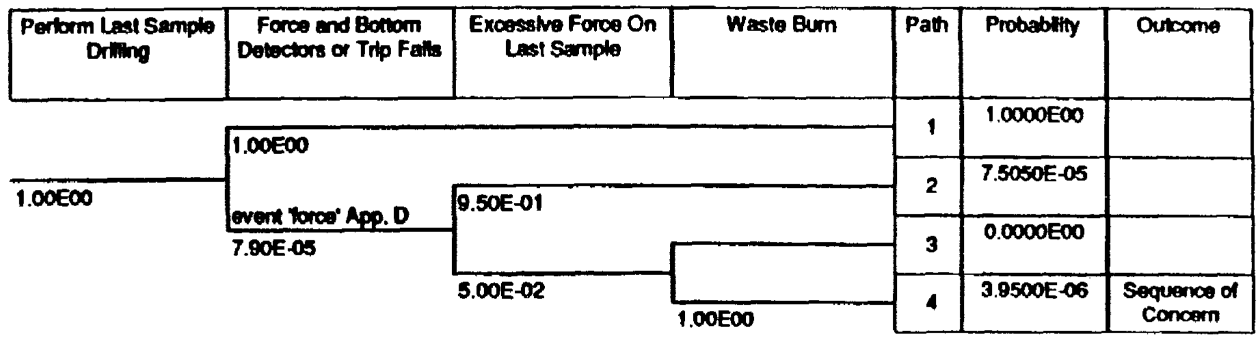
Overheat Waste: Excessive Force All but Last Sample (Sections 4.2.6 and 4.4)



Overheat Waste: Excessive Force All but Last Sample (Sections 4.2.6 and 4.4) Unmitigated Event Tree



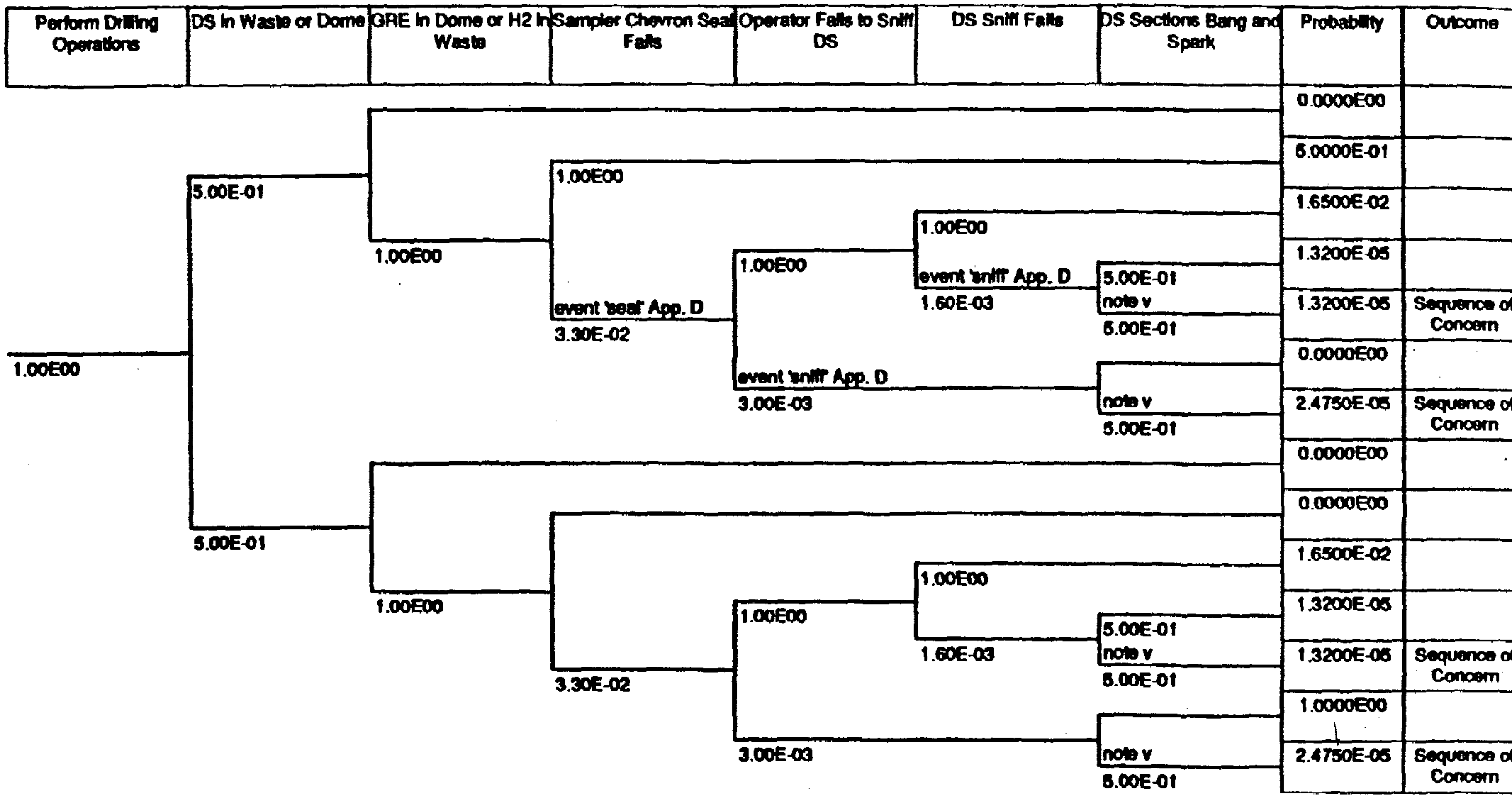
Overheat Waste: Excessive Force Last Sample (Sections 4.2.6 and 4.4)



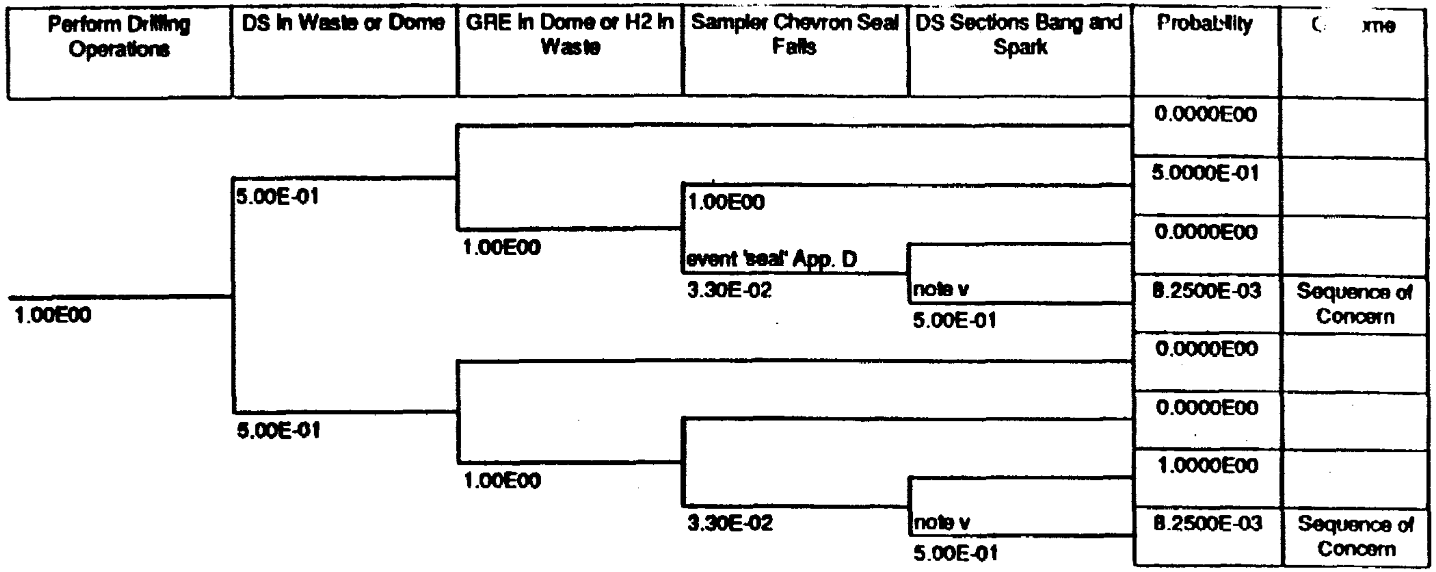
Overheat Waste: Excessive Force Last Sample (Sections 4.2.6 and 4.4) Unmitigated Event Tree

Perform Last Sample Drilling	Excessive Force On Last Sample	Waste Burn	Path	Probability	Outcome
1.00E00	9.50E-01		1	9.5000E-01	
			2	0.0000E00	
	5.00E-02	1.00E00	3	5.0000E-02	Sequence of Concern

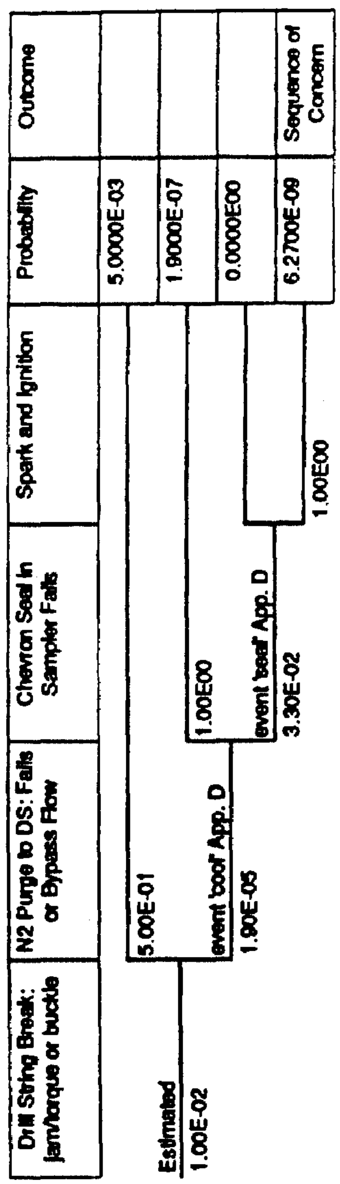
Spark from DS Sections (Section 4.3.3)



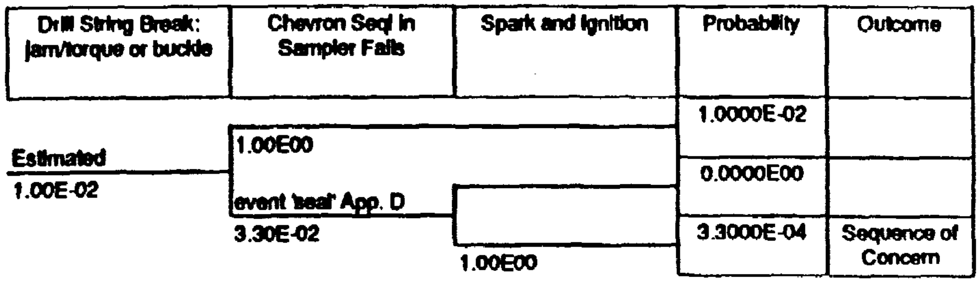
Spark from DS Sections (Section 4.3.3) Unmitigated Event Tree



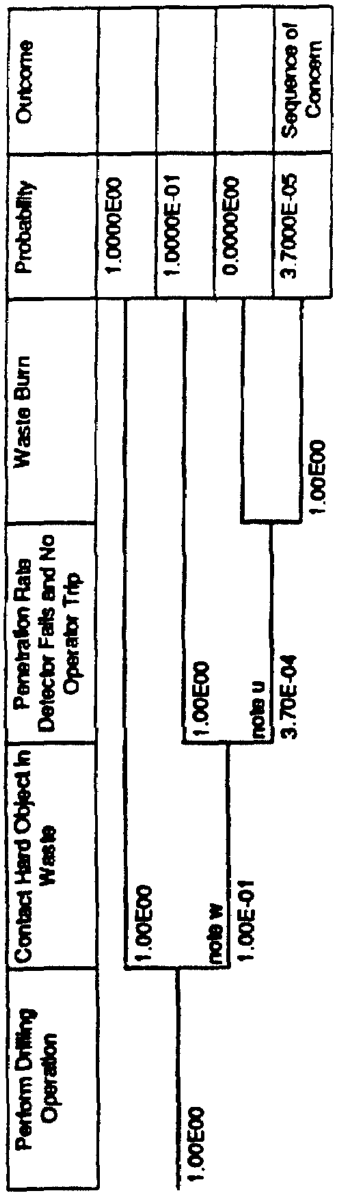
Drill String Break Drill String Fire (Section 4.3.5)



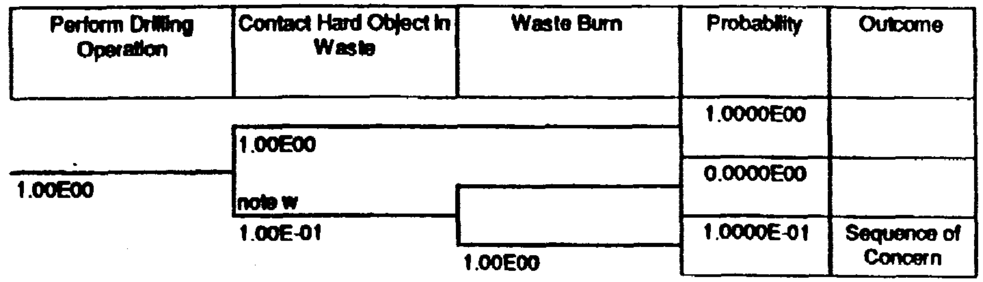
Drill String Break Drill String Fire (Section 4.3.5) Unmitigated Event Tree



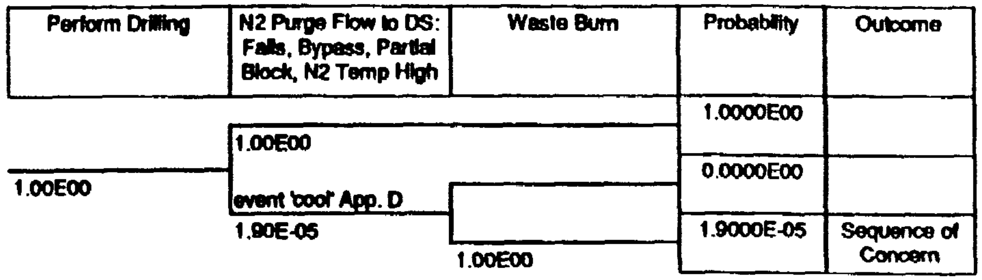
Slow Penetration Rate (Section 4.4)



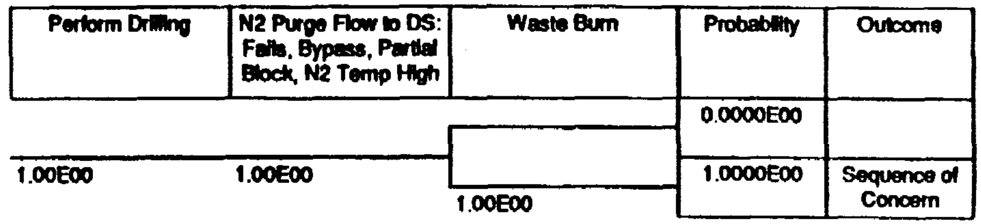
Slow Penetration Rate (Section 4.4) Unmitigated Event Tree



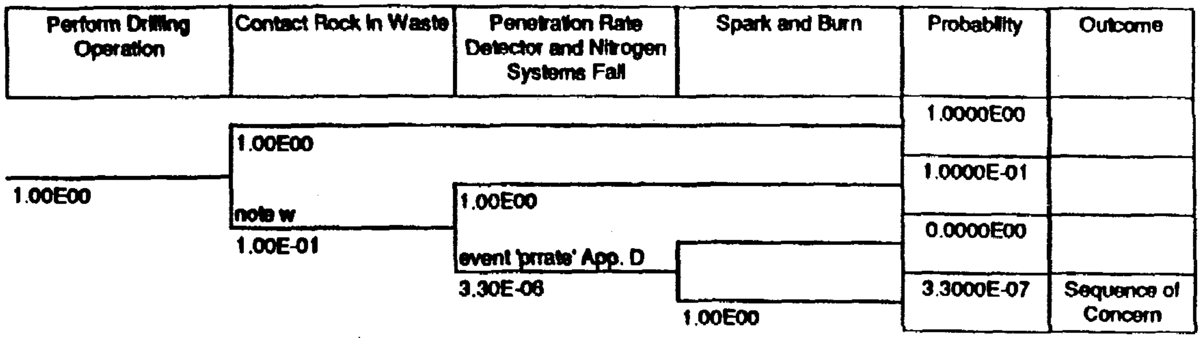
Overheat Waste: Loss of N2 Cooling to Drill Bit (Section 4.4)



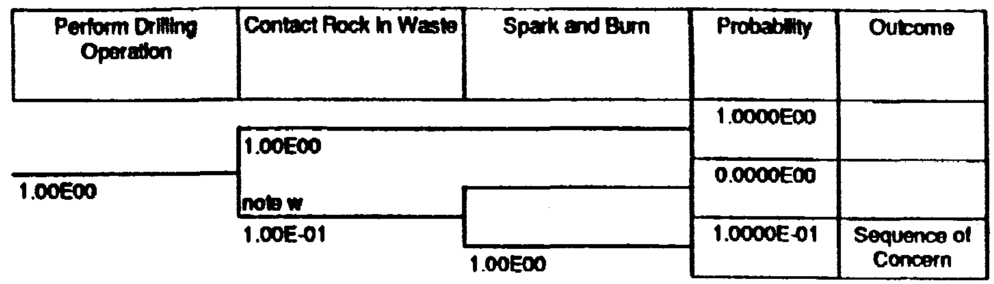
Overheat Waste: Loss of N2 Cooling to Drill Bit (Section 4.4) Unmitigated Event Tree



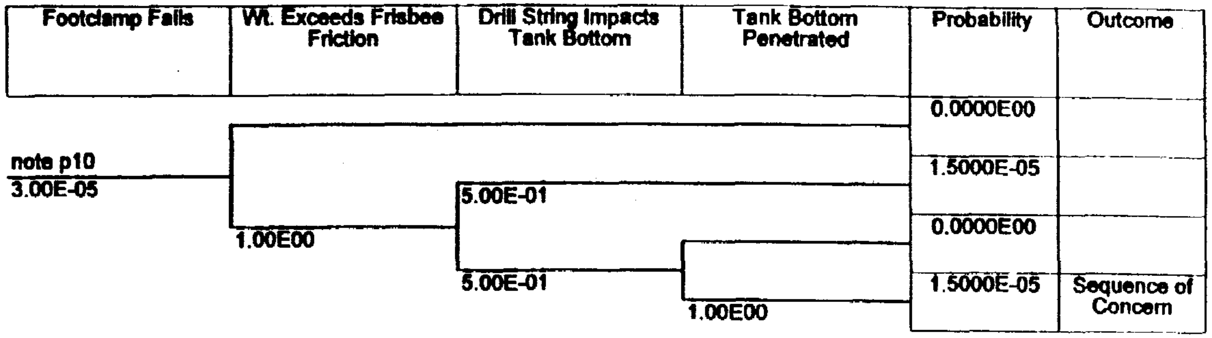
Hit Rock in Waste (Section 4.4)



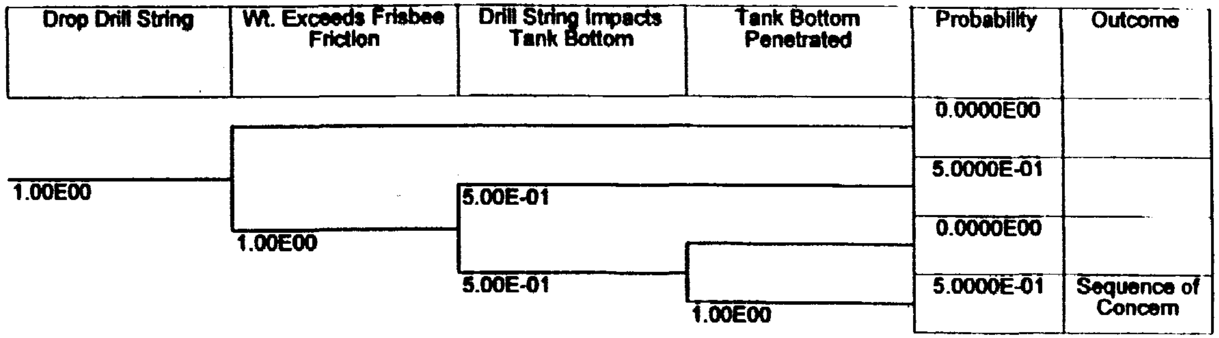
Hit Rock In Waste (Section 4.4) Unmitigated Event Tree



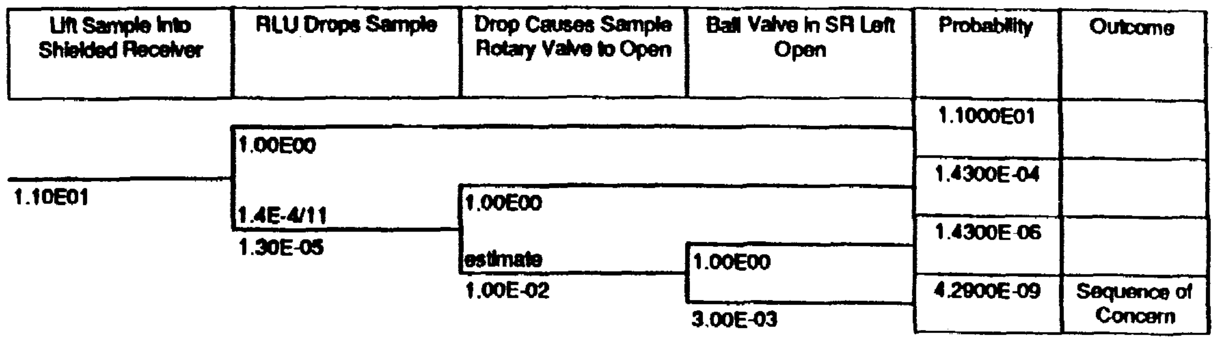
Dropped Drill String Penetrates Tank Bottom (Section 4.6.2)



Dropped Drill String Penetrates Tank Bottom (Section 4.6.2) Unmitigated Event Tree



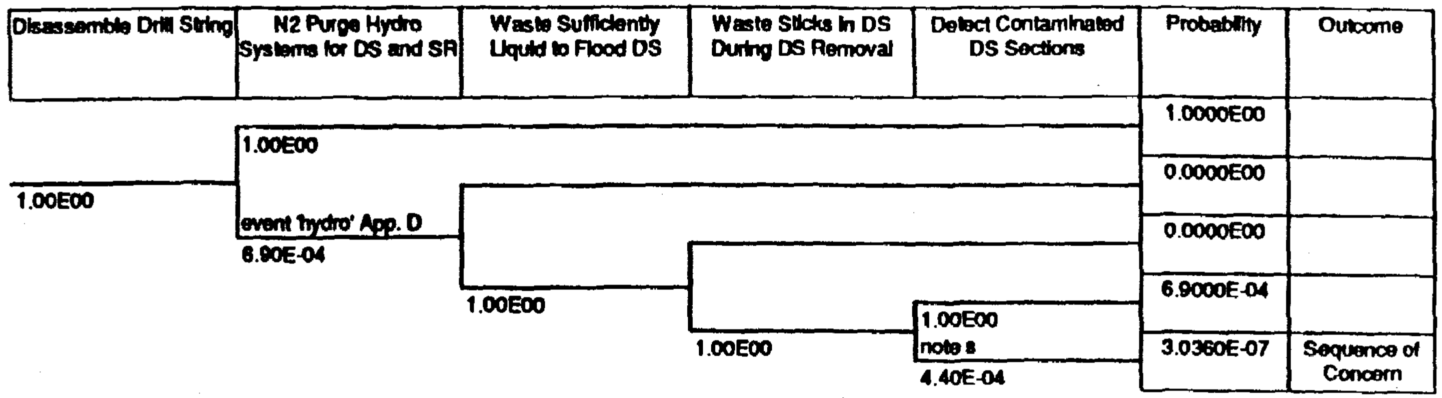
Sample Spill from Shielded Receiver (Section 4.8)



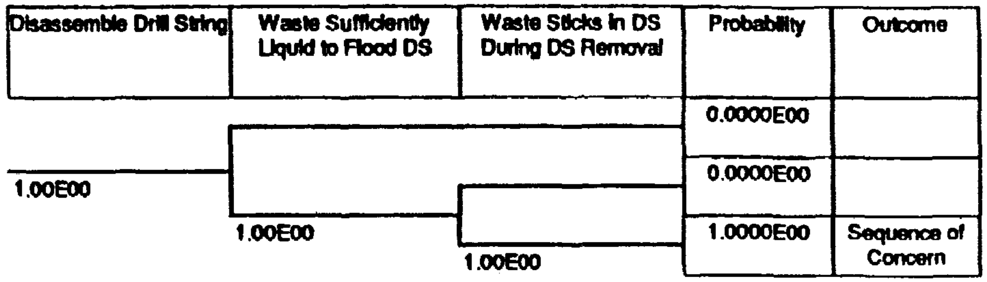
Sample Spill from Shielded Receiver (Section 4.8) Unmitigated Event Tree

Lift Sample Into Shielded Receiver	Drop Causes Sample Rotary Valve to Open	Ball Valve In SR Left Open	Probability	Outcome
	9.90E-01		1.0890E01	
1.10E01	1.00E-02		1.1000E-01	

Spill Waste from Contaminated Drill String Interior (Section 4.8)



Spill Waste from Contaminated Drill String Interior (Section 4.8) Unmitigated Event Tree

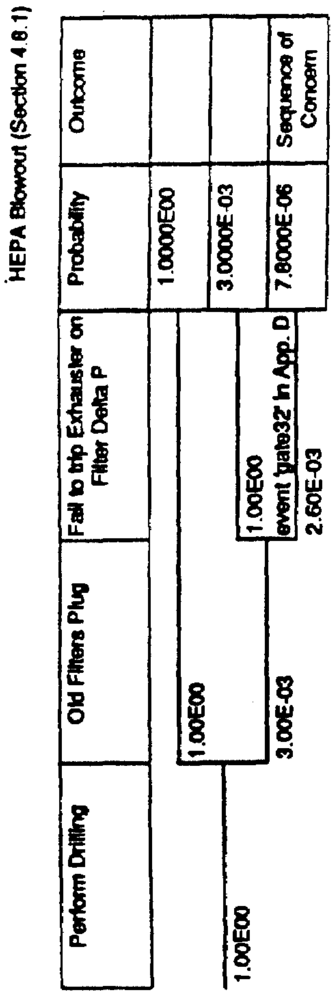


Spill Waste from Contaminated Drill String Exterior (Section 4.8)

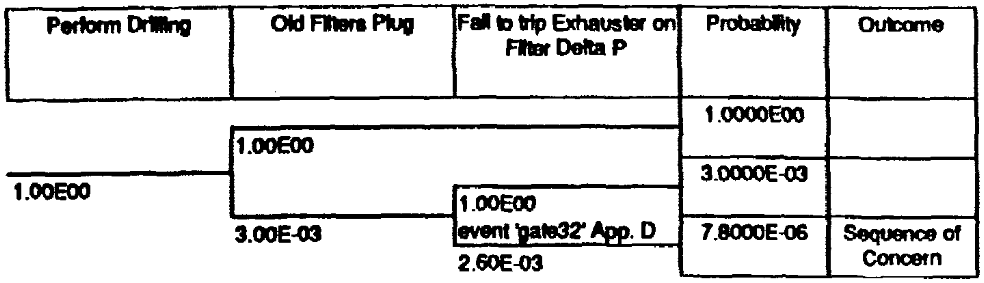
Disassemble Drill String	Wash removes Waste from DS Exterior	Visual Detection of Waste on DS Exterior	Detect Contaminated DS Sections	Probability	Outcome
1.00E00	1.00E00			1.0000E00	
	estimate 1.00E-01	1.00E00		1.0000E-01	
		5.00E-02	1.00E00	5.0000E-03	
			note s 4.40E-04	2.2000E-06	Sequence of Concern

Spill Waste from Contaminated Drill String Exterior (Section 4.8) Unmitigated Event Tree

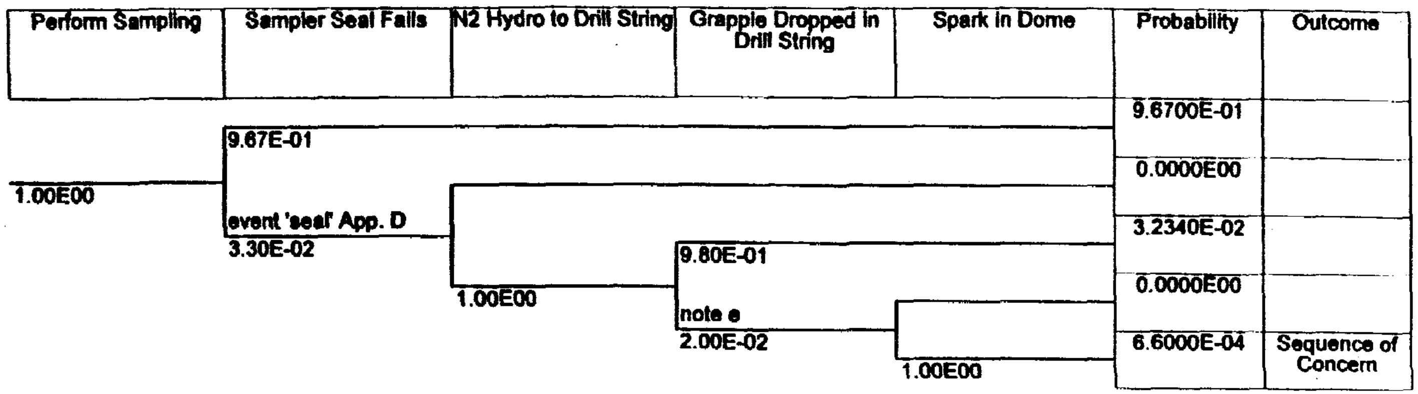
Disassemble Drill String	Wash removes Waste from DS Exterior	Visual Detection of Waste on DS Exterior	Probability	Outcome
1.00E00			1.0000E00	Sequence of Concern


HEPA Blowout (Section 4.8.1)
Perform Drilling
Old Filters Plug
Fail to trip Exhauster on Filter Delta P
Probability
Outcome
1.00E00
1.00E00
3.00E-03
1.00E00
event 'gate32' in App. D
2.60E-03
1.0000E00
3.0000E-03
7.8000E-06
Sequence of Concern

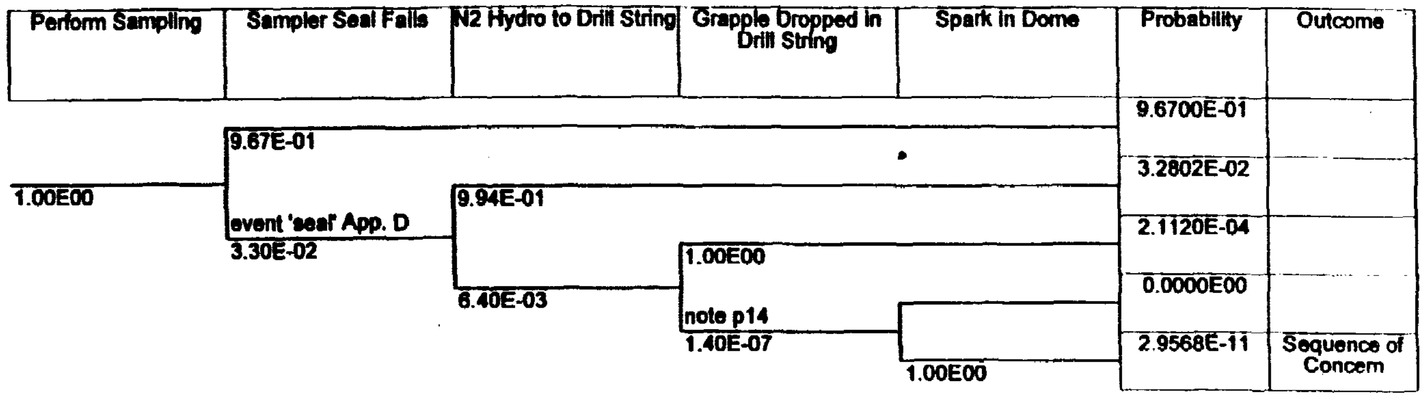
HEPA Blowout (Section 4.8.1) Unmitigated Event Tree



Drop Grapple in Drill String Unmitigated (Section 4.3.2.1)



Drop Grapple in Drill String Mitigated (Section 4.3.2.1)



Notes for Accident Event Trees	
Note a.	6.3E-5/lift [NUREG -0612] x 25 sq m/465 sq m [area exhauster to tank] x 2 lifts/activity [estimate] = 6.8E-6
Note b.	Big Tear Discovered after Shutdown prior to Restart
Note c.	Assumes 25 Risers and 10 Pieces of Equipment x value from Mathematica Calculation [2.6E-5] for total value of 6.5E-3
Note d.	Assumes 1 Riser and 10 Pieces of Equipment x value from Mathematica Calculation [5.6E-4]
	(superceded by addition of inlet stack to inlet HEPA path: removed from analysis)
Note e.	0.02 prob. Hangup per activity [WHC info] x (0.05 + 0.02) [failure detect hangup in 2 min + fail to recover by change motor direction] = 1.4E-3
Note f.	0.02 prob. Hangup per activity [WHC info] x (0.005 + 0.002) [failure detect hangup watching through window + fail to recover by change motor direction] =1.4E-4
Note g.	Rubber gasket failure 2.9E-7/hr [blue book] x 2196 hours = 6.4E-4
Note h.	0.001 first time (commission) + 0.01 second time = 0.011
Note i.	freq. Lightning strike 5E-4/yr [WHC-SD-SARR-027 Rev 0]
Note j.	144 hrs per act/8766 hrs per yr = 1.64E-2 yr/act
Note k.	spark modeled as bearing seizure leading to fan impeller break and collision with fan housing
	1.6E-6/hr [NPRD-91 frictional bearings] x 0.10 shaft breaks [estimate] x 144 hrs operation = 2.3E-5
Note l.	removed from analysis
Note m.	1.5E-3/tank/yr [LANL 241SY101 PRA Page D-5] x 144 hr per act/8766 hr per year = 2.5E-5/act
Note n.	0.1 for fuel fire in non-qualified area [CA]
Note o.	6.3E-5 drops/lift [NUREG 0612] x 20 lifts/act [estimate] = 1.2E-6 (includes operator error)
Note p.	prob 1/3 jacks fail + prob mis-set 1 of 3 jacks + prob drive off ramp= 3 (72 hrs*9E-6/hr [NPRD-91 shaft locking collar]) + 3(0.001) + 0.001 = 5.9E-3
Note q.	ash blockage, LANL 241SY101 PRA Page C-46: 3.8E-4/yr/2 act/yr = 1.9E-4 (removed from analysis)
Note r.	LANL 241SY101 PRA Page D-4: 5.2E-3/tank yr/2 act per yr = 2.6E-3
Note s.	0.0001 (commission) + 5E-6/hr*1hr [WSRC-TR-93 rad monitor Table 6] +0.0003 [I&C] + 3E-5/hr*1hr = 4.4E-4
Note t.	Assuming new NH_3 detection system is one-of-two for success with reliability equivalent to H_2 detection system
Note u.	Assume 1/1 penetration trip design and use value calculated for failure to trip with the single force detector (7.4E-3) and use 0.05 for operator backup trip for total of 3.7E-4
Note v.	Engineering Judgment
Note w.	0.2 probability for needing rotary core drilling while sampling *0.5 probability of hitting hard layer = 0.1 total value

E.5. REFERENCES

1. L. Abeyta and B. Lopez, "Computer Code SANET, Version 2.0," Science and Engineering Associates, Inc., Albuquerque, NM (October 1994).

2. J. M. Butner and J. L. Darby , "Quantification of Aeeident Sequences for Rotary Mode Core Drilling," Los Alamos National Laboratory report TSA10-CN-SA-TH-089 (January 11, 1996).

3. Alan D. Swain, "Accident Sequence Evaluation Program Human Reliability Analysis Procedure," US Nuclear Regulatory Commission report NUREG/CR-4772 (February 1897).

4. G. W. Hannaman and A. J. Spurgin, "The Systematic Human Action Reliability Procedure (SHARP)," Electrical Power Research Institute report EPRI NP3583, Project 2170-3, Interim Report (June, 1994).

5. J. L. Darby and J. M. Butner, "Reliability of Systems for Rotary Mode Core Sampling," Los Alamos National Laboratory report TSA10-CN-SA-HAZ-004 (February 15, 1996).

APPENDIX F

THERMAL ANALYSIS OF ROTARY DRILLING

F.1. INTRODUCTION

Figure F-1 illustrates the phenomena occurring at a drill bit tooth for normal cutting and for the case with a dull drill bit that is not cutting. Also, the figure shows some of the nomenclature used in this appendix.

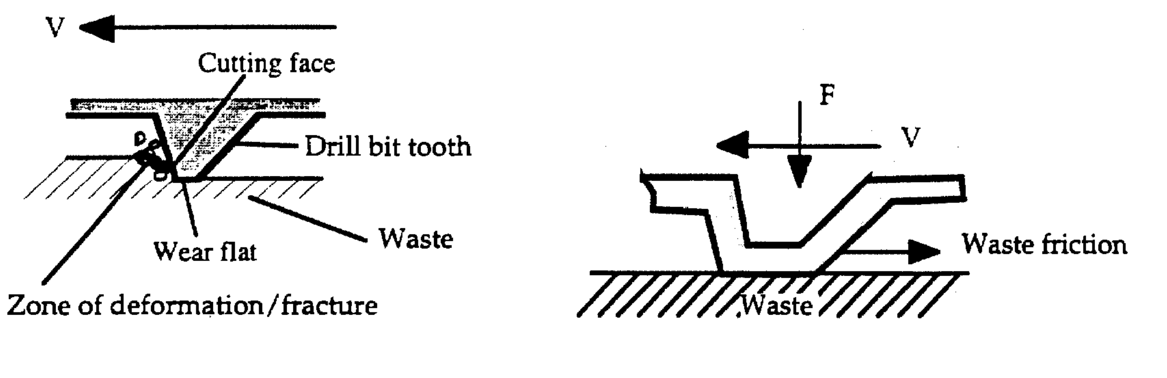


Fig. F-1. Sketch illustrating the cutting process of the drill bit.

When the bit is cutting well [Fig. F-1(a)] there is a zone in front of the bit tooth where most of the work is taking place. The material being drilled is compressed and fractured. The zone in front of the teeth where the compression and fracturing takes place is at a high pressure compared to the region where the purge gas flows. This pressure difference causes the chips to be squeezed out along the cutting face of the bit. The purge gas cools the fracture zone and the chips and then carries the chips radially outward. The energy that goes into compressing and fracturing the material is mostly converted to thermal energy. If the drilling is proceeding efficiently, most of the energy goes into the chips. Frictional energy dissipation occurs on the wear-flat as it slides over the substrate and on the cutting face where the chips are squeezed past. Conceptually, the maximum temperature can occur in the chips because of the mechanical-to-thermal energy conversion as the material is compressed and fractured, or along one of the bit surfaces where frictional heating occurs.

In inefficient cutting with dull drill bit teeth [Fig. F-1(b)], penetration may be difficult to achieve. In this scenario, the drill bit and waste in the waste friction zone attain similar temperatures in a short time. In this case, the maximum waste temperature would occur at the interface between the bit and the waste.

A hazard associated with high waste temperatures is the exothermic propagating chemical reaction. Waste ignition could result with unacceptable consequences. In

Appendix G safe waste temperature limits are established to prevent propagating exothermic chemical reactions in the tank during rotary core sampling. A limit of 150°C has been set for bulk material in the vicinity of the drill bit. A limit of 180°C has been set for temperatures that may occur over small regions (a few chips in diameter) and for short times. These temperature limits are intended to prevent exothermic chemical reactions from being initiated. Laboratory experiments are conducted with the prototype drill bit by Westinghouse Hanford Company (WHC).[1] These tests were designed to provide the data necessary to set operational limits and to demonstrate that the waste temperature limits will not be exceeded.

The purpose of this appendix is to evaluate the test results and determine an adequate basis for setting limits for the drilling operation to ensure that temperature limits will not be exceeded. Other objectives are to discuss how laboratory test results are applicable to real conditions in tanks.

F.2. BACKGROUND

Some drill bit thermal modeling and experimental work has been done for oil and geothermal well drilling. In these cases, the interest in thermal modeling was driven by the need to maximize the life of synthetic diamond cutters. The rate of degradation of these cutters is a function of temperature. Prakash and Appl[2] developed a finite element model of an oil well drilling bit and the rock being cut. Glowka and Stone[3] developed a finite element model for a bit for geothermal applications that examined only the friction component of energy dissipation in which the wear-flat slides over the substrate. In both of these papers, the primary interest was in the temperature of the drill bit. The temperature of the material being cut was only considered as it related to the bit temperature.

In addition to the papers on thermal modeling of drill bits, there are papers that discuss the mechanical energy input per unit volume of material removed. In the rock drilling literature this concept goes by the term "specific energy." Teale[4] discusses this concept and provides numerical values for several materials. Units are expressed as in. $lbf/in.^3$ or MJ/m^3. Teale shows that the minimum specific energy for a rock-drilling operation is equal to the compressive strength (σ) of the material. This is shown by the following equation, where "SE" is the specific energy, "F" is force, "A" is area, "x" is distance, and "length" and "force" are generalized dimensions:

$$SE\left(\frac{\text{length}\cdot\text{force}}{\text{length}^3}\right)=\frac{\int F\,dx}{\int A\,dx}=\frac{\int \sigma A\,dx}{\int A\,dx}=\sigma\left(\frac{\text{force}}{\text{length}^2}\right) \qquad \text{(F-1)}$$

Applying a pressure equal to the compressive strength through some distance gives a specific energy that is numerically equal to the compressive strength if an appropriate system of units is used.

Teale[4] shows examples of specific energy for laboratory tests of rotary drilling in several different sandstones. Specific energies ranged from near the compressive strength of about 6,000 in. lbf/in.^{3} to about 20,000 in. lbf/in.^{3}. Rabia[5] showed that the specific energy in a field drilling operation was often higher than laboratory drilling operations by a factor of about 2. He shows values of specific energy for field drilling of different rock types that range from 16,000 in. lbf/in.^{3} to 66,000 in. lbf/in.^{3}. These values represent the total power input to the drill bit and include frictional losses as well as the energy required to fracture the material being cut.

A quantity similar to specific energy has been defined for machining.[6,7] This quantity is known as the "unit horsepower," and is defined as the horsepower needed to remove one cubic inch of material per minute (hp/in.^{3}/min). Operating at less than optimal conditions increases the energy needed to perform the machining operation. Handbook values range from 0.25 hp/in.^{3}/min for soft nonferrous metals and alloys, including free-machining brass, cast aluminum, and zinc alloy to 1.3 hp/in.^{3}/min for hard ferrous alloys. The difference between machining a ductile material and a brittle material is in the nature of the fracturing. To machine a ductile material, shearing takes place along a plane. To drill a brittle material, the material is compressed to the compressive strength, causing a number of fractures to propagate into the material.

The transformation of mechanical to thermal energy takes place along the fracture surfaces of the material being drilled or machined. The temperature that occurs along these fracture surfaces may be significantly higher than the average temperature reached when the thermal energy is distributed over the entire volume of the material removed. The analyses in this appendix consider only these average temperatures. Some of this thermal energy may be transferred to the drill bit, some to the substrate, and some to the coolant, although most of the thermal energy probably heats the chip. If all the mechanical energy needed to remove a chip is converted to thermal energy in the chip, the average temperature rise can be calculated. Table F-1 gives the values for specific energy and unit horsepower discussed above. The original unit is given in bold face. The temperature rise is calculated using values for specific heat and density given by WHC for Tank BY-104 waste simulant.[8]

F.3. SAFETY ENVELOPE TESTS

The operating safety envelope has been defined by Keller.[8] The safety envelope was obtained by performing experiments with a prototype drill bit and waste simulants. Thermal properties of these simulants were expected to represent typical properties of salt cake. The rotational speed, downward force, and nitrogen purge flow rate were varied. The number of data for a given set of parameters was limited. At maximum operating parameters (55 rpm, 1170 lbf, 20 scfm) the maximum drill bit temperature rise was observed to be 35°C. The maximum waste temperature in single-shell tanks (SSTs) was considered to be 93°C. The critical drill bit temperature

TABLE F-1
LITERATURE VALUES FOR SPECIFIC ENERGY AND UNIT HORSEPOWER

Material	Specific Energy (in. lbf/in.^{3})	Specific Energy (MJ/m^3)	Unit horsepower (hp/in.^{3}/min)	Average Temp. Rise (°C)
Marble[4]	1,200,000	8,274	3.03	6,049
Marble[4]	70,000	483	0.177	353
Pennant sandstone[4]	13,780	95.0	0.035	69.5
Darley dale sandstone concrete[4ts]	7,210	49.7	0.0182	36.3
Monkato stone[5]	1,581	10.90	0.00399	8.0
Rockville granite[5]	22,826	157.38	0.0576	115
Dresser basalt[5]	54,204	373.72	0.37	273
Soft nonferrous metals[6]	99,000	683	0.25	499
Hard ferrous alloys[6]	514,800	3,549	1.3	2,595

was set to 150°C. Thus, the drill bit temperature increase was limited to 57°C. Because the maximum experimentally measured drill bit increase was 35°C, the rotary-mode core sampling (RMCS) operations were considered to be justified (Ref. 8).

Testing by Keller[8] did not measure the waste chip temperature but the drill bit surface temperature. Keller also performed out-of-limit tests. In these tests, the system is operated with maximum operating conditions and a loss of nitrogen; an increase in downward force or speed is simulated. These tests are used to establish the shut-down period after an alarm on operating parameters is received. Our assessment of the envelope testing indicated that the most important parameter for keeping the drill bit below the critical temperature at which an exothermic reaction can occur is the nitrogen purge flow. Loss of nitrogen flow at maximum operating conditions can heat the drill bit up to 57°C in 5 to 10 seconds. The most important parameter, applied torque, was not measured by Keller.

The data from the tests performed by Keller[8] were found to be insufficient to determine the safety envelope parameters. Recently, Witwer[1] conducted more bounding tests using dry pumice blocks with new procedures and instrumentation. These new envelope tests included torque measurements and numerous temperatures, including purge gas inlet and outlet temperature, bit surface and side temperatures, drill string temperatures, chip and pumice temperatures, exhaust air temperatures, etc.

The new test series included thermocouple temperature measurements on two drill bit teeth. Additional thermocouples were placed within the pumice in the path of the drilling and in the purge gas. Some tests used a stainless-steel sheath over some of the thermocouples within the pumice. The bit depth, rpm, down force, and torque were also measured. Tests were done with different down forces. Also, in some of the tests, the purge gas was turned off to simulate a loss of purge gas flow condition. The pumice blocks used as a test material were very abrasive, and the drill bits wore quickly. The penetration rate was good at the start of the test and then decayed to zero as the drill bit teeth wore down. These tests had a period with reasonably good cutting followed by a transition from good cutting to no cutting, and finally, a period in which the worn drill bit was spinning without cutting. Test conditions are summarized in Table F-2. The details of these test results are discussed by Witwer.[1]

The first five tests were performed without nitrogen flow to assess the rate of increase of the bit temperature. The rest of the tests are aimed to determine the safety limits as well as understand the drilling process. Some tests are performed to address partial plugging in the drill bit. These tests were performed by plugging four of the six purge holes.

F.4. ANALYSES METHODOLOGY

The analysis portion of this report is broken down into two major parts. Figure F-2 shows an energy flow diagram. The mechanical-to-thermal energy conversion discussion makes up the first of these major parts. This part is the key for understanding the drilling thermal processes. The second major part deals with the redistribution of heat. Results in this section tend to clarify and validate the results of the previous section. These pieces also are necessary to understand the experimental results.

TABLE F-2
ENVELOPE TEST CONDITIONS

Test ID	F (lbf)	V (rpm)	Q (scfm)	Drill Bit	Simulant
RETMP-09	1170	55	0	Sharp	Pumice
RETMP-10	1170	55	0	Sharp	Pumice
RETMP-10A	1170	55	0	Dull	Pumice
RETMP-10B	1170	55	0	Dull	Pumice
RETMP-11	1170	55	0	Sharp	Pumice
TORQTST-5	1170	55	0,20,30	Sharp	Pumice
TORQTST-6	1170	55	20	Sharp	Pumice
TORQTST-7	1170	55	20	Sharp	Pumice
TORQTST-9	650	30	30	Sharp	Pumice
TORQTST-10	1170	55	21	Sharp	Pumice
TORQTST-11	900	55	30	Sharp	Pumice
TORQTST-12	900	55	30	Sharp	Pumice
TORQTST-14	750	55	30	Slug therm.	
TORQTST-16	750	55	30		
TORQTST-17	750	55	30	4 plugged holes	
TORQTST-19	750	30	30	4 plugged holes	
TORQTST-20	900	55	30	4 plugged holes	
TORQTST-21	750	55	30	4 plugged holes	
TORQTST-22	650	55	30	4 plugged holes	
TORQTST-23	750	55	30		Steel

F.4.1. Derivation of Drilling Energy Conversion Equations

Figure F-3 shows a drawing of the drill bit. This bit is a core drilling bit with 18 teeth in 3 rings with 6 teeth per ring. The bit is sintered bronze material. The faces of the teeth have a negative rake angle of about 30° for the two inner rings. That is, the cutting face of each tooth is inclined so that the top of the tooth leans toward the material being cut rather than away. A bit of this type is also referred to as a drag bit. This bit is a commercially available, proprietary design. The bit material is soft enough to prevent damage to a steel tank liner should one be encountered. Figure F-4 shows the free body diagram used in the analysis of this bit.

Summing forces in the X and Y directions gives the following equations:

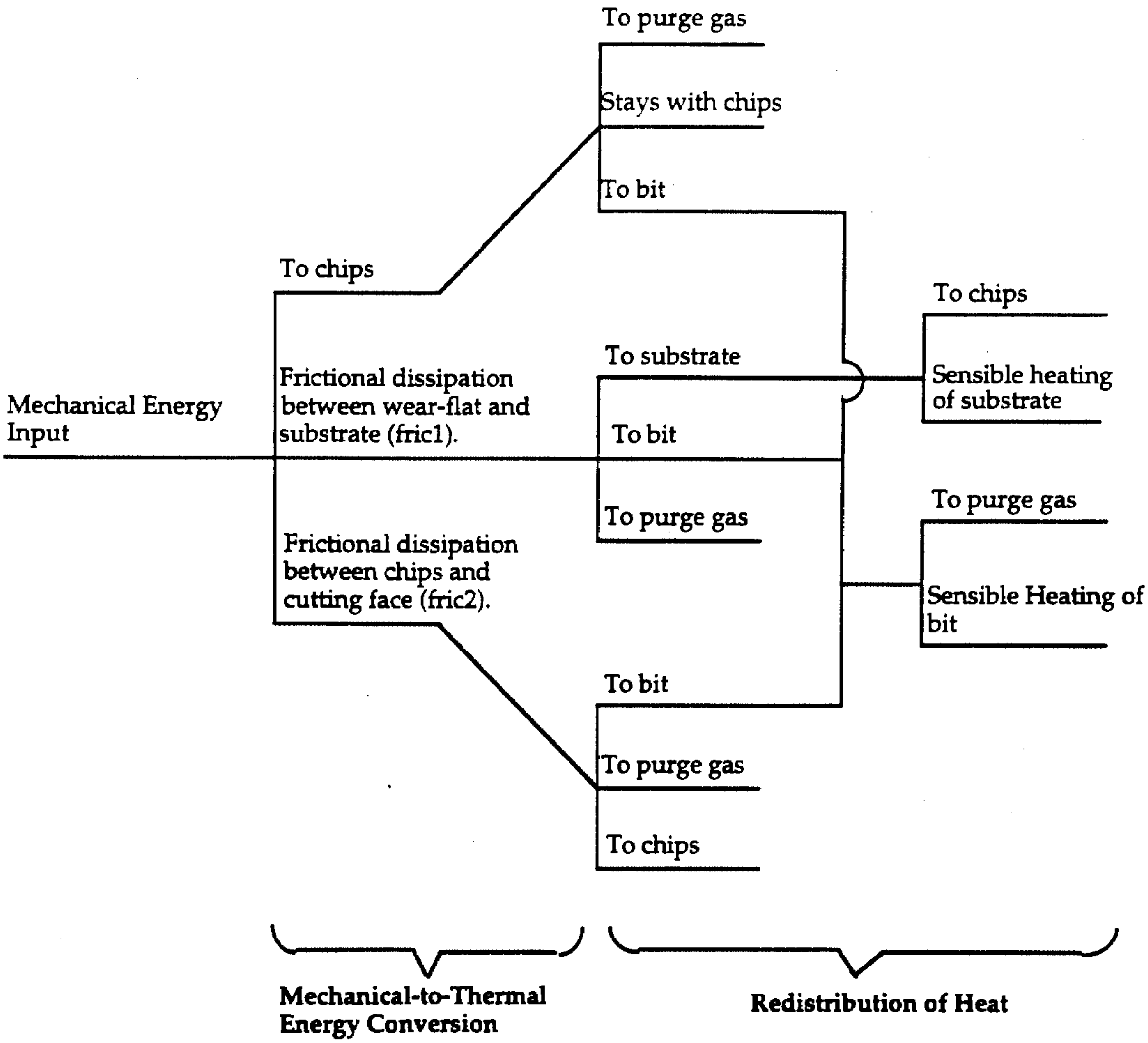


Fig. F-2. Drilling energy flow diagram.

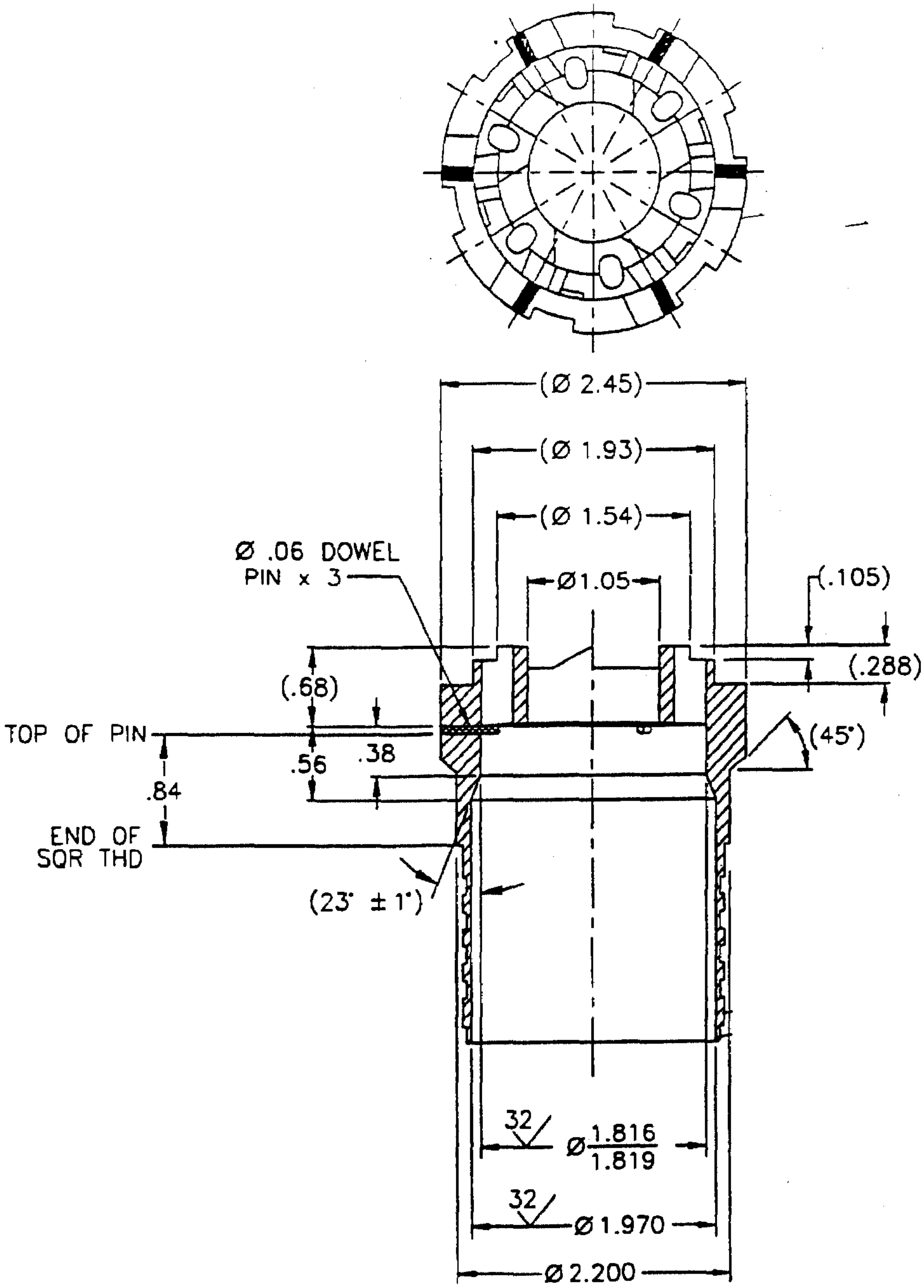
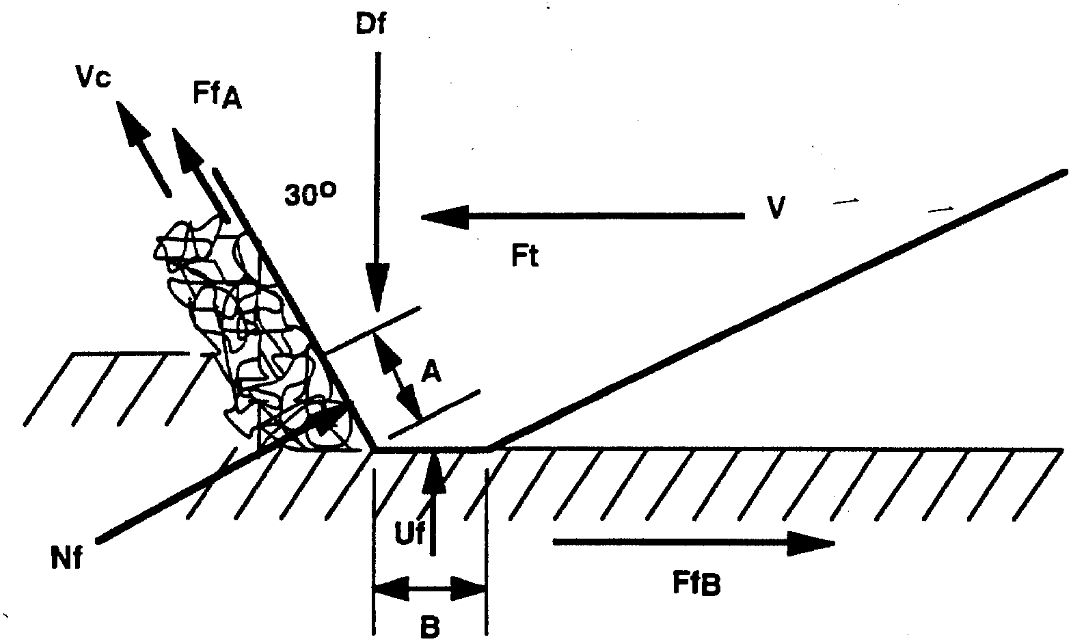


Fig. F-3. Drawing of Drill Bit.



Df is the down force.

Nf is the normal force at the cutting surface.

Uf is the upward force of acting on the wear-flat (surface of length B).

Ff_B is the frictional force acting on the wear-flat surface.

Ff_A is the friction force acting on the cutting face.

Vc is the velocity of the chips relative to the face, assumed equal to V.

V is the cutter velocity.

Ft is the force from torque times radius.

A is the area of the face where the cutting takes place.

B is the area of the wear-flat.

Fig. F-4. Free body diagram of drill bit tooth.

$$Uf - Df + Nf \sin(30^{\circ}) + Ff_A \cos(30^{\circ}) = 0 \qquad \text{(F-2)}$$

$$Ff_B + Nf \cos(30^{\circ}) - Tq/r_{avg} - Ff_A \sin(30^{\circ}) = 0 \qquad \text{(F-3)}$$

where Tq is the torque and r_{avg} is the average radius.

These equations have four unknowns, so an additional two equations are needed to achieve closure. Four possible equations were identified:

$$Ff_B = Cf_B\, Uf \qquad \text{(F-4)}$$

$$Ff_A = Cf_A\, Nf \qquad \text{(F-5)}$$

$$Nf = \sigma A \qquad \text{(F-6)}$$

$$Uf = \sigma B \qquad \text{(F-7)}$$

where Cf_B is the coefficient of friction between the wear-flat and the substrate, Cf_A is the coefficient of friction between the cutting face and the chips, and σ is the compressive strength.

It proved advantageous to use different combinations of Eqs. (F-4) to (F-7) under different circumstances and to determine different quantities. The coefficient of friction where the wear-flat slides over the substrate can be found from Eqs. (F-2) to (F-4) for cases where the bit becomes worn [Fig. F-1 (b)] and where Nf and Ff_A go to zero. Because the coefficient of friction is independent of the contact area, it should be reasonable to assume that this value is a constant, or nearly so, over the range of conditions.

The coefficient of friction on the cutting face (Cf_A) cannot be determined directly as is the case for the coefficient of friction on the wear-flat. However, the coefficient of friction is generally taken as a property of the contacting materials, and the contacting materials are the same at the cutting face and the wear-flat. The material (chips) sliding across the cutting face differs from the substrate in that the chips have been broken up and are no longer a single mass. However, these chips are still under high pressure (about 10,000 psi) and may act like a solid body as they are forced past the cutting face. That is, the chips, which are rough irregular solids, probably cannot move relative to one another when they are under high pressure. Thus, they probably act more like a solid than a fluid in the region between the material being cut and the cutting face. This suggests that Cf_A should at least be approximately equal to Cf_B.

Combining Eqs. (F-2) to (F-5) with the assumption that $Cf = Cf_A = Cf_B$ gives the following equations:

$$Nf = \frac{-Df\,Cf + \dfrac{Tq}{r_{avg}}}{(\cos 30^\circ - 2\ Cf\ \sin 30^\circ - Cf^2 \cos 30^\circ)} \tag{F-8}$$

$$Uf = Df - Nf \sin 30^\circ - Nf\ Cf\ \cos 30^\circ \tag{F-9}$$

As the area of contact between the material being cut and the cutting face (area A) decreases, Nf, the normal force on the cutting face, decreases. These equations do not have the correct behavior as the cutting face contact area decreases. Thus, they will break down as the bit wears and the penetration rate decreases. The initial attempts to analyze a full data set on a point-by-point basis with a spread sheet used these equations. As the test progressed and the cutting rate decreased, the lack of closure got larger. Alternative sets of equations were derived in response to this problem. Using Eqs. (F-8) and (F-9) with Eqs. (F-6) or (F-7) allows us to back out a value for σ, the compressive strength. These equations have been used for conditions with good cutting to obtain values for σ. The equation set that was ultimately used for the full test analysis includes σ as a parameter.

Combining Eqs. (F-2), (F-3), (F-4), (F-6), and (F-7), gives an alternative set of equations from which σ may also be found.

$$Ff_A = \frac{\dfrac{Cf\ Df}{Denom} + \dfrac{A}{B}\,Df\,\dfrac{\cos 30^\circ}{Denom} - \dfrac{Tq}{r_{avg}}}{\dfrac{Cf \cos 30^\circ}{Denom} + \dfrac{A}{B}\dfrac{(\cos 30^\circ)^2}{Denom} + \sin 30^\circ} \tag{F-10}$$

where

$$Denom = 1 + \frac{A}{B}\sin 30^\circ$$

$$Uf = \frac{Df - Ff_A \cos 30^\circ}{Denom} \tag{F-11}$$

The value for the wear-flat area (area B) cannot be determined from the data because it is a function of the wear of the bit teeth. Also, as the bit wears, the assumption that the force on the wear-flat area is sufficient to match the compressive strength of the material may break down. Thus, Eqs. (F-10) and (F-11) have been used to validate the results of Eqs. (F-8) and (F-9) under conditions with good cutting. To use these, a wear-flat dimension was assumed. If results from these two sets of equations are consistent, it is assumed that this supports the validity of the conditions for the use of these equations. Equations (F-10) and (F-11) also do not have the correct behavior as cutting face contact area decreases.

A third set of equations was derived using Eqs. (F-2), (F-3), (F-5), and (F-6). Then

$$Nf = \sigma A \quad \textbf{(F-12)}$$

$$Ff_A = Nf\, Cf_A \quad \textbf{(F-13)}$$

$$Uf = Df - Nf \sin 30° - Ff_A \cos 30° \quad \textbf{(F-14)}$$

$$Ff_B = \frac{Tq}{r_{avg}} - Nf \cos 30° + Ff_A \sin 30° \quad . \quad \textbf{(F-15)}$$

These equations have the correct behavior as the cutting face contact area becomes small but do require that the value of s, the compressive strength, be known. Values for σ were obtained for conditions with good cutting using Eqs. (F-8) to (F-11) in analyses that examined only selected times during the tests considered. The value of σ obtained in this manner was used with Eqs. (F-14) and (F-15) to analyze one complete data set. It is assumed that σ is a constant. It is possible that as the bit wears, the size of the chips broken out will decrease, resulting in an increase in s. That is, more energy per unit volume is required to produce small particles than to produce large particles. In tests with simulants, a distribution of particle sizes was measured.[9] These are already skewed toward small particle sizes. Over 80% of the particles by mass were smaller than 40 mm, and 50% were smaller than 20 mm. Less than 3% were greater than 100 mm. A 1-in./min cutting rate at 55 rpm gives a tooth penetration depth of 77 mm. If the maximum chip size is limited by the depth of cut as the bit dulls, there will be fewer large particles and more small particles. Because most of the particles were small in the samples measured, this suggests that eliminating the larger particles from the distribution will not make a large change in the size distribution by mass. Thus, the change in the energy required to remove a given volume of chips is not expected to change significantly as the penetration decreases, and the constant σ assumption should be reasonable. To put this argument another way, the measured particle distribution suggests that, for the most part, the material was being crushed to a fine powder rather than broken out as chips. Decreasing the scale of cutting will still result in the material being crushed to a fine powder, though the few larger chips that were being produced may no longer be produced.

The power terms can be derived by multiplying Eq. (F-3) by r_{avg} w. Doing this and rearranging gives

$$Tq\,\omega - Ff_B\, r_{avg}\, \omega - Nf\, r_{avg}\, \omega \cos 30° + Ff_A\, r_{avg}\, \omega \sin 30° = 0 \quad \textbf{(F-16)}$$

This equation assumes that the velocity in the downward direction is negligible compared to the velocity from the rotation. This also assumes that the velocity of the chips is equal to the velocity of the drill bit, which means that the thickness of the layer of chips passing across the drill bit face is equal to the thickness of the layer being cut. If a thinner layer passes across the bit face, the velocity would be higher. If a thicker layer passes over the bit face, the velocity would be lower. The first term is the power input, and the second term is the frictional dissipation between the wear-flat and the substrate. The third term is the power required to compress and fracture the material being cut, and the fourth term is the frictional dissipation at the location where the chips are squeezed across the cutting face. The third term may be readily shown to equal the compressive strength times the volumetric cutting rate. The difference in sign between the fourth term and the second and third terms should be noted. This sign difference means that the energy that goes into the frictional work as the chips are squeezed across the cutter face comes from the energy that was used to compress and fracture the chips. Further, the fourth term is a mechanical work term that acts on the bit and helps pull it along. Thus, it is possible for the third term, which is the energy to compress and fracture the chips, to be greater than the first term, which is the energy input to the drill string. Thus, at any moment, previously stored energy is released, and additional energy is stored as elastic compression.

To calculate the temperature rise of the chips, it has been assumed that the energy given by the third term minus the fourth term goes to heating the chips. The temperature rise from this energy should be practically instantaneous. The heat is generated along the fracture surfaces and is then transferred mostly into the chips, although some may be transferred to the purge gas and also to the bit. Including all of this energy is a conservative assumption. There may be additional elastic compressive energy that is recovered in the velocity of the chips as they decompress as well. These components, though expected to be small, contribute to the conservatism of this temperature rise calculation. That is, the calculated temperature increase will be greater than the actual temperature increase.

To calculate the maximum temperature of the chips, the calculated temperature rise has been added to the measured bit temperature. That is, the temperature of a given layer of material immediately before cutting was assumed to be equal to the bit temperature. This assumes that the temperature measured by the thermocouple on the bit teeth is indicative of the interface temperature, which is in turn indicative of the layer average temperature. This is a conservative assumption, at least for conditions with reasonably good cutting. As a layer of material is removed, a fresh, cooler layer is exposed. The frictional heating generated on the surface being cut raises the surface temperature to the interface temperature almost immediately. It takes a longer time for the rest of the layer to approach the surface temperature. Thus, the surface temperature should provide a conservative (high) estimate for the temperature of a layer just before it is cut.

These equations have been applied in two different ways. First, in scoping analyses, portions of tests were analyzed. Average data points for a period of interest were picked off the plots. The mechanical-to-thermal-energy conversion equations derived as shown above were applied. In addition, other calculations that might clarify any the energy distribution terms were made. These included one-dimensional (1-D) slab calculations for cases with no cutting and temperature decay calculations for the chips produced by the cutting. Secondly, for one test, the energy conversion and distribution terms were calculated on a point-by-point basis. This served to validate our understanding of the phenomena involved. The details of the calculations are provided in Ref. 10.

F.4.2. Two-Dimensional (2-D) Transient Heat Transfer Model of Drilling Process

F.4.2.1. Model Description

In order to better understand the thermal energy transfer in the drilling process, a 2-D transient heat transfer model was also developed. The primary function of the model is to determine the maximum waste temperature as a function of drilling conditions. The model can then be used to determine the drilling condition limits to avoid reaching the stated temperature limits: 150°C for the substrate and 180°C for the chips. A parametric study can be done using a 2-D model in order to study the effect of extrapolated parameters involved in the drilling process. The model is a conduction/convection solution, where a conduction solution through the solid materials is coupled with a flow solution of the purge gas.

F.4.2.1.1. Conduction Solution. The general heat transfer equation solved is

$$\rho C_p \frac{\partial T}{\partial t} = -\nabla \cdot q + \frac{Q}{V} \quad . \qquad \text{(F-17)}$$

The equation is solved numerically. The coordinate system is fixed to the drill bit; therefore, the drilled material is moving (in effect flowing) with respect to the grid. Therefore, as the bit penetrates, an additional term is added to the drilled material heat transfer solution. In effect, this is a steady state, constant property, incompressible flow solution. The material that "flows" through the upper boundary of the drilled material is added to the gas flow.

F.4.2.1.2. Flow Solution. The flow solution is solved separately from the conduction solution. The time frame of the flow solution is much shorter than for the conduction solution. The gas transit time through the system is much less than one second, and the transit time around the bit is on the order of milliseconds. Therefore, a steady-state solution can be used to approximate the flow at each conduction time step.

The flow solution is obtained by setting up a nodal 1-D flow path based on a path-through system. Specified at each node are the node length, flow area, hydraulic diameter, the heat transfer area, and the surface temperature of the conduction nodes that surround the flow node. The heat transfer between the flow and conduction nodes is then given by the standard internal flow relations (h is interpolated between Re of 2000 and 3000 to provide a transition between the laminar and the turbulent flow):

$$Q_w = hA_{ht}(T_w - T_g) \quad \text{where:} \quad h = h1 \text{ if } Re<2000 \qquad \text{(F-18)}$$

$$h = h2 \text{ if } Re>3000$$

$$h = h1 + (h2-h1)(Re-1000)/2000$$

$$h1 = \frac{4.364k}{D_H} \qquad h2 = \frac{.023k}{D_H} Pr^{.3} Re^{.8} \qquad \text{(F-19)}$$

Q_w is used both in the conduction solution and to calculate the gas temperature as

$$Tg_k = \frac{1}{\dot{m}C_{P_k}}\left(\dot{m}_{k-1}C_{P_{k-1}}Tg_{k-1} + \dot{m}_{chip_k}C_{P_{chip}}T_{sub} + Q_{w_k} + Q_{gas_k}\right) \qquad \text{(F-20)}$$

where: $\dot{m}_k = \dot{m}_{k-1} + \dot{m}_{chip_k}$.

Q_{gas} is the energy deposition directly into the gas from the chips and T_{sub} is the temperature of the substrate at the location where the chips are being generated. Also, as chips are added to the flow caused by drilling, the specific heat and other properties of the flow are adjusted. It is assumed that the gas and chips mix uniformly and come instantaneously to equilibrium.

F.4.2.1.3. Energy Deposition. In the above equations, two important parameters have yet to be determined, Q_{gen} and Q_{gas}. First, it is conservatively assumed that all of the drill power is deposited in the system as thermal energy. Then it is assumed that this energy results from either breaking up the chips (Q_{drill}) or friction (Q_{fric}),

$$Q_{tot} = tw = Q_{drill} + Q_{fric} \ . \qquad \text{(F-21)}$$

The fractions are then broken up further into components that go to the gas, bit, or substrate. In the code, the chip energy and frictional components are determined by:

$$Q_{drill} = \frac{E_{sp}}{\dot{z}A_{drill}} \quad \text{and} \quad Q_{fric} = tw - Q_{drill} \ . \qquad \text{(F-22)}$$

Here E_{sp} is the specific energy of the drilled material. The fractional splitting of these powers into their gas, bit, and substrate components are specified in the input. The resulting energy deposition fractions are

$$Q_{gen,bit} = f_{drill,bit}Q_{drill} + f_{fric,bit}Q_{fric} \ , \qquad \text{(F-23)}$$

$$Q_{gen,sub} = f_{drill,sub}Q_{drill} + f_{fric,sub}Q_{fric} \ , \text{ and} \qquad \text{(F-24)}$$

$$Q_{gas} = f_{drill,gas} Q_{drill} \quad \text{(F-25)}$$

These fractions are determined from benchmarking the experimental drilling.

F.4.2.1.4. Maximum Theoretical Chip Temperature. It is assumed that all of Q_{drill} goes into heating up a chip before energy is transferred elsewhere as

$$T_{chip} = T_{sub} + \frac{Q_{chip}\Delta t}{\rho V C_p} = T_{sub} + \frac{E_{sp}}{\rho C_p} \quad \text{(F-26)}$$

This number places a conservative bound on the maximum chip temperature and is meant only as an absolute upper limit. The chip temperature will be discussed further in the results section.

F.4.2.1.5. Model Uncertainties and Limitations. There are two major model limitations: (1) The model is 2-D, so that the drill bit is smeared in the azimuthal direction. This does not allow for localized heating effects in the "tooth" or the effects of a plugged flow channel, and (2) The flow solution is one-species (chips/gas mix as one fluid). This does not allow for a separate calculation of chip temperature. Other minor limitations are that the model assumes constant properties, and the flow solution is steady state (which would only matter if very small conduction time steps are required).

There are several uncertainties in the model that may significantly affect the results. These include: drilling energy deposition fractions, friction energy deposition fractions, purge gas heat transfer coefficient, bit/pumice interface conductivity, and material properties. These uncertainties have been limited by benchmarking the model with the experimental drilling results.

F.5. RESULTS

The mechanical-to-thermal energy conversion equations show that the energy transfer to the bit can be resolved into three major components, two frictional components and the mechanical energy needed to compress and fracture the material into chips. The analyses show that the frictional components can account for the temperatures measured in the tests. The most significant of the frictional components produces heat between the drill bit and substrate. This heat will be transferred into the bit and into the substrate. The maximum temperature will occur at the interface. The drill bit thermocouples were located on bit teeth where they could measure the interface temperature. Thus, to the extent that the pumice was a limiting material for frictional dissipation, the bit temperature measurements from the test series on pumice blocks should be indicative of the maximum bulk material temperature. A comparison of temperatures between the test series done with pumice blocks as a test material and earlier tests with waste simulants as test materials show that the testing with the pumice blocks produced the highest temperatures. Thus, the coefficient of friction between the bit and the pumice was probably higher than the coefficient of friction between the bit and any of the other materials. Pumice block consists of hard particles in a binder material. This produces a very abrasive material that should have a high coefficient of friction. Thus, it is expected that the testing done on pumice blocks produced bulk temperatures that are limiting, or at least very nearly so.

The mechanical energy needed to fracture the material into chips causes an increase in the temperature of the chips. This temperature increase comes in addition to any temperature increase while the material was part of the substrate and was heated by the frictional dissipation. Thus, a conservative approach to finding the maximum chip temperature is to calculate a temperature increase for the chips and add the interface temperature, as measured on the bit, to this.

Two separate models are used to determine the substrate and chip temperatures. The first model is based on 1-D conduction solutions with adequate boundary conditions and consideration of a force-balance equation. A 1-D model is a first-order approach and is considered in Section 4.1. A 1-D model is used at the earlier phase of study to evaluate expected chip temperatures and to evaluate material properties important to the cutting process. In Section 4.2, a more detailed 2-D model is developed to simulate drilling. The 2-D model is more realistic and considers solution of a moving boundary of the drill bit. The energy equation is solved for the moving drill bit by considering the energy exchange between both solid-solid and fluid-solid. In the remainder of this section, the results of the 1-D model (Section 5.1) and then the 2-D model (Section 5.2) are discussed.

F.5.1. Results Obtained from 1-D Analysis

Two sets of comparisons are performed. The first set involved an evaluation of three tests, Tests TORQTST 6, 12, and 16. All of these tests used a rotational speed of 55 rpm, and 30 scfm purge gas flow (see Table F-2). The nominal down forces were 1170 lbf, 900 lbf, and 750 lbf. These three tests are analyzed to determine the forces involved in cutting, chip, drill bit, and substrate temperatures by solving the energy and force balance equations given in the previous sections. Details of the analysis are available in Reference 10. Parameters involved in analysis are averaged over a period in which cutting was either effective (constant penetration) or not effective (no penetration). In the second series, only Test 15 is analyzed. For Test 15, time-averaged test parameters are not used but the analysis is performed for each transient recorded data point when the cutting was observed. This test defines the safety limits for RMCS.

F.5.1.1. Effective Waste Cutting

Table F-3 shows some key results obtained from three tests for times near the beginning of the tests when there was good penetration. Temperature increase estimates were obtained from the energy balances. Compressive strength was calculated from the force balance for these tests. The value for compressive strength determined from conditions with good cutting was about 10,000 lbf/in.^{2} with an

TABLE F-3
ANALYSIS RESULTS, TESTS 6, 12, AND 16

Test	Downforce (lbf)	Chip Temperature Increase from Energy Balance (°C)	Compressive Strength Estimates (lbf/in.^{2})
TORQTST6	1170	39.0-45.5	9227-11420
TORQTST12	900	42.2-50.4	9482-9513
TORQTST16	750	30.8-31.9	9230-9730

estimated uncertainty of ±2000 lbf/in.^{2} (Ref. 10). Using σ = 10,000 lbf/in.^{2} gives a temperature increase of 45°C for compressing and fracturing the chips. These temperature increases are in addition to increases from frictional heating of the substrate before cutting.

The calculation using Eqs. (F-11) to (F-14) with a compressive strength of 10,000 lbf/in.^{2} was performed for Test 15. Figure F-5 shows the measured bit temperature with calculated bit and chip temperatures. The figure shows that, with conservative assumptions, the increase in drill bit/substrate interface temperature approach but do not exceed the ΔT = 60°C safety limit. The calculated chip temperature increase, about 83°C, is also lower than the safety limit of ΔT = 90°C. This calculation presents the first evidence that when the operating parameters are limited with a downward force of 750 lbf, a rotational speed of 55 rpm, and a minimum purge flow of 30 scfm, a local waste ignition is not expected to occur when there is reasonable penetration. However, this conclusion is valid only if the hard waste layers expected in the tanks have similar properties to pumice in terms of both thermal and cutting processes of drilling.

If there is a reactive layer harder than pumice in the tanks, the truck has enough power available to produce higher torque. In this case, it is possible that chip and substrate temperature may exceed the safety limits. However, when the torque increases as a consequence of encountering a harder material, the penetration rate is expected to decrease. As mentioned in the next section, the penetration rate must be above 0.75 in./min. Therefore, higher torque should correspond to lower penetration rates. As a summary, if the waste layers in SST tanks are not harder than pumice, the proposed safety limits adequately protect against waste ignition hazards based on the results obtained from the 1-D model for effective cutting defined by a penetration rate higher than 0.75 in./min.

F.5.1.2. Frictional Heating with No Penetration

In all of the tests on the pumice blocks, the penetration rate slowed and then decreased to zero as the bit became worn. The data for the tests that used the limits of 750 lbf for the down force, 55 rpm for the rotational velocity, and 30 scfm for the purge gas flow, showed acceptable temperatures for conditions with a worn bit spinning on the substrate. The analyses showed that there was significant conduction into the bit for these conditions, and this limited the heat transfer to the slab, and thus the slab temperature. Results of Test 15 show that the drill bit and the corresponding substrate interface temperature is lower than the safety limit of $\Delta T = 60°C$, even when there is not good penetration and as long as nitrogen flow is available. However, this mode of operation in real drilling is not desired because the cause for no penetration will not be known. No penetration could be the result of encountering a hard reactive or nonreactive layer, metal, or other nonmetal object with different properties. The real waste is not expected to have a layer as hard as pumice. Note that every test done by Witwer[1] resulted in worn drill teeth. WHC engineers indicated to us that one sampling activity requires two rotary-mode core drillings out of a total of 10 samples. WHC engineers also expressed the fact that they have never failed to penetrate hard layers in Hanford tanks. Considering this experience as the available data for conditions of waste, it is not expected that the drill bit will encounter any reactive waste layer harder than pumice. However, if a waste layer is as hard as pumice, no penetration would be observed as experienced in laboratory testing.

One of the other reasons why the frictional mode of operation is not desired is that the transition from effective cutting to the frictional mode is not understood clearly. When the downward force was 1170 lbf, in Test 6, a large temperature variation, about 50°C, is observed in the transition region. Although the force is lowered to 750 lbf, the reasons for these higher temperature oscillations are not clearly understood. It is concluded that a penetration rate control is needed. The main reason for this control is to prevent drilling against reactive waste material that is harder than pumice. The lack of penetration rate control also prevents applied torque from being above the values observed in envelope testing.

F.5.1.3. Applicability of Envelope Testing to Real Conditions

Table F-4 compares properties of the pumice material to the properties of the waste simulant materials developed by WHC.[8] All of the properties except the compressive strength calculated from drilling tests, the specific heats, and thermal diffusivities were measured by WHC.

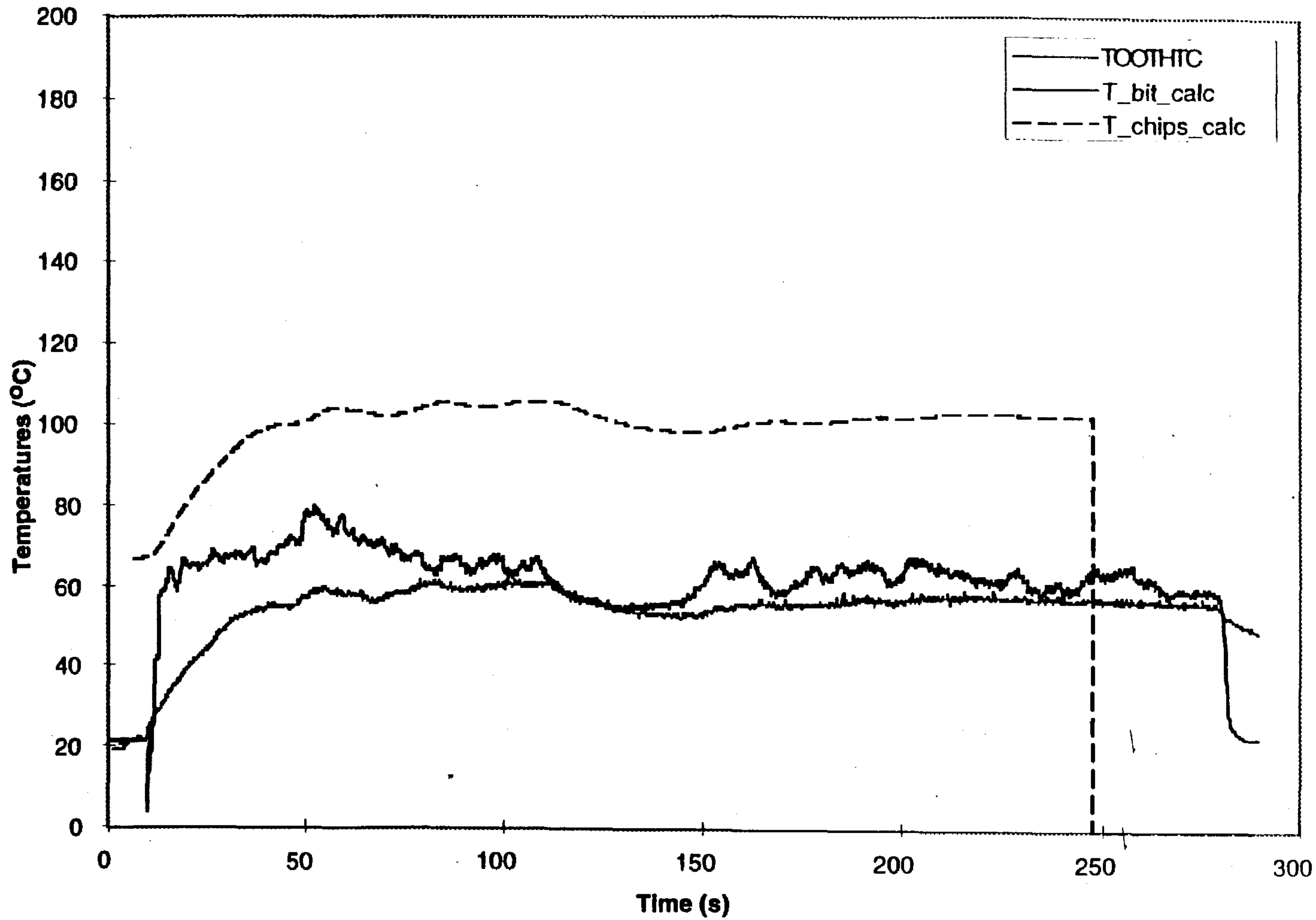


Figure. F-5. Test 15 - Measured bit and calculated bit and chip temperatures.

TABLE F-4
COMPARISON OF WASTE SIMULANT AND PUMICE TEST MATERIAL

Property	Evaporator Bottoms	BY-104 Simulant	Pumice Block
Bulk density (kg/m^3)	1560	1410	1600
Unconfined compressive strength (psi)	905	3,264	
Calculated compressive strength from drilling tests (psi)			10,000
Direct shear strength (psi)		459	
Penetrometer resistance (psi)	23,520	34,507	
Thermal conductivity (W/m K)	2.32	1.67	1.03
Specific heat (kJ/kg K)		0.97*	0.88**
Thermal diffusivity (m^2/s)		1.221×10^{-6}	7.315×10^{-7}

* Estimate based on handbook value for predominate material.

** Handbook value.

The physical and thermal properties are comparable for pumice and the BY-104 simulant. The density times the specific heat products for the BY-104 simulant and the pumice block are within three percent of each other. Thus, the energy storage terms are very comparable. The lower thermal diffusivity coefficient of the pumice block tends to slow the spread of heat and keep temperatures higher. Thus, the pumice block testing produced temperatures that are conservative compared to the BY-104 simulant, and WHC has identified the BY-104 simulant as the limiting waste simulant.[8]

The pumice blocks consist of hard pumice grains in a binder material. This makes the pumice material very abrasive. The coefficient of friction between the bit and the pumice was evaluated as 0.4. The temperature at the bit/substrate interface where the bit temperatures were measured is determined primarily by frictional heating. The earlier series of tests[8] with the BY-104 simulant showed lower temperatures. (Torque was not measured for this series of tests, so the effective compressive strength during drilling and the coefficient of friction cannot be calculated from the test data.) The temperatures suggest that the coefficient of friction between the bit and the BY-104 simulant was lower than the value deduced for the bit and pumice. The maximum average chip temperature is a function of two things, (1) the temperature of the waste material layer just before cutting and (2) the energy addition during the cutting process. The effects are additive. The temperature of the material before cutting is primarily a function of the frictional heating, and this was lower for the simulant materials.

The measured compressive strength for the BY-104 simulant is less than one-third the compressive strength deduced from the testing on the pumice blocks. Because the method of determination is very different, these values are not directly comparable. Rabia[5] showed that specific energy values for a series of drilling tests were often about twice the laboratory measured values for the compressive strength of the same materials. Even if the effective compressive strength during drilling conditions were three times the laboratory-measured value, the chip temperature rise from the compressing and fracturing operation would be less than the corresponding value for the tests on pumice blocks. Thus, this temperature should be lower for the BY-104 simulant for comparable drilling conditions.

Three reasons were identified for why the maximum temperature during drilling of the BY-104 simulant or comparable material should be lower than the corresponding maximum temperature during drilling in the pumice block. All three of these factors contribute independently of the others. Thus, the pumice block tests should be bounding for maximum temperature if the BY-104 simulant material can be considered as reasonably representative of the hard waste layers in the tanks. Operating limits based on test data from drilling in the pumice blocks should be conservative for materials that are limited by the BY-104 waste simulant properties. This applies to normal cutting and to off-normal conditions such as the bit becoming dull and no longer drilling and a loss of purge gas flow.

Hitting objects harder than pumice in the waste such as a rock, particularly over a small fraction of the bit face, could cause high temperatures if attempts were made to continue drilling. Drilling materials (nonreactive and reactive) harder than pumice may cause the applied torque to be increased, at least initially. Typical torque values measured in envelope tests varied between 35 and 85 ft lbf. There is power available to increase the torque. In an ideal situation, if the ratio of torque to the penetration rate defining the specific energy were controlled, safety limits would be implemented with extremely high confidence because the chip and substrate temperatures primarily depend upon the energy density (or unit horse power) which is linearly proportional to the torque and inversely proportional to the penetration rate. As discussed previously, the penetration rate must be monitored and controlled. Torque measurements are not easy and reliable although application of a torque limiter would be easy to implement. However, without torque measurements, operating safety limits involving downward force, rotational speed, nitrogen force, and penetration rate provide conservative protection for any waste ignition hazard.

The lower limit for the penetration rate of 0.75 in./min was set as protection against drilling in a material with a higher compressive strength than the pumice blocks. In the pumice block tests, there was an initial period with good penetration followed by a period with declining penetration, and finally a period with no penetration. The 0.75 in./min penetration rate represents a value at which the transition from the period of good penetration to the period with rapidly declining penetration occurs. In the pumice blocks, the nominal drilling parameters allow drilling with a bit that is at most slightly worn. If a layer of material with a higher compressive strength (which would give higher chip temperatures) is encountered during drilling, the penetration rate will drop below the lower limit. The operators could continue drilling only after a ten-minute cooling period following a trip initiated by out-of-tolerance down force on force, rotational speed, purge flow, or penetration rate. Additional attempts to restart drilling would begin with a cooled substrate. Then, the only energy component contributing to the temperature increase would be the energy to compress and fracture the chips. If the 0.75 in./min penetration rate could not be attained, drilling would be stopped automatically before the substrate could heat substantially and increase the chip temperatures.

Although this limit significantly reduces the possibility of producing chips at a temperature higher than the 180°C limit should a harder material be encountered, this does not guarantee that the temperature limit cannot be exceeded. If the limit is exceeded, only a very small volume of excessively hot chips will be produced for only a very short period of time. The chips are produced in an environment in which they are immediately surrounded by relatively cold nitrogen purge gas with a high convection heat transfer coefficient. Thus, they are expected to cool to below 180°C in much less than 0.1 s and have no detrimental effect.

F.5.1.4. Cases with Inadequate Nitrogen Flow

In several of the tests, the purge gas flow was shut off after the drill had stopped penetrating. With this condition, the energy balance becomes very simple, with only frictional energy dissipation and then conduction, either into the bit or into the substrate. Test 16 was one of the tests with this condition. Figure F-6 shows that the temperatures were measured and that the purge gas was shut off after the drill stopped penetrating. A 1-D slab analysis was performed for the time 60 s after the purge gas was turned off. To determine the effect of the conduction into the bit, an equivalent convection heat-transfer problem was determined by trial and error. In this case, a convection coefficient of 550 watt/m^2K was needed to match the measured temperature. Thus, there was significant conduction heat transfer to the bit. The operating requirements specify that the drilling be stopped for a loss of purge gas. If all the frictional dissipation went into the substrate for even a short period of time before drilling was stopped, an overheat condition could occur. This result shows that there is sufficient heat transfer to the bit to provide some margin for shut-down time should a loss of cooling occur. If all the energy generated were going into the slab, the time for the surface temperature to rise above the limit would be small. The cooling capacity of the bit gives some margin for spin-down time, should a loss-of-purge-gas-flow condition be encountered. The automatic controls on the drill system are to be set to immediately stop the drilling if a loss-of-purge-gas-flow condition occurs.

F.5.1.5. Chip Temperature Decay in Purge Gas

The maximum chip temperature occurs immediately after energy is added to the material to compress and fracture it. The chips are immediately entrained in the purge gas. This cools the chips quickly. This is important in that the chips have little time to heat any material other than the purge gas.

Two estimates were made for the cooling of these particles. WHC[8] measured a particle size distribution for drilling in simulant materials. The slip velocity was calculated for the top particle size in each range reported by WHC. This was done by equating the weight of the particle and the drag on the particle because of the slip velocity. The drag was calculated from a standard correlation for the drag on a sphere as a function of the Reynolds number. An iterative solution results. Once the velocities had been obtained for each size, a standard correlation for the convective heat transfer was used to estimate the convective heat transfer coefficient (h). References 11 and 12 were checked for appropriate correlations. None were found with a range of applicability that included the small Reynolds numbers being calculated. A correlation with a stated lower limit of applicability of Re = 17 was selected. The extrapolation to lower Reynolds numbers is uncertain. The Reynolds numbers calculated from the slip velocities ranged from 3×10^{-6} to 6.4. The convection coefficient for each size and then a reduced temperature for each particle size as a function of time were calculated. A mass-averaged reduced temperature was also calculated as a function of time. This was used to estimate the chip-to-gas heat-transfer rate.

The second approach was similar, but a natural convection correlation was selected. The Grashof numbers calculated were well below the stated limit of applicability.

Using the forced convection correlation, the mass-weighted average particle goes through 63% of the change from the initial hot condition to the gas temperature in 0.1 s. The 150 micron particle size, which is the largest in the given distribution goes through 44% of its cooling in 0.1 s.

Using the natural convection correlation, the mass-weighted average particle goes through 98.7% of its cooling in 0.1 s, and the 150-micron particle size goes through 65% of its cooling in 0.1 s. Figure F-7 shows the temperature decrease for the mass-weighted average chips as a function of time for the cases discussed above.

Although both of these estimates use correlations outside the stated range of applicability, resulting in a large uncertainty for the above estimates, the conclusion that the chips cool to much less than the temperature limit in the order of 0.1 s should be valid.

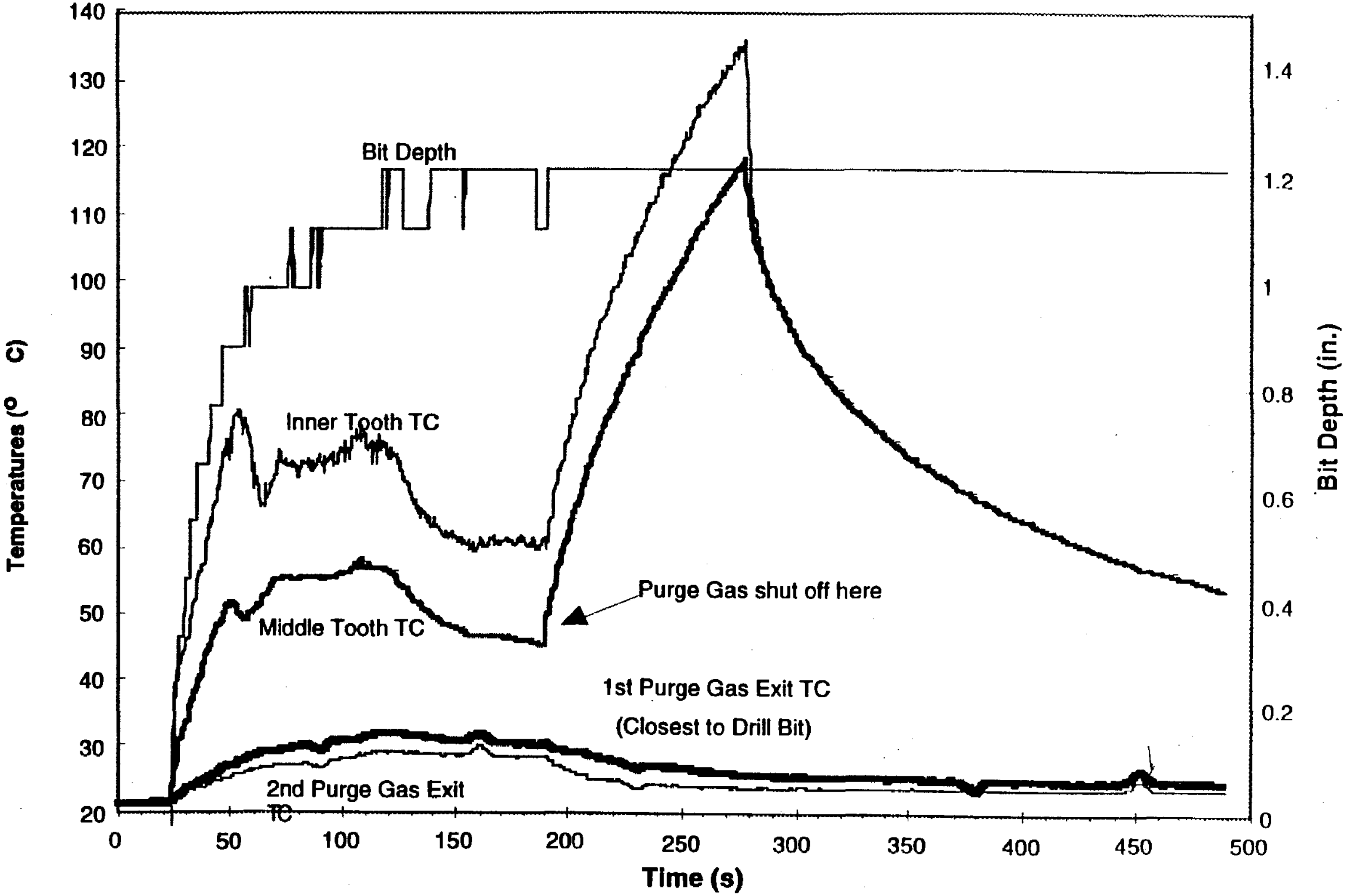


Figure F-6. Test 16 – Measured temperature data.

Attempts were made to apply the above ca..ulations to the purge gas conditions at the exit thermocouples to work back to ave..ge chip temperatures immediately after cutting. These attempts did not produce a..y conclusive re..lts. They do support the use of the 180°C limit for the chips because these calcu...tions demonstrate that the chips cool from near this limit to well below this limit in less than 0.1 s.

F.5.2. Results of 2-D Finite Difference Transient Heat Transfer Modeling

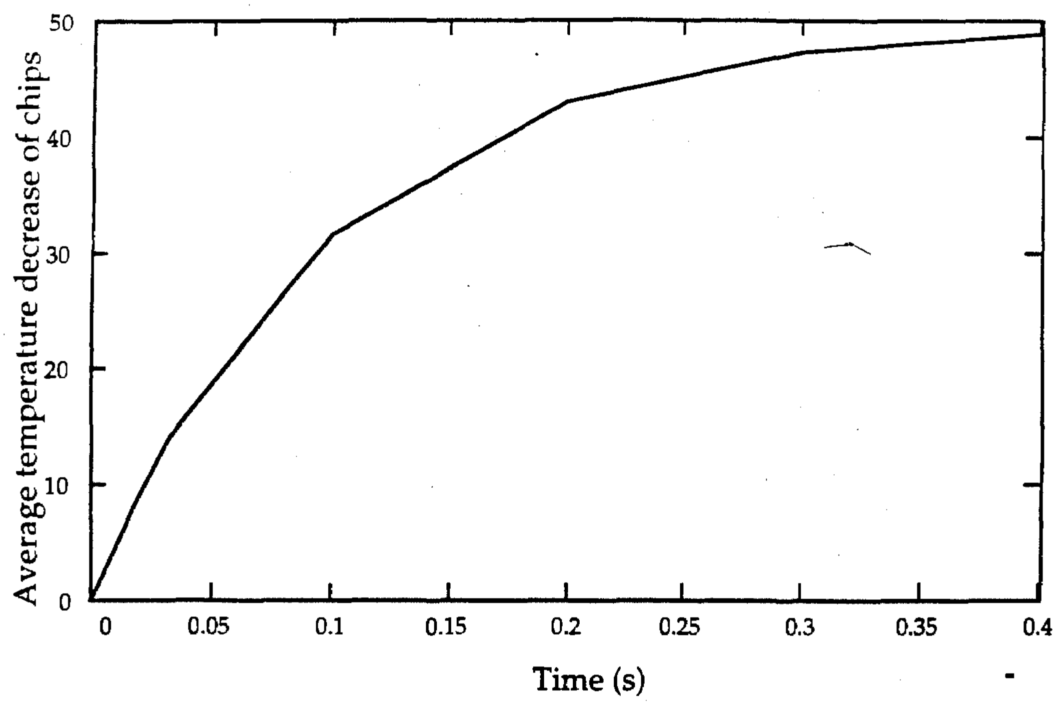
F.5.2.1. Experimental Benchmarking

To begin, the model has been benchmarked versus two separate experimental tests: TORQTST16 and TORQTST23. These tests have printouts that contain most of the information necessary to obtain an energy balance (Ref. 13). In addition, TORQTST23 (which involves drilling into steel), contains reliable temperature measurements below the drilling surface. Initially, the energy deposition fractions (and to a small extent the material properties) were varied so that the experimental and computational results matched for each case separately. A fixed set of parameters was then determined combining the results of the two cases.

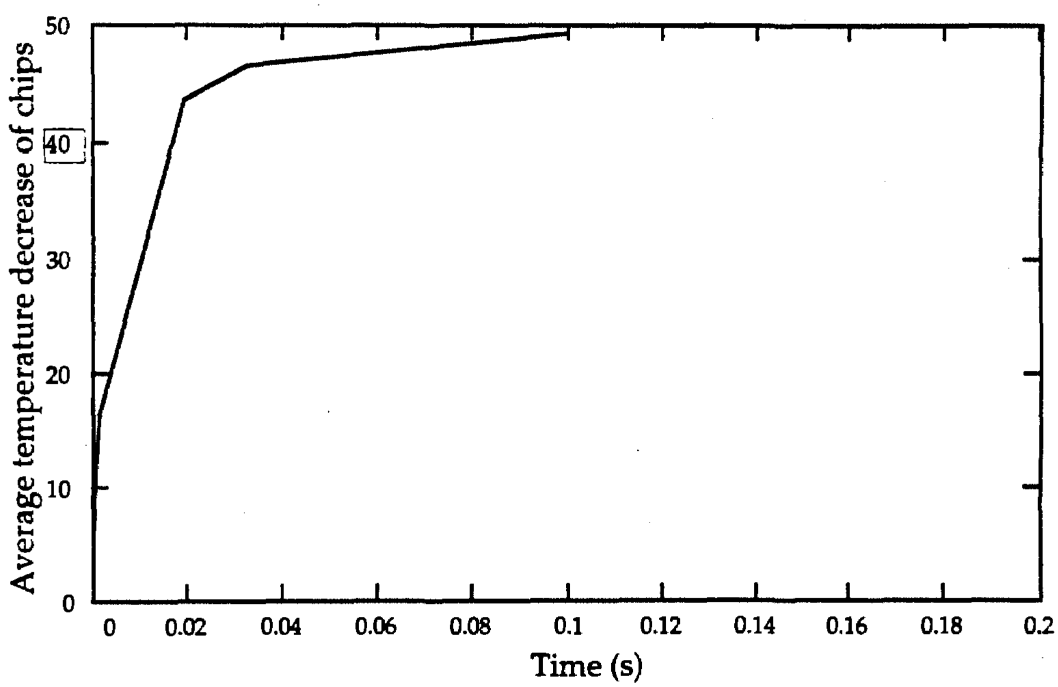
Next, the model was used to calculate temperatures for three additional tests: TORQTST15, TORQTST17, and TORQTST18. No model parameters were adjusted in assessing the model against these three tests. The calculated results conform fairly well with the experimental results for each test, especially considering the uncertainty in the experimental measurements. The results for some of these calculations are shown in Figure F-8. The calculated results are plotted alongside the experimental bit temperature. The experimental gas flow temperatures are not plotted, but they conform within 1°C of the calculated temperatures. TORQTST23 involved drilling into a steel slug; the experimental and calculated temperatures in the slug are also plotted for this case. The agreement between experimental measurements and calculated data for tests TORQTST15, 17, and 18 indicates that this model can be used for further parametric analysis.

F.5.2.2. Substrate Temperature

The primary result of this heat transfer analysis is the maximum substrate temperature as a function of time and drilling conditions. The substrate temperature limit has been set at 150°C; therefore, the model was used to determine how long it would take to reach this temperature under specific drilling conditions. The time to reach 120°C was also calculated to provide a conservative number. The time to reach each temperature was calculated as a function of torque, penetration rate, and initial waste temperature. The material properties were taken to be the same as for the experimental pumice, which is assumed to be a bounding condition (i.e. the waste is expected to have a higher specific heat and a lower specific energy).



(a)



(b)

Fig. F-7. **Average chip temperature decrease predicted using (a) forced convection correlation and (b) natural convection correlation.**

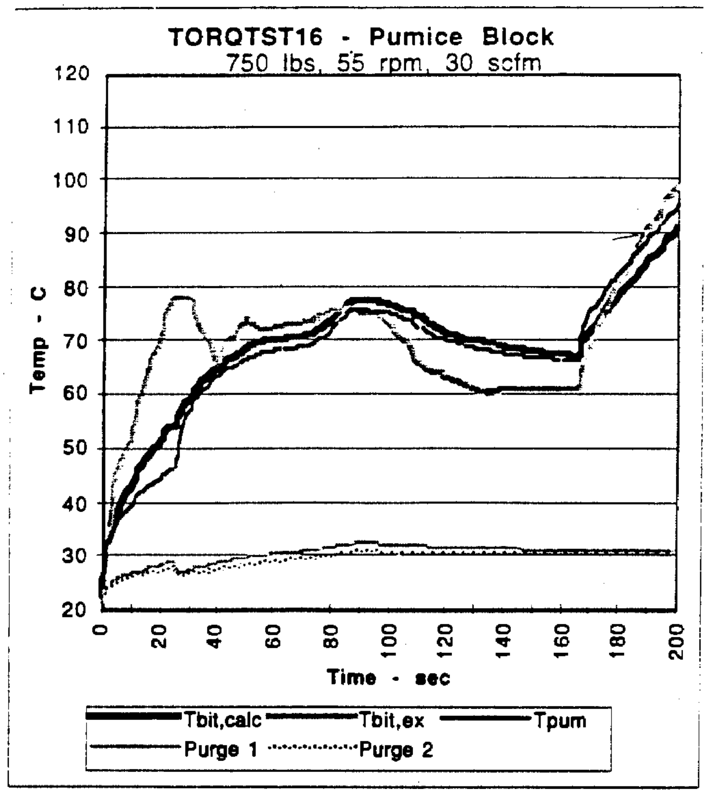


Fig. F-8(a). Comparison of calculated and measured temperatures of Test 16.

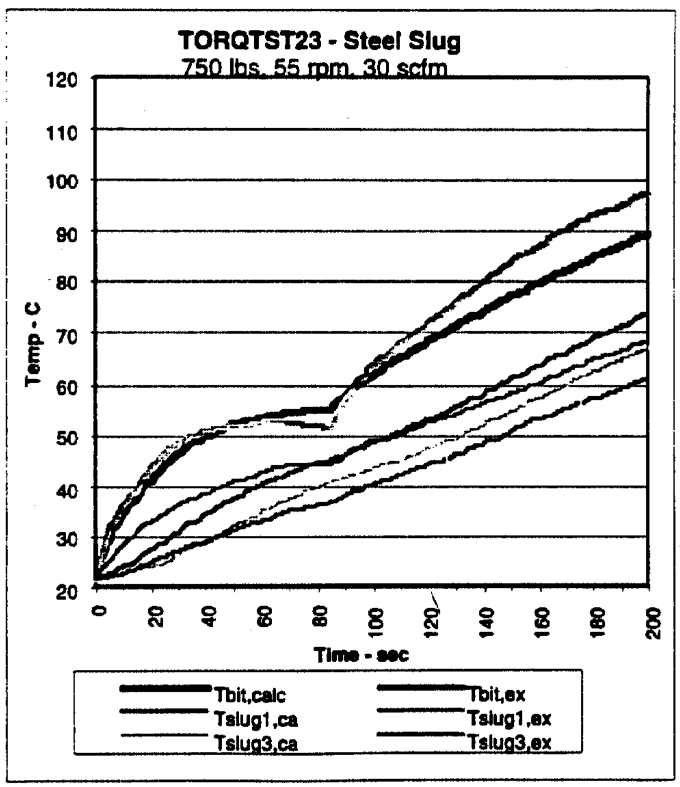


Fig. F-8(b). Comparison of calculated and measured temperatures of Test 23.

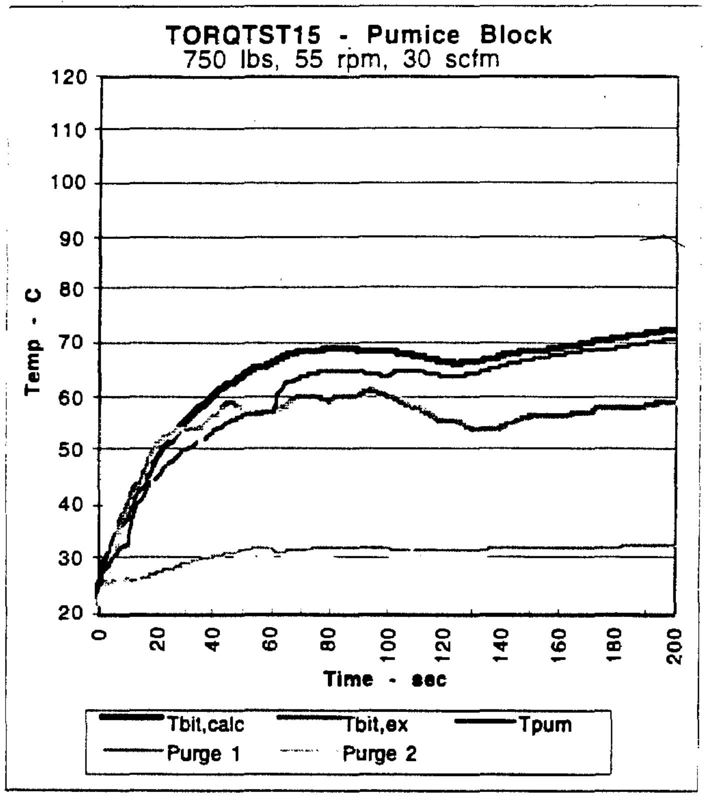


Fig. F-8(c). Comparison of calculated and measured temperatures of Test 15.

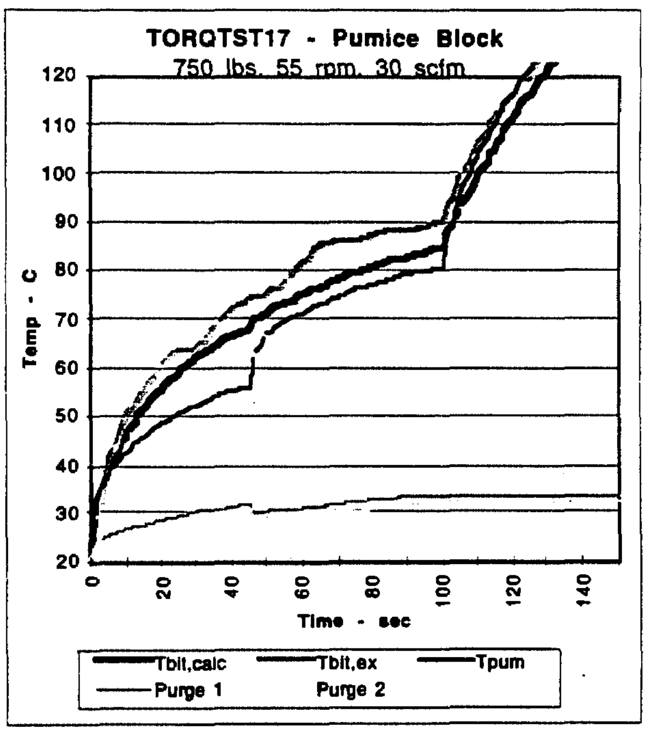


Fig. F-8(d). Comparison of calculated and measured temperatures of Test 17.

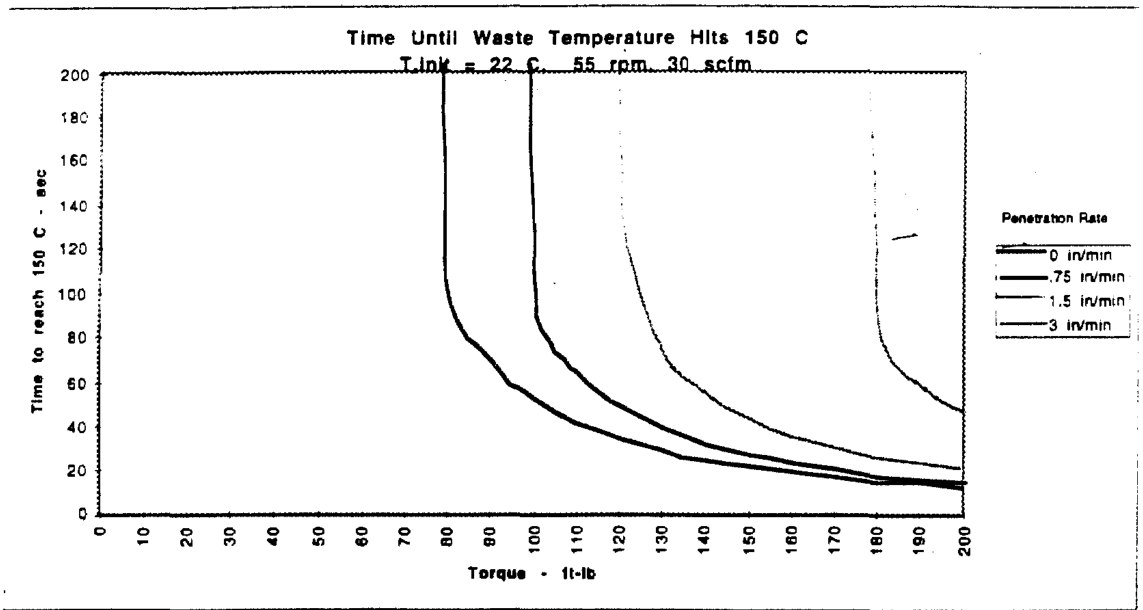


Fig. F-9. Time to reach 150°C as a function of torque for various penetration rates and an initial temperature of 22°C.

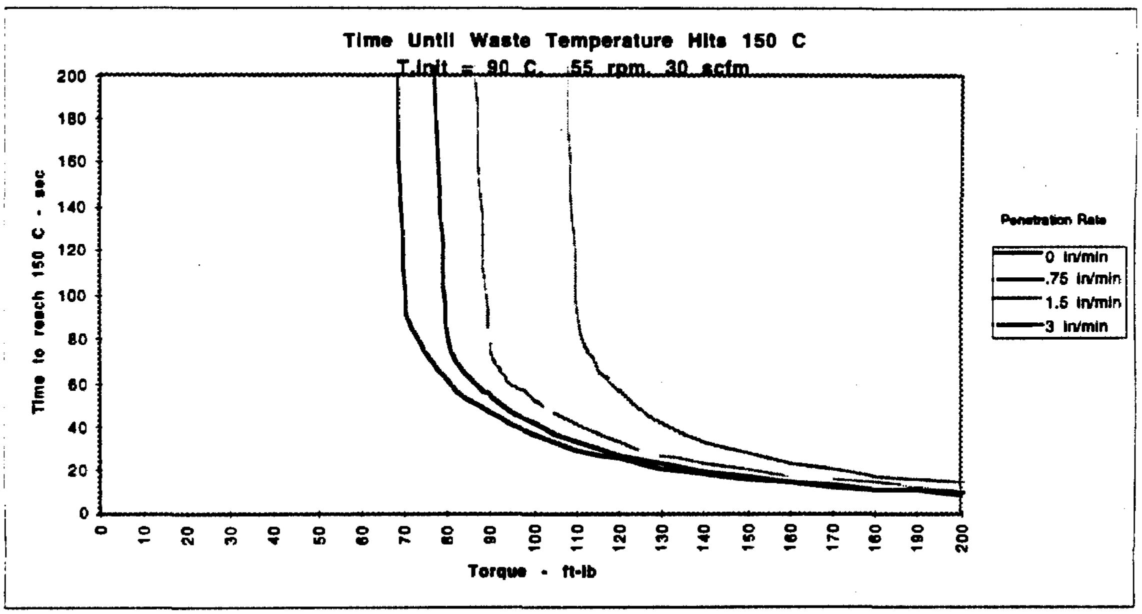


Fig. F-10. Time to reach 150°C as a function of torque for various penetration rates and an initial temperature of 90°C.

All of the results are obtained for a down force of 750 lb, a drill speed of 55 rpm, and a purge gas flow rate of 30 scfm. For this calculation, it was conservatively assumed that all of the energy goes into the bit and substrate (i.e., none goes directly to the gas). These results are plotted for the 150°C limit in Figs. F-9 and F-10. On the plots, any condition to the lower left of a given line will produce a maximum temperature below 150°C. Some of the results are also listed in tabular form below in Table F-5.

In Table F-5 above "nr" means that the temperature was not reached in 5 minutes. In this case, the system reaches a quasi-steady state, where the energy input equals the energy taken away by the gas plus the energy conducted away to the system

TABLE F-5
TEMPERATURE INCREASE CALCULATIONS

		Initial Temp = 22°C		Initial Temp = 90°C	
Torque (ft-lb)	Penetration Rate (in./min)	Time to Reach 120°C	Time to Reach 150°C	Time to Reach 120°C	Time to Reach 150°C
50	0.00	nr	nr	110	nr
50	0.75	nr	nr	152	nr
50	1.50	nr	nr	nr	nr
50	3.00	nr	nr	nr	nr
100	0.00	28	52	19	36
100	0.75	39	97	20	42
100	1.50	74	nr	22	53
100	3.00	nr	nr	26	nr
200	0.00	7	12	4	9
200	0.75	8.5	15	5	10
200	1.50	11	20	5	11
200	3.00	20	47	6	15

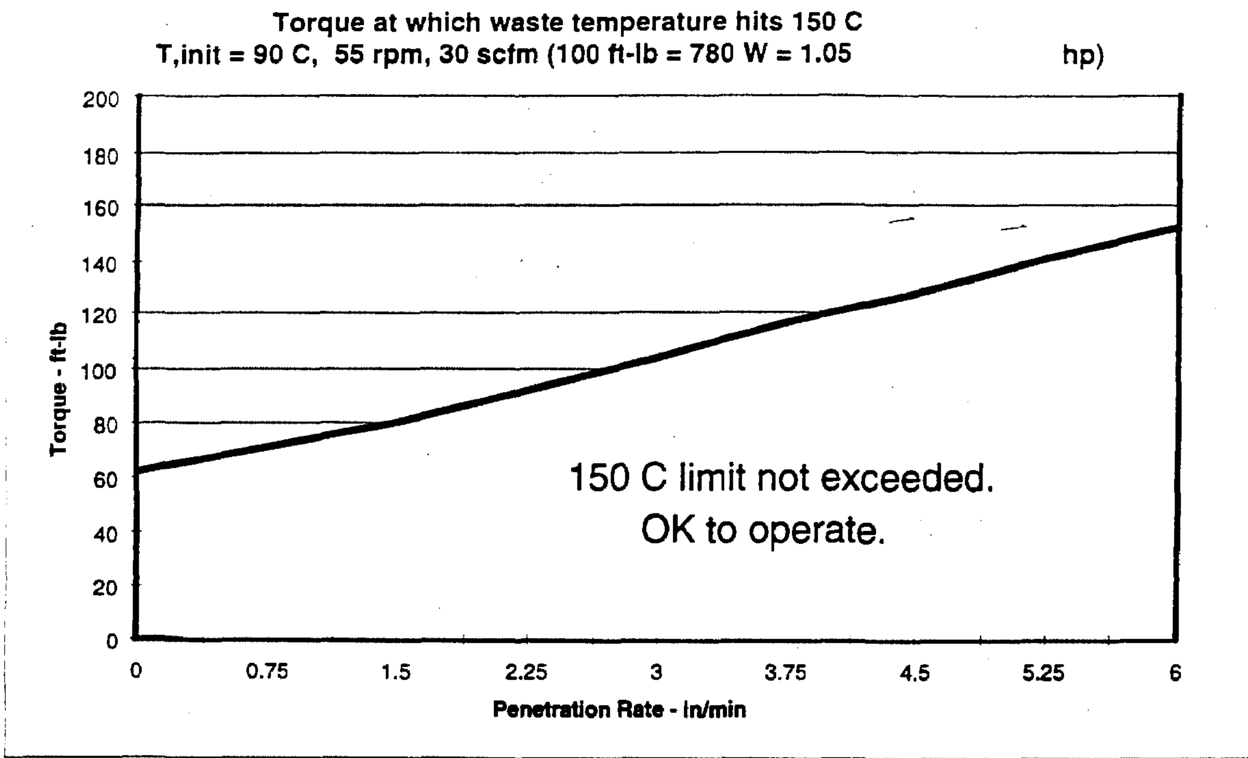


Fig. F-11. Torque at which waste temperature reaches 150°C as a function of penetration rate.

"capacitance." Of course, because the system has a finite heat capacity, a steady state is not truly achieved until all of the energy is removed by the gas, but for a system this size, this will take place over the course of hours. So for this analysis, if the temperature has not reached its limit in 5 minutes, it is safe to assume that the temperature will not rise substantially over the course of several more minutes. In effect, "nr" means that the temperature will not be exceeded over any practical drilling time period.

In summary, the data in Table F-4 and in Figures F-9 and F-10 indicate that if the torque is limited to 60 ft lbf, there are no conditions in which the 150°C limit will be violated. At 100 ft lbf, the temperature limit is not violated at a penetration rate of more than 3 in./min, and at low penetration rates, the limit is not exceeded for more than 30 seconds. A 200-ft-lbf torque leaves about a 10-second window to halt operations or for the drill to break before temperature limits are violated. Figure F-11 plots that maximum allowable torque as a function of penetration rate that will not result in exceeding the 150°C limit. This data can be used to determine the optimum limits in terms of torque, penetration rate, and time for the drilling process. Also, the torque and penetration rate limits should consider the maximum chip temperature, which is discussed below.

Several off-normal conditions were also considered. One case studied an increased purge gas flow of 55 scfm, with an initial temperature of 90°C and a penetration rate of .75 in./min. For a torque of 100 ft lbf the temperature did not even reach 150°C, as opposed to the 30 scfm case that reached 150°C in 42 seconds. For 200 ft lbf the temperature reached 150°C in 12 s as opposed to 10 s. From this result, it can be seen that more safety margin would be provided if the penetration is alarmed at 1 in./min value and the operator can take an action to increase the purge flow to 55 scfm before tripping the drill rig engine. However, the implementation of this suggestion as a control would be not easy because the time to reach the trip value may be so short.

Another case studied was a situation in which the system had reached a quasi-steady state at 3 in./min, 50 ft lbf, 750 lb, 30 scfm, and 55 rpm, and then the down force was suddenly increased to 4500 lb. Similarly, a case was studied in which the drill speed was increased to 110 rpm (as opposed to the down force). Temperature plots are shown for these two cases on Figures F-12 and F-13. Because the 4500-lb case increases the torque by a factor of 6, the temperature passes through 150°C in only a few seconds. The 110 rpm case doubles the torque, and the temperature reaches 150°C about 80 s after the drill speed is increased. The cases studied above indicate that the period in which the operator can take corrective actions after a trip is initiated can be very short. Therefore, the drilling operation must be shut down immediately (in the time required by the data acquisition system to ensure the

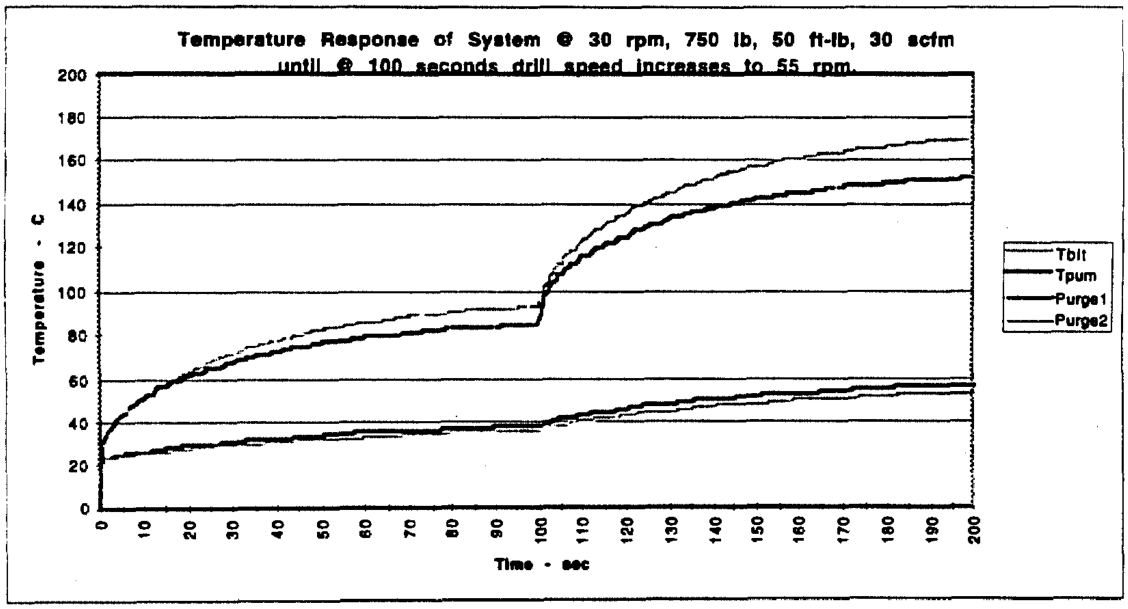


Fig. F-12. Temperature histories during an abnormal operation; speed is increased.

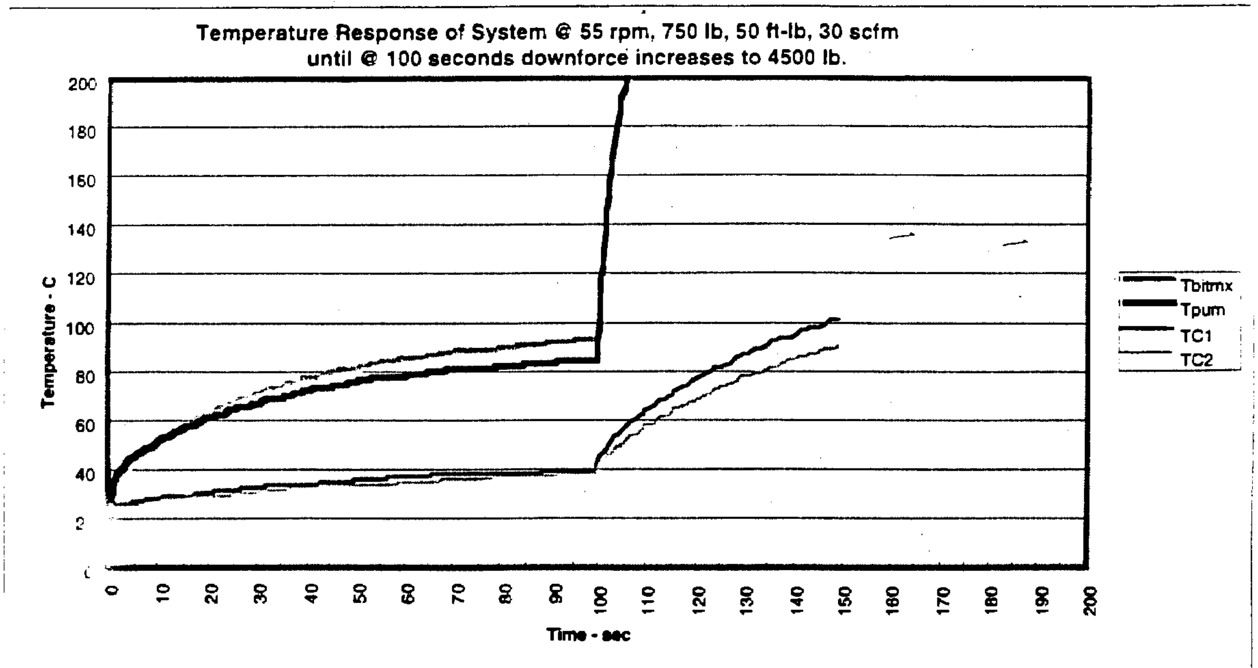


Fig. F-13. Temperature histories during an abnormal operation force is increased.

signal is real), when the downward force exceeds 750 lbf, rotational speed exceeds 55 rpm, or the purge flow becomes less than 30 scfm. Alarm values are not determined in this appendix. However, alarm values may be selected as long as they are lower than trip values by considering a proper waiting period.

F.5.2.2.1. Chip Temperature. As mentioned earlier, this model does not attempt to calculate the chip temperature. The only number calculated is the maximum theoretical chip temperature. This is equal to the substrate temperature at the location of drilling, plus a finite ΔT associated with the energy deposited in the chips caused by drilling of the material. If the very conservative assumption is made that all of the drilling energy goes to the chip, then this ΔT is equal to the specific energy of the material divided by the heat capacity. For the pumice used in the experiments, this ΔT is on the order of 30°C (based on a specific energy of 40 MJ/m^3, which can be inferred from TORQTST18). Because the drilling conditions discussed above limit the substrate temperature to 150°C, then this also limits the chip temperature to 180°C (if it is assumed that the pumice is a limiting material on the basis of specific-energy-to-heat-capacity ratio).

However, it is still possible, although unlikely, that a waste material could be encountered that has a high enough specific energy to heat capacity ratio to cause more than a 30°C chip temperature rise. There is no way to absolutely avoid this possibility. The likelihood of exceeding 180°C could be decreased by setting the substrate temperature limit below 150°C, which would provide more margin for chip ΔT. Also, torque and/or penetration rate limits could be imposed so that the drill is tripped as soon as such a material is encountered (although experiments have shown that the bit wears rapidly as harder materials are encountered, so these limits may not add much safety margin, especially if the detection/trip time is relatively slow). In either case, because the trip or bit wear is not instantaneous, a few chips may be produced that exceed the quoted maximum temperature. Fortunately, it has been determined that the chips cool very rapidly (<< 1 s), so that even if the chip temperature does exceed 180°C for a short time, the risk appears to be negligible.

There are two conclusions that can be drawn from the experimental results that support the contention that the chips are not hot for a substantial period of time; both involve the purge gas temperature. First, there is no abrupt rise in purge gas temperature as drilling begins. If a large fraction of the energy were going to the chips, and then to the gas, there would be an abrupt step increase in the purge temperature in the first few seconds. Because this increase is not seen, then the chips are either not getting very hot, or they are transferring energy quickly to the bit and substrate. Second, the downstream thermocouples do not show any evidence of chip energy deposition as the flow moves downstream. This implies that the chips have lost most of their energy before the flow reaches the thermocouples. The only other possibility is that the chips remain hot as they travel through the entire system. However, the measured gas temperatures are consistent with a total energy balance, and it is unlikely that the thermocouple would read the correct mean (1-species) temperature if the chips were hotter than the gas. Also, simple calculations confirm that the chip cool-down time is << 1 sec.

As mentioned before, ideally the control of the ratio of torque-to-penetration rate would provide reliable protection against waste ignition hazards. These two parameters, however, are not independent. Suppose a hard object/layer is encountered during drilling that is progressing with a good penetration rate. The penetration rate will decrease and the engine would increase the torque to continue drilling. At this point, torque may exceed values that were observed in envelope testing. If material is cut, some penetration can be achieved. Note that drill bit teeth are also starting to be worn out. Based on envelope testing results, teeth became worn down in about 1 minute. If material is much harder than pumice, this period is expected to be on the order of seconds because drill bit teeth material is designed to be worn down if metal objects are drilled. Once teeth get worn down, the penetration rate becomes zero, and the torque will decrease. Current design features only include the monitoring of the penetration rate. There is an automatic shut-down feature when penetration rate decreases below 0.75 in./min. Controlling only the penetration rate will provide protection against exceeding the temperature limits, although until teeth are worn out, there is a short period in which chips and substrate may get hotter than current limits. However, because of nitrogen-cooling capability, chips and substrate will to be cooled and not cause a propagating reaction. In order to further increase safety, a possible design improvement would be the inclusion of a torque limiter or meter. The established controls provide adequate protection for waste ignition hazards.

F.6. CONCLUSIO!

The analyses in this appendix show that the temperature of the chips generated during the drilling tests may have exceeded the measured temperatures from the testing. The chip temperatures during the pumice block testing did not exceed the 180°C (ΔT = 90°C) limit [(and exceed the 150°C (ΔT = 60°C)] limit for only a very brief time immediately after cutting. The 180°C limit seems appropriate for the chips because they are small, the total volume of chips is small, and they are entrained in the relatively cool nitrogen purge gas immediately after being cut. This cools the chips quickly and limits their contact with the bulk material. These analyses also show that the pumice blocks used for a test material are a limiting material in comparison to the waste simulants tested. Thus, the analyses in this appendix support the conclusion that core drilling can be undertaken without exceeding emperature limits if the specified drilling parameter limits are maintained.

The tests analyzed were done on pumice blocks. The temperatures measured on the bits for the drilling tests on pumice blocks were higher than temperatures measured for tests with any of the simulant materials. The analyses suggest that the measured temperatures are dominated by frictional heating of the bulk material. Thus, the drilling tests on these pumice blocks were the most limiting tests for frictional heating. Because of the poor contact between the chips and the areas where the thermocouples were located, it is doubtful that the testing could measure chip temperatures. These are a function of the starting temperature of the material being cut and the compressive strength. The compressive strength calculated from these tests is also about three times higher than the highest value for compressive strength reported by WHC[8] for waste simulant materials. The conversion of compressive strength to specific energy and to thermal energy is condition dependent, and the margin between compressive strength calculated from these tests and the compressive strength measured for the simulants is notable. One can conclude that the average temperatures resulting from the mechanical-to-thermal conversion process are probably lower with simulant materials than with pumice blocks.

In addition to examining normal drilling conditions, experiments were analyzed to determine the temperature response during off-normal conditions. These include a loss of purge gas flow and the spinning of a worn drill bit with no penetration. In these cases, there is sufficient sensible capacity of the system to prevent overheating if attempts to continue drilling are stopped within a reasonable time period. Operational limits set using the test data should be satisfactory if the material conditions encountered during the drilling are no more severe than seen in the drilling tests with the pumice blocks. Comparisons between the pumice properties and waste simulant materials suggest that the pumice blocks provided more severe drilling conditions than are likely to be encountered in the tanks. Should harder materials be encountered, higher temperatures could be reached.

To summarize, the properties of the pumice block used for drill testing produced more severe temperature conditions than the simulant materials produced for an earlier set of tests. If the simulants are reasonably representative of the materials in the tanks, the drilling tests on the pumice blocks were bounding for temperatures. If harder materials are encountered in the tanks, higher temperatures could be produced. A control is established to limit the penetration rate to 0.75 in./min. This control requires an automatic shutdown when the penetration rate is less than 0.75 in./min. This control provides the necessary protection to prevent a propagating waste reaction, although temperature limits may be exceeded for a very short period. Waste temperature limits established in this SA are already conservative, and no credit is considered for water in the waste. The analyses as well as simulants used in the laboratory experiments are on the conservative side. Therefore, it is concluded that controls established in this SA provide adequate protection against propagating an exothermic waste reaction as a result of rotary drilling if the established limits are not exceeded.

F.7. REFERENCES

1. K.S. Witwer, "Envelope Testing for Rotary-mode Core Sampling," Westinghouse Hanford Company reprot WHC-SD-WM-TRP-252 (June 1996).

2. V. Prakash and F. C. Appl, "Temperature Distribution in Synthetic Diamond Cutters During Orthogonal Rock Drilling," *SPE Drilling Engineering*, 137-143 (June 1989).

3. D. A. Glowka and C. M. Stone, "Thermal Response of Polycrystalline Diamond Compact Cutters Under Simulated Downhole Conditions," *Soc. Petroleum Engineers Journal*, 143-156 (April 1985).

4. R. Teale, "The Concept of Specific Energy in Rock Drilling," *Int. J. Rock Mech. Mining Sci.* ,Vol. 2, 57-73 (1965).

5. H. Rabia, "Specific Energy as a Criterion for Drill Performance Prediction," *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.*, Vol. 19, 39 to 42 (1982).

6. C. Donaldson, G. H. LeCain, and V. C. Goold, *Tool Design*, Third Ed., (McGraw Hill, New York, New York, 1973).

7. T. Baumeister, E. A. Avallone, and T. Baumeister III, editors, *Marks' Standard Handbook for Mechanical Engineers*. 8th ed. (McGraw Hill, New York, New York, 1978).

8. C. M. Keller, "Core Drill Operating Envelope Test Report," Westinghouse Hanford Company report WHC-SD-WM-TRP-123 (1993).

9. P. M. Francis, "Aerosol Study for the Rotary Mode Exhauster," Westinghouse Hanford Company report WHC-SD-WM-ES-225, Rev. 1. (March 1993).

10. D. A. Siebe, "Thermal Analysis of Rotary-Mode Core Drilling," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-111 (February 1996).

11. J. P. Holman, *Heat Transfer*, 3rd ed. (McGraw Hill, New York, New York, 1972).

12. S. Kakac, R. K. Shah, and W. Aung, Eds. *Handbook of Single-Phase Convective Heat Transfer* (John Wiley & Sons, New York, New York, 1987).

13. D. I. Poston, "Two-dimensional Transient Heat Transfer Analysis of Rotary Drilling Process," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-109 (February 1996).

APPENDIX G

WASTE AND CRUST IGNITION

G.1. INTRODUCTION

In this appendix, the waste and crust ignition issues are discussed. Waste ignition is a hazard considered to be the result of drilling. The drill bit cutting includes several modes in terms of heat generation and heat transport that are discussed in Appendix F. In an efficient cutting mode, waste chips created by the drill bit teeth can be hotter than the drill bit or teeth temperature. When there is no efficient penetration, a zone where frictional heating between the drill bit and waste exists. In the first part of the appendix, we discuss the operating safety requirements for drilling. In the second part, we examine another accident in which the drill string is postulated to be dropped on a dry crust. We discuss the possibility of a crust ignition and propagation.

G.2. REACTIVE CHEMICAL HAZARDS

Mixtures of sodium nitrate and sodium nitrite with organic compounds can produce violent exothermic reactions.[1,2] Reaction rates generally increase with increasing temperature. For exothermic reactions, increasing the reaction rate increases the heat generation rate. Increasing the temperature of the mixture that reacts exothermically can create an imbalance between heat generation and heat transfer out of the system. This imbalance can create a thermal runaway.

Rotary-mode core sampling (RMCS) causes local heating of the waste. These "hot spots" near the drill string may cause a localized thermal runaway. The consequences of such a local thermal runaway are the following:

- A local thermal runaway may result in temperatures in excess of the autoignition temperature of a flammable-gas mixture trapped in the waste.

- A local thermal runaway will increase the gas-generation rate. There are three potential hazards associated with increased gas generation: increased production of aerosols, production of flammable gases, and production of toxic gases.

- The high temperatures produced by a local thermal runaway may vaporize some of the nuclides, which would result in an increased release rate.

- A local thermal runaway may propagate through the entire tank. Propagation of a thermal runaway could produce very high temperatures, which would result in severe structural damage of the tank.

The consequences of these hazards have been evaluated to determine if these hazards are a significant concern.

- The auto-ignition temperature of hydrogen-air mixtures is reported to be 400°C (Ref. 3), and the autoignition temperature of hydrogen nitrous oxide mixtures may be lower.[4] The maximum temperature produced by waste containing 1.0 wt % total organic carbon (TOC) is estimated to be ~400°C. Therefore, a runaway reaction may produce temperatures exceeding the autoignition temperature, even if it contains only a small amount of organic carbon sustaining an exothermic reaction. Exceeding the autoignition temperature is a real hazard.

- The maximum gas-generation rate is estimated to be 3.6 scfm. The maximum volume that could be generated is 250 scf. The nominal nitrogen flow in the drill string is 30 scfm. The maximum gas-generation rate is small compared to the nitrogen flow, so that gas generation will not have a significant impact on aerosol formation. Tests on dry waste surrogates indicate that nitrous oxide is formed during a runaway reaction.[5] Hydrogen is generated in the waste at normal waste temperatures. There is no reason to expect that these reactions will stop at elevated temperatures; therefore, hydrogen generation is possible. The ignition of ~1000 scf of a stoichiometric mixture of hydrogen and nitrous oxide under the waste surface will cause structural damage; therefore, generating 250 scf of hydrogen or nitrous oxide could be a significant contributor to a flammability hazard. If all of the gas generated is nitric oxide (NO) or nitrogen dioxide (NO_2), the maximum concentration at 100 m from the tank is <1 ppm; so there is no toxic gas hazard.

- Volatile nuclides can be a problem in a waste vitrification plant. If an uncontrolled reaction produces very high temperatures, cesium and strontium may vaporize. A bounding calculation predicts a maximum dose of <1 mrem Committed Effective Dose Equivalent (CEDE) at 100 m from the tank. Therefore, vaporization of nuclides is not a hazard.

- If an exothermic reaction propagates throughout the tank, the consequences could be severe. The volume of waste involved in a propagating reaction could be a factor 100,000 times greater than a local reaction. Consequences that are negligible for local exothermic reactions could be significant for a propagating reaction. The high temperatures generated would cause a structural failure of the tank. A propagating exothermic reaction is a significant hazard.

A local runaway reaction is a real hazard. The primary concerns are that a runaway exothermic reaction could be an ignition source in a flammable-gas tank, and a local reaction may propagate. The generation of flammable gases or oxidants is a lesser concern because a flammable-gas hazard already exists in the tanks of interest, and there are no consequences of a flammable-gas release unless there is an ignition source.

G.3. LOCAL RUNAWAY REACTIONS

G.3.1. Review of Existing Data

Data on exothermic chemical reaction have been obtained using waste samples and using waste surrogates and simulants.

A review of the chemical analyses performed on waste samples was conducted. Between 1974 and 1995, differential thermal analysis (DTA) and differential scanning calorimetry (DSC) were performed on 169 samples obtained from 70 different tanks. In many cases, the reports do not give the onset temperature for exothermic reactions. They only state that no exothermic reactions were observed below 200°C. Such data are useful in establishing a lower bound on the onset temperature. Of the 169 samples, onset temperatures of <200°C were reported for 17. The lowest onset temperature reported was 180°C for several samples obtained from Tanks 241-SY-101 and 241-SY-103.

Several studies have been performed on waste surrogates and waste simulants. Schelle et al.[5] studied several waste surrogates and a waste simulant using DSC and accelerated rate calorimetry (ARC). The onset temperatures measured by DSC range from 220°C to 364°C. The lowest values correspond to tests with a waste simulant that includes many of the minor waste components, such as nickel, chromium, and iron. Onset temperatures as measured by the ARC are between 113 and 290°C. The onset temperatures measuring <180°C were obtained using the waste simulant. Although low-onset temperatures were measured between 110 and 120°C, a self-sustaining reaction did not occur until the temperature reached 150°C. A reactive system screening tool (RSST) also was used to measure onset temperatures.[6,7] The measured onset temperatures were 150°C and 180°C. The lower temperature was obtained using the waste simulant discussed above.

G.4. CRITERIA TO AVOID LOCAL RUNAWAY

Local runaway reactions can be avoided by maintaining the waste temperature below the onset temperature for exothermic reactions. The standard practice is to subtract 100°C from the onset temperature as determined by DSC and to subtract 50°C from the measured onset temperature as determined by ARC.[8] The reasons for these large safety margins is uncertainty. The scanning rate affects the onset temperature of DSC and RSST. The sensitivity of the instrument is also a consideration. Differences between waste simulants and actual waste is also a source of uncertainty as are variations in waste composition. Other factors such as good heat transfer and short time periods can reduce the need for the safety margin applied to the measured onset temperature.

Two length scales must be considered when evaluating the potential for local runaway reactions. The first scale to consider is the microscopic scale. Strain energy added as the drill bit cuts into the waste will heat fragments to temperatures that are greater than the drill bit temperature. The size of these fragments and chips are estimated to be between 1 µm and 150 µm. In Ref. 9, p. 6, the particle size distribution was determined to be 1 to 100 µm. The samples were collected from drilling tests in simulants. This range was measured by using an optical microscopy technique used by Pacific Northwest National Laboratory (PNNL). Using the same single-shell waste simulant samples from the same collection, Westinghouse Hanford Company's (WHC's) Plutonium Finishing Plant Laboratory covered a particle size range of 0.1 to 10 µm with a laser diffraction analysis. They are small-sized chips, and they are cooled relatively quickly (Ref. 10). The second scale to consider is macroscopic. The drill bit and the surrounding waste will be heated above the bulk temperature of the waste, but it will be cooler than the fragments formed at the drill tip. The thermal inertia of the drill bit and the surrounding waste is much greater than the microsized fragments. Differences in the time scale and the heat transfer rates justify different temperature limits for these two cases.

First, consider the temperature limit for small fragments. The limit will be based on the available data for actual waste samples. The large amount of data available on actual waste samples addresses the problems of errors in surrogate and simulant tests and variability in waste composition. The large number of waste samples obtained from a large number of different tanks addresses the problem of variability in waste composition. Because of the large number and variety of waste samples analyzed, the large margins often applied to onset temperatures measured by DSC and ARC are not appropriate.

The DTA and DSC results for actual waste samples are used to establish the maximum temperature limit. A comparison of data for waste surrogates and simulants is done with results for actual waste samples so that the surrogates and simulants are not unreasonable models of the waste. Therefore, data for waste surrogates and simulants are used as additional evidence that the proposed limit is reasonable. Because this safety assessment (SA) addresses rotary-mode sampling in all single-shell, flammable-gas tanks, the limit must be bounding for all tanks. Therefore, the limit is based on the lowest measured onset temperature of 180°C. The proposed limit for heating of small waste fragments is 180°C. Because the limit is based on a large number of waste samples and because the fragments cool relatively quickly, no additional safety margin is applied to the lowest measured onset temperature.

This temperature limit is supported by the onset temperature measured for waste surrogates, but it is not supported by the onset temperatures measured for the waste simulant data. Exceeding the measured onset temperature for exothermic reactions does not imply that a runaway reaction will occur. Heat transfer also must be considered. The first-order stability criterion for a runaway reaction in a single fragment is

$$\left(\frac{dT}{dt}\right)_o < \frac{6 \cdot U \cdot (T_o - T_s)}{\rho \cdot c_p \cdot D} , \qquad \text{(G-1)}$$

where

$\left(\frac{dT}{dt}\right)_o$ = self-heating rate at the initial temperature of the fragment,
U = heat transfer coefficient for the fragment,
T_o = initial temperature of the fragment,
T_s = temperature surrounding the fragment,
ρ = density of the fragment,
c_p = heat capacity of the fragment, and
D = diameter of the fragment,
k = thermal conductivity.

Conservative parameters are used to estimate the critical self-heating rate. The heat transfer coefficient is assumed to be 5 watts/m^2 K, the density of a fragment is ~2.7 g/cm^3, and the heat capacity is ~1.8 J/g K. The maximum particle diameter of 150 µm is used in the calculation, and the temperature of the surrounding waste is assumed to be 160°C. The critical self-heating rate for a fragment is estimated to be ~50°C/min. The heating rate used in the DSC and RSST is 1 to 10°C/min, depending on the experiment; therefore, these devices should be able to detect self-heating rates of <50°C/min. Therefore, the onset temperature measured by these devices should be a conservative estimate of the stability limit for a fragment. To relate this self-heating rate to the self-heating rate observed in the ARC, it must be divided by the Φ factor[11]

$$\left(\frac{dT}{dt}\right)_{ARC} = \frac{1}{\Phi} \cdot \left(\frac{dT}{dt}\right) . \qquad \text{(G-2)}$$

The Φ factor accounts for the thermal inertia of the calorimeter, and the value is ~4 for the experiments discussed in Ref. 5. The reaction should be stable if the self-heating rates measured for the ARC tests in Reference 5 are <12°C/min. Below the onset temperature, the self-heating rate is <0.025°C/min, so the experiments with waste surrogates support the proposition that a thermal runaway does not occur in a fragment with a temperature of 180°C. The self-heating rate for the waste simulant is ~0.04°C/min. Although this value is greater than the criteria for determining the onset temperature, it is much less than the stability limit for fragments. The self-heating rate data obtained from the ARC supports the 180°C temperature limit for fragments.

Time is a consideration when evaluating the stability of exothermic reactions if the material is heated for a short period of time; therefore, runaway reactions may not be a problem. In an adiabatic system, there is a period of time before a thermal runaway occurs during which the self-heating rate is relatively small. This period is called the induction time. The adiabatic induction time is a useful gauge for making a qualitative evaluation of whether the duration of the drilling operation is long enough to be a concern. If the drilling duration is less than the adiabatic induction time, runaway reactions should not be a problem. The first-order estimate of the adiabatic induction time is

$$t_I = \frac{R \cdot T_o^2}{E_a \cdot \Phi \cdot \left(\frac{dT}{dt}\right)_o}, \qquad \text{(G-3)}$$

where

t_I = induction time,
R = gas constant,
E_a = activation energy, and
Φ = Φ factor for the calorimeter.

Based on the data in Ref. 5, a reasonable, but conservative, estimate of the activation energy is 240 kJ/mole. An upper bound for the self-heating rate at 180°C is the heating rate of 1°C/min used for the DSC and RSST. The lower bound for the adiabatic induction time of a fragment at 180°C is 7 min. The temperature of the fragment as a function of time can be approximated by the following equation:

$$T = T_s + (T_o - T_s) \cdot \exp\left(-\frac{6 \cdot U}{\rho \cdot c_p \cdot D} \cdot t\right). \qquad \text{(G-4)}$$

The typical Biot number (UD/k) for 150 µm waste chips is <0.1; therefore, Eq. (G-4) is adequate. The time constant for cooling is ~24 s, which is much less than the adiabatic induction time. The life of a hot fragment is much less than the induction time, which supports the 180°C temperature limit for fragments.

The estimates of the critical self-heating rate and the adiabatic induction time indicate that there is considerable margin in the 180°C temperature limit for fragments. This margin justifies using the minimum measured onset temperature of waste samples as the limit.

Next, a limit must be set for the drill-bit temperature and the average temperature of the waste surrounding the drill bit. As discussed above, the large margins often applied to the measured onset temperatures are not applicable. However, some margin is warranted because thermal inertia may be an important factor at the macroscopic scale. Therefore, a 20°C margin is applied to the minimum measured onset temperature for actual waste samples. The maximum allowable temperature for the drill bit and the surrounding waste is 160°C.

This temperature limit is supported by the onset temperature measured for waste surrogates, but it is not supported by the waste simulant onset temperature data. As discussed above, the onset temperatures measured for the waste simulants may not be applicable because heat transfer also must be considered. The first-order stability criterion for a runaway reaction for the waste immediately surrounding the drill bit is

$$\left(\frac{dT}{dt}\right)_t < \sqrt{\frac{\alpha}{t}} \cdot \frac{(T_t - T_s)}{\Delta x} , \qquad \textbf{(G-5)}$$

where

$\left(\frac{dT}{dt}\right)_t$ = self-heating rate at time t,
α = thermal diffusivity of the waste,
t = duration of the heating caused by drilling,
T_t = temperature of the waste near the drill string at time t,
T_s = temperature of the bulk waste, and
Δx = thickness of the area affected by the drill.

This criterion accounts for the heating of the waste surrounding the drill string. The equation predicts that the stability decreases with time because frictional heating of the waste reduces heat transfer. Significant heating only occurs near the drill bit. The length of the drill bit is ~3 in., and the minimum penetration rate is ~0.5 in./min. Therefore, heating caused by drilling affects the waste at a given location for <10 min. The lower bound on waste thermal diffusivity is 0.0008 cm^2/s, a bounding temperature for all flammable-gas tanks is 95°C, and the thickness of material affected by the drill is assumed to be 0.5 cm. The limiting self-heating rate, given the temperature control of 160°C, is 9.0°C/min. The heating rate used in the DSC and RSST is 1 to 10°C/min; therefore, these devices should be able to detect self-heating rates of <9.0°C. Therefore, the onset temperature measured by these devices should be a conservative estimate of the stability limit. Equation (G-2) is used to relate this self-heating rate to the self-heating rate observed in the ARC. As stated above, the Φ factor is ~4 for the experiments discussed in Ref. 5. Therefore, the reaction should be stable if the self-heating rate measured for the ARC tests in Ref. 5 is <2.3°C/min. Below the onset temperature, the self-heating rate is <0.025°C/min; therefore, the experiments with waste surrogates support the proposition that a thermal runaway does not occur at 160°C. The self-heating rate for the waste simulant at 160°C is ~0.03°C/min. Although this value is greater than the criteria for determining the onset temperature, it is much less than the stability limit. The self-heating rate data obtained from the ARC supports the 160°C temperature limit.

Time is also considered. The adiabatic induction time can be estimated from Eq. (G-3). A lower bound for the adiabatic induction time at 160°C is 54 min. This estimate is greater than the maximum time allowed for drilling a segment. Because the system is not adiabatic, the actual induction time will be greater than the adiabatic induction time. Thus, the duration of the operation at 160°C is too short for a thermal runaway to be a problem.

The margins for the critical self-heating rate and the adiabatic induction time are smaller on the macroscopic scale than they are for waste fragments. The lesser margin justifies setting the temperature limit below the minimum measured onset temperature. Also, the temperature limit for the macroscopic scale is based on an assumed heating time of 10 min. No experiments have been performed in which actual waste samples, waste simulants, or waste surrogates were maintained at 120°C for >10 min. Additional tests are required to confirm that local heating of the waste for >10 min is safe before the conservatism in the temperature limit may be reduced.

G.5. PROPAGATING EXOTHERMIC REACTIONS

The consequences of propagating an exothermic reaction are serious. The criterion of no local runaway reaction provides protection against propagating exothermic reactions. Because the consequences are very severe and because exceeding the temperature limits is credible, additional measures are required to prevent a propagating exothermic reaction. Rotary-mode sampling should not be performed in tanks in which a propagating exothermic reaction can occur.

G.5.1. Review of Criteria

Criteria have been proposed for evaluating the possibility of a propagating exothermic reactions in the waste.[11] According to these criteria, no propagation is possible if one of following conditions is satisfied:

$$\begin{cases} \text{TOC (wt.\%)} < 4.5 + 0.15 \cdot (\text{wt.\% } H_2O) \text{ or} \\ 20\,\% \geq \text{wt.\% } H_2O \end{cases} \tag{G-6}$$

These criteria are based on experimental data for waste surrogates,[12] and they are plotted in Fig. G-1.

Chemical energy density is used in the chemical process industries to screen for potential reactive chemical hazards.[8] This method may also be useful in evaluating reactive chemical hazards in the Hanford waste tanks. In this method, the degree of hazard as a function of enthalpy of reaction is given in Table G-1. A low degree of hazard means that a deflagration is possible but not likely.

If the chemical energy density criteria are used to evaluate the potential for a propagating exothermic reaction, a low degree of hazard should be sufficient protection considering that controls have been established to prevent local runaway reactions. Therefore, the heat of reaction must exceed -300 cal/g waste in dry waste for a propagating exothermic reaction to occur. Evaporation of water will provide additional protection against propagation. Therefore, basic energy density limit will be modified to account for the heat of vaporization of water. In wet waste, propagating reactions are assumed to be impossible if the heat of reaction does not exceed -300 cal/g waste minus the latent heat of vaporization of water.

In order to compare the chemical energy density approach used as a screening in the Chemical Process Industries to the criteria given by Eq. (G-6), the heat of reaction is required. The largest heat of reaction was determined using linear programming, which is the method used by the American Society for Testing and Materials (ASTM) in the CHETAH program for evaluating reactive chemical hazards. A maximum value of -9.7 kcal/g total organic carbon (TOC) was obtained for the oxidation of sodium hydroxy-ethanol-diamine-triacetic acid (NaHEDTA). NaHEDTA was one of the complexants used at Hanford. Decomposition of NaHEDTA and other complexants into less energetic compounds is expected as a result of radiolysis. Therefore, the heat of reaction of -9.7 cal/g TOC is a bounding value rather than a realistic estimate of the heat of reaction. Based on data for waste surrogates, a heat of reaction of -6.0 kcal/g TOC should be typical of actual waste samples.[5,7]

By assuming a heat of reaction of -6.0 kcal/g, the maximum TOC content can be estimated as a function of the moisture content. The limit based on a chemical energy density of 300 cal/g waste is plotted in Fig. G-1. This limit approximates the criteria proposed by Webb et al.[11] for water content <20 wt %, which indicates that the 300 cal/g waste is a reasonable limit. This comparison demonstrates that the criterion given by Eq. (G-6) is equivalent to the chemical energy density method for the waste surrogates.

G.5.2. Probability of a Propagating Exothermic Reaction

Because the consequences of a large scale propagating reaction are not acceptable, the working criterion for evaluating safety is whether this accident is credible (i.e., has a frequency $>10^{-6}$/yr). The frequency of a large-scale propagating reaction is estimated using an event-tree model of waste variability. Although this SA applies only to flammable-gas tanks, all 100-series single-shell tanks (SSTs) were considered in this appendix. There are currently 19 single-shell flammable-gas tanks: A-101, AX-101,

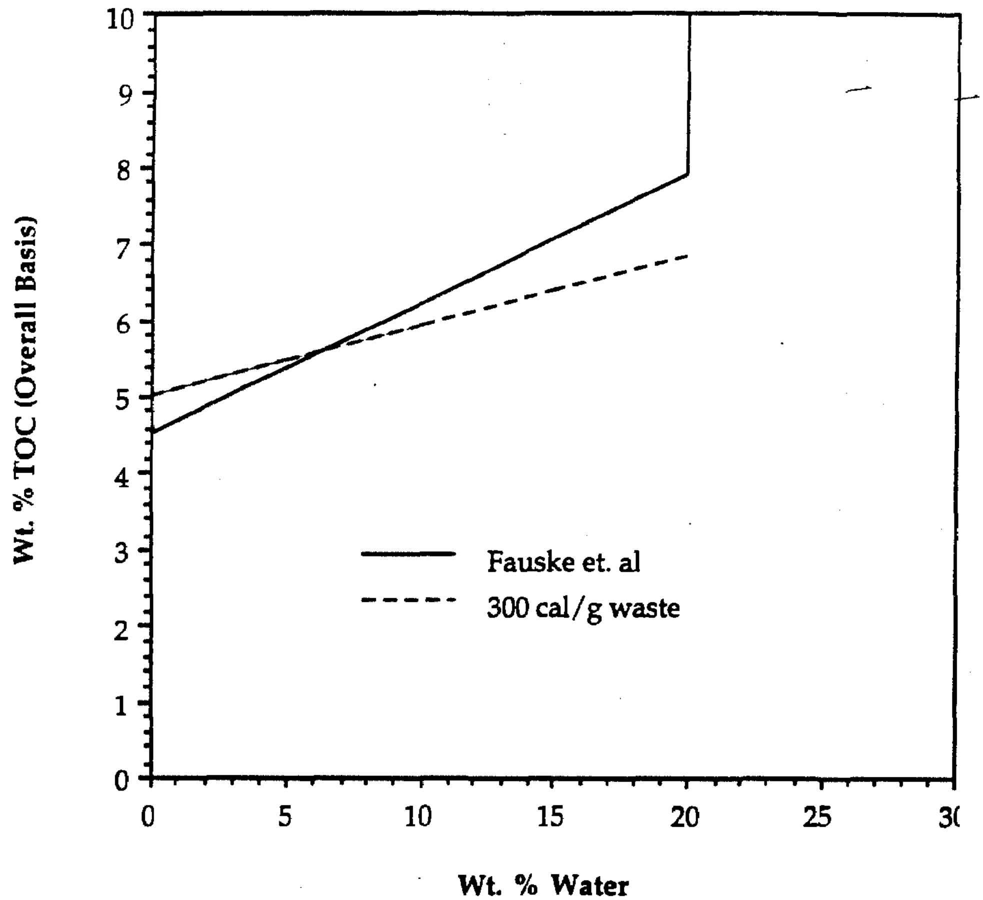


Fig. G-1. Proposed criteria for no propagation of exothermic reactions in the waste.

TABLE G-1
DEGREE OF HAZARD AS A FUNCTION OF ENTHALPY OF DECOMPOSITION OR REACTION

Degree of Hazard	Maximum Enthalpy of Decomposition/Reaction (kcal/g)	Possible Qualitative Interpretations of the Classifications
High	< -0.7	Violently exothermic; detonation likely
Medium	-0.3 to -0.7	Exothermic; detonation possible; deflagration likely
Low	-0.1 to -0.3	Deflagration possible
Very Low	> -0.1	Propagation unlikely

AX-103, S-102, S-111, S-112, SX-101, SX-102, SX-103, SX-104, SX-105, SX-106, SX-109, T-110, U-103, U-105, U-107, U-108, and U-109.[11] Twenty-three additional tanks have been listed as possible flammable-gas tanks: A-103, BX-107, BY-101, BY-102, BY-105, BY-106, BY-109, C-104, C-107, S-101, S-103, S-105, S-106, S-107, S-109, TX-102, TX-111, TX-112, TX-113, TX-115, U-102, and U-106. The following tanks have a potential to be added to the list: B-111, B-201, B-202, S-104, T-201, T-202, T-203, T-204, TX-116, TX-117, U-110, and U-111.

G.5.2.1. Event-Tree Analysis

The sequence of events leading to a propagating reaction must be determined in an event-tree analysis to evaluate the frequency of a propagating reaction accident. Three things must happen in order for a propagating exothermic reaction to occur: (1) the drilling controls must be exceeded, which will cause heating of the waste, (2) the drill temperature must increase to the ignition temperature of the waste, and (3) the failure must occur in waste sufficiently rich in organics to support propagation.

The waste surrogate data indicate that both TOC concentration and the distribution of organic species affect the ability of the waste to support a propagating reaction.[13] The variability of heat of reaction observed in samples taken from Tank 241-SY-101 indicates variability in the distribution of organic species within a tank.[14] At least two variables are required to characterize the organic compounds. Heat of reaction and wt % TOC are used in the study. Because heat of reaction is used to characterize the organic compounds, the chemical energy density is used to evaluate the probability of a propagating exothermic reaction. It is easier to incorporate variability into the organic compounds by using the energy density method than by using the criteria given by Eq. (G-6).

An event tree for evaluating the probability of a propagating reaction is shown in Fig. G-2. The initiating event in the event tree corresponds to exceeding one of the drilling controls. Based on a reliability analysis of the operation, the frequency of violating a drilling control is 2.3×10^{-4}/yr.

Violating one of the drilling controls will cause the waste to heat. Bounding tests performed using a dry pumice block indicate that failure of a control could result in temperatures in excess of waste ignition temperature. In real waste, the maximum temperature will depend on the hardness of the waste and the moisture content. The ignition temperature also is expected to vary. Because of the factors, the probability of ignition given failure of the controls is <1.0; however, there is insufficient data and understanding to quantify the probability. Therefore, the probability of ignition given a control failure is assumed to be 1.0.

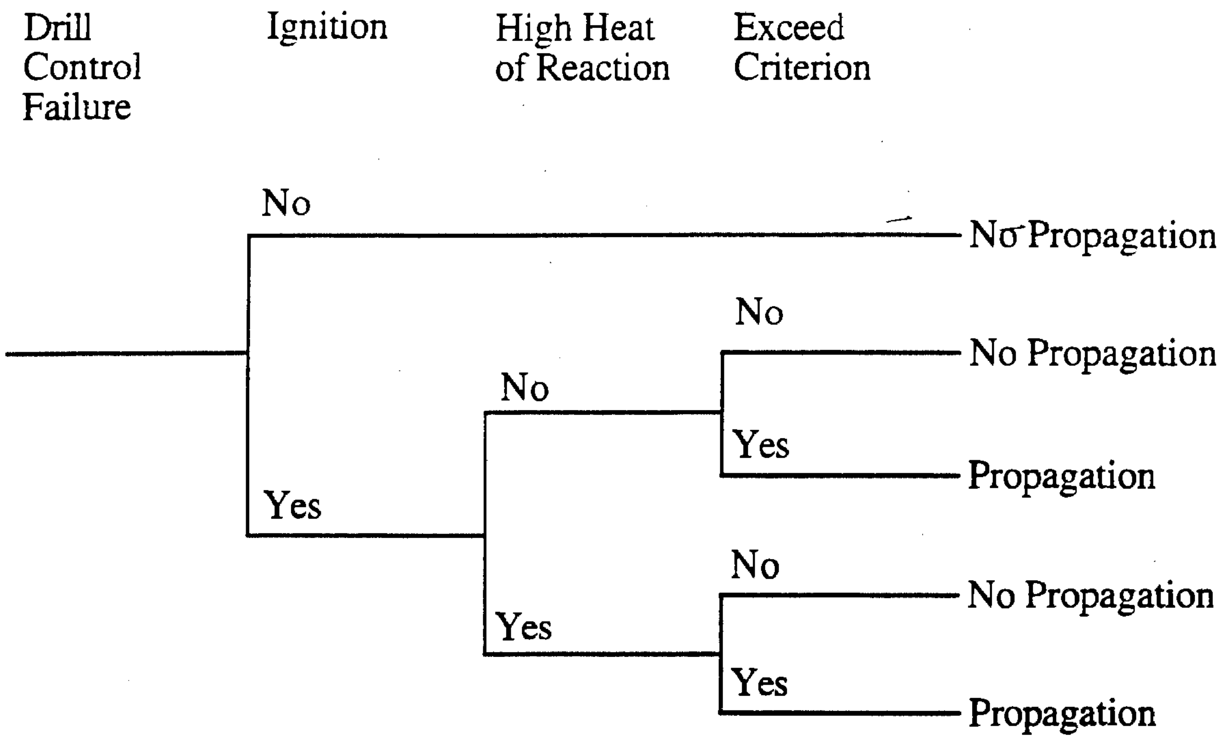


Fig. G-2. Event tree for propagating exothermic reactions.

To simplify the analysis, the variability heat of reaction is incorporated into the event-tree model by using two bins: a low-heat-of-reaction bin and a high-heat-of-reaction bin. The first bin is waste with a heat of reaction <-6.5 kcal/g TOC. The second bin is waste with a heat of reaction between -6.5 kcal/g TOC and the bound value of -9.7 kcal/g TOC. The high heat of reaction compounds are the original organic complexants, so high heat of reaction bin represents waste rich in these organic compounds. Because of degradation of the organic complexants with time, a zone or layer rich in the original complexants is very unlikely. The probability of drilling control failure in a zone containing high heat of reaction organic compounds is assumed to be 0.1. Core sample data from Tank 241-SY-101 are consistent with this assumption.

The final branch in the event tree determines whether the waste exceeds the chemical energy density criterion. The chemical energy density limit is a function of the heat of reaction bin, the TOC concentration, and the moisture content. Because the drill is assumed to fail at a random location in the waste, the probability of exceeding the limit is equal to the fraction of the waste that exceeds the limit. There are two possible methods of evaluating this probability: (1) statistical analysis of data and (2) evaluation of the fill history. These two methods are complementary. Statistical methods quantify the observed variability, which cannot be determined from the current analysis of waste history. Analysis of waste history can be used to identify the possibility of remnant organic layers that cannot be detected by statistical analysis. The statistical estimates of probability are based on Pacific Northwest

National Laboratory's (PNNL's) analysis of variance (ANOVA) model.[12] Estimates based on fill history were obtained from a review of work performed at Los Alamos National Laboratory.[15]

As shown in Fig. G-2, only two branches of the event tree corresponding to propagating exothermic reaction. The frequency of a propagating reaction is the sum of the frequencies for these two branches.

$$f_{prop} = f_i \cdot \begin{bmatrix} Pr(\text{Low } \Delta H_{rx}) \cdot Pr(\text{Exceeding Limit} | \text{Low } \Delta H_{rx}) + \\ Pr(\text{High } \Delta H_{rx}) \cdot Pr(\text{Exceeding Limit} | \text{High } \Delta H_{rx}) \end{bmatrix}, \qquad \text{(G-7)}$$

where

f_{prop} = frequency of a propagating reaction, and
f_i = frequency of the initiating event.

PNNL provided probability estimates obtained from their ANOVA model for all single-shell tanks.[16] The results for 100-series tanks are given in Table G-2. Both the median value and the 95% upper bound are given. The frequencies of propagating reactions were computed for each 100-series tank. The results are given in Table G-3. The table contains estimates based on the median values predicted by the ANOVA model, as well as estimates based on the 95% upper bound. Safety decisions should be based on the 95% upper bound because it accounts for the uncertainty associated with estimating the probabilities for tanks with no waste sample data.

Two factors were considered in evaluating waste history: the maximum TOC concentration in the organic remnant layer and the volume of the high TOC remnant layer. The TOC concentration is related to the reactivity of the waste in the remnant layer, and the probability of violating a drilling control in an organic remnant layer is related to its volume. Two problem tanks, A-106 and C-107, were identified by this method. Tank C-103 is also a problem because it contains a floating organic layer. This SA does not address exothermic reactions of a floating organic layer.

TABLE G-2
ANOVA MODEL PREDICTIONS OF THE FRACTION OF WASTE THAT IS REACTIVE

Tank Number	Assay Data Available	Low Heat of Reaction Waste		High Heat of Reaction Waste	
		Median	95% Bound	Median	95% Bound
A-101	Yes	1.5×10^{-6}	2.0×10^{-4}	5.0×10^{-4}	9.1×10^{-3}
A-102	Yes	1.2×10^{-5}	1.3×10^{-3}	2.5×10^{-3}	5.0×10^{-2}
A-103	Yes	1.6×10^{-6}	1.7×10^{-4}	6.0×10^{-4}	1.0×10^{-2}
A-104	No	2.9×10^{-7}	8.6×10^{-4}	1.5×10^{-4}	3.6×10^{-2}
A-105	No	4.4×10^{-8}	5.8×10^{-4}	3.8×10^{-5}	3.1×10^{-2}
A-106	Yes	1.6×10^{-6}	4.5×10^{-4}	6.2×10^{-4}	1.5×10^{-2}
AX-101	No	1.2×10^{-7}	1.8×10^{-4}	4.4×10^{-5}	1.0×10^{-2}
AX-102	Yes	2.5×10^{-3}	3.5×10^{-2}	9.2×10^{-2}	2.7×10^{-1}
AX-103	No	1.4×10^{-7}	4.1×10^{-4}	7.4×10^{-5}	1.3×10^{-2}
AX-104	No	6.0×10^{-8}	1.1×10^{-3}	4.3×10^{-5}	2.9×10^{-2}
B-101	No	1.6×10^{-7}	5.8×10^{-4}	7.1×10^{-5}	1.1×10^{-2}
B-102	No	1.2×10^{-6}	1.3×10^{-3}	2.2×10^{-4}	4.1×10^{-2}
B-103	Yes	0.0	3.7×10^{-9}	3.2×10^{-9}	3.4×10^{-6}
B-104	No	0.0	2.1×10^{-8}	5.0×10^{-9}	2.3×10^{-5}
B-105	No	7.6×10^{-8}	1.6×10^{-4}	5.2×10^{-5}	7.6×10^{-3}
B-106	No	1.7×10^{-10}	5.1×10^{-6}	5.1×10^{-7}	6.8×10^{-4}
B-107	No	5.7×10^{-12}	1.0×10^{-6}	3.9×10^{-8}	1.6×10^{-4}
B-108	No	1.4×10^{-10}	3.1×10^{-6}	4.2×10^{-7}	8.6×10^{-4}
B-109	No	2.1×10^{-10}	4.9×10^{-6}	2.9×10^{-7}	6.0×10^{-4}
B-110	Yes	0.0	4.5×10^{-11}	1.1×10^{-11}	7.4×10^{-8}
B-111	Yes	3.1×10^{-13}	1.7×10^{-8}	2.5×10^{-8}	9.5×10^{-6}
B-112	No	2.8×10^{-11}	1.6×10^{-6}	4.3×10^{-7}	1.0×10^{-3}
BX-101	No	1.6×10^{-9}	1.3×10^{-5}	2.0×10^{-6}	1.5×10^{-3}
BX-102	No	2.3×10^{-10}	4.2×10^{-6}	3.3×10^{-7}	6.3×10^{-4}
BX-103	No	2.2×10^{-12}	2.9×10^{-7}	1.3×10^{-7}	2.0×10^{-4}
BX-104	Yes	4.3×10^{-8}	5.5×10^{-5}	2.8×10^{-5}	2.8×10^{-3}

TABLE G-2 (cont)
ANOVA MODEL PREDICTIONS OF THE FRACTION OF WASTE THAT IS REACTIVE

Tank Number	Assay Data Available	Low Heat of Reaction Waste		High Heat of Reaction Waste	
		Median	95% Bound	Median	95% Bound
BX-105	Yes	2.6×10^{-8}	4.9×10^{-5}	6.5×10^{-6}	1.9×10^{-3}
BX-106	No	5.2×10^{-11}	8.2×10^{-6}	2.6×10^{-7}	5.0×10^{-4}
BX-107	Yes	0.0	1.7×10^{-9}	3.8×10^{-10}	7.6×10^{-7}
BX-108	No	3.7×10^{-10}	1.5×10^{-5}	3.0×10^{-7}	8.9×10^{-4}
BX-109	No	9.6×10^{-8}	2.3×10^{-4}	5.3×10^{-5}	9.8×10^{-3}
BX-110	Yes	3.2×10^{-10}	2.3×10^{-7}	3.1×10^{-7}	1.9×10^{-5}
BX-111	No	2.7×10^{-10}	2.7×10^{-6}	4.1×10^{-7}	2.5×10^{-4}
BX-112	Yes	3.2×10^{-9}	6.6×10^{-6}	5.3×10^{-6}	5.6×10^{-4}
BY-101	No	1.4×10^{-7}	2.6×10^{-4}	6.1×10^{-5}	9.4×10^{-3}
BY-102	No	1.8×10^{-7}	2.8×10^{-4}	6.8×10^{-5}	1.1×10^{-2}
BY-103	No	4.5×10^{-7}	3.0×10^{-4}	8.4×10^{-5}	1.0×10^{-2}
BY-104	Yes	1.2×10^{-7}	3.1×10^{-4}	5.3×10^{-5}	7.6×10^{-3}
BY-105	No	1.7×10^{-7}	3.3×10^{-4}	5.7×10^{-5}	7.5×10^{-3}
BY-106	Yes	8.5×10^{-9}	1.8×10^{-6}	3.3×10^{-6}	8.1×10^{-5}
BY-107	No	2.8×10^{-7}	4.0×10^{-4}	6.8×10^{-5}	1.1×10^{-2}
BY-108	No	1.6×10^{-7}	6.2×10^{-4}	4.6×10^{-5}	1.1×10^{-2}
BY-109	No	1.1×10^{-7}	2.1×10^{-4}	4.7×10^{-5}	1.1×10^{-2}
BY-110	No	2.4×10^{-7}	3.9×10^{-4}	5.6×10^{-5}	7.6×10^{-3}
BY-111	No	1.3×10^{-7}	2.5×10^{-4}	4.6×10^{-5}	1.1×10^{-2}
BY-112	No	1.6×10^{-7}	2.4×10^{-4}	7.7×10^{-5}	6.9×10^{-3}
C-101	No	4.1×10^{-7}	7.0×10^{-4}	1.3×10^{-4}	1.9×10^{-2}
C-102	No	1.1×10^{-7}	1.8×10^{-4}	4.5×10^{-5}	8.1×10^{-3}
C-103	Yes	3.4×10^{-7}	2.8×10^{-4}	2.8×10^{-4}	1.4×10^{-2}
C-104	No	3.8×10^{-7}	1.6×10^{-4}	1.2×10^{-4}	5.9×10^{-3}
C-105	No	8.2×10^{-8}	1.5×10^{-5}	3.9×10^{-5}	2.0×10^{-3}
C-106	No	6.4×10^{-9}	8.1×10^{-6}	6.4×10^{-6}	7.6×10^{-4}

TABLE G-2 (cont)
ANOVA MODEL PREDICTIONS OF THE FRACTION OF WASTE THAT IS REACTIVE

Tank Number	Assay Data Available	Low Heat of Reaction Waste		High Heat of Reaction Waste	
		Median	95% Bound	Median	95% Bound
C-107	No	1.6×10^{-7}	2.7×10^{-4}	4.3×10^{-5}	1.1×10^{-2}
C-108	Yes	1.1×10^{-11}	2.1×10^{-8}	9.4×10^{-8}	9.1×10^{-6}
C-109	Yes	7.0×10^{-9}	4.1×10^{-7}	1.3×10^{-5}	1.9×10^{-4}
C-110	Yes	0.0	2.6×10^{-9}	4.2×10^{-9}	4.9×10^{-6}
C-111	Yes	0.0	1.0×10^{-8}	1.3×10^{-8}	6.2×10^{-6}
C-112	Yes	6.0×10^{-9}	5.5×10^{-7}	2.0×10^{-5}	3.2×10^{-4}
S-101	No	3.7×10^{-7}	5.5×10^{-4}	9.0×10^{-5}	1.1×10^{-2}
S-102	No	1.3×10^{-7}	2.4×10^{-4}	5.3×10^{-5}	7.3×10^{-3}
S-103	No	6.1×10^{-7}	4.8×10^{-4}	1.3×10^{-4}	1.7×10^{-2}
S-104	No	1.5×10^{-11}	6.1×10^{-8}	1.0×10^{-7}	2.2×10^{-5}
S-105	No	2.1×10^{-7}	2.2×10^{-4}	5.7×10^{-5}	7.8×10^{-3}
S-106	No	6.2×10^{-7}	6.3×10^{-4}	7.7×10^{-5}	1.3×10^{-2}
S-107	No	3.8×10^{-8}	8.2×10^{-5}	2.6×10^{-5}	4.1×10^{-3}
S-108	No	1.1×10^{-7}	2.5×10^{-4}	4.7×10^{-5}	6.6×10^{-3}
S-109	Yes	1.1×10^{-11}	1.1×10^{-7}	2.8×10^{-8}	1.9×10^{-5}
S-110	No	2.4×10^{-7}	2.9×10^{-4}	4.9×10^{-5}	7.9×10^{-3}
S-111	No	9.5×10^{-5}	2.6×10^{-3}	4.0×10^{-3}	3.3×10^{-2}
S-112	No	1.9×10^{-7}	2.5×10^{-4}	4.8×10^{-5}	8.2×10^{-3}
SX-101	No	5.1×10^{-7}	6.8×10^{-4}	8.0×10^{-5}	1.1×10^{-2}
SX-102	Yes	6.7×10^{-7}	1.2×10^{-4}	1.0×10^{-4}	2.7×10^{-3}
SX-103	No	8.4×10^{-8}	1.2×10^{-4}	4.5×10^{-5}	8.3×10^{-3}
SX-104	No	4.1×10^{-7}	3.8×10^{-4}	7.3×10^{-5}	9.3×10^{-3}
SX-105	No	2.1×10^{-7}	3.2×10^{-4}	6.5×10^{-5}	8.4×10^{-3}
SX-106	No	4.2×10^{-7}	3.0×10^{-4}	8.7×10^{-5}	9.7×10^{-3}
SX-107	No	1.9×10^{-10}	4.5×10^{-6}	3.3×10^{-7}	8.0×10^{-4}
SX-108	No	1.9×10^{-10}	7.9×10^{-6}	3.0×10^{-7}	5.8×10^{-4}

TABLE G-2 (cont)
ANOVA MODEL PREDICTIONS OF THE FRACTION OF WASTE THAT IS REACTIVE

Tank Number	Assay Data Available	Low Heat of Reaction Waste		High Heat of Reaction Waste	
		Median	95% Bound	Median	95% Bound
SX-109	No	2.1×10^{-7}	4.5×10^{-4}	7.8×10^{-5}	1.1×10^{-2}
SX-110	No	2.2×10^{-10}	7.7×10^{-6}	6.1×10^{-7}	9.3×10^{-4}
SX-111	No	1.6×10^{-10}	5.2×10^{-6}	4.0×10^{-7}	1.5×10^{-3}
SX-112	No	1.4×10^{-10}	5.8×10^{-6}	4.6×10^{-7}	5.2×10^{-4}
SX-113	No	2.1×10^{-11}	9.3×10^{-7}	2.3×10^{-7}	4.7×10^{-4}
SX-114	No	7.6×10^{-11}	7.7×10^{-6}	3.0×10^{-7}	3.5×10^{-4}
SX-115	No	5.4×10^{-11}	1.3×10^{-5}	3.0×10^{-7}	1.5×10^{-3}
T-101	No	2.2×10^{-10}	7.6×10^{-6}	3.3×10^{-7}	9.7×10^{-4}
T-102	Yes	0.0	3.4×10^{-7}	1.0×10^{-8}	8.2×10^{-5}
T-103	No	5.7×10^{-11}	6.0×10^{-6}	2.2×10^{-7}	7.3×10^{-4}
T-104	Yes	0.0	1.0×10^{-10}	5.6×10^{-10}	3.7×10^{-7}
T-105	Yes	4.7×10^{-10}	2.1×10^{-7}	1.5×10^{-6}	6.6×10^{-5}
T-106	No	9.7×10^{-10}	4.3×10^{-5}	1.0×10^{-6}	4.4×10^{-3}
T-107	Yes	4.0×10^{-12}	1.5×10^{-9}	5.6×10^{-9}	3.7×10^{-7}
T-108	No	4.1×10^{-8}	3.3×10^{-4}	5.0×10^{-6}	3.8×10^{-3}
T-109	No	2.4×10^{-10}	5.8×10^{-6}	4.5×10^{-7}	5.7×10^{-4}
T-110	No	2.5×10^{-8}	9.0×10^{-5}	2.7×10^{-5}	7.4×10^{-3}
T-111	Yes	3.8×10^{-11}	2.1×10^{-8}	9.4×10^{-7}	4.7×10^{-5}
T-112	No	0.0	6.4×10^{-7}	3.1×10^{-8}	1.5×10^{-4}
TX-101	No	2.0×10^{-7}	5.9×10^{-4}	8.5×10^{-5}	1.9×10^{-2}
TX-102	Yes	1.4×10^{-9}	1.7×10^{-6}	2.8×10^{-6}	4.5×10^{-4}
TX-103	No	1.6×10^{-10}	2.5×10^{-6}	2.7×10^{-7}	5.7×10^{-4}
TX-104	No	1.6×10^{-7}	4.6×10^{-4}	1.1×10^{-4}	1.6×10^{-2}
TX-105	No	8.9×10^{-8}	1.5×10^{-4}	4.5×10^{-5}	7.6×10^{-3}
TX-106	No	6.8×10^{-8}	1.4×10^{-4}	3.9×10^{-5}	7.3×10^{-3}
TX-107	No	3.0×10^{-7}	9.2×10^{-4}	1.2×10^{-4}	3.0×10^{-2}
TX-108	No	1.3×10^{-7}	2.2×10^{-4}	6.7×10^{-5}	1.2×10^{-2}

TABLE G-2 (cont)
ANOVA MODEL PREDICTIONS OF THE FRACTION OF WASTE THAT IS REACTIVE

Tank Number	Assay Data Available	Low Heat of Reaction Waste		High Heat of Reaction Waste	
		Median	95% Bound	Median	95% Bound
TX-109	No	1.6×10^{-7}	2.9×10^{-4}	4.5×10^{-5}	7.7×10^{-3}
TX-110	No	8.2×10^{-8}	1.7×10^{-4}	3.8×10^{-5}	7.1×10^{-3}
TX-111	No	1.1×10^{-7}	1.9×10^{-4}	4.2×10^{-5}	1.0×10^{-2}
TX-112	No	6.1×10^{-8}	1.8×10^{-4}	3.4×10^{-5}	4.7×10^{-3}
TX-113	No	6.5×10^{-8}	1.3×10^{-4}	3.5×10^{-5}	5.1×10^{-3}
TX-114	No	5.6×10^{-8}	1.5×10^{-4}	3.5×10^{-5}	5.9×10^{-3}
TX-115	No	3.9×10^{-8}	1.6×10^{-4}	3.6×10^{-5}	9.3×10^{-3}
TX-116	No	9.5×10^{-8}	2.5×10^{-4}	5.3×10^{-5}	8.2×10^{-3}
TX-117	No	4.7×10^{-8}	1.0×10^{-4}	3.2×10^{-5}	5.7×10^{-3}
TX-118	No	1.6×10^{-6}	4.9×10^{-4}	3.1×10^{-4}	1.3×10^{-2}
TY-101	Yes	5.1×10^{-12}	1.5×10^{-7}	3.0×10^{-8}	3.1×10^{-5}
TY-102	Yes	0.0	3.9×10^{-8}	7.7×10^{-8}	1.9×10^{-5}
TY-103	Yes	0.0	7.0×10^{-9}	3.7×10^{-8}	5.3×10^{-6}
TY-104	Yes	4.3×10^{-11}	8.0×10^{-9}	5.6×10^{-7}	1.7×10^{-5}
TY-105	Yes	5.0×10^{-10}	2.1×10^{-6}	9.7×10^{-7}	3.4×10^{-4}
TY-106	Yes	1.3×10^{-10}	1.7×10^{-7}	4.6×10^{-7}	1.2×10^{-4}
U-101	No	6.6×10^{-11}	5.4×10^{-6}	2.1×10^{-7}	9.9×10^{-4}
U-102	No	3.4×10^{-8}	1.7×10^{-4}	2.5×10^{-5}	5.1×10^{-3}
U-103	Yes	4.5×10^{-5}	2.6×10^{-3}	1.6×10^{-3}	2.9×10^{-2}
U-104	No	1.2×10^{-7}	3.4×10^{-4}	7.2×10^{-5}	1.5×10^{-2}
U-105	Yes	7.5×10^{-4}	1.7×10^{-2}	2.1×10^{-2}	1.9×10^{-1}
U-106	No	8.5×10^{-7}	7.4×10^{-4}	1.4×10^{-4}	1.8×10^{-2}
U-107	No	6.4×10^{-7}	6.5×10^{-4}	1.3×10^{-4}	1.3×10^{-2}
U-108	No	5.3×10^{-7}	3.8×10^{-4}	8.1×10^{-5}	1.2×10^{-2}
U-109	No	4.5×10^{-7}	5.5×10^{-4}	1.2×10^{-4}	1.0×10^{-2}
U-110	Yes	3.3×10^{-11}	2.9×10^{-9}	8.8×10^{-9}	2.3×10^{-7}
U-111	Yes	1.0×10^{-7}	8.1×10^{-5}	6.4×10^{-5}	4.1×10^{-3}
U-112	No	1.1×10^{-10}	7.6×10^{-6}	4.2×10^{-7}	8.3×10^{-4}

TABLE G-3
FREQUENCY OF A PROPAGATING EXOTHERMIC REACTION AS A RESULT OF ROTARY MODE CORE SAMPLING

Tank Number	Flammable-Gas Tank	Sample Status	Assay Data Available	Frequency of Propagation (yr^{-1})	
				Best Estimate	95% Bound
A-101	Yes	Pushed	Yes	1×10^{-8}	3×10^{-7}
A-102	No		Yes	6×10^{-8}	1×10^{-6}
A-103	Possible		Yes	1×10^{-8}	3×10^{-7}
A-104	No		No	4×10^{-9}	1×10^{-6}
A-105	No		No	9×10^{-10}	8×10^{-7}
A-106	No		Yes	2×10^{-8}	5×10^{-7}
AX-101	Yes		No	1×10^{-9}	3×10^{-7}
AX-102	No	Pushed	Yes	3×10^{-6}	1×10^{-5}
AX-103	Yes		No	2×10^{-9}	4×10^{-7}
AX-104	No		No	1×10^{-9}	9×10^{-7}
B-101	No		No	2×10^{-9}	4×10^{-7}
B-102	No	Pushed	No	5×10^{-9}	1×10^{-6}
B-103	No		Yes	7×10^{-14}	8×10^{-11}
B-104	No	Pushed	No	1×10^{-13}	5×10^{-10}
B-105	No	Pushed	No	1×10^{-9}	2×10^{-7}
B-106	No		No	1×10^{-11}	2×10^{-8}
B-107	No		No	9×10^{-13}	4×10^{-9}
B-108	No		No	1×10^{-11}	2×10^{-8}
B-109	No		No	7×10^{-12}	2×10^{-8}
B-110	No		Yes	3×10^{-16}	2×10^{-12}
B-111	No		Yes	6×10^{-13}	2×10^{-10}
B-112	No		No	1×10^{-11}	2×10^{-8}
BX-101	No		No	5×10^{-11}	4×10^{-8}
BX-102	No		No	8×10^{-12}	2×10^{-8}
BX-103	No		No	3×10^{-12}	5×10^{-9}
BX-104	No		Yes	7×10^{-10}	8×10^{-8}
BX-105	No		Yes	2×10^{-10}	5×10^{-8}
BX-106	No		No	6×10^{-12}	1×10^{-8}

TABLE G-3 (cont)
FREQUENCY OF A PROPAGATING EXOTHERMIC REACTION AS A RESULT OF ROTARY MODE CORE SAMPLING

Tank Number	Flammable-Gas Tank	Sample Status	Assay Data Available	Frequency of Propagation (yr^{-1})	
				Best Estimate	95% Bound
BX-107	Possible		Yes	9×10^{-15}	2×10^{-11}
BX-108	No		No	7×10^{-12}	2×10^{-8}
BX-109	No		No	1×10^{-9}	3×10^{-7}
BX-110	No		Yes	7×10^{-12}	5×10^{-10}
BX-111	No	Pushed	No	1×10^{-11}	6×10^{-9}
BX-112	No		Yes	1×10^{-10}	1×10^{-8}
BY-101	Possible		No	1×10^{-9}	3×10^{-7}
BY-102	Possible	Pushed	No	2×10^{-9}	3×10^{-7}
BY-103	No	Pushed	No	2×10^{-9}	3×10^{-7}
BY-104	No		Yes	1×10^{-9}	2×10^{-7}
BY-105	Possible	Pushed	No	1×10^{-9}	2×10^{-7}
BY-106	No	Pushed	Yes	8×10^{-11}	2×10^{-9}
BY-107	No		No	2×10^{-9}	3×10^{-7}
BY-108	No		No	1×10^{-9}	4×10^{-7}
BY-109	Possible	Pushed	No	1×10^{-9}	3×10^{-7}
BY-110	No		No	1×10^{-9}	3×10^{-7}
BY-111	Possible		No	1×10^{-9}	3×10^{-7}
BY-112	No		No	2×10^{-9}	2×10^{-7}
C-101	No		No	3×10^{-9}	6×10^{-7}
C-102	No		No	1×10^{-9}	2×10^{-7}
C-103	No		Yes	6×10^{-9}	4×10^{-7}
C-104	Possible		No	3×10^{-9}	2×10^{-7}
C-105	No		No	9×10^{-10}	5×10^{-8}
C-106	No		No	2×10^{-10}	2×10^{-8}
C-107	Possible		No	1×10^{-9}	3×10^{-7}
C-108	No		Yes	2×10^{-12}	2×10^{-10}
C-109	No		Yes	3×10^{-10}	4×10^{-9}

TABLE G-3 (cont)
FREQUENCY OF A PROPAGATING EXOTHERMIC REACTION AS A RESULT OF ROTARY MODE CORE SAMPLING

Tank Number	Flammable-Gas Tank	Sample Status	Assay Data Available	Frequency of Propagation (yr^{-1})	
				Best Estimate	95% Bound
C-110	No		Yes	1×10^{-13}	1×10^{-10}
C-111	No		Yes	3×10^{-13}	2×10^{-10}
C-112	No		Yes	5×10^{-10}	7×10^{-9}
S-101	Possible		No	2×10^{-9}	4×10^{-7}
S-102	Yes		No	1×10^{-9}	2×10^{-7}
S-103	Possible		No	3×10^{-9}	5×10^{-7}
S-104	Possible		Yes	2×10^{-12}	5×10^{-10}
S-105	Possible		No	1×10^{-9}	2×10^{-7}
S-106	Possible		No	2×10^{-9}	4×10^{-7}
S-107	Possible		No	6×10^{-10}	1×10^{-7}
S-108	No		No	1×10^{-9}	2×10^{-7}
S-109	Possible		Yes	7×10^{-13}	5×10^{-10}
S-110	No		No	1×10^{-9}	2×10^{-7}
S-111	Yes		Yes	1×10^{-7}	1×10^{-6}
S-112	Yes		No	1×10^{-9}	2×10^{-7}
SX-101	Yes		No	2×10^{-9}	4×10^{-7}
SX-102	Yes		Yes	3×10^{-9}	9×10^{-8}
SX-103	Yes		No	1×10^{-9}	2×10^{-7}
SX-104	Yes		No	2×10^{-9}	3×10^{-7}
SX-105	Yes		No	2×10^{-9}	3×10^{-7}
SX-106	Yes		No	2×10^{-9}	3×10^{-7}
SX-107	No		No	8×10^{-12}	2×10^{-8}
SX-108	No		No	7×10^{-12}	2×10^{-8}
SX-109	Yes		No	2×10^{-9}	3×10^{-7}
SX-110	No		No	1×10^{-11}	2×10^{-8}
SX-111	No		No	9×10^{-12}	4×10^{-8}
SX-112	No		No	1×10^{-11}	1×10^{-8}

TABLE G-3 (cont)
FREQUENCY OF A PROPAGATING EXOTHERMIC REACTION AS A RESULT OF ROTARY MODE CORE SAMPLING

Tank Number	Flammable-Gas Tank	Sample Status	Assay Data Available	Frequency of Propagation (yr^{-1})	
				Best Estimate	95% Bound
SX-113	No		No	5×10^{-12}	1×10^{-8}
SX-114	No		No	7×10^{-12}	1×10^{-8}
SX-115	No		No	7×10^{-12}	4×10^{-8}
T-101	No		No	8×10^{-12}	2×10^{-8}
T-102	No		Yes	2×10^{-13}	2×10^{-9}
T-103	No		No	5×10^{-12}	2×10^{-8}
T-104	No		Yes	1×10^{-14}	9×10^{-12}
T-105	No		Yes	3×10^{-11}	2×10^{-9}
T-106	No		No	2×10^{-11}	1×10^{-7}
T-107	No		Yes	1×10^{-13}	9×10^{-12}
T-108	No		No	1×10^{-10}	2×10^{-7}
T-109	No		No	1×10^{-11}	1×10^{-8}
T-110	Yes		No	6×10^{-10}	2×10^{-7}
T-111	No		Yes	2×10^{-11}	1×10^{-9}
T-112	No		No	7×10^{-13}	4×10^{-9}
TX-101	No		No	2×10^{-9}	6×10^{-7}
TX-102	Possible		Yes	7×10^{-11}	1×10^{-8}
TX-103	No		No	6×10^{-12}	1×10^{-8}
TX-104	No		No	3×10^{-9}	5×10^{-7}
TX-105	No		No	1×10^{-9}	2×10^{-7}
TX-106	No		No	9×10^{-10}	2×10^{-7}
TX-107	No		No	3×10^{-9}	9×10^{-7}
TX-108	No		No	2×10^{-9}	3×10^{-7}
TX-109	No		No	1×10^{-9}	2×10^{-7}
TX-110	No		No	9×10^{-10}	2×10^{-7}
TX-111	Possible		No	1×10^{-9}	3×10^{-7}
TX-112	Possible		No	8×10^{-10}	2×10^{-7}

TABLE G-3 (cont)
FREQUENCY OF A PROPAGATING EXOTHERMIC REACTION AS A RESULT OF ROTARY MODE CORE SAMPLING

Tank Number	Flammable-Gas Tank	Sample Status	Assay Data Available	Frequency of Propagation (yr^{-1})	
				Best Estimate	95% Bound
TX-113	Possible		No	8×10^{-10}	1×10^{-7}
TX-114	No		No	8×10^{-10}	2×10^{-7}
TX-115	Possible		No	9×10^{-10}	3×10^{-7}
TX-116	Possible		No	1×10^{-9}	2×10^{-7}
TX-117	Possible		No	7×10^{-10}	2×10^{-7}
TX-118	No		Yes	8×10^{-9}	4×10^{-7}
TY-101	No		Yes	7×10^{-13}	8×10^{-10}
TY-102	No		Yes	2×10^{-12}	5×10^{-10}
TY-103	No		Yes	9×10^{-13}	1×10^{-10}
TY-104	No		Yes	1×10^{-11}	4×10^{-10}
TY-105	No		Yes	2×10^{-11}	8×10^{-9}
TY-106	No		Yes	1×10^{-11}	3×10^{-9}
U-101	No		No	5×10^{-12}	2×10^{-8}
U-102	Possible	Pushed	No	6×10^{-10}	2×10^{-7}
U-103	Yes	Pushed	Yes	5×10^{-8}	1×10^{-6}
U-104	No		No	2×10^{-9}	4×10^{-7}
U-105	Yes		Yes	6×10^{-7}	8×10^{-6}
U-106	Possible	Pushed	No	3×10^{-9}	6×10^{-7}
U-107	Yes		No	3×10^{-9}	4×10^{-7}
U-108	Yes		No	2×10^{-9}	4×10^{-7}
U-109	Yes	Pushed	No	3×10^{-9}	4×10^{-7}
U-110	Possible		Yes	2×10^{-13}	6×10^{-12}
U-111	Possible	Pushed	Yes	2×10^{-9}	1×10^{-7}
U-112	No		No	1×10^{-11}	2×10^{-8}

G.5.2.2. Summary

Safety decisions should be based on the 95% upper-bound frequency estimates given in Table G-3. Fill history considerations indicate that core drilling in Tanks A-106 and C-107 may be a problem because these tanks may contain a significant organic remnant layer. Floating organic layers have not been addressed; therefore, core drilling in Tank C-103 is not covered by this SA. Only those tanks that are designated as flammable-gas tanks and that are listed in Table G-3 are within the scope of this SA. This SA does not address reactivity hazards associated with ferrocyanide compounds because none of the current flammable-gas tanks are on the ferrocyanide watchlist. The tanks currently on the ferrocyanide watchlist are BY-103, BY-104, BY-105, BY-106, BY-107, BY-108, BY-110, BY-111, BY-112, C-108, C-109, C-111, C-112, T-107, TX-118, TY-101, TY-103, and TY-104.

G.6. CRUST IGNITION CAUSED BY IMPACT

This section assesses the possibility of causing a propagating crust ignition as a result of a drill-string drop. The drill string is held by a hydraulic foot clamp during rotary-mode sampling operations. If the clamp fails (although this is unlikely), the drill string could be dropped on the crust. The impact kinetic energy of the drill string is identified as a crust-ignition hazard because some of the crust or waste is being heated past its ignition temperature. In this section we examine the crust ignition issue.

G.6.1. Kinetic Energy Determination

A key variable controlling the heat input is the kinetic energy of the drill string. Kinetic energy is maximized at a certain drop height because the weight of the drill string increases and the impact velocity decreases as the drop height decreases. The formulation of Miller (Ref. 17) is used to maximize the kinetic energy for a drop. The kinetic energy is given by

$$KE = \frac{1}{2}(m+M)\,V^2 \quad , \qquad \text{(G-8)}$$

where

- m = the mass of the sampler in the drill string, 2.86 kg (6.3 $_m$),
- M = the mass of the drill-string column, and
- V = the velocity on impact.

The maximum length of the drill string is based chosen conservatively as a 16.5-m (648-in.) distance from the riser flange to the tank bottom. The waste depth is minimized in Tank AX-103 at 1.07 m (42 in.). Consequently, the length of the falling drill string is a function of the fall distance, in other words, the distance from the bottom of the drill string to the surface of the waste.

The impact velocity depends on the fall distance. Substitution of all terms into kinetic energy equation gives KE as a function of fall-distance squared. From this expression, there is a unique drop distance that maximizes the kinetic energy. This distance is found to be 7.7 m (25.3 ft). The associated maximum kinetic energy is estimated as 3640 J.

G.6.2. Frictional Ignition

One of the effects of drill string impact is friction between the waste particles. Friction can ignite gun powder and other pyrotechnic mixtures.[18,19] However, sensitivity to friction is attributed to elemental sulfur and not the organic compounds.[18,19] The waste stored at the Hanford Site is basic. Elemental sulfur is not expected to exist under the basic conditions typical of Hanford waste; frictional ignition is not expected.[18]

G.6.3. Absorption of Impact Energy

Another possible effect of drill-string impact is conversion of the kinetic energy into heat. Based on the discussion in Section 2 of this appendix, local exothermic reactions will not occur during drilling operations if the waste temperature is below 160°C. This criterion also applies to the impact of the drill string on a hard crust. No local exothermic reaction will occur if the crust is not heated to 160°C.

The strain energy absorbed by the crust as a result of impact will affect a volume that expands at a 45° angle away from the falling object. Therefore, assuming that all of the energy is absorbed by a hemisphere with a radius equal to the radius of the drill string is conservative. The conservative energy balance for the impact is:

$$KE = \frac{2\pi}{3} \cdot r^3 \cdot \rho \cdot c_p \cdot (T - T_o) \ , \qquad \text{(G-9)}$$

where

- KE = kinetic energy of the falling drill string,
- r = radius of the drill bit,
- ρ = density of the crust,
- T = temperature after impact, and
- T_o = initial temperature of the crust.

The radius of the drill bit is 2.86 cm, the bulk density of dry crust material is assumed to be ~1.35 g/cm^3, and the heat capacity of the waste solids is ~1.8 J/g K. The bound initial temperature is 95°C. The maximum waste temperature as a result of impact is 126°C, so significant local exothermic reactions are not expected to occur.

5.4. Propagation of Exothermic Reactions in a Crust

The criteria for nonpropagating exothermic reactions in the waste developed in Section 4.1 of this appendix also apply to a crust layer. If the crust material satisfies these criteria, exothermic reactions are not expected to propagate.

If heat transfer to the dome is neglected, the stability criterion given by Fauske[7] applies. The critical radius required for propagation is

$$r_{crit} = \sqrt{\frac{3.32 \cdot \alpha \cdot R \cdot T^2}{\frac{dT}{dt} \cdot E_a}} \,, \qquad \text{(G-10)}$$

where

r_{crit} = critical radius,
α = thermal diffusivity,
R = gas constant,
T = temperature of the sphere,
$\frac{dT}{dt}$ = self-heat rate, and
E_a = activation energy.

The temperature in this equation is absolute temperature. Because the crust is assumed to be porous, the thermal diffusivity is assumed to be 0.0004 cm^2/s, which is half the value used in Section 3.2. The temperature is determined from Eq. (G-9). Section 3.2 states that a conservative estimate of the activation energy is 240 kJ/mole and that a conservative estimate of the self-heating rate at 180°C is 1°C/min. However, to extrapolate to lower temperatures, a lower activation energy is the conservative value. The lower bound on activation energy based on Reference 5 is 20 kJ/mol. Therefore, a conservative estimate of the self-heating rate at 126°C is 0.008 K/s, which is a very conservative estimate based on the waste surrogate and waste simulant data. The conservative value of the critical radius is 3.3 cm, which is larger than the radius of the drill bit. Therefore, dropping the drill string on a crust will not initiate a propagating exothermic reaction. This result is consistent with the results for local exothermic reactions. If a drop accident does not cause significant local exothermic reactions, there will be no propagating exothermic reactions.

G.7. SUMMARY AND CONCLUSIONS

Local runaway reactions are a hazard in the Hanford Site waste tanks. The high temperature produced by runaway reactions is an ignition source for flammable gas and a local runaway may initiate self-propagating exothermic reactions in the waste. Local runaway reactions can be prevented by establishing waste temperature limits. The following limits are placed on temperatures:

- The temperature of small waste fragments produced at the drill tip must not exceed 180°C.

- The temperature of the drill bit and the average temperature of the waste affected by drilling must not exceed 160°C for more than 10 min.

Because failure of the controls implemented to satisfy these temperature limits can fail, the possibility of a propagating exothermic reaction must be considered. Because the consequences of a large-scale propagating reaction are potentially very severe, FG/RMCS is not permitted unless it can be demonstrated that the frequency of a propagating exothermic reaction is $<10^{-6}$/yr. The frequency of a propagating exothermic reaction in each tank is given in Table G-3. Safety decisions should be based on the 95% upper bound. In addition, core drilling should not be performed in Tanks A-106 and C-107 because fill history indicates that these tanks may contain a significant organic remnant layer. This SA does not cover Tank C-103 because it contains a floating organic layer.

The possibility of a propagating ignition in tank waste following the drop of a sampler drill string is examined. The maximum kinetic energy was found as 3640 J when the drill string drops 26.0 ft. This energy will not heat the waste above the onset temperature of exothermic reactions, so there will be no local exothermic reaction or self-propagating reaction.

G.6 REFERENCES

1. L. Bretherick, Bretherick's Handbook of Reactive Chemical Hazards, 4th Ed. (Butterworths, London, England, 1990).

2. O. Kubaschewski, C. Alcock, and P. Spencer, *Materials Thermochemistry*, (Pergamon Press, Oxford, England, 1993).

3. F. Lees, Loss Prevention in the Process Industries (Butterworths, London, England, 1980).

4. K. Jones, "Nitrogen" in *Comprehensive Inorganic Chemistry*, J. Bailar, Ed. (Pergamon Press, New York, 1973).

5. D. Scheele, R. Shell, J. Sobolik, and L. Burger, "Organic Tank Safety Project: Preliminary Results of Energetics and Thermal Behavior Studies of Model Organic Nitrate and/or Nitrite Mixtures and a Simulated Organic Waste," Pacific Northwest Laboratory report PNL-10213 (August 1995).

6. N. Kirch, "Adiabatic Calorimetry (RSST and VSP) Test with Sodium Acetate," Westinghouse Hanford Company report WHC-EP-0683 (September 1993).

7. H. Fauske, "Waste Simulant PAS94A and Exothermicity," Fauske & Associates, Inc., letter to Bob Cash, Joe Meacham, and Dave Turner (December 14, 1995).

8. Center for Chemical Process Safety, Guidelines for Chemical Reactivity Evaluation and Application to Process Design, American Institute of Chemical Engineers, New York, New York (1995).

9. P. M. Francis, "Aerosol Study for the Rotary Mode Exhauster," Westinghouse Hanford Company report WHC-SD-WM-ES-225, Rev. 1 (March 29, 1993).

10. D. A. Siebe, "Thermal Analysis of Rotary-Mode Core Drilling," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-111 (February 1996).

11. B. M. Hanlon, "Waste Tank Summary Report for Month Ending October 31, 1995," Westinghouse Hanford Company report WHC-EP-0182-91 (January 1996).

12. J. Stewart, D. Turner, M. Plys, B. Malinovic, J. Grigsby, D. Camainoni, P. Healser, W. Samuels, and J. Toth, "Preliminary Safety Criteria for Organic Watch List Tanks at the Hanford Site," Westinghouse Hanford Company report WHC-SD-WM-SARR-033 (November 1995).

13. H. Fauske, M. Epstein, D. Dickinson, R. Cash, D. Turner, and J. Meacham, "The Contact-Temperature Ignition (CTI) Criteria for Propagating Chemical Reactions Including the Effect of Moisture and Application to Hanford Waste," Westinghouse Hanford Company report WHC-SD-WM-ER-496, Rev. 0 (September 1995).

14. D. Herting, D. Bechtold, B. Crawford, T. Welsh, and L. Jensen, "Laboratory Characterization of Samples Taken in May 1991 from Hanford Waste Tank 241-SY-101," Westinghouse Hanford Company report WHC-SD-WM-DTR-024 (1991).

15. S. Agnew, "History of Organic Carbon in Hanford HLW Tanks: HDW Model Rev. 3," Los Alamos National Laboratory report LA-UR-96-989 (March 1996).

16. P. G. Heasler, "Reactive Waste Estimates for Hanford Single Shell Tanks", Pacific Northwest National Laboratory letter report, August 1996.

17. W. O. Miller, "Retained Gas Sampler Drill String Drop Analysis," Los Alamos National Laboratory Calc-Note TSA-6-CN-WT-SA-ST-075-0 (January 1995).

18. G. Beitel, "Chemical Stability of Salt Cake in the Presence of Organic Materials," Atlantic Richfield Hanford Company report ARH-LD-11 (April 1976).

19. R. Lancaster, T. Shimizu, R. Butler, and R. Hall, *Fireworks—Principles and Practice* (Chemical Publishing Co., Inc., New York, 1972).

APPENDIX H

DUST EXPLOSION IN THE DOME

H.1. INTRODUCTION

The rotary-core drilling generates a dust aerosol. Some of the aerosol produced during the core drilling will disperse into the vapor space of the dome, some of it will settle on the top of the waste, and some of it will flow into the ventilation line of the exhauster. The concentration in the dome of any given tank is discussed in Appendix Q. The objective of this appendix is to evaluate the possibility of dust explosions in the dome space of a flammable-gas single-shell tank (SST).

H.2. EVALUATION OF BUREAU OF MINES EXPERIMENT

The Bureau of Mines (BOM)[1] performed experiments on the dust explosions. The dust particles used in the experiments have the same particle characteristics as those generated in the SSTs during the core-drilling operation. However, the real composition of the salt cake in the SSTs is unknown. An appropriate salt-cake simulant must be used. According to Reference 2, the selection of a simulant was based largely on the following criteria: (1) the average particle density dictates the size distribution of aerosol, (2) the majority of tanks that plan to do rotary drilling are salt-cake tanks and have a high sodium nitrate content, and (3) sodium nitrate would be the most crystalline of all rotary-mode tank solids and therefore would be the waste type that would form the most dust. The simulant used in the BOM experiment covered the sodium nitrate concentration ranging from 0% to 90%. This should cover the sodium nitrate concentration of salt cake in the SSTs.

The dust-particle distribution of simulant is another important factor in studying dust explosion. In Reference 2, a particle distribution analysis was performed on a dust sample generated by the rotary-mode core drilling test operations. The sample was a single-shell tank waste simulant RBM#2, prepared by the Westinghouse Hanford Company (WHC) Chemical Engineering Laboratory (CEL). Two methods were used to analyze the particle distribution, (1) scanning by an optical microscope with automatic image analysis performed by a dapple system and (2) laser diffraction analysis performed on a Brinkman particle-size analyzer. Both sets show a size range between 0 to 150 microns. The actual dust-particle size distribution was not measured in the BOM experiment. However, the fuel and oxidant dusts for these tests were pulverized and sieved through a 200-mesh screen. The test aerosols were apparently very close to those given above.

Another important parameter in studying dust explosions is the minimum explosion concentration. The minimum explosion concentration for various dusts ranges from 0.025 to 2.0 oz/ft^3 (0.1 oz/ft^3 = 100 g/m^3) as given in Reference 3. The dust concentration used in the test ranged from 300 to 2000 g/m^3. It covered the minimum explosion concentration specified in Reference 4. Therefore, the dust concentration was adequately selected.

The minimum cloud ignition energy for various dust concentrations is also given in Reference 3. It ranges from 0.01 to 1.92 joules. The ignition source used in the experiment was a very strong 5,000 J pyrotechnic igniter, which is much higher than the minimum cloud ignition energy given in Reference 3. Therefore, the ignition source should be able to ignite the dust simulant.

The measurement system consists of two optical dust probes measuring the uniformity of dust probe and strain-gauge pressure transducer to measure the pressure generated by the igniter and the pressure from any flame propagation if the dust ignites. The pressure history and degree of mixing in the test vessel were measured as desired.

H.3. EXPERIMENTAL RESULTS FROM BOM TESTS

The results from the BOM test are given in Reference 1. The results are summarized below.

The mixture of 15% Na_4EDTA, 56.7% $NaNO_3$, and 28.3% $NaNO_2$ in air produced a pressure ratio of less than one. The mixture not only did not deflagrate but actually reduced the pressure from the igniter.

The 10% NPH, 60% $NaNO_3$, and 30% $NaNO_2$ mixture dispersed in air produced pressure ratios greater than one. In these tests there was some burning of the NPH fuel that was within the igniter flame, but they are still not considered to be propagating deflagrations according to the standard propagation criteria. The pressure rises were low. This implies that there was essentially no propagation continuing after the igniter flame ended.

The mixture of 10% polyethylene, which ignites easily, and 90% $NaNO_3$ dispersed in nitrogen produced less of a pressure rise than would be expected from the igniter alone.

The pure fuels (EDTA and NPH) would be explosion hazards if dispersed in air, but the mixture of 15% EDTA and 85% oxidant or 10% NPH and 90% oxidant would not be considered explosion hazards when dispersed in air or nitrogen.

H.4. BOUNDING ANALYSIS

The ratio of the radionuclide concentration in the dome to the concentration in the liquid during operation of the airlift circulators is given by R. Kimura and S. Johnson.[4] Airlift circulators were used to simulate the effect of the nitrogen cooling during rotary-core sampling. The ratio of radionuclide concentration in the dome to the concentration in the liquid varies from 1.8×10^{-9} to 3.5×10^{-7}. Assuming the concentration of the aerosol is the same as the liquid concentration and the waste density is 1.6 g/cm^3, the concentration of waste in the dome is calculated as 0.56 g/m^3. Adding 350 g to this value, which is caused by rotary-mode core sampling (RMCS) operations, makes a dome concentration of 0.81 g/cm^3.

Examination of the available waste composition data indicates that the total organic carbon (TOC) concentration in the waste is bounded by 50 g TOC/L. In terms of weight percentage, it is estimated as 3.1 wt%. The organic carbon concentration in the dome is found as 0.025 g TOC/m^3.

The organic compounds in the waste are a complex mixture of degradation products of the chelating agents. It is very difficult to estimate the heat of combustion of this mixture. However, by examining the similar organic constituents, we can roughly estimate the maximum heat of combustion per gram of carbon. We examined 32 compounds including cyanide compounds. The maximum heat combustion of $(CH_3)_2NH$ is -898 kJ/g C. Sodium acetate, which is a likely degeneration product, has a heat of combustion of -310 kJ/g C. We used the upper bound value of -898 kJ/g C to estimate the combustion energy generated by the dust during RMCS activity.

The combustion energy associated with the dust is calculated as -22.5 kJ/m^3. This energy can be converted into an equivalent hydrogen concentration. The heat of combustion for hydrogen is -241.8 kJ/mol H_2. The equivalent hydrogen concentration is 0.0931 mol H_2/m^3. Using the ideal gas law, the concentration in terms of ppm was estimated as 2292 ppm. The flammability limit for hydrogen in air is 40,000 ppm (4%). This very conservative calculation indicates that combustible dust contains less than 6% of the energy contained in a flammable hydrogen-air mixture. Therefore, we can neglect the contribution of combustible dust. The presence of dust in a flammable hydrogen-air mixture would not result in an explosion.

H.5. CONCLUSIONS

The range of $NaNO_3$ concentrations in the dust and dust distribution in BOM tests were believed to be very close to those in SSTs. The ignition source was strong enough to generate deflagration in the igniter . The test results showed that the mixture of pure fuel and oxidant ($NaNO_3$) would not propagate deflagrations and would not result in an explosion when dispersed in air or nitrogen.

The bounding analysis showed that the energy contribution of combustible dust is negligible and that the presence of dust in a hydrogen-air mixture would not result in explosion. In summary, the probability of dust explosion appears to be extremely unlikely.

H.6. REFERENCES

1. K. L. Cashdollar, "Interim Report — Core Drilling into Waste Tanks," Pittsburgh Research Center, Bureau of Mines Interim report WHC-SD-WM-ES-219 (June, 1993).

2. P. M. Francis, "Aerosol Study for the Rotary Mode Exhauster," Westinghouse Hanford Company report WHC-SD-WM-ES-225 (March, 1993).

3. A. E. Cote and J. L. Linville, *Fire Protection Hand Book*, Sixteenth Edition, (National Fire Protection Association, Quincy, Massachusetts, 1990).

4. R. Kimura and S. Johnson, "Tank 101-AZ Vapor Space Radionuclide Concentrations and Partition Function," Rockwell International internal letter 65950-86-607 to D. J. Squires (October 14, 1986).

APPENDIX I

DOME COLLAPSE ACCIDENTS

I.1. OBJECTIVE

The objective of this appendix is to compute the bounding respirable waste released during a dome collapse accident in a single-shell tank (SST). The amount of waste material released is used in this safety assessment (SA) to estimate the radiological and toxicological consequences of a dome collapse accident.

I.2. DOME COLLAPSE AND RELEASE SCENARIOS

In Section 2.1, we discuss the various accident scenarios that may lead to a dome collapse. Section 2.2 discusses the different mechanisms for material release during a dome collapse.

I.2.1. Dome Collapse Scenarios

As discussed in Sections 3 and 4 of this SA, there may be multiple initiators that result in a dome collapse. In general, the following accident sequences have a potential of collapsing the dome:

- **A deflagration in the dome (either initiated in the dome or initiated elsewhere and propagated into the dome).** The consequences of this scenario are discussed in this appendix. A deflagration is believed to lead to the bounding accident sequence because

1. Convection associated with the deflagration can entrain additional aerosol.

2. The tank blowdown following the deflagration potentially can release aerosol before the actual dome collapse occurs.

3. The initial tank blowdown will temporarily lift some soil above the dome, potentially increasing the effective collapse distance.

4. Following the deflagration, extensive concrete cracking could result in dome collapse occurring quasi-coherently (where increased coherency would increase the aerosol produced upon impact with the waste).

5. The air heated by the deflagration can start a natural convection flow that will assist in the release of aerosol.

6. With a deflagration, there is perceived to be an increased possibility (relative to most other dome collapse sequences) of an associated waste burn that could provide additional aerosol and energy for dispersal.

- **A deflagration in the waste.** As discussed in Appendix C of this SA, this is a less likely scenario for dome collapse. For the short-term release, the approach used for fragmentation of waste following a dome deflagration is conservatively bounding regardless of whether a waste burn has occurred. For the long-term release, the deflagration accident sequence includes the possibility of a burn for waste remaining in the tank.

- **Dome overloading.** This accident is prevented through administratively controlling the allowable loads over the tank dome. The consequences of a dome collapse resulting from overloading are bounded by the consequences of a collapse resulting from deflagration.

- **Dome space vacuum.** Dome buckling is possible if a large vacuum is created in the dome space. Increased ventilation rates with blocked inlets may result in such an accident. The initiators are administratively controlled, and the consequences are bounded by a dome collapse as a result of deflagration in the dome space.

- **Seismic event.** The consequences of a dome collapse as a result of a seismic event are bounded by the dome collapse as a result of deflagration in the dome space.

I.2.2. Material Release Mechanisms

In computing the total material release as a result of dome collapse, we analyzed the following mechanisms that contribute to the total release:

- Initial material that is suspended in the dome space before the accident;
- Material entrained from the waste surface during deflagration;
- Material entrained from the failed high-efficiency particulate air (HEPA) filters;
- Solid material fragmented by impact during dome collapse;
- Liquefied material splashed by impact during dome collapse,
- Solid material released during dome collapse, deposited outside the dome, and resuspended.
- Liquefied material entrained by the wind from a open pool of waste after the dome collapse.

These mechanisms are analyzed in Sections 3 through 6 of this appendix. A more detailed development may be found in (Ref. 1).

I.3. INITIAL DOME LOADING AND HEPA FILTER LOADING

In the Mixer Pump SA developed for Tank SY-101, a bounding dome volume loading of 0.64 kg (1.41 lb_m) was used (Ref. 2). A high value was used for SY-101 because that tank used to experience periodic gas-release events (rollovers) that were very energetic and that resulted in considerable surface motion. Thus, there was a plausible mechanism of entraining considerable waste material into the dome space during these rollovers.

SSTs do not exhibit similar energetic rollover behavior. For SSTs, the maximum dome loading may result from some intrusive activities such as rotary-mode core sampling (RMCS). At the end of a drilling step, a maximum value of 0.35 kg (0.77 lb_m) is estimated for the SST dome loading.[3]

The energetic respirable material release from the failed HEPA filters during a dome burn in Tank SY-101 is estimated to be less than 0.5 kg (1 lb_m).[2] This number is expected to be less for the SSTs because the number of filters is less and the ventilation flow rates are lower.

In this analysis, it is conservatively assumed that the total respirable release resulting from the initial dome loading and HEPA failures is ≤ 0.6 L or 1 kg (2.2 lb_m). As shown later in this appendix, this release is negligible compared to uncertainty in potential releases during the impact phase of dome collapse.

I.4. MATERIAL ENTRAINED DURING A DEFLAGRATION

The only credible deflagration mechanism believed capable of failing the dome is one where the gas has been released to the dome air space so that the dome failure pressures can be exceeded. The temporary pressures of a postulated gas deflagration in the waste may produce some aerosol, but the available energy is small compared to the waste heat capacity. Even if we assume that 10% of the waste volume is a homogeneous, interconnected stoichiometric hydrogen-nitrous oxide mixture at 1.5 atm., the resulting heat of combustion is 10.85 MJ/m^3 of waste. The waste heat capacity in 0.9 m^3 is 2.6 MJ/°C. Consequently, combustion of this gas will only raise the average waste temperature by about 4°C. More details are given in Ref. 4.

Based on numerical simulation of the SY-101 dome space deflagration (Ref. 2) and using the entrainment correlation given in Ref. 5, the entrainment from the waste surface is estimated as 5.45 kg (12 lb_m) for a deflagration front moving at ~45 m/s (150 ft/s). This value is believed to be conservative and will be used for SSTs also. Note that the entrainment correlation given in Ref. 5 is derived using dry powders and is possibly more applicable to SST conditions in which the waste surface may be drier than the SY-101 waste. The correlation in Ref. 5 is independent of particle size, and it was taken from experiments ranging from 4.5 μm to 48 μm aerodynamic equivalent diameter (AED). Therefore, a respirable fraction (RF) of 0.52 from Ref. 6 was applied to obtain a respirable release of 1.8 L or 2.8 kg. As shown later in this appendix, this release is within the uncertainties of other potential releases during the impact phase of the dome collapse.

I.5. MATERIAL RELEASE DURING DOME COLLAPSE

The phenomenology associated with calculating the amount of respirable material released during dome collapse is complex, especially given that the waste material properties are not fully understood. With present algorithms for calculating dome collapse and for the short-term release, the key parameters are the drop height and the associated tank air volume. The larger the drop height, the greater the impact on the waste and the more aerosol that can be produced. Ignoring the watch list tanks that are interim-stabilized, the drop height is bounded by the 30.2 ft (9.2 m) distance in Tank SX-101 and a tank air volume of 115,600 ft^3 (3,273 m^3). The short-term release is based on these tank dimensions, and it assumes the waste composition can correspond to any watch list SST.

Two difference collapse geometries are perceived to exist, depending on the waste composition. First, if the primary contents of the tank are salt cake or salt cake with some sludge but minimal liquid, the collapsing concrete and soil have limited waste penetration. Second, if the tank contents can be assumed to behave more like a slurry or as salt cake and sludge with extensive interstitial liquid, the fall of material into the tank is assumed to produce a splash and penetrate the waste.

I.5.1. Impact on Salt Cake.

In this situation, the concrete and soil are assumed to collect upon the waste. The aerosol produced is that from the initial impact on each unit area of waste. Additional fragmented waste produced later in the collapse sequence is trapped by the initial soil and concrete debris layer. The analysis objective is to evaluate releases from the initial impacts conservatively. Two numbers are desirable, the airborne release from the tank and the respirable release from the tank. Because of uncertainties in the phenomenology, two methods were used to determine the respirable release.

I.5.1.1. The Airborne Release. In this analysis, an upper limit to the airborne release was determined from an aerosol concentration limit. The appropriate limit is necessarily a transient one. One such limit is ~1 kg/m^3, which is possible to achieve in a dust explosion (Ref. 7). This number is not a hard limit; for example, the Fire Protection Handbook (Ref. 8) does reference some dust explosion experiments performed with 2 kg/m^3. Nevertheless, it is four orders of magnitude

above a tentative Sutter (Ref. 9, p. 2.66) recommendation of 100 mg/m^3 "...as a maximum upper-limit quasi-stable air concentration after an explosive event."
The 100 mg/m^3 limit appears difficult to justify for a transient situation. Hinds (Ref. 7) states that as a rule of thumb, coagulation is neglected in laboratory experiments and industrial hygiene work if the aerosol number density is less than 10^6/cm^3. Fig. I-1 shows a plot of aerosol concentrations with a number density of 10^6

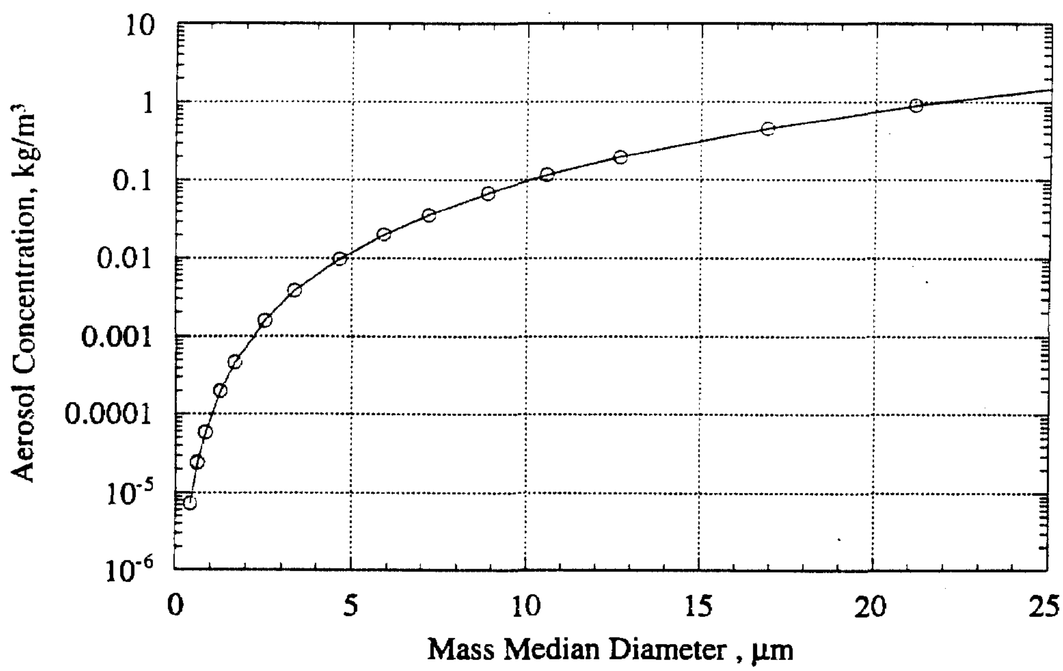


Fig. I-1. Concentration for 1E+6 particles/cm^3 using a lognormal distribution.

particles per cm^3. Lognormal distributions were assumed with a geometric standard deviation, σ_g, of 2 and a particle density of 1.6 g/cm^3. For the 1 kg/m^3 lognormal distribution in Fig. I-1, in other words, the point with a mass median diameter (MMD) of 21.8 µm, the RF is 0.072. These are particles with a AED of less than 10 µm. For a 3273 m^3 tank volume, this RF is not negligible.

To examine the transient situation more closely, scoping calculations of aerosol agglomeration and aerosol scrubbing by terminal velocity soil particles are evaluated in Ref. 1. They suggest that with an overall concentration of 1 kg/m^3, respirable particles will only exist for a few seconds. A lower concentration limit is believed appropriate. However, at this time, selection and justification of a lower number would require numerical calculations that were beyond the scope of this analysis. The airborne concentration adopted here is used in Sections 5.1.3 and 6.0.

I.5.1.2. Respirable Release Using the MacDougall Equation.[10]

The first approach to determine the respirable release involves a formula for a respirable release developed by MacDougall, Scully, and Tillerson (Ref. 10). This formula is independent of the airborne concentration, and is given by

$$V_R = 2\times10^{-10} \times (E_{imp}/Vol) \times Vol \ , \qquad \text{(I-1)}$$

where

V_R = respirable release volume,

E_{imp} = impact energy, (J),

Vol = volume of material that absorbs the impact energy, m^3, which is also the volume to which the respirable fraction applies.

Equation (I-1) was derived from a series of Argonne National Laboratory (ANL) experiments (Refs. 11, 12, and 13) involving the brittle fracture of small samples of glass, ceramics, uranium dioxide pellets, and concrete. Most tests were in the energy range, E_{imp}/Vol, of 10^6 to 10^7 J/m^3. These energy densities were compared to dome collapse energy densities by formulas from two separate approaches: a projectile penetration equation (Ref. 14) and a relationship describing the crater produced by assuming the collapse energy is equivalent to TNT (Ref. [15]). Dome collapse energy densities of from 7.1×10^6 to 3.6×10^7 J/m^3 were obtained, suggesting that the ANL energy density range is reasonable to apply to the dome collapse accident.

Available calculations of dome loading (Refs. 16, 17, and 18) illustrate that cracking and failure of the dome proceeds from the center outward. An idealized diagram of this collapse mode is given in Fig. I-2. Because of the difficulty in determining aerosol escape with a coherent collapse, and because of the spreading of soil from previously collapsed segments preventing further direct impact on such covered waste, an evaluation was performed varying the fraction of the dome credited with

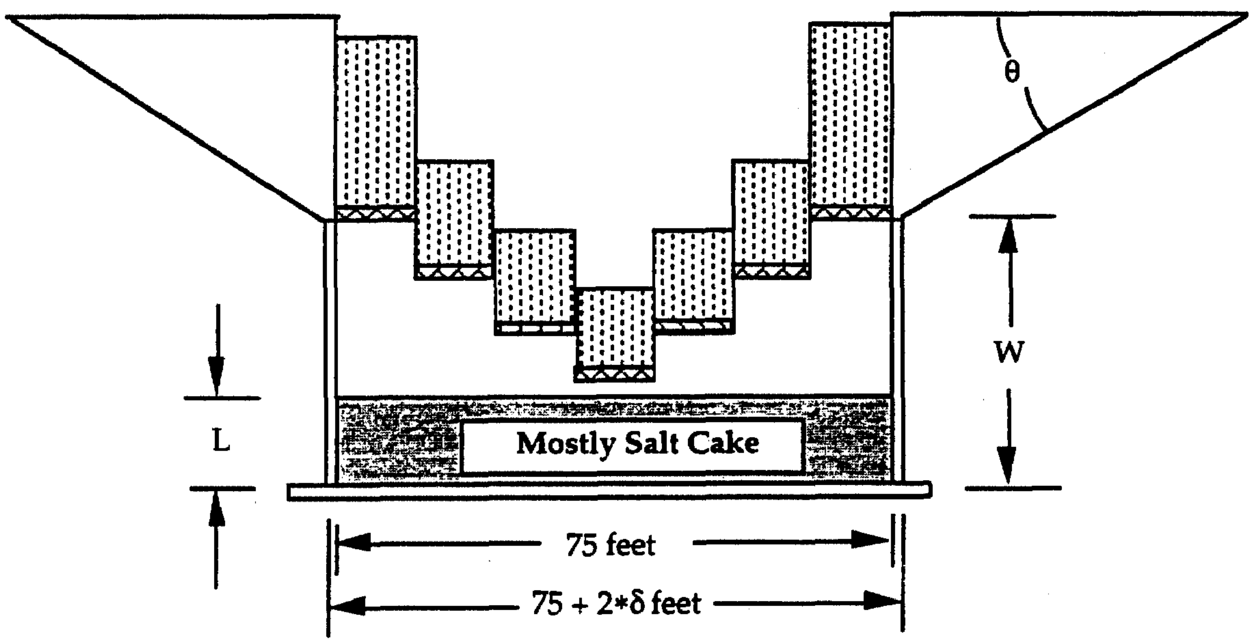


Fig. I-2. Schematic of dome collapse on salt cake.

collapsing coherently on salt cake that is not covered by previous debris. Because the variable Vol does not influence Eq. (I-1) results, the release depends only on the E_{imp} associated with the collapsing mass. The results of this analysis are given in Fig. I-3,

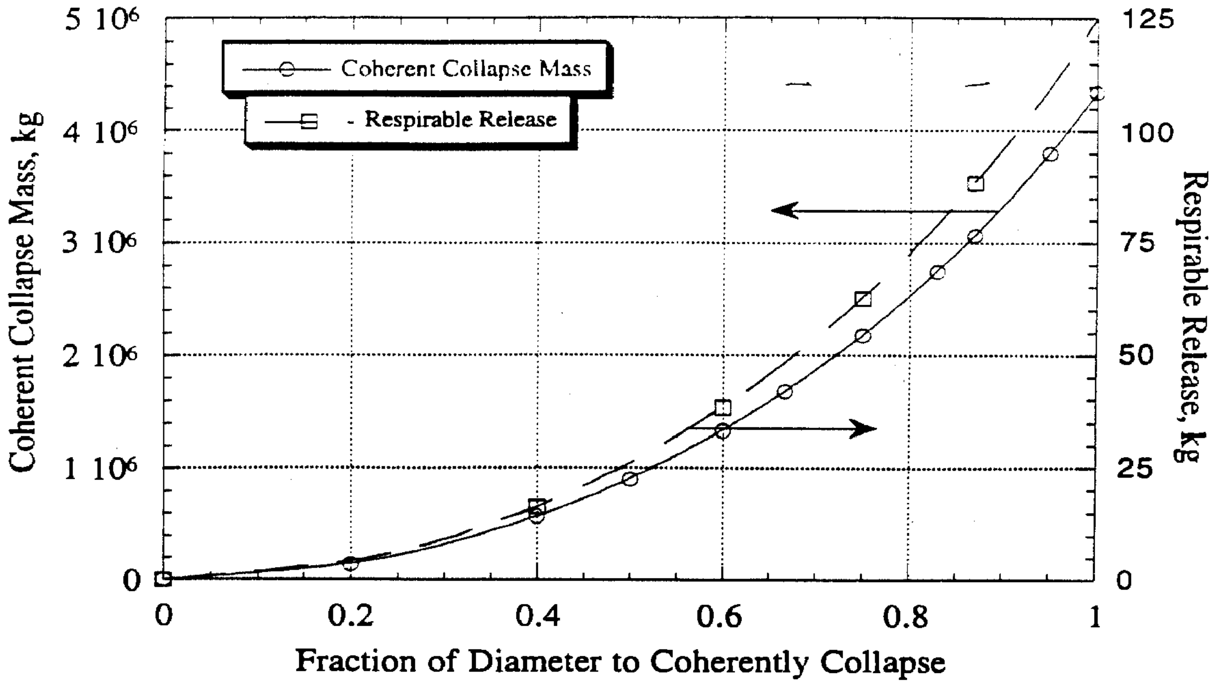


Fig. I-3. Coherent collapsing mass and associated respirable release.

which assumes that the minimum depth of soil above the dome is 10 ft. Because of coherency limitations caused by the strongly reinforced haunch region of the dome, a conservative estimate was judged to involve coherent collapse of the concrete and soil up a limiting diameter of ~90%. This release is 60 L or 96 kg (with a waste density of 1600 kg/m^3) of respirable aerosol.

I.5.1.3. Respirable Release Using an Energetics Analogy

Collapse does not have to be so coherent. It could start during tank depressurization after the initial deflagration. Expansion calculations show that the residual gas can remain hot, at 600 K or more, and Siebe (Ref. 19) notes that a 150-μm particle has a heat-transfer time constant of about 0.1 s. In short, some of the organic carbon could undergo combustion in airborne particulate. To evaluate a bounding case, a respirable fraction for the 1 kg/m^3 of particulate in the tank air was calculated using the prescription of Halverson and Mishima (Ref. 20), which relates the heat of combustion to aerosol formation by an explosive source. To be conservative, σ_g was set to 2.5. Results as a function of the heat of combustion are given in Fig. I-4. The heat of combustion, ΔH, upper bound was assumed to be 300 cal/g (1.26 MJ/kg).

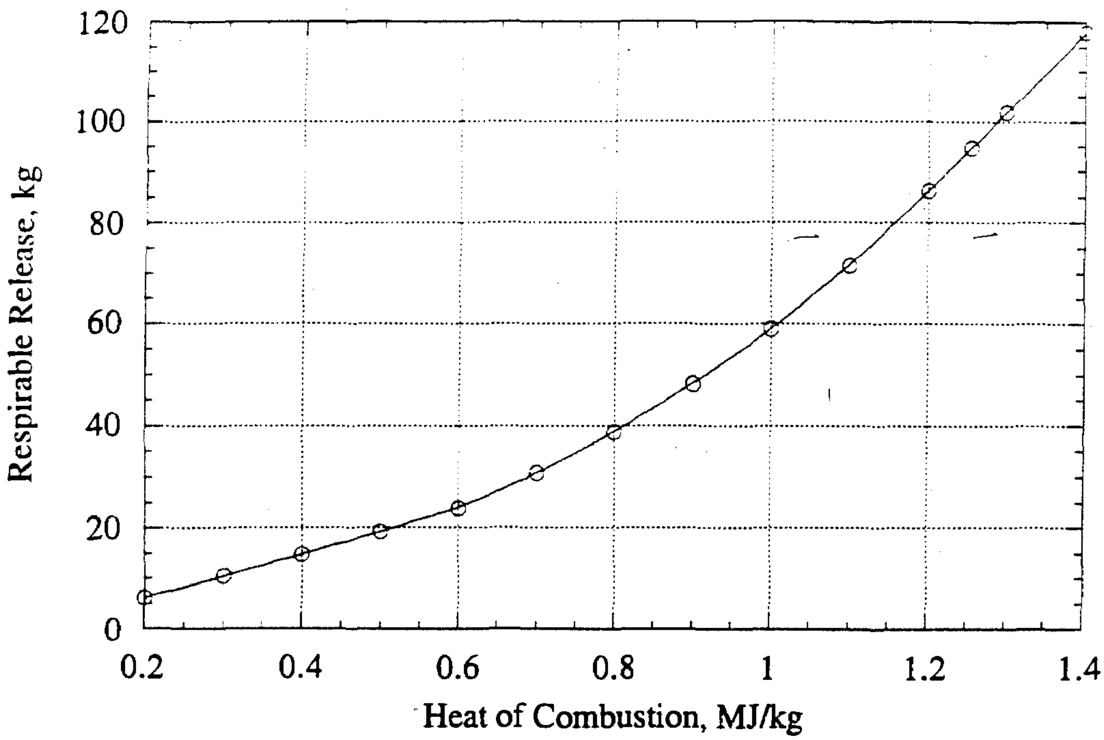


Fig. I-4. Respirable release treating a burn using an explosion prescription.

This ΔH gives an RF of 0.0289; application to the assumed 3273 kg of airborne waste in the tank gives a respirable release of 95 kg. This release is highly conservative. As shown in Appendix H of this SA, combustion propagation is very difficult to achieve in dusts produced from simulants of waste in the Hanford SSTs.

I.5.2. Impact on Liquefied Waste

I.5.2.1. A Scoping Assessment Simulating Impact As An Equivalent Spill.

For liquefied waste, the MacDougall formula for brittle impact does not apply. A splash should be represented. The approach adopted was to model the splash as an equivalent spill, during which the spill energy is assumed to be equivalent to the dome collapse energy. Eq. (26) of a study by Ballinger et al. (Ref. 21) was used to get the airborne release fraction. The Ballinger correlation is based primarily on the Archimedes number, which represents the ratio of gravitational forces to viscous forces. For the gravitational forces, an effective height was used multiplying the real height by the ratio of the mass of the dome over the mass of the waste layer that absorbed the impact. The collapse mass was assumed to contain all the soil out to the angle of repose (30°) because the initially impacting mass may sink, exposing further waste to impact. At the top of the dome, the minimum soil thickness was 10 ft at a conservative density of 120 lb_m/ft^3 (1920 kg/m^3). With the addition of a 100 lb_m/ft^2 external load on the dome, the total collapsing mass was 1.34×10^7 kg. For the viscous forces, the viscosity of the waste was conservatively estimated to be 20 cP, the minimum supernatant liquor viscosity for Tank SY-101.

Results as a function of the waste thickness that is assumed to absorb the energy are given in Fig. I-5. A conservative bound for the waste thickness was judged to be 1 ft.

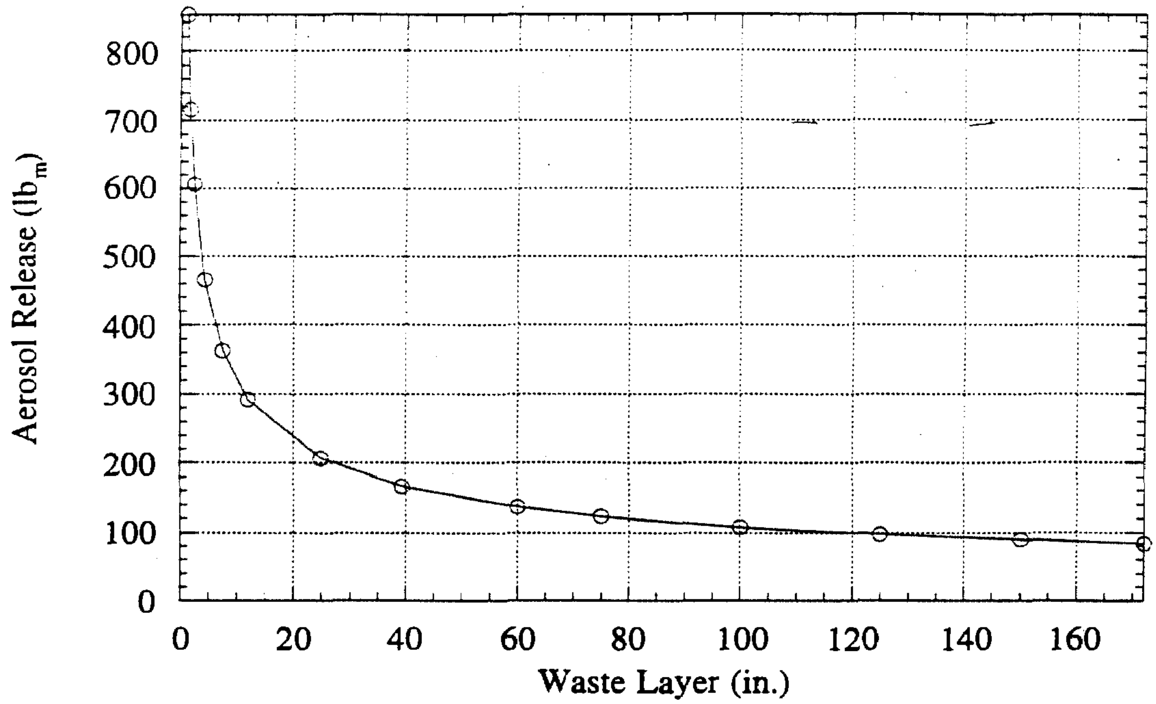


Fig. I-5. Amount of aerosolized material as a function of an energy-absorbing layer.

This gives a 132-kg (291-lb_m) airborne release. DOE-HDBK-3010-94 (page 3-4, Ref. 22) states that a bounding RF for a 3-m spill is 0.8. Ballinger's correlation for the aerodynamic MMD strongly increases as a function of impacting velocity. Consequently, an RF of 0.8 should be bounding for higher drop heights. Using an RF = 0.8 gives a respirable release of 106 kg.

I.5.2.2. Quasi-Mechanistic Considerations Assuming a Continuous Collapse

The analysis in Sec. 5.2.1 is unrealistic in that the simulated coherent collapse leaves no path through the debris allowing the aerosol to escape. An improved picture is to assume that the dome collapse in incoherent. Such a picture is shown in Fig. I-6. The main effect of the filling of the tank by the collapsing dome is to decrease the effective drop distance. (From the impact equations used to obtain the energy density in Sec. 5.1.2, the ratio of the impacting mass to waste mass may be assumed as approximately constant.) The Ballinger correlation depends on the drop height to the 1.35 power. By assuming the Fig. I-6 incoherent collapse, the correlation can be averaged (integrated) over the drop height, reducing the airborne release by a factor of 2.35. The RF is calculated by assuming 0.8 for fall heights greater than 3 m, and RF = 1.0 for that part of the fall height that is less than 3 m. This gives an average RF of 0.84. The respirable release is 0.84 x 132/2.35 = 47 kg.

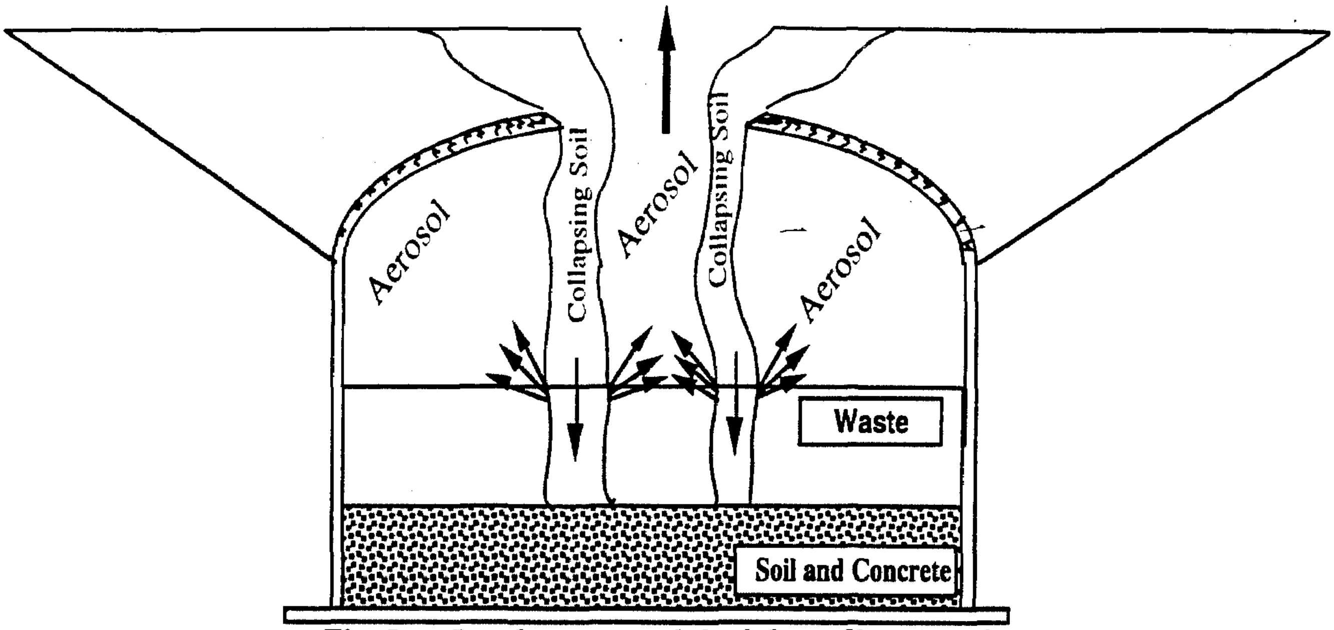


Fig. I-6. Incoherent model of the collapsing dome.

I.6. DOME COLLAPSE LONG-TERM RELEASES

The main concern is atmospheric entrainment of aerosol before post-accident recovery operations can contain the release. There are three situations that require consideration. First, the salt cake impact has produced airborne waste that may have settled outside the dome and can be resuspended. Second, the logical extension of the model shown in Fig. I-6 results in a pool of liquefied waste that can be entrained. Third, if buried waste has been ignited, the heat can release additional toxic or radioactive gases.

For the salt cake impact, the airborne release is approximately 1 kg/m^3 times the tank air volume of 3273 m^3 in Sec. 5.1.1. Conservatively, we could assume that ~3000 kg might settle onsite. Part could be resuspended as respirable particulate. The bounding release rate for aerodynamic entrainment and resuspension is 4E-5/h with an RF = 1.0 from DOE-HDBK-3010-94 (page 5-4, Ref. 22). Multiplication gives 0.12 kg/h, or about 20 kg for a 7-day release.

For the liquefied waste case, the volume of the collapsing soil and concrete is 227,800 ft^3 (6451 m^3). After collapse, only 12 ft (3.66 m) will exist between the bottom of the final soil surface and the ground surface even if collapse occurs into an empty tank. The most conservative configuration for long-term releases is to use the assumption that no waste is absorbed by the soil. Instead, a pool of waste is postulated to form on the top of the collapsed soil. Entrainment can occur from this pool. Assuming the volume of the pool is the volume of the waste in Tank A-101, the volume of the pool is 127,010 ft^3 (3597 m^3), the radius of the pool is 74.1 ft (22.6 m), the depth of the pool center is 9.18 ft (2.8 m), and the surface of the pool is

2.82 ft (0.86 m) below the surface of the ground. The pool surface area is 17,300 ft^2 or about 1600 m^2.

With variable winds and property uncertainties, pool entrainment is a difficult problem. The approach was to take the bounding DOE-HDBK-3010-94 (page 3-5, Ref. 22) entrainment rate of 4×10^{-6}/h for outdoors, assessed as applicable to large pools and ponds with windspeeds to 30 mph (13.4 m/s). The RF is 1.0. This rate applies to the mass in a 1-cm active layer. The respirable aerosol released in 7 days is

$$(1600\ m^2)(0.01 m)(1600\ kg/m^3)(4 \times 10^{-6}/h)(168\ h) = 17.2\ kg.$$

Gases released from a buried waste burn could not be assessed fully at this time. An adiabatic temperature rise is (300 cal/g)(4.184 J/cal)/(1.8 J/g-°C) ≈ 700°C. Potentially, vaporization of some cesium compounds would be possible. However, condensation of escaping gases on soil particles would appear to preclude release. At this time, the conservatism in the resuspension and entrainment calculations would seem sufficient to allow respirable releases from buried waste to be ignored as long as burial can be maintained.

I.7. CONCLUSIONS

During the dome collapse accident, the conservative estimate for the prompt release of respirable aerosol is obtained as follows:

Initial dome loading:	0.6 L
Entrainment during deflagration:	1.8 L
Solid respirable aerosol from impact:	~60.0 L
TOTAL	62.4 L

Because of the neglect of the rapid reduction phenomena from aerosol agglomeration and from possible aerosol scrubbing by incoming soil during the release from the tank, the prompt release would be bounded by 62.4 L of solid particulate during the dome collapse.

Using the receptor doses for 1 L release given in Appendix R, the onsite receptor dose for the prompt release may be calculated as 17,200 rem. The offsite receptor dose is 9.3 rem.

These numbers are conservative if one considers the maximum concentrations that can be sustained in a plume or a cloud. In order to receive 17,200 rem, the on-site individual must inhale 7.2×10^{-4} L of waste. Sutter[9] states that the concentrations in dust storms range between 0.5 g/m^3 and 10 g/m^3. The concentration at the face of a mine would be 0.5 g/m^3, and in smog it would be 50 mg/m^3. If one assumes that, by expansion, dispersion, agglomeration, and deposition, the concentration in the plume drops to the lower dust storm limit of 1 g/m^3 (or 6.3×10^{-4} L of waste/m^3 of air), the on-site individual must inhale ~1 m^3 of air. Using a 3.3×10^{-4} m^3/s breathing rate, the individual must remain in the dust cloud for ~50 min. It is highly unlikely that an individual at 100 m from a catastrophic accident will remain in the cloud for such an extended period of time without protection or without leaving the premises. These calculations indicate that the doses resulting from the dome collapse accident are conservatively estimated. However, to remove some of the conservatism, a more detailed analysis of entrainment, dispersion, agglomeration, deposition, and resuspension must be performed under different weather conditions.

Releases from liquefied waste are on the same order of magnitude. The doses resulting from liquid releases are about an order of magnitude less than the doses resulting from an equal volume of solid releases (see Appendix R). Thus, the liquid releases are not further considered in the dome collapse accidents. Present analysis suggests that incoherence in the collapse may reduce the magnitude of the liquid release by a factor of 2. However, the extent of and effects from incoherence in a dome collapse pose questions that deserve more study.

The long-term entrainment from an open pool of waste following the dome collapse is bounded by 12.5 L/wk of solid resuspended respirable aerosol.

I.8. REFERENCES

1. W. Bohl and C. Unal, "Dome Collapse Accidents For Single-Shell Flammable Watch List Tanks," Los Alamos National Laboratory Calc-Note TSA6-CN-WT-SA-TH-108 (March 1996).

2. L. H. Sullivan et al., "A Safety Assessment for the Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," Los Alamos National Laboratory report, LA-UR-92-3196, Rev. 14 (March 31, 1995).

3. R. T. Perry, "Aerosol Mass in the Dome," Los Alamos National Laboratory Calc-Note TSA6-CN-WT-SA-TH-096 (December 1995).

4. K. O. Pasamehmetoglu, "Additional Dome Collapse Calculations For Single-Shell Flammable Watch List Tanks," Los Alamos National Laboratory Calc-Note TSA6-CN-WT-SA-TH-093 (December 1995).

5. J. D. Iverson, "Particulate Entrainment by Wind," Department of Aerospace Engineering, Iowa State University report Project 1699, ISU-ERI-Ames-85010, prepared for Los Alamos National Laboratory under Subcontract No. 9-X54-K9610-1 (July 1984).

6. D. R. MacFarlane, D. W. Stack, J. Kindinger, R. K. Deremer, S. R. Medhekar, and T. J. Mikschl, "Probabilistic Safety Assessment for Hanford High-Level Waste Tanks," Los Alamos National Laboratory report, LA-UR-95-1900, TSA-11-94-R110 (November 1995).

7. W. C. Hinds, "Aerosol Technology, Properties, Behavior, and Measurement of Airborne Particles" (John Wiley and Sons, New York, NY, 1982).

8. R. F. Schwab, "Dusts," Chapter 12, Section 3, from A. E. Cote, P. E., Editor-in-Chief, Fire Protection Handbook (National Fire Protection Association, Quincy, Massachusetts, 1992).

9. S. L. Sutter, "Accident Generated Particulate Materials and Their Characteristics—A Review of Background Information," Pacific Northwest Laboratory report NUREG/CR-2651, PNL-4154 (May 1982).

10. H. R. MacDougall, L. W. Scully, and J. R. Tillerson, "Preliminary Preclosure Radiological Safety Analysis," Appendix F in "Site Characterization Plan Conceptual Design Report," Sandia National Laboratory report SAND84-2641 (1987).

11. W. J. Mecham, L. J. Jardine, R. H. Pelto, G. T. Reedy, and M. J. Steindler, "Interim Report of Brittle-Fracture Impact Studies: Development of

Methodology," Argonne National Laboratory report ANL-81-27 (October 1981).

12. L. J. Jardine, W. J. Mecham, G. T. Reedy, and M. J. Steindler, "Final Report of Experimental Laboratory-Scale Brittle Fracture Studies of Glasses and Ceramics," Argonne National Laboratory report ANL-82-39 (October 1982).

13. W. J. Mecham, L. J. Jardine, G. T. Reedy, and M. J. Steindler, "General Statistical Description of the Fracture Particulates Formed by Mechanical Impacts of Brittle Materials," Ind. Eng. Chem. Fundam., 22, pp. 384-391 (1983).

14. C. W. Young, "Equations for Predicting Earth Penetration by Projectiles: An Update," Sandia National Laboratory report SAND88-0013 (July 1988).

15. "Effects of Impact and Explosion," Summary Technical Report of Division 2, NDRC, Volume 1, Copy No. 247, U. S. Government War Department, Washington D. C. (Columbia University, Division of War Research, New York, New York, 1946).

16. L. J. Julyk, "Static Internal Pressure Capacity of Hanford Single-Shell Waste Tanks," Westinghouse Hanford Company report, WHC-SD-WM-TI-623 (August 1994).

17. E. A. Rodriguez, R. F. Davidson, and M. L. Walsh, "Comparison of ABAQUS and EPIC Nonlinear Transient Dynamic Models for a Hydrogen Burn Event of Hanford Site High-Level-Waste Tank 241-SY-101," Los Alamos National Laboratory report LA-UR-95-3441 (October 1995).

18. R. F. Davidson, M. L. Walsh, E. A. Rodriguez, "EPIC Hydrodynamic Code Modeling of Hanford Site HLW Tank 241-SY-101 for Bounding Hydrogen Detonation," Los Alamos National Laboratory draft report (December 1995).

19. D. A. Siebe, "Thermal Analysis of Rotary-Mode Core Drilling," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-111 (February 1996).

20. M. A. Halverson and J. Mishima, "Initial Concepts on Energetics and Mass Releases During Nonnuclear Explosive Events in Fuel Cycle Facilities," Pacific Northwest Laboratory report PNL-5839, NUREG/CR-4593, US Nuclear Regulatory Commission (August 1986).

21. M. Y. Ballinger, J. W. Buck, P. C. Owczarski, and J. E. Ayer, "Methods for Describing Airborne Fractions of Free Fall Spills of Powders and Liquids," Pacific Northwest Laboratory report NUREG/CR-4997, PNL-6300 (October 1987).

22. U. S. Department of Energy, "Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities," U.S. Department of Energy Handbook DOE-HDBK-3010-94 (October 1994).

APPENDIX J

HYDROGEN DIFFUSION INTO DRILL STRING AND BURN/DETONATION ANALYSIS

J.1. INTRODUCTION

During the core-sampling operation, nitrogen will flow through the drill string and out the drill bit. The purpose of the nitrogen flow is to cool the drill bit, to provide the lift necessary to remove drill cuttings from the annulus bore, and to maintain a hydrostatic pressure at the drill bit to keep the waste out of the drill string during sampler change. During the sample retrieval process, the waste and flammable gases such as hydrogen, nitrous oxide, ammonia, and methane will flow into the drill string in case of loss of nitrogen flow. The gas concentration will reach the low flammable-gas limit, and a gas burn will occur if a spark is generated because of friction. The objective of this appendix is two-fold:

- To calculate the potential for flammable-gas accumulation in the drill string when the nitrogen purge system is lost; and
- To consider the possibility of transition from deflagration to detonation and to estimate the over-pressure ratio and the rate-of-pressure rise. The over-pressure ratio and the rate-of-pressure rise will be used as boundary conditions for the structure analysis.

J.2. HYDROGEN DIFFUSION INTO THE DRILL STRING

The following sections provide a summary of the analysis methodology and the results of the calculations for the hydrogen diffusion into the drill string.

J.2.1. Analysis

For constant density and diffusion coefficient and for no convective flow, Reference 1 gives the following governing equation for one-dimensional transient diffusion of species a into species b,

$$\frac{\partial c_a}{\partial t} = D_{ab}\nabla^2 c_a \quad , \qquad \textbf{(J-1)}$$

where

c_a = volumetric concentration of species a, kg-moles/m^3.

D_{ab} = diffusion coefficient of species a into species b, m^2/s.

Given the assumptions above and for only one species diffusing into another, the volumetric concentration of the mixture will also be constant so that Eq. (J-1) can be rewritten in terms of mole fraction or volume fraction, assuming ideal gases.

$$\frac{\partial x_a}{\partial t} = D_{ab} \nabla^2 x_a \ , \qquad \text{(J-2)}$$

where

x_a = mole fraction of species a.

If the flow area varies, but the diffusion process can be assumed to be one-dimensional, then Equation (J-2) can be rewritten as

$$\frac{\partial x_a}{\partial t} = \frac{D_{ab}}{\bar{A}} \frac{\partial}{\partial z} \left(A \frac{\partial x_a}{\partial z} \right) , \qquad \text{(J-3)}$$

where

A = flow area, which is a function of z, m^2 and

$\bar{A}$ = average flow area over the volume of interest, m^2.

For this problem, the initial condition is that the mole fraction of hydrogen in the drill string be zero. The boundary conditions are that the mole fraction of hydrogen at the bottom of the drill string (i.e. z = 0) be one and that the diffusion flux of hydrogen at the top of the drill string be zero, which implies the gradient of the mole fraction of hydrogen at z = L is zero.

Equation (J-3) is solved numerically.[2] An analytical solution to Eq. (J-2) with the initial conditions and boundary conditions given above exists. Comparison of the analytical solution with the finite-difference solution for constant flow area indicates that because of the numerical diffusion, the finite difference solution diffuses hydrogen faster than the numerical solution on the order of 10% absolute relative error, which is conservative.

The diffusion coefficient for hydrogen in nitrogen was obtained from curve fitting parameters to the CHEMKIN[3] database. These curve-fitting parameters indicate that the diffusion coefficient for hydrogen in nitrogen increases from 0.682 cm^2/s at 20°C to 1.042 cm^2/s at 90°C. A conservative value of 1 cm^2/s was chosen for this analysis. The molecular diffusion coefficient varies as the inverse of the absolute pressure. For this analysis, a conservative pressure of 1 atm was chosen.

The diffusion of one species into another because of thermal gradients is governed by the thermal diffusion ratio. The mass flux of species a into species b because of a temperature gradient is given by Eq. (J-4) as,

$$j_a^{(t)} = -\left(\frac{c^2}{\rho}\right) M_a M_b D_{ab} k_T \nabla \ln T \quad , \tag{J-4}$$

where

$j_a^{(t)}$ = mass flux of species a into species b caused by a thermal gradient, kg/m^2-s,

c = molar concentration of the mixture, kg-moles/m^3,

ρ = density of the mixture, kg/m^3,

M_a = molecular weight of species **a**, kg/kg-mole,

M_b = molecular weight of species **b**, kg/kg-mole,

k_T = thermal diffuse ratio, and

T = gas temperature, K.

From Eq. (J-4) it can be seen that the sign of thermal diffusion ratio determines the direction of the thermal diffusion for a given species. If the thermal diffusion ratio is positive, then species **a** moves toward the colder temperature; when the thermal diffusion ratio is negative, then species a moves toward the hotter temperature. Experimental values for the thermal diffusion ratio for hydrogen diffusing into nitrogen caused by a thermal gradient are given in Reference 2 for 264 K as -0.0548 to -0.0663, depending upon the hydrogen mole fraction. The negative thermal diffusion ratio indicates that hydrogen diffusion caused by thermal gradients will diffuse toward a higher temperature region and nitrogen will diffuse toward the colder temperature region. Therefore, it is conservative to neglect this effect. Hydrogen will diffuse into a rotary-core drill string faster by neglecting the effect of hydrogen diffusion caused by thermal gradients because the waste is anticipated to be at a higher temperature than the nitrogen gas in the drill string. An order of magnitude solution can be obtained based on a steady-state solution of the case in which the molecular diffusion is balanced by the thermal diffusion as,

$$\Delta x_a = -k_T \ln\left(\frac{T_2}{T_1}\right) \quad , \tag{J-5}$$

where

T_2 = hot gas temperature, K, and

T_1 = cold gas temperature, K.

Δx_a = difference in steady-state hydrogen mole fraction at the hot temperature minus the hydrogen mole fraction at the cold temperature.

Evaluating Eq. (J-5) with experimental values in Reference 1 yields a difference in hydrogen mole fraction at a hot temperature minus the hydrogen mole fraction at a cold temperature at steady-state to be on the order of 1.4%. Therefore, the magnitude of the effect is not significant.

Based on past analyses, the buoyancy effect of hydrogen gas mixing with air or nitrogen is significant. The actual mixing of hydrogen with the drill-string nitrogen gas may be faster than the conservative diffusion calculation presented in this appendix. The actual mixing of retained gas with the drill-string nitrogen gas may be limited by how fast the retained gas can diffuse from the waste to the drill bit. However, if the drill bit is in a relatively large retained gas bubble, then diffusion and mixing of retained gas with the drill-string nitrogen gas will not be limited by diffusion of retained gas through the waste.

J.2.2. Results

Equation (J-3) was solved for two geometries. Both geometries were assumed to be 320 in., which represents the smallest length for the drill string to still be in contact with the waste. The small flow area geometry assumes that the seal in the bottom of the rotary-core drill string has failed completely and that the available flow area for diffusion of hydrogen into the drill string is an annulus with an o.d. of 1.82 in. and an i.d. of 1.78 in. Drill-string gas volume continues to be an annulus with a varying i.d. until the elevation is above the latching mechanism. For the bit-flow area geometry, the drill-string geometry is a cylinder at all elevations with a diameter of 1.91 in. and with an inlet flow for hydrogen diffusion equal to the available bit-flow area. The average hydrogen concentration in the rotary-core drill string as a function of time is given in Fig. J-1 for the small flow area geometry and the bit-flow area geometry. From Fig. J-1 it can be seen that for the bit-flow area geometry, the average concentration rises faster than for the small flow area geometry. The bit-flow area geometry case reaches an average flammable-gas concentration within 25 minutes, while the small-flow area case reaches an average flammable-gas concentration within 180.0 minutes.

Figure J-2 shows the results for hydrogen concentration versus axial level for selected times into the transient for the small-flow area case. You can see that the first few feet of the drill string that is an annulus for this case fills with hydrogen relatively quickly. The discontinuity in the slope of the results occurs when the geometry goes from an annulus to a cylinder. For the bit-flow area case, shown in Figure J-3, there is no discontinuity in the slope of the hydrogen concentration versus z curve, because the geometry is a uniform cylinder. By comparing Figs. J-2 and J-3, it can be seen that the larger inlet area for the bit-area case results in a larger diffusion rate of hydrogen into the drill string. Within 24 hours, both calculations indicate significant concentrations of hydrogen from the top to the bottom of the drill string.

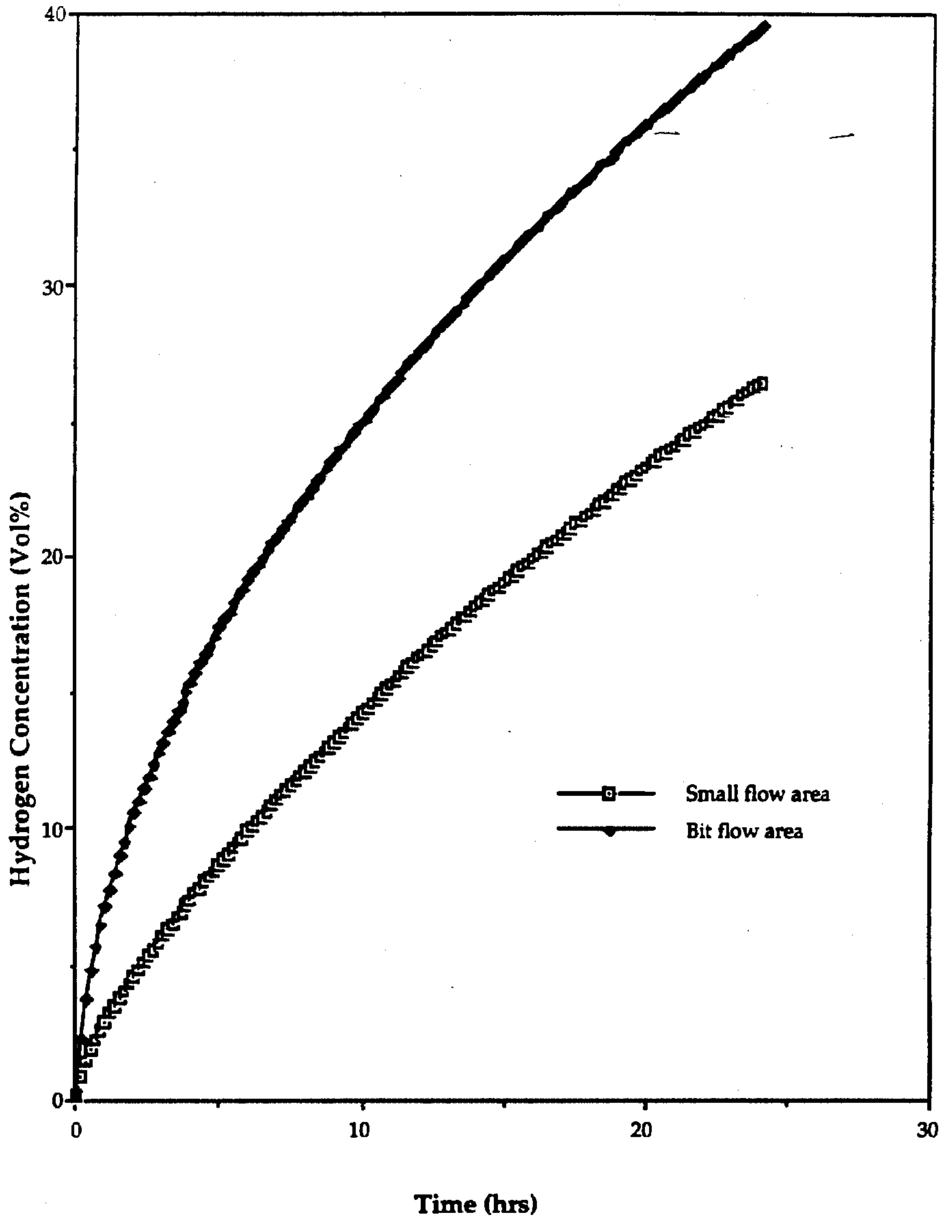


Fig. J-1. Average hydrogen concentration in the drill string.

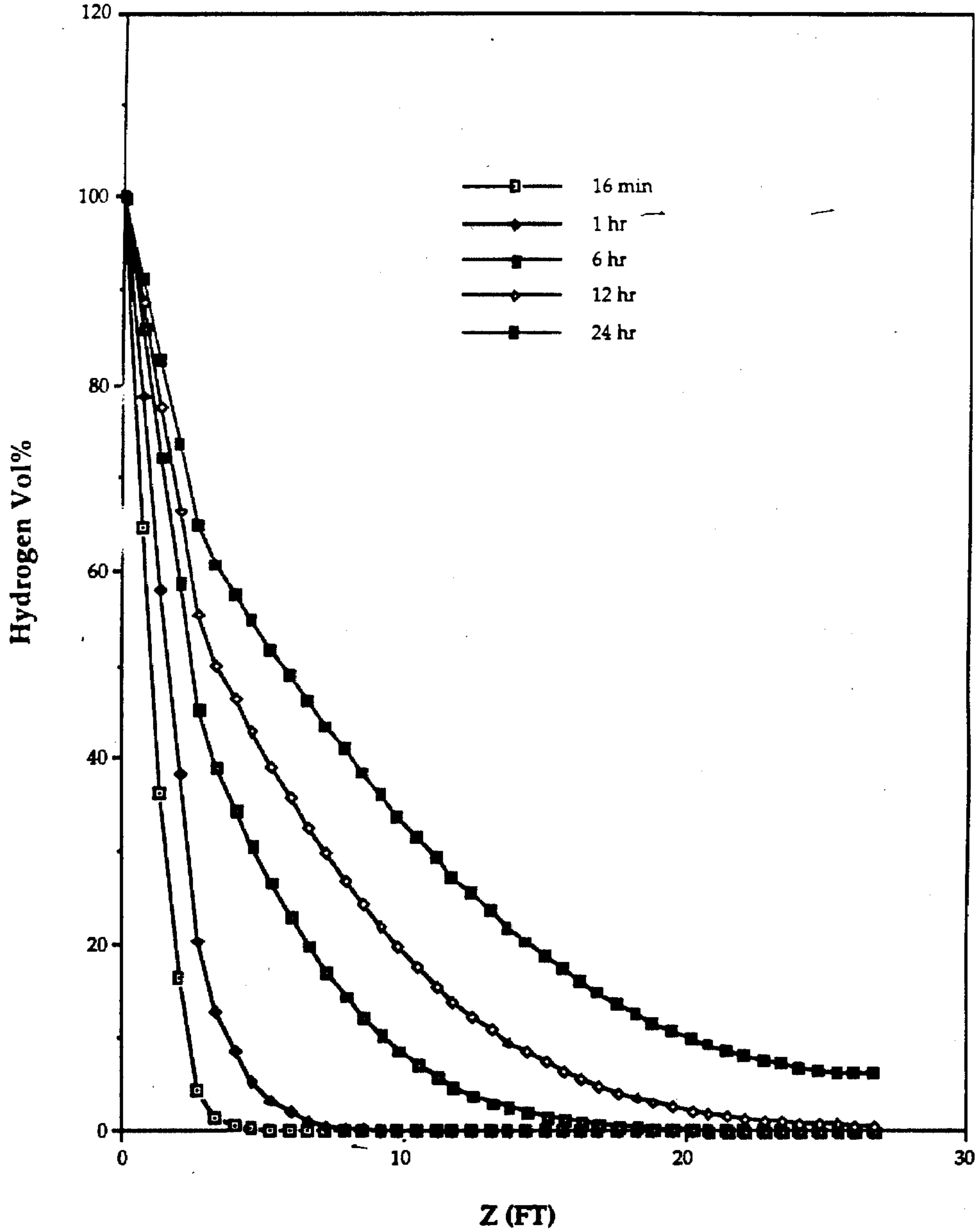


Fig. J-2. Hydrogen volume fraction versus axial location for small flow area case.

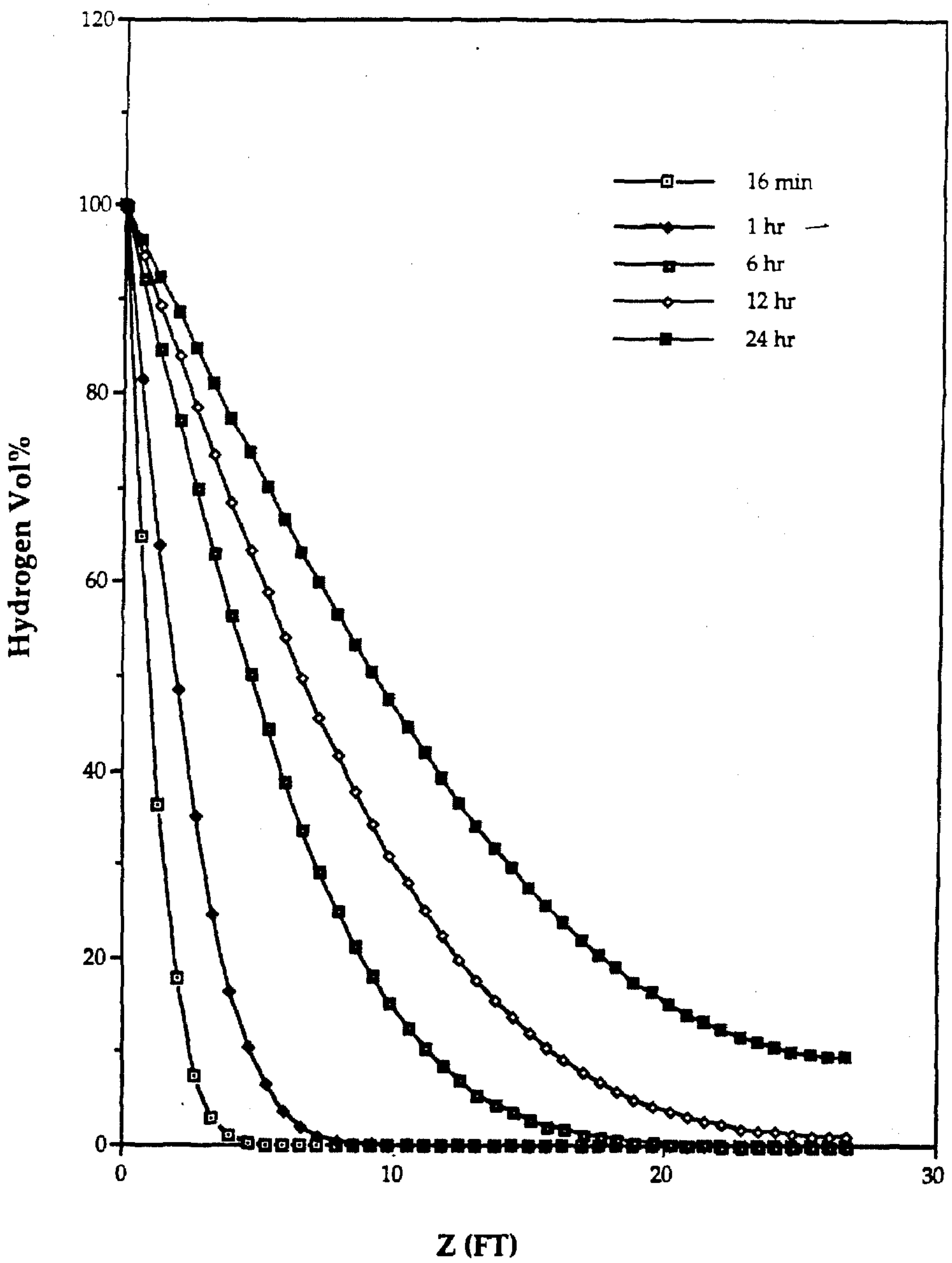


Fig. J-3. Hydrogen volume fraction versus axial position for big flow area case.

The maximum molecular mass-diffusion flux into the drill string occurs at the first-time step of each transient calculation. The following results were obtained for the maximum mass-diffusion volumetric flow of hydrogen into the rotary-core drill stream: (a) for a small-area case, 0.000122 cfm, (b) for a bit-flow area case, 0.000448 cfm.

An order-of-magnitude analysis can be used to verify these numbers. The mass-diffusion flux at the entrance to the drill string can be written as

$$j_a = -cM_aD_{ab}\nabla x_a \quad , \qquad \text{(J-6)}$$

where j_a = mass diffusion flux caused by the concentration gradient, kg/m^2-s.

Evaluating Eq. (J-6) for P = 1 atm, T = 303 K, a diffusion coefficient of 1 cm^2/s and the gradient of the concentration profile on the order of -10 yields j_a = 8.064e-05 kg/m^2-s or in terms of a volumetric flux yields, q_a = 0.001 m/s of hydrogen.

For the small-flow area case, the inlet flow area is 0.000232 m^2 and for the bit-flow area case the inlet flow area is 0.00133 m^2, which results in a peak volumetric flow of hydrogen into the drill string caused by hydrogen diffusion of 0.000232 liters/s (0.000492 cfm) for the small-flow area case and 0.0009 liters/s (0.00019 cfm) for the bit-flow area case. These order-of-magnitude results are consistent with the numerical solutions to the transient diffusion equation.

Results obtained from Eq. (J-6) are independent of the pressure chosen because the molar concentration for an ideal gas mixture is proportional to the pressure, and the diffusion coefficient is inversely proportional to the pressure. However, the volumetric flux depends upon one over the density, and the density is directly proportional to pressure. Therefore, as pressure increases, density will increase, and the volumetric flow of hydrogen caused by diffusion will decrease.

J.2.3. Summary and Conclusions

A conservative estimate of the diffusion rate of hydrogen into the rotary-core drill string based on two different geometries indicates that within 20 minutes to 180 minutes, depending upon the inlet flow area, there will be a significant concentration of hydrogen within the drill string. It is a conservative assumption that the retained gas, which includes its own oxidizer, will diffuse as fast as hydrogen by itself. Based on this conservative analysis, the average retained-gas concentration within the rotary-core drill string following the failure of sampler chevron seal will exceed 4% within 180 minutes and following a nitrogen purge system failure with the test section removed, will exceed 4% within 20 minutes. Concentrations high enough to support a detonation (assuming an oxidizer is present) are reached within minutes in the first few feet of rotary-core drill string drilling for both cases, and the average concentrations for the rotary-core drill string reach detonation limits again, assuming an oxidizer is present within 3 to 11 hours.

The maximum diffusion flux of hydrogen into the rotary-core drill string occurs at the first-time step into the transient solution. The maximum volumetric flow of hydrogen into the drill string was calculated for the bit-flow area geometry based on an order of magnitude analysis to be 0.00019 cfm.

J.3. BURN AND DETONATION ANALYSIS IN THE DRILL STRING

The assumptions for this analysis are as follows:

1. The nitrogen pressurization system failed to operate for more than 10 h;
2. A burn is generated by a spark resulting from metal friction in the drill string;
3. The gases in the drill string are well mixed; and
4. The fuel is hydrogen only; this assumption is reasonable because the hydrogen concentration may be very high, as discussed in Appendix C.

J.3.1. Burn Analysis

Burn can probably occur in two places in the drill string during a loss-of-nitrogen-flow accident. One is between the drill bit and the bottom of the universal sampler. The other one is between the top of the universal sampler and the ball valve. However, the geometry at both locations, which are the two closed ends of a pipe, is similar. Therefore, a 1D burn-combustion code can be used to analyze the problem and to estimate the overpressure and the-rate-of-pressure rise, dP/dt, in the drill string.

The problem was solved with GASBURN, which is a derivative of the GASFLOW code.[4] The code strips the chemical reaction subroutines in GASFLOW and solves the 1D hydrodynamic equations. The result calculated by GASBURN is given in Reference 5. The maximum overpressure is 30%, which is a little above the stoichiometric value of 29.5%.

In Reference 5, the pressure ratio calculated by the GASBURN code is compared with the data obtained by the Bureau of Mines (BOM).[6] The measured pressure ratio, which is defined as the ratio of maximum absolute explosion pressure to the initial pressure, is in good agreement with that calculated with the adiabatic constant-volume combustion model. If we convert the overpressure calculated by GASBURN to the pressure ratio, the pressure ratio calculated by GASBURN is in good agreement with that calculated by BOM. This comparison shows that the chemical reaction model in GASBURN is properly modeled.

We can either use the overpressure calculated by GASFLOW or the experimental data for the safety analysis. To estimate the overpressure in the drill string, we need to know the hydrogen concentration. In Section 2 of this appendix, we calculate a concentration of 30% when the axial position of the universal sampler is about 10 ft above the rotary drill in about 12 h. The hydrogen concentration of 30% is the point at which maximum pressure occurs. The calculated overpressure is about 6.3 bars or 630 kPa.

For structure analysis, we need to estimate the rate of pressure rise in the drill string. The maximum rate-of-pressure rise, which is defined as $K_G = (dP/dt)V^{1/3}$ bar-m/s, is obtained from the BOM experiment. The maximum rate of pressure rise for 30% hydrogen is about 1120 bar-m/s (from the Appendix, "Detailed Listing of Flammability Test Data").[6] The i.d. of the test chamber is 2 ft. The volume of the test chamber is 4.1888 ft^3 or 0.118613 m^3. The rate-of-pressure rise is 2279.5 bar/s. It should be noted that the data of K_G are scattered from 456 to 1120 bar-m/s.

The BOM data were obtained from a spherical chamber. However, the drill string is in cylindrical geometry. The BOM data may not be applicable to drill-string geometry. We used the GASFLOW code to calculate the over-pressure and the rate-of-pressure rise in a pipe of 1.91 in. in diameter and 10 ft in length. The over-pressure and the rate-of-pressure rise are ~9.0 bar and ~2280 bar/s. The results are similar to those calculated for a spherical chamber as above.

J.3.2. Detonation Analysis

Consider a tube with a very large length-to-diameter ratio (L/D) such as the drill string case containing a combustible mixture whose normal burning velocity is high relative to the velocity of sound of the unburned gas. With these circumstances, ignition at a closed end can cause the flame to accelerate to such an extent that a detonation eventually occurs in the tube. The phenomena of transition from deflagration to detonation is probably the least-understood aspect of detonation theory at this time. The critical parameters for controlling the transition are the tube diameter, the tube length, and fuel concentration. Detailed discussions of these parameters are given in Reference 7 and are summarized below.

The critical cell size in a detonation is a fairly easy quantity to measure. It ties with the chemical reaction rate having the gross macroscopic propagation behavior of detonations. The further a mixture is from stoichiometric, and hence the less energetic the chemical reaction, the larger is the detonation cell size. In Reference 8, the detonation cell size for a hydrogen-to-air mixture at atmospheric pressure is measured.[8] The minimum detonation cell width is about 0.6 inches. The required diameter for propagating the detonation wave is about one-third of the detonation cell width. Therefore, it only needs a 0.2-in.-diameter tube to propagate a detonation wave generated by a stoichiometric mixture. The i.d. of the drill string is much larger than that value. Hence, if any detonation generates in the drill string, it may propagate in the drill string.

The induction distance (the distances from the igniter to the location in the detonation tube where the flame propagation rate first attains detonation velocity) are an important parameter to control wave propagation. If the tube is too short, then the wave never reaches it maximum velocity. Bollinger performed an experimental study to measure the induction distances in hydrogen nitrous oxide mixtures.[9] For a 79-mm i.d. tube, the induction distance for 30% hydrogen is about 200 cm. The ratio of induction distance to the tube diameter is about 23. The L/D for the drill string is about 60, which is much longer than the above ratio. Therefore, in the drill string, the wave speed may reach the detonation wave speed, which is about 2000 m/s for the stoichiometric mixture.

Hydrogen and air mixtures near stoichiometric (~ 29.5% hydrogen) are known to be detonable. Mixtures departing from stoichiometric, either in the hydrogen-lean or hydrogen-rich direction are increasingly more difficult to detonate. It has been generally believed that hydrogen-air mixtures with mixture ratios of <18% or >58% hydrogen, could not be detonated. As shown in Section 2 of this appendix, the hydrogen concentration in the drill string reaches 30% in 16 minutes at 2 ft above the rotary drill. One operation of drilling takes about 30 minutes. By that time, the hydrogen concentration is already above 18%. Therefore, some burn in the drill string may detonate.

Akbar and Shepherd performed an experiment to study deflagration-to-detonation transition (DDT) using the gas mixture similar to the 101-SY waste gas mixture (42.8% H_2, 36.4% N_2O, and 28.8% N_2) with various dilutions.[10] This study shows that the waste gas mixture produced DDT up to 50% of dilution with air. The waste gas composition may contain higher concentrations of hydrogen (see Appendix C). Therefore, DDT may be produced in the drill string.

Theoretical detonation pressure for hydrogen-to-air mixtures in a pipe can be calculated through a numerical method by solving the differential equation for isentropic compression in the burn gas. Reference 8 shows the theoretical detonation pressure and temperature, and reflected detonation pressure and temperature for hydrogen-to-air mixtures. The pressure ratio is about 15 at 30% H_2 before the pressure wave is reflected back from the tube end. The final over-pressure is about 15 bars. Using the detonation velocity 2000 m/s (see page 2-50, Ref. 7) and a detonation cell with 10 mm, the rate-of-pressure rise is about 3×10^6 bar/s. It should be noted that we did not use the reflected pressure because an increase in the rate of first compression pressure is high enough to fail the structure of the drill string.

J.3.3. Conclusions

From the above analysis, the overpressure and the rate-of-pressure rise during a burn in the drill string are 630 kPa and 2279.5 bar/s, respectively. During a detonation in the drill string, the overpressure and the rate-of-pressure rise are 15 bars (1.5×10^6 Pa) and 3×10^6 bar/s, respectively. A DDT may occur in the drill string. Therefore, any burn in the drill string may result in a detonation because the rate of pressure rise is very high (3×10^6 bar/s) during the detonation. Consequently, the structure of the drill string is conservatively assumed to fail.

J.4. REFERENCES

1. R. B. Bird, et.al., "Transport Phenomena," (John Wiley & Sons, New York, NY 1960).

2. J. W. Spore, "Bounding Hydrogen Diffusion Analysis in Rotary Core Drill String," Los Alamos National Laboratory TSA-10 Calc-Note TSA-CN-WT-SA-GR-048 (December 1995).

3. R. J. Kee and J. A. Miller, "A Structured Approach to the Computational Modeling of Chemical Kinetics and Molecular Transport in Flow Systems," Sandia National Laboratory report SAND86-8841 (December 1993).

4. J. R. Travis, K. L. Lam, and T. L. Wilson, "GASFLOW: A Three-Dimensional Finite-Volume Fluid-Dynamics Code for Calculation of the Transport, Mixing, and Combustion of Flammable Gases in Geometrically Complex Domains," Los Alamos National Laboratory report LA-UR-94-2207 (July 11, 1994).

5. J. C. Lin, "Drill String Detonation," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-GR-050 (January 1996).

6. K. L. Cashdollar, et. al., "Laboratory Flammability Studies of Mixtures of Hydrogen, Nitrous Oxide, and Air," Westinghouse Hanford Company report WHC-SD-WM-ES-219, Rev. 0 (June 1992).

7. A. L. Camp, et. al., "Light Water Reactor Hydrogen Manual," Sandia National Laboratories report NUREG/CR-2726, SAND82-1137 (June 1983).

8. C. M. Guirao, et. al., "Hydrogen-Air Detonations," presented at the 1982 International Combustion Symposium, Haifa, Israel (1982).

9. L. E. Bollinger, J. A. Laughrey, and R. Edse, "Experimental Detonation Velocities and Induction Distances in Hydrogen-Nitrous Oxide Mixtures," ARS Journal, Vol. 32, 81-82 (1962).

10. R. Akbar and J. E. Shepherd, "Detonation in N2O-H2-N2-Air Mixtures," Rensselaer Polytechnic Institute, Department of Mechanical Engineering report prepared for Los Alamos National Laboratory under contract C-4836 (June 18, 1993).

APPENDIX K

TOXICOLOGICAL CONSEQUENCE ANALYSIS METHODOLOGY

K.1. INTRODUCTION

This appendix discusses the methodology used in quantifying the toxicological consequences of accidental releases during rotary-mode core sampling (RMCS) operations.

K.2. METHODOLOGY

The methodology provided in References 1 and 2 are adopted for consistency with other safety basis documents used at the Hanford Site Tank Farms.

K.2.1. Release of Toxic Gases

For gaseous releases, the receptor doses are obtained as

$$C = \frac{\frac{\chi}{Q}}{1 + V \times \frac{\chi}{Q}} \times S \times V \quad , \qquad \textbf{(K-1)}$$

where C is the receptor dose,

χ/Q is the atmospheric dispersion factor given in Table K-1,

V is the gas-release volume (puff release) or gas-release volume flow rate (continuous release), and

S is the species concentration at the source.

For $(V)(\chi/Q) << 1$, which is the case for the accidents analyzed in this safety assessment (SA), Eq. (K-1) reduces to

$$C = \frac{\chi}{Q} \times S \times V \quad . \qquad \textbf{(K-2)}$$

The atmospheric dispersion coefficients are obtained using the computer code GXQ, which uses the methods in the Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145 (Ref. 3). The atmospheric dispersion coefficient is the time-integrated normalized air concentration at the receptor for toxicological releases. For puff releases, the atmospheric dispersion coefficient is the instantaneous maximum concentration at the receptor. Only the plume meander correction was used in the calculations. The coefficients used to calculate dose or concentration are presented in Tables K-1. The acute release values were developed for weather conditions that result in downwind concentrations exceeded only 0.5% of the time in the maximum sector (16 sectors) or 5% of the time for the overall site. The larger of the two values was used as the integrated bounding value for on-site and off-site individuals. The chronic annual average χ/Q values were obtained by calculating chronic annual average values for each sector and using the highest one for calculation purposes. The value is suitable for long-term releases but not for accidents. All the releases analyzed in this safety assessment (SA) are either puff releases or releases that occur in less than 1 h. Thus, the plume meander correction or the chronic annual average values for the atmospheric dispersion coefficients are not used.

Reference 2 suggests that releases with a duration of less than 3.5 s must be treated as puff releases for the on-site receptor. Likewise, releases less than 420 s must be treated as puff releases for the off-site receptor.

This SA is also interested in releases from a 5-m (15-ft) tall stack. The atmospheric dispersion coefficients for this problem are not provided in References 1 and 2. The AI-RISK model,[4] which was previously used in the Tank 101-SY Mixer Pump SA,[5] was used to obtain the atmospheric dispersion coefficients for the stack releases.

For a ground point source release with no initial momentum and buoyancy, the 95% atmospheric dilution coefficient for a 100-m receptor is obtained as 3.26 E-02 using AI-RISK.[6] Thus, the AI-RISK results are in good agreement with the atmospheric dilution coefficient given in Table K-1 for an on-site receptor. There is no concern about off-site values because for toxic-gas releases analyzed in this SA, the off-site consequences are always less than 1 ppm (Sec. 5) and taking credit for the stack release in the calculation is not necessary. Table K-2, obtained from References 6 and 7, summarizes the AI-RISK results for the conditions of interest.

TABLE K-1
DISPERSION COEFFICIENTS

RECEPTOR	Continuous Release χ/Q (s/m^3)	Puff Release χ/Q (1/m^3)
On-site	3.44 E-02	9.85 E-03
Off-site	1.88 E-05	4.45 E-08

The receptor doses for a 1 m^3 or 1 m^3/s release of a pure toxic gas and summarized Table K-3 were obtained using the atmospheric dilution coefficients given in Tables K-1 and K-2.

K.2.2. Release of Toxic Solid/Liquid Waste

To determine the acceptance limits for liquid/solid waste material, WHC uses different types of composite waste for different tank groupings.[2] The risk associated with waste releases is divided into three categories: particulate, toxic effects, and corrosive effects. The chemical species in the composite waste are divided into toxic and corrosive bins. Within each bin, the allowable releases are computed using the "sum of the fractions" methodology. The minimum among the three categories (particulate, toxic, and corrosive) is chosen in each frequency range. For further details on the methodology used in determining the maximum acceptable waste releases, the readers are referred to Reference 2. The resulting maximum acceptable releases for single-shell tank liquid and solid releases are given in Table 5-4 in Section 5 of this SA. Note that the values reported in Table 5-4 represent the release quantities at the source because the atmospheric dispersion coefficients already are factored in arriving at these magnitudes.

TABLE K-2
ATMOSPHERIC DISPERSION COEFFICIENTS OBTAINED FROM AI-RISK

Release Type	χ/Q (s/m^3)
GROUND RELEASE, D = 0 m, V = 0.1 m/s, T = 300 K	3.26 E-02
STACK RELEASE (15 ft), D = 0 m, V = 0.1 m/s, T = 300 K	5.12 E-03
STACK RELEASE (15 ft), D = 0 m, V = 1 m/s, T = 300 K	5.12 E-03
STACK RELEASE (15 ft), D = 0.3 m, V = 0.1 m/s, T = 300 K	5.03 E-03
STACK RELEASE (15 ft), D = 0.3 m, V = 1 m/s, T = 300 K	4.24 E-03
STACK RELEASE (15 ft), D = 0.3 m, V = 10 m/s, T = 300 K	1.05 E-03
STACK RELEASE (15 ft), D = 0.1 m, V = 15 m/s, T = 300 K	2.20 E-03
STACK RELEASE (15 ft), D = 0.1 m, V = 23 m/s, T = 300 K	1.31 E-03

D: source diameter, V: source vertical velocity, T: source temperature

TABLE K-3
RECEPTOR DOSES FOR A 1-M^3 OR 1-M^3/S TOXIC-GAS RELEASE

	ON-SITE (ppm)		OFF-SITE (ppm)	
RELEASE TYPE	Cont.	Puff	Cont.	Puff
Ground, D = 0 m, V = 0.1 m/s	34,400	9850	19	5
Stack, D = 0 m, V = 0.1 m/s	5120	5120	19	5
Stack, D = 0.3 m, V = 0.1 m/s	5030	5030	19	5
Stack, D = 0.3 m, V = 1 m/s	4240	4240	19	5
Stack, D = 0.3 m, V = 10 m/s	1050	1050	19	5
Stack, D = 0.1 m, V = 15 m/s	2200	4240	19	5
Stack, D = 0.1 m, V = 23 m/s	1310	1050	19	5

K.3. REFERENCES

1. "Tank Waste Composition and Atmospheric Dispersion Coefficients for Use in Accelerated Safety Analysis Consequence Assessment," Westinghouse Hanford Company report WHC-SD-WM-SARR-016, Rev. 1 (October 1995).

2. "Toxic Chemical Considerations for Tank Farm Releases," Westinghouse Hanford Company report WHC-SD-WM-SARR-011, Rev. 1 (October 1995).

3. "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," US Nuclear Regulatory Commission Regulatory Guide 1.145, (USNRC, Washington, DC 1982).

4. Y. Y. Chien, and D. MacFarlane, "AI-RISK: A Computer Program for Calculating Doses and Health Risk from Accidental Release of Radioactive Materials," Los Alamos National Laboratory report LA-UR-92-2636, (July 1992).

5. L. H. Sullivan et al., "A Safety Assessment for the Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," Los Alamos National Laboratory report LA-UR-92-3196, Rev. 14 (March 31, 1995).

6. C. Unal, "Evaluation of Atmospheric Dispersion Coefficients at Elevated Discharge Temperatures, Velocities, Diameters and Release Heights by Using AI-RISK Computer Program," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-078 (August 1995).

7. C. Unal, "Toxicological Consequences of Ammonia and Nitrous Oxide Releases During Rotary Mode Core Sampling," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-104 (January 1996).

APPENDIX L

PROBABILITY OF GAS-RELEASE EVENTS DURING INTRUSION

L.1. BACKGROUND

In this appendix, a probabilistic model is developed to determine the gas-release event (GRE) characteristics during an intrusive operation in flammable-gas single-shell tanks (SSTs). The intrusive operations considered in this SA are rotary-mode and push-mode core sampling in flammable watch list tanks. Undoubtedly, some SSTs may have a GRE likelihood and consequences that are much lower than the ones obtained in this appendix. However, a tank-by-tank analysis was not the intent of this appendix.

As discussed below, there is very limited empirical information to develop such a probabilistic model based on data alone. Consequently, the model incorporates "expert judgment" combined with

- the limited data during intrusive activities in flammable-gas tanks,
- the information gained from laboratory experiments with simulants, and
- a general understanding of gas retention and release mechanisms in SSTs.

Because the approach has limited empirical support, the current model must not be used for eliminating safety features or defense-in-depth controls until further knowledge can be gained. The probabilistic model is merely intended for use in comparing the bounding consequences against the Westinghouse Hanford Company (WHC) Risk Guidelines (RGs) that require a realistic estimate of frequencies and allow for qualitative estimates for phenomena for which there are a lack of data. This safety assessment (SA) was developed using the following step-wise approach:

1. The most important issue is to develop a spark-management strategy that is appropriate for a hazardous flammable-gas environment such as the one summarized above and detailed in Appendix B of this SA.
2. The quantification of the reliability of the equipment used to protect against burns also must provide reasonable assurance that all practicable preventive measures are taken against burn accidents. It is believed that the equipment failure probabilities on the order of 10^{-4} to 10^{-5} per operation is acceptable, considering the type of operation. Appendices D and E show that this objective also is achieved in this SA.
3. The probabilistic GRE model discussed in this appendix was introduced only after the completion of these first two steps in order to obtain realistic accident frequencies.

The order in which these steps are taken is identical to the order in which this SA was developed. This order should not be reversed until further data and understanding for SST gas retention and release mechanisms are available.

In SSTs, burn accidents result in unacceptable consequences because even a small pressurization in the dome may result in dome failure, potentially followed by a catastrophic collapse. In order to meet the RGs, one must demonstrate that such burn accidents have a frequency of less than 10^{-6}/yr. However, burn accidents are not the only accidents that may result in dome failure. The design basis earthquake (DBE) has a return period of 7500 yr (frequency > 1 x 10^{-4}/yr). SSTs are designed to withstand a 0.20-g ZPA (zero-period acceleration), but there is high probability that a DBE of magnitude 0.20 g may produce structural failure of the dome because of potential cracks that occurred immediately after back-filling. Thus, the baseline dome collapse frequency for the SSTs is ~10^{-4}/yr, and this frequency is independent of rotary-mode core sampling (RMCS). Even if one assumes that the failure frequencies are equivalent to burn and dome collapse frequencies, the dome collapse risk is less than the base-line risk associated with a DBE as discussed above. Introducing the GRE probability only demonstrates that the incremental risk is negligible compared to the base-line risk.

The next stage is to convert the failure probabilities into accident frequencies. The major accidents in the flammable-gas tanks are burn accidents that require the existence of a flammable-gas mixture combined with an equipment failure resulting in a spark. In order to obtain realistic accident frequencies, one needs to know the probability of experiencing flammable-gas atmosphere in the regions where sparks can exist. Unfortunately, the potential gas-release volume, gas-release rate, and gas composition data necessary to develop such a model for SSTs are scarce. Likewise, the gas retention and release mechanisms for SSTs are not fully understood so that one may develop a realistic or bounding model of an expected GRE during waste intrusive activities. On the other hand, through the limited data obtained during similar intrusive activities, through educated estimates of the waste contents and properties pertinent to gas retention and gas release, and through laboratory experiments conducted with simulants, it is possible to obtain an expert opinion on the likelihood of GREs during intrusive activities.

In order to determine the GRE probability model, the recent data available from intrusive operations in flammable-gas SSTs and double-shell tanks (DSTs) was considered. The data and the conclusions are summarized in the next section. In Section 3, the probability distributions are obtained based on the implications of the limited data and "expert interpretation" of the existing knowledge. Section 4 summarizes and concludes this appendix.

L.2. AVAILABLE SOURCE OF INFORMATION

There are some data obtained during intrusive activities in SSTs that can be used to develop likelihood arguments for the GREs. Likewise, there is a limited amount of modeling performed for the gas retention and release mechanisms in the SSTs. However, given the uncertainty of the physical and chemical properties of the waste, such theories also must be used in accounting for large uncertainties associated with the quantitative results.

L.2.1. Summary of Available Data

WHC Characterization Field Engineering screened the recent flammable-gas concentration data obtained during and after intrusive activities in flammable-gas DSTs and SSTs.[1] A total of 49 intrusive sampling events (core sampling and auger sampling) alone were evaluated for 21 tanks sampled. One possible evidence of a GRE was observed in tank level data (A-103). Waste surface or liquid level drops for 34 of the sampling events showed no GRE. During 12 of the events, the plots had insufficient or non existent data on which to draw a conclusion. During two of the events, minor changes were observed during sampling activities, but the changes were well within the normal data scatter. Only one change for Tank A-103 during March of 1986 was questionable. The waste surface showed a 2.4 in. drop between March 24 and March 31, 1986. The level drop occurred when the lower segment samples were removed on March 25 to March 26, 1986. During the second core taken on March 31 through April 3, no level drop was observed.

No GREs were evident based on temperature data. Twenty-six of the activities' plots showed no evidence of a GRE activity. For 23 events the plots either had either insufficient or nonexistent data on which to draw a conclusion. If a rollover type of GRE were to have occurred, that would have been observed in the temperature data.

Tank vapor space monitoring data indicated three of the seventeen tanks monitored using a combustible gas meter (CGM) or other hydrogen monitoring equipment during waste-intrusive activities showed a very minor increase in the flammable-gas concentration during the sampling event. Three events showed small gas releases estimated to be ~50 ft^3. The dome vapor space never exceeded 9% of the lower flammability limit (LFL) during any of these events.

All the sampling activities contained in the database took place in tanks from the Flammable Gas Watch List (FGWL) or tanks recommended for the FGWL. Seventeen of these tanks are SSTs.

Reference 1 also provides observations during 38 liquid observation well (LOW) installations in SSTs in 1984. The database includes LOW installation in all the Flammable Watch List tanks except AX-103, which currently has a waste level of 42 in. During these activities, no flammable-gas monitoring was done. The temperature data are all insufficient to draw any conclusions, or are nonexistent. Waste surface level drop data showed that a GRE did not occur in 23 of the 38 installations. During seven events, the data were insufficient to draw any conclusions. During another seven events, small variations (well within the normal data scatter) were observed. Only one level change for SX-104 on May 24, 1984, was questionable. The waste surface showed a 2.1 in. drop. The data show that the level dropped on 1 to 8 days before the LOW installation. However, the potential exists that the data logs might have been off for a couple of days, and that the level drop actually occurred during the LOW installation.

Typically, ammonia can be smelled at 20 ppm. At higher concentrations, the smell can cause discomfort. No strong ammonia odor problem was reported during these activities. Because the SSTs typically do not have an active ventilation system, even small concentrations of ammonia in the dome space may result in exceeding the smell detection levels above an open riser. However, considering most of these activities took place more than ten years ago, it is likely that such occurrences (if they existed) are not in the data logs.

Likewise, no complete or partial temperature inversion (typical of rollovers) was observed during these activities. Also, no perturbations in the local temperature that would indicate waste motion were observed.

Unfortunately, these data cannot be formalized into a complete statistical model. The benefit of these data is to suggest that, qualitatively, a large GRE resulting in hazardous flammable-gas concentrations in the dome space is not a likely event during the intrusive activities. Quantitatively, the data may be used in a number of different ways:

It can be stated that 2 out of 87 activities resulted in a detectable GRE, suggesting a frequency of 2.3×10^{-2}. Accounting only for the activities in the SSTs, the probability becomes 2 out of 77 (2.6×10^{-2}). Also subtracting the activities in which the level data were inconclusive, the probability becomes 2 out of 58 (3.4×10^{-2}). However, this approach does not apply to a bounding tank, and at best it provides an overall probability of a GRE in the flammable-gas tanks. The LOWs are installed in A-101 (waste level ~345 in.) and AX-101 (waste level 278 in.), which have the largest waste volumes in the SSTs that are on the original FGWL. Tank A-103, which showed a 2.4 in. level drop between March 25 and March 26, 1986, also has a large waste volume (waste level ~370 in.). The other possible 2-to 3-in. level drop corresponds to Tank SX-104 that has less than 240 in. of waste.

A 3-in. level drop would correspond to 1600 ft^3 of gas release, assuming that the gas is originally compressed at 1.5 atm. Unfortunately, the level measurements were not taken frequently enough to estimate the release rate. No dome pressure data were reported in Reference 1 to assess the gas-release rate based on dome pressurization.

Another pertinent set of data analysis is provided in Reference 2. In this study, all the data from the original FGWL tanks were screened for GRE behavior. The study concluded that the tanks can be categorized in four groups:

Category 1: The tanks that exhibit neither periodic release behavior nor waste growth. Tanks 103-AX, 111-S, 112-S, 103-SX, 106-SX and 109-SX are in this category.

Category 2: The tanks that do not exhibit waste growth, but periodic release behavior is indeterminate. Tanks 101-AX, 101-SX, 102-SX, 103-SX, 104-SX and 105-SX are in this category.

Category 3: Tanks that exhibit periodic release behavior. Only Tank 101-A is in this category. These tanks exhibited 2-to 3-in. surface level variations between 1988 and 1993 that may be indicative of slow periodic releases.

Category 4: Tanks that exhibit waste growth but do not exhibit periodic release behavior. Tanks 102-S, 110-T, 103-U, 105-U, 107-U, 108-U, and 109-U are in this category.

It must be noted, however, that Reference 2 was primarily interested in natural GRE behavior as opposed to a GRE during an intrusion. Recent detailed analysis of the waste level history in Tank A-101 indicates that the observed level fluctuations are possibly not a result of periodic releases. They are likely to be caused by random measurement errors.[3]

L.2.2. Summary of Available Simulant Experiments

The experience with SST waste simulants is primarily developed at Pacific Northwest National Laboratory (PNNL). The discussion below provides a summary of the PNNL experience to date with SST simulants.** The simulants are aimed at simulating the physical characteristics of SST waste (sludge and salt cake) as opposed to chemical properties. The simulants are typically prepared using various clay, bentonite, and water mixtures, and gas is generated with the use of hydrogen peroxide.

Simulant experiments have been conducted to measure the retained fraction of gas generated within a simulant as a function of shear strength. These experiments were conducted without an overlying supernatant layer, which is typical of many SSTs. The results show that essentially all the generated gas is retained until a maximum retention capacity of the sludge is reached. Beyond the point of maximum retention, which is about 35% void, any additional generated gas and some of the retained gas is released. The results show that the maximum gas retention depends on the sludge shear strength. For the strongest sludges, the maximum retention is about 30% void. The maximum retention increases to a peak value of about 40% void as the sludge strength decreases. Together, these data show that sludges are quite capable of retaining a high void fraction of gas, and it can be inferred that it is difficult to release bubbles trapped in the sludge. To date, a few very qualitative experiments have been conducted in which small rods are inserted into the waste to initiate a release. These experiments have

** Private communications with P. Gauglitz (PNNL) and K. Pasamehmetoglu (LANL) (February 1996) and a desk-top demonstration by P. Gauglitz (PNNL) at the January 17, 1996, Flammable Gas Data Review meeting.

shown that the intrusion releases a small amount of retained gas, and that the release comes out of a region immediately adjacent to the intrusion.

Another interesting set of simulant experiments conducted by PNNL is related to the effect of the supernate thickness on the rollover strength. Some SSTs show a thin layer of supernate on top of the sludge layer. The experiments show that with thick supernate layers the rollover is quite energetic, and a substantial amount of gas is released. On the other hand, the rollovers with thin supernate layers are very un-energetic, and very little gas (if any) is released during the rollover.

While developing a rigorous statistical model based on simulant experience alone is not appropriate, the simulant data are quite valuable in developing a best-estimate prediction for the GRE behavior in SSTs.

L.2.3. Summary of Available Models

The DSTs on the FGWL all indicate that there may be a convective layer over the nonconvective layer where the gas is trapped. The prompt gas-release mechanism is postulated to be the density inversion or the Rayleigh-Taylor instability.[4] The observation of the axial temperature profiles and the waste types that are in the SSTs do not support the Rayleigh-Taylor instability as being a likely gas-release mechanism. Likewise, the waste-level history of the SSTs does not show rather rapid level increases followed by sudden level drops that were observed, for instance, in Tank 101-SY during and after a rollover.

A necessary condition for a rollover is the existence of a density inversion, where a layer becomes less dense than the layer above it. This implies that the layer above has been able to release gas generated in it, while the layer below is retaining the generated gas. In an SST with a significant supernatant layer or convective layer (CL), then most of the gas generated in that layer will be released. If the layer below the supernatant or CL has sufficient strength to retain most of the generated gas, a density inversion can develop. A rollover will result when the hydrostatic forces between the two layers are sufficient to cause the lower layer to flow as a fluid. This illustrates the second condition necessary for a full tank rollover; the lower layer waste strength must be large enough to retain gas, but not large enough to preclude fluid flow under hydrostatic forces. If the lower layer strength is too large, then a full tank rollover does not occur and gas is released through local eruptions and/or mini-rollovers. Without a significant supernatant level or CL, it is possible in an SST that there be significant variations in waste properties between two layers so that the upper layer releases gas while the lower layer retains gas. However, if this were occurring, then a continuous level growth would be observed until the rollover of the lower layer. Also, even during an unlikely event of a rollover in an SST, the rollover is expected to progress very slowly, and gas-release rates are expected to be much smaller than the gas-release rates observed in DSTs (e.g., 101-SY).

A semi-qualitative evaluation of gas-release mechanisms in SSTs is provided in Reference 5, which suggests that while rollover is possible in the SSTs, it is not a likely mechanism. Because of the limited volume of the supernatant liquid, during an unlikely rollover event, the gas releases would be small. Also unlikely is a mechanism whereby large bubbles (1 m diameter) are stored in the waste and released during an intrusion. Intrusion into the largest expected bubble based on conservative estimates of waste properties, indicates that 350 ft^3 of retained gas could be released over an ~20 minute time period. The total release during this unlikely mechanism also is postulated to be small. The most likely mechanism that could lead to a large gas release appears to be a "mud pot" fed by dendritic bubbles if a chimney is opened to the dendritic bubble region as a result of the intrusion. The calculations reported in Ref. 5 indicate that 700 ft^3/h releases may be expected through this "unlikely" mechanism. Finally, the fracture of a dry sludge or dry salt cake are other possible, but unlikely, mechanisms quoted in Ref. 5. Releases through this mechanism are estimated to be at a smaller rate than the 700 ft^3/h value obtained for the "mud pot" mechanism.

During RMCS operations, the drill string is rotated at 55 rpm and a nitrogen purge flow of 30 ft^3/min is used. If it is assumed that the drill string disturbs a region that is 20 times its diameter (4 in.) and is inserted at 2 in./min, the gas volume disturbed would be ~1 ft^3/min (assuming a conservative void of 20% in the waste) resulting in a total release of less than 200 ft^3. However, nitrogen purge also may scrub soluble ammonia out of the waste. Conservatively, assuming that the ammonia partial pressure in the waste is 0.6 atm and that ammonia comes in equilibrium with nitrogen instantaneously, an ammonia release rate may be obtained as 45 ft^3/min. This value is in agreement with the conservative magnitude obtained in Ref. 6. However, such a high ammonia release rate would be possible until the liquid immediately around the drill string is depleted and a mass transfer resistance to ammonia forms in the liquid. Thus, the total release volume would be < 500 ft^3 (Ref. 6). Based on these discussions, one could argue that the release rates during RMCS would be ~1 ft^3/min for insoluble gases. Large ammonia releases rates are possible for a short period during drilling.

Among the 19 SSTs that are on the original FGWL, A-101 has the largest waste volume. Based on the available data, a data reconciliation analysis for the gas inventory of A-101 was performed.[3] The results indicate that the gas inventory estimate for A-101 is 6300 ft^3 with a standard deviation of 1300 ft^3. Thus, the gas inventory for this tank, at two standard deviations level, would be less than 9000 ft^3.

The gas-release mechanisms during salt well pumping (SWP) of A-101 are discussed in Reference 7. During SWP operations, liquid waste will drain from the waste into the salt well and reduce the effective hydrostatic head as seen by the retained gas bubbles. The reduced hydrostatic head and liquid level in the waste can be related to the gas-release volume and rate. Gas-release rates for a given liquid drainage rate depend upon the assumed bubble size and distribution. Based on a range of assumed conditions the calculated gas-release rate was typically less than 1 to 2 ft^3/min.

L.3. PROBABILISTIC MODEL

In this section, the knowledge developed by the limited data, limited modeling results, and the expert-judgment are set into a probabilistic model. In order to develop a probabilistic model of reaching or exceeding hazardous conditions in the dome space, one needs probabilistic models for the gas-release rate, the gas-release volume, and the gas composition. These models may then be combined into a hydrodynamic model of dome space to compute the consequences of different-sized gas releases.

First, the discussion provided in the previous section is cast into a qualitative model. The qualitative likelihood matrix is provided in Table L-1. In Table L-1 qualitative likelihood definitions included following frequencies; a-Range 1 is defined as an event with a frequency of 1, b-Range 2 is defined as an event with a frequency of 10^{-1}, c-Range 3 is defined as an event with a frequency of 10^{-2}, d-Range 4 is defined as event with a frequency of 10^{-3}, e-Range 5 is defined as an event with a frequency less than 10^{-3}.

TABLE L-1
QUALITATIVE LIKELIHOOD MATRIX FOR GAS-RELEASE VOLUMES AND RATES

	Volume (ft^3)			
Rate (ft^3/min)	**100**	**500**	**2500**	**10,000**
1	Range 1	Range 2	Range 3	Range 4
10	Range 2	Range 2	Range 3	Range 4
100	Range 3	Range 4	Range 4	Range 4
1000	Range 4	Range 4	Range 5	Range 5

The gas-release volume break-down in Table L-1, is based on unnoticeable level drop (100 ft^3), 1 in. level drop (~500 ft^3), 5 in. level drop (2500 ft^3) and nearly 20 in. level drop (10000 ft^3). The data that is considered in Section 2.1. shows that a level drop > 2.5 in. was not observed in any of the intrusive activities covered in the database.

The rate range shown in Table L-1 is obtained by considering the orders-of-magnitude, based on the discussions provided in the previous section. Even at slow release rates, larger release volumes are less likely because:

1. Typically release will occur from the waste volume immediately around the intrusive device, and

2. Flammable gas monitors will detect the gas release and terminate waste penetration, which is expected to stop the induced gas release.

For release volumes that are never observed in the SSTs, a qualifier of "Range 3" is assigned. The existing models do not predict release volumes corresponding to Range 3 and less likely categories, except for a rollover and seismic event that can liquefy the waste by vigorous shaking. Even for these Range 3 events the release volume is limited by the fraction of total retained gas. The maximum values shown in Table L-1 (10,000 ft^3) corresponds to the largest GRE volume observed in Tank 101-SY before mitigation. Similar events have not been observed in any of the SSTs.

The rate range shown in Table L-1 is obtained by considering the orders-of-magnitude, based on the discussions provided in the previous section. Only rollovers and seismic shaking may result in release rates on the order of 100 ft^3/min or greater, while resulting in large release volumes. There is a remote possibility of tapping into a high pressure gas region which may result in large release rates but a very small volume. Thus, while small volume releases at high releases rates are believed to be Range 4 events, large volumes with large releases rates are in Range 5 event category.

The qualitative matrix may be quantified for the gas-release volume and gas releases rates assuming that these two are independent parameters. In the quantification process, the following probabilities were assigned: a probability of 1 for Range 1 event, 10^{-1} for Range 2 event, 10^{-2} for Range 3 event and 10^{-3} for Range 4 event. Thus, the quantitative results may be approximated as a logarithmic distribution given by

$$P(Q' \geq Q) = \left(\frac{Q}{100}\right)^{-1.5} \quad \text{for} \quad Q \geq 100\,\text{ft}^3. \qquad \textbf{(L-1)}$$

Likewise, the release rate may be approximated by a logarithmic distribution given by

$$P(q' \geq q) = (q)^{-1} \quad \text{for} \quad q \geq 1\,\text{ft}^3/\text{min}. \qquad \textbf{(L-2)}$$

L.3.1. Effect of Release Volume and Release Rate on Dome Concentrations

This section, the relationship between the gas-release rates and the peak dome concentrations are quantified. In order to quantitatively assess the reduction in the flammable-gas inventory, the following simple mathematical model is used for the dome space waste gas concentration: [8]

$$V\frac{dX}{dt} = q - X \cdot f \quad , \qquad \textbf{(L-3)}$$

where V is the dome volume = 1416 m^3 (50,000 ft^3),

X is the dome-averaged waste gas concentration,

t is the time,

q is the waste gas-release rate into the dome, and

f is the entilation flow rate.

For simplicity, it is assumed that the gas-release rate is constant and the gas release is modeled as a pulse function as illustrated in Fig. L-1. Thus, the gas release is characterized by the following parameters (only two of them are independent): q: gas-release rate, T: gas release duration, and Q: total gas-release volume (Q = q x T).

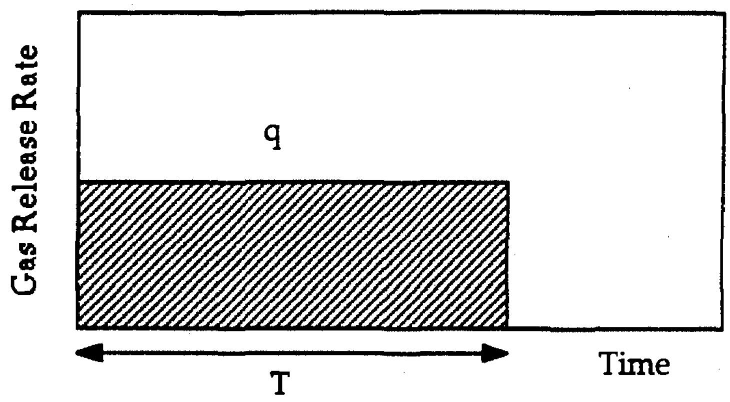


Fig. L-1. Gas-release rates as a function of time.

The solution for Eq. (L-3) is obtained as

$$X(t) = \begin{cases} \frac{q}{f}\left[1 - \exp\left(-\frac{f}{V}t\right)\right] & \text{if } 0 \le t \le T \\ \frac{q}{f}\left[1 - \exp\left(-\frac{f}{V}T\right)\right]\exp\left[-\frac{f}{V}(t-T)\right] & \text{if } t > T \end{cases} \qquad \text{(L-4)}$$

where it is assumed that the initial concentration in the dome (before the beginning of the gas-release event) is zero. The peak dome concentration is obtained as

$$X_{max} = \frac{q}{f}\left[1 - \exp\left(-\frac{f}{V}T\right)\right] = \frac{q}{f}\left[1 - \exp\left(-\frac{f}{q}\frac{Q}{V}\right)\right] . \qquad \text{(L-5)}$$

If q > f (which is always the case when active ventilation is not available), the discharge rate is set equal to the gas-release rate during a gas-release event. Thus, the solution of Eq. (L-3) becomes

$$X(t) = \begin{cases} 1 - \exp\left(-\frac{q}{V}t\right) & \text{if } 0 \le t \le T \\ \left[1 - \exp\left(-\frac{q}{V}T\right)\right]\exp\left[-\frac{f}{V}(t-T)\right] & \text{if } t > T \end{cases} \qquad \text{(L-6)}$$

The peak concentration for this case becomes

$$X_{max} = 1 - \exp\left(-\frac{q}{V}T\right) = 1 - \exp\left(-\frac{Q}{V}\right) \quad . \tag{L-7}$$

As shown by Eq. (L-7), when the gas-release rate is greater than the ventilation flow rate, the peak concentration is independent of the release rate and is a function of the release volume only. This is also illustrated in Fig. L-2 that shows the peak dome concentrations for Q = 2000 ft^3 (Q/V) = 0.04 as a function of q/f. As shown in this figure, for q/f > 0.4, the peak concentration is nearly independent of the gas-release rate. At q/f < 0.4, the peak concentration rapidly decreases with decreasing q/f. But even at q/f = 0.1, the peak concentration decreases to 3.3% compared to the maximum value of 3.9%.

Based on these discussions, one could argue that, for a ventilation flow rate of 200 ft^3/min, for gas releases > 10 ft^3/min, the gas-release rate has a minimum effect on the final results. On the other hand, for gas releases around 1 ft^3/min, the ventilation flow substantially suppresses the peak concentration for an extended period of time. The peak concentration in the dome for a 1 ft^3/min gas-release rate would be 5000 ppm, regardless of the release volume.

L.3.2. Gas Composition

There is considerable uncertainty in the gas composition as discussed in Appendix C. The maximum hydrogen concentration may be as high as 90% (App. B). However, that estimate assumes that there is no nitrogen, ammonia, or water vapor in the release gas (all of those species are known to exist in the waste gases). Without any ammonia, the LFL for this hydrogen-rich mixture would be 4%. Based on discussions provided in Appendix C, a bounding ammonia fraction of 60% may be used for the SSTs.

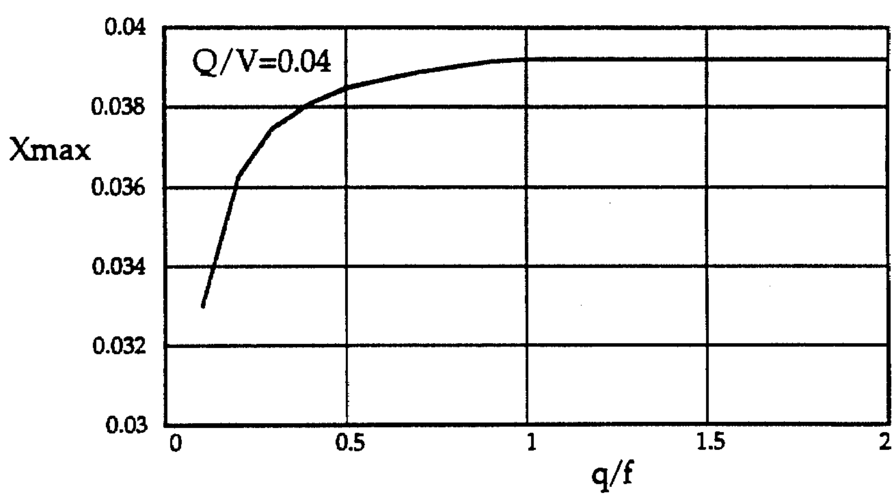


Fig. L-2. Peak dome concentration as a function of gas-release rate.

Adding ammonia (that is also known to exist) reduces the LFL. For a given release volume, a larger ammonia fraction in the released gas would imply a smaller hydrogen fraction. Thus, a larger release volume is needed to reach the LFL. The net effect is that the most conservative case is the maximum hydrogen in the waste gas even though the LFL for that mixture is the highest. While it is still bounding, the use of 50% hydrogen in the waste gas would be a good estimate for probability calculations. In the subsequent analysis, a uniform distribution is used for hydrogen between 50% and 90% and conservatively assume that the rest of the gas is ammonia. Neglecting the other gas species, which are also known to be generated in the waste, provides an additional degree of conservatism in the above calculations.

L.3.3. Time-at-Risk Estimates

Another important parameter for the burn probability estimates is the time-at-risk. The time-at-risk is the period of time when the dome volume remains above the LFL. The results of the ventilation study documented in Ref. 8 are shown in Fig. L-3 for different release volumes. For this example, it is assumed that the ventilation flow rate is 250 ft^3/min and that the dome volume is 50000 ft^3. The hydrogen concentration in the release gas is 90%, and the LFL is 4%. Figure L-3 is provided as an example without crediting the expected low release rates. The results of more detailed calculations are given in the next section.

L.4. RESULTS

A code was written to perform the following tasks:

(1) perform Monte Carlo sampling from probability of frequency distributions for: gas-release rate, gas volume, and gas composition,

(2) calculate dome gas thermodynamic properties for each set of sampled gas release values, and

(3) bin the calculated thermodynamic gas properties into various bins to provide probability of frequency distributions for these thermodynamic properties.

Equation L-1 was used for the probability of frequency distribution for the gas-release volume. Equation L-2 was used for the probability of frequency distribution for the gas-release rate. The exhauster was assumed to run continuously through the GRE. Stopping the drilling operations upon detection of flammable gases and potentially stopping the gas release is not modeled. Using information from WHC, the exhauster flow rate was set at 200 ft^3/min and the initial tank pressure was set at -0.5 in. w.g. Nitrogen cooling flow to the drill bit was set at 35 ft^3/min. The details of the analysis are provided in Ref. 9.

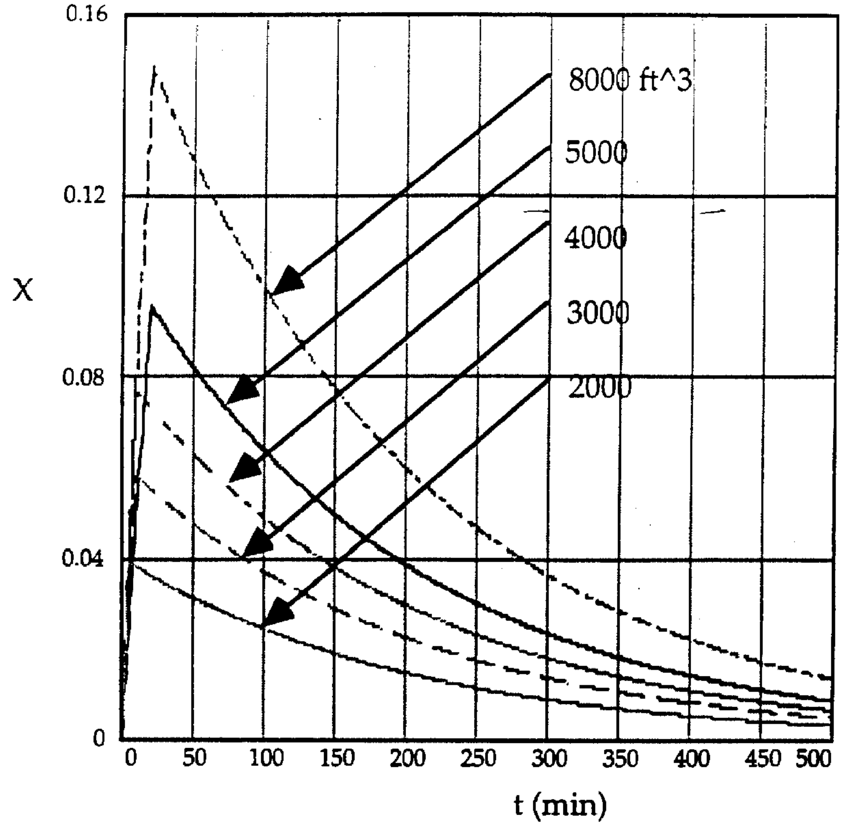


Fig. L-3. Dome space concentration as a function of release volume and time.

A uniform probability density function was used for the fraction of hydrogen in the gas between a lower limit of 0.5 and an upper limit 0.9. The fraction of the gas that was not hydrogen was assumed to be ammonia.

In these calculations, a uniform dome mixing was assumed. Three-dimensional analysis show that for ventilation flow rates ≥ 200 ft^3/min, the release gases mix fairly uniformly in the dome space.[10]

L.4.1. LFL Results

A sample size of 400,000 was used. The probability that LFL is exceeded in the dome and that the tank pressure is positive was calculated to be 7.0E-5. The probability of exceeding twice the LFL is 3.5E-5.

The mean time that LFL was exceeded in the dome was calculated to be 0.12 minutes. Using a mission time of 144 hours, this implies that the probability that LFL is exceeded during an event that is random in time is: 0.12/(144*60) = 1.4E-5.

In these calculations, a conservative estimate of the LFL is used to define the hazardous conditions because the calculations given in Ref. 10 show that the release gases mix fairly uniformly in the dome space with a ventilation flow rate ≥ 200 ft^3/min. Thus, as long as the ventilation is operable, the probability of a plume burn in or above the dome space is very unlikely. However, if the ventilation system fails, the probability of a plume burn in the dome increases because uniform mixing in the dome may not occur.

There are two accident scenarios for failed ventilation:

1. Ventilation fails without tripping the drilling operations that subsequently cause a GRE;

2. Ventilation fails during a GRE; and

3. Ventilation is intentionally shut down because of high flow (> 250 ft^3/min)

The simple calculations given in Appendix C show that the dome pressure limit may be exceeded if a waste gas volume of 1000 ft^3 is burned in the dome space. This volume corresponds to a dome concentration greater than 25% of the LFL. Using the above models, the probability of exceeding 25% of the LFL in the dome space is < 5E-2. The combined probability of ventilation failure (conservatively estimated as 0.1/activity) and failure to shut down the drilling operations (1.4E-3) is estimated as 1.4E-4 per activity. Thus, the frequency of exceeding 25% of the LFL during RMCS operations without ventilation is 7E-6/activity, which is an order of magnitude smaller than the frequency of exceeding the LFL.

For the second scenario, the mean time above the LFL and 25% of the LFL are obtained as 0.12 min and 5 min, respectively, during an activity. Using the conservative estimate of 0.1 failure per activity (144 h), the failure probability during the time period while the dome is above the LFL is 1.4E-6. The failure probability while the dome is above 25% of the LFL is 5.8E-5. These numbers are smaller than the probability of exceeding the LFL while the ventilation is operable.

Finally, the intentional exhauster trip is considered in the analysis. The exhauster trips if the flow rate exceeds 250 ft^3/min. During a rapid gas-release event, the exhauster flow rate is expected to exceed the nominal 200 ft^3/min flow rate. The probability of exceeding the 250 ft^3/min flow rate is calculated as 2.5E-3. The probability of exceeding the 250 ft^3/min flow rate for more than 1.5 min is calculated as 4E-5. The exhauster trip is delayed by 5 min once the 250 ft^3/min limit is exceeded. This design feature minimizes the possibility of losing the exhauster as a result of excessive flow during a GRE.

L.4.2. Toxic Gas Releases

To provide information for evaluating release of toxic gas, the code was run with a fixed concentration of 60% ammonia and a sample size of 50,000. The results are summarized in Table L-2.

TABLE L-2
PROBABILISTIC RESULTS FOR DOME SPACE AMMONIA CONCENTRATIONS

Concentration Bins	Positive Dome Pressure	Negative Dome Pressure
0 - 6000 ppm	6.2E-03	9.7E-01
6000 - 10,000 ppm	5.2E-04	1.8E-02
10,000 - 25,000 ppm	2.4E-04	5.9E-03
25,000 - 50,000 ppm	1.0E-04	5.6E-04
> 50,000 ppm	2.0E-05	1.0E-04

L.4.3. Conclusions

In this appendix, a quantification of the GRE probabilities are presented based on the best-estimate interpretation of the state of knowledge of gas releases during intrusion in the SSTs. The probability values quoted in this appendix may be used in evaluating the best-estimate accident frequencies in comparing the conservative accident consequences with the risk guidelines. An uncertainty analysis is not performed because such an analysis is not required for accident frequency estimates. However, although point estimate GRE probabilities are combined with failure rate frequencies in Section 4 of this SA, the GRE probabilities must be viewed as order-of-magnitude estimates. At least an order-of-magnitude uncertainty must be considered in making decisions critical to the safety of the RMCS operations.

In the accident analysis (Section 4 of the SA), two probability numbers were used. For potentially continuous (if the GRE is undetected) spark sources, the probability of exceeding the LFL is used as 7E-5. For spark sources that are random in time, the ratio of mean time at risk to the total mission time (144 h) is used as 1.4E-5. This analysis is based on the assumption that a waste-intrusive event triggers a large enough GRE to result in exceeding hazardous conditions. Without intrusion, a natural release that exceeds the LFL is assumed to be less likely than an event during intrusion. A detailed analysis of Tank 101-A level data indicates that periodic natural releases in that tank are very unlikely[3] and that the maximum level changes are not sufficient to result in a GRE that exceeds the LFL. However, all the tanks are not analyzed to the same level of detail as Tank A-101. Consequently, a GRE probability is a checklist item that must be addressed for each specific tank (see Section 7 of this SA).

L.5. REFERENCES

1. J. S. Schoefield, "Evidence of Release Events During Waste Intrusive Activities in Flammable Gas Watch List (FGWL) and Proposed FGWL Tanks," Westinghouse Hanford Company internal memorandum to B. Barton (February 21, 1996).

2. B. D. Nichols, S. W. Eisenhawer, and J. W Spore, "Bounding Gas Release Calculations of Flammable Gas Watch List Single-Shell Tanks," Los Alamos National Laboratory report, LA-UR-94-1323 (1994).

3. W. L. Kubic, "Summary, Review and Analysis of Data for Tank 241-A-101," Los Alamos National Laboratory Calc-Note, TSA10-CN-WT-SA-DA-001 (January 1996).

4. L. H. Sullivan et al., "A Safety Assessment for the Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," Los Alamos National Laboratory report LA-UR-92-3196, Rev. 14 (March 31, 1995).

5. R. T. Allemann, "A Discussion of Some Mechanisms for Sudden Gas Release from Single-Shell Waste Tanks," Pacific Northwest Laboratory letter report PNL-WTS-101095 (October 1995).

6. J. D. Hudson, B. J. Palmer, and C. W. Stewart, "The Potential for Flammable Concentrations of Ammonia Resulting from Core Drilling Operations," Pacific Northwest National Laboratory letter report PNL-WTS-112295 (November, 1995).

7. J. W. Spore, "Conservative Gas Releases for Tank 241-A-101," Los Alamos National Laboratory Calc-Note, TSA10-CN-WT-SA-GR-046 (January 1996).

8. K. O. Pasamehmetoglu, "Issues Associated with the Use of An Exhauster During Saltwell Pumping Activities in Single-Shell Tanks that are on the Flammable Gas Watchlist" Los Alamos National Laboratory Calc-Note, TSA10-CN-WT-SA-TH-107 (January 1996).

9. J. L. Darby, "Monte Carlo/Thermodynamic Model for Dome Gases", Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-114 (February 1996).

10. P. Sadasivan, "Effects of Exhauster Flow Rates on Consequences of a GRE in 101-A," Los Alamos National Laboratory Calc-Note, TSA10-CN-WT-SA-GR-054 (February 1996).

APPENDIX M

UNFILTERED RELEASES AND NITROGEN ADDITIONS

M.1. INTRODUCTION

In this appendix, the unfiltered releases are quantified and the effect of nitrogen addition are discussed during rotary-mode core sampling (RMCS) operations. First, in the next section, the amount of aerosol that is suspended in the dome space during RMCS operations is discussed.

M.2. DOME LOADING DURING RMCS OPERATIONS

During drilling operations, aerosols will be carried into the dome. Some will be transported to the high-efficiency particulate air (HEPA) filter, while others will settle out on the crust. In this appendix, an estimate is given of the bounding value for the mass of aerosols to be found in the tank dome during drilling operations.

The TRAC-TE code was developed by Science Applications International Corporation to calculate the mass of aerosols that would be carried to the HEPA filter during drilling operations. Part of the results output from the code is the mass of aerosols found in the dome under various operating conditions. This code and the results of calculations are discussed in Reference 1; however, this code is not available to us at this time. Thus, the analysis presented in these notes is based on the results of analyses using the TRAC-TE code found in Reference 1.

In Appendix G of Reference 1, the results for two relevant bounding cases of salt drilling, calculated using TRAC-TE, are presented. The two relevant cases presented are based on 700 scfm flow. The results are based on a total drilling depth of 266 inches and a schedule of 40 minutes of drilling (19 inches) followed by 60 minutes delay before starting the next drilling period. In Case 1, Appendix G-1 of Reference 1, the exhauster is on only during drilling, but in Case 2, Appendix G-2 of Reference 1, the exhauster is on continually. The results take into account the settling of the aerosol created and the flow of material up the stack to the HEPA filter. The cases are referred to as bounding because they maximize the amount of material transported to the stacks. The results for the first 700 minutes, i.e., seven drilling and waiting periods for these two cases are given here in Table M-1. Note that equilibrium has been reached.

The results in Table M-1 have simply been extracted from Appendix G-1&2 of Reference 1. The results given are the amount of material in the dome, up the stack, or cumulative grams made airborne at the end of the time period given. The amount of material made airborne in any 40 minute drilling period, 3106 grams, is the total amount drilled minus the 1 in. diameter sample. This would be a 2.5 in. diameter and 19 in. long cylinder less the 19 in long and 1 in diameter sample.

TABLE M-1
GRAMS OF AEROSOL IN THE TANK DOME AND GRAMS TRANSPORTED UP TO STACK FOR 700-SCFM FLOW

Time (minutes)	Total (grams made airborne)	Case 1 on during drilling (grams in dome)	Case 2 continuous exhauster (grams in dome)	Case 1 on during drilling (grams up stack)	Case 2 continuous exhauster (grams up stack)
40	3106	249	249	131	131
100	3106	44	17	0	59
140	6212	262	254	149	138
200	6212	52	19	0	62
240	9318	266	255	152	138
300	9318	55	19	0	62
340	12424	267	255	154	139
400	12424	56	19	0	62
440	15530	267	255	154	139
500	15530	56	19	0	62
540	18636	267	255	154	139
600	18636	56	19	0	62
640	21741	268	255	154	139
700	21741	57	19	0	62

An exhaust flow of 250 scfm (rather than a flow of 700 scfm) with continuous exhauster flow is closer to actual operating conditions. The amount of material going into the stack over the entire time period, i.e., 1440 minutes, for the 250 scfm case is given in Table 2 of Reference 1, but the amount of material in the dome is not presented. In Table 2 of Reference 1, the same information is given for 700 scfm and has been taken from the results presented in Appendix G-2 of Reference 1. However, it is the equilibrium material in the dome at 250 scfm that is of interest here, and this value will be determined below.

The material given that goes into the stack, according to Reference 1, contains only those particles with a diameter less than 5.5 µm. Reference 1, page 11, states, "These values assume that the low transport velocities in the exhaust riser can carry only smoke sized particle, 5.5 µm and less, out the riser." Note that this is conservative since the objective here is to determine the maximum amount of material in the dome.

From Table 2 of Reference 1, the amount of material going up the stack is 901 grams for the 250-scfm case and 1741 grams for the 700-scfm case at the end of 1440 minutes. Thus, when the flow is 250-scfm, only 52% of the material flows out the stack when compared with the flow in the 700-scfm case for continuous exhauster flow.

Referring to Table M-1, note that for Case 2 at equilibrium there are 255 grams in the dome and 139 grams going up the stack. If the flow is reduced to 250 scfm, then it is assumed that 48% (100%-52%) of this 139 grams will remain in the dome. Because some of this material will also settle, a conservative first estimate value of material in the dome is:

$$255\text{g} + 0.48 \times 139\text{ g} = 322\text{ g}.$$

Note that there is a compounding factor. Table 2 of Reference 1 is based only on those particles less that 5.5 µm. However, Table M-1 here assumes that all size particles flow up the stack. Referring to Table G-2 of Reference 1, it is found that 39% of the mass of airborne particles calculated to escape are larger than 5.5 µm at the end of the 700 minutes. It is expected that this mass to remain in the dome. Thus, as a bounding value, this mass should also be added to the mass in the dome. Thus, the bounding value for the material in the dome is:

$$255\text{ g} + 0.39 \times 139\text{ g} + 0.48\,(0.61 \times 139\text{ g}) = 350\text{ g}.$$

This calculation states that 39% of the material that is calculated to go up the stack will not do so because of size, and it is assumed that it will remain in the dome. Of the remaining 61% that would go up the stack in the 700-scfm case, 48% will remain in the dome in the 250-scfm case of interest here. This material that was earlier calculated to go up the stack is assumed not to settle out of the dome.

A less conservative value may be found by assuming a fraction of this material now remaining in the dome will settle out. An estimate of the amount that may settle out is 94%, which is based on the results given in Appendix G-2 in Reference 1. Thus, the less conservative, but more realistic, value is

$$255\text{ g} + 0.06[(0.39 \times 139\text{ g} + 0.48(0.63 \times 139\text{ g})] = 261\text{g}.$$

Hereafter, the bounding value of material found in the dome during drilling operations is 350 g for the continuous exhauster operation at 250 scfm. Prior to RMCS operations, there may be additional suspended waste in the dome. To bound the background concentration, 600 g (1.32 lb) of aerosol in the tank dome is used. This number is used in the safety assessment of mixer pump operations[2] in the 101-SY tank and is based on a very conservative fog limits during a rollover. Typically, quasi-steady particulate concentrations less than 100 mg/m^3 are expected for SSTs. For a 1416-m^3 (50,000-ft^3) dome, the maximum amount would be 142 g (0.31 lb). Note that the unfiltered releases discussed in the next section are inversely proportional to the dome volume. Consequently, they are directly proportional to the concentration and the releases would not be affected by the larger dome volumes. Thus, total aerosol in the dome during RMCS operations may be bounded conservatively by ~0.6 kg (1.3 lb).

M.3. UNFILTERED RELEASES

The following unfiltered releases are considered in this appendix:

- Release as a result of a gas-release event (GRE) during operation or removal (including material entrained from the drill string as a result of decontamination system failure);
- Continuous release from the exhauster after HEPA failure; and
- Continuous releases during open riser period with ventilation failure.

Releases from spill accidents or HEPA filter failures are considered separately.

M.3.1. Unfiltered Releases Caused by a GRE

Unfiltered releases can occur in operation and removal. During installation, before intruding into the waste, a gas release event is not expected; therefore, only the operation and removal phase will involve unfiltered material releases.

One can estimate the amount of material entrained out of the tank during a GRE using the following simple equation:

$$M_T = M_o \frac{Q}{V} \quad , \qquad \textbf{(M-1)}$$

where Q is the total gas release into the dome, M_0 is the initial dome loading [0.6 kg (1.3 lb)], and V is the dome volume [1415.8 m^3 (50,000 ft^3) based on Reference 3]. This simple model is based on the following assumptions:

1. The aerosol waste generated by the drilling and the waste gas released during a GRE are homogeneously mixed in the dome space;

2. The waste gas mixes homogeneously in the dome during a GRE;

3. The gas release rates are high enough to pressurize the dome [which is conservative for GREs expected in the single-shell tanks (see App. L)]; and

4. All the suspended material flows out of an open riser that is not protected by a HEPA filter (this is also very conservative because the inlet and exhaust headers are equipped with HEPA filters).

Using the probabilistic model developed in Appendix L combined with the conservative assumptions listed above, the resulting waste release from an open riser is tabulated as a function of the gas release as shown in Table M-2.

The release rates are computed for toxicological consequence analysis which require a 15-min average value. Thus, it is assumed that the total release occurs over a 15-min period. This assumption is conservative because the release rates for the three cases analyzed about would be greater than 66 ft^3/min, 333 ft^3/min, and 666 ft^3/min, which are comparable to 101-SY rollover releases.[2] Such high release rates are not expected for the SSTs (see Appendix L).

These releases are applicable to removal and operation time periods. During operation, however, the nitrogen purge system must fail for an unfiltered release to occur through the open riser. Thus, the likelihood of an unfiltered release during operation is much lower than a release during removal.

TABLE M-2
UNFILTERED AEROSOL RELEASE AS A FUNCTION OF GAS RELEASE

Frequency (per activity)	GRE Volume (ft^3)	Material Release (g)	Release Rate (g/s)
10^{-2} (anticipated)	1000	12 g	0.013
10^{-4} (very unlikely)	5000	60 g	0.07
10^{-6} (extremely unlikely)	10000	120 g	0.13

Another scenario is concerned with a GRE during removal with a contaminated drill string. The amount of waste on the drill string (inside or outside) during removal could vary. Under normal conditions, waste should not be inside, and the outside is decontaminated. If the decontamination is not effective or failed and a GRE occurs during removal, additional waste would be entrained from the contaminated drill string. To estimate the entrainment, it is assumed that there is a 3-mm-thick waste layer on one 19-in. drill rod. Note that each drill rod is removed individually. The total amount of waste on one drill rod becomes 370 g. It is assumed that 1% of this amount would be entrained resulting in an additional 3.7 g. This scenario assumes the failure of decontamination and seal or sampler latching. Thus, the frequency of the additional release is much lower than the frequencies listed in Table M-2. Considering the conservative assumptions made in obtaining the results in Table M-2, any additional releases resulting from decontamination failure combined with a GRE are neglected.

M.3.2. Continuous Release through the Exhauster After HEPA Failure

This scenario is concerned with the releases through the exhauster if the HEPA filters fail. The failure of the HEPA filters will be detected by the high flow or low pressure drop readings. Failure to shut down the exhauster will result in unfiltered material release. The frequency of this accident is dominated by the failure to shut the exhauster down following a HEPA failure, which is in the unlikely to extremely unlikely range. The maximum ventilation flow rate is 250 ft^3/min (0.12 m^3/s). Based on a 1-kg (2.2-lb) dome loading, a continuous release of 0.08 g/s will be experienced. Thus, the consequences of material release caused by a GRE bounds this accident.

M.3.3. Continuous Release with Ventilation Failure

If the riser is open and the gauge pressure inside the tank becomes positive, an unfiltered release will occur. Ventilation system failure with open-tank conditions has been identified as one of these conditions. Controls are established to help ensure that this kind of release is minimized. No operation can be started if the ventilation system is not working properly. However, the ventilation system can fail during the periods when the riser is open. If the ventilation system were to fail to maintain pressure inside the tank at less than atmospheric pressure, the continuous generation of gases in the tank would cause a release. In comparison to other releases driven by a GRE, this release is small. The gas release out of an open riser as a result of natural convection and steady-state gas release out of the waste is expected to be bounded by 0.03 m^3/s (60 ft^3/min), resulting in a material release of 0.02 g/s. The frequency of this accident is also small (in the unlikely to extremely unlikely range). The consequences of material release caused by a GRE bounds this accident.

M.4. NITROGEN ADDITIONS

Nitrogen addition is of concern because it may (1) result in dome pressurization, and/or (2) cause a gas release.

Nitrogen gas is added to the tank during normal RMCS operations. Nitrogen is added to the waste at a rate of 30 to 50 ft^3/min. Each sampling may take from 2 to 38 minutes. It is assumed an average drilling period of 10 minutes in the reliability study. This safety assessment (SA) assumes that two full sampling activities will be performed in a tank per year. Each sampling activity would include 11 samples. Thus, the drilling time per year per tank would be 220 minutes. The total nitrogen addition into waste during drilling is 11,000 ft^3 per year using a maximum flow rate of 50 ft^3/min.

The hydrostatic head also supplies nitrogen with a flow rate of 0.3 ft^3/min. Removing samples is assumed to take 2 hours. For two samples, the total nitrogen addition per day would be 72 ft^3. This is a relatively small amount added during drilling. The riser will be purged with about 5 ft^3/min. However, this will be added to the tank dome.

Past experience in air additions to Tank 101-SY can be used in understanding the expected response of the tank caused by nitrogen injection.[4] From 1987 to 1989, Tank 101-SY was air-lanced periodically. In 1989, the air lancing was performed almost daily. This air-lance data from each air-lancing operation was examined that introduced 28.3 m^3 (1000 ft^3) of air into the waste. Examination of the level data indicates that there is no systematically observed pattern, in terms of change of waste level, with respect to the air lancing. The level does not always increase or decrease after each air-lancing operation. Generally the level continued to increase (in an average sense) until a small or a big GRE occurred. In some cases, the level tended to stay constant or decreased slightly after several days following the air lancing. However, these small changes were insignificant because they did not change the level-time plot significantly.

The observations above suggest that introducing air in the waste does not immediately cause a rollover with a significant gas release. Adding air to the waste is expected to increase the level growth rate. This conclusion assumes that some fraction of added air will remain entrapped in the waste as bubbles. The added nitrogen can stay in the waste or rise to the surface depending upon the yield stress of the waste. In a worst-case condition, the released nitrogen can form large bubbles (Ref. 5) and gives criteria for a spherical bubble to move.

The bubble diameter-yield stress relation is plotted in Fig. M-1. This figure illustrates that large bubbles can be created if the yield stress of the waste sludge is high (and if it exists). There is a possibility that released nitrogen can be held in the waste, especially at the bottom of the tank where the yield stress is thought to be relatively high. The total amount of nitrogen added during RMCS is significant. If this nitrogen is somewhat retained in the waste, a GRE initiated by a rollover could be observed.

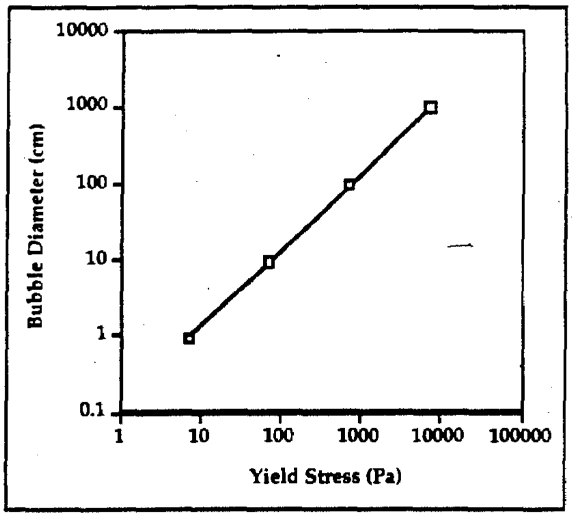


Fig. M-1. Bubble-diameter to yield-stress relation at the initiation of a bubble motion.

However, note that the daily gas-generation rate in a full tank is expected to be around 100 ft^3/d using 101-SY data resulting in a rate of level rise of 0.15 to 0.2 in./d. None of the SSTs experience large level growth rates, suggesting that they have reached a steady state whereby the gases that are generated are being released to the dome. Thus, it is very likely that the additional nitrogen also would be released continuously to the dome through the release paths that are available for the generated gas. It is even more likely that the nitrogen would be released from the hole created by the drilling. However, while flowing into the dome space, nitrogen may entrain some of the retained gas. The most likely gas-release mechanism would be the scrubbing of ammonia by the nitrogen flow. Initial ammonia releases as high as 34 ft^3/min are predicted by Reference 6. However, Reference 6 also suggests that such high release rates will not last forever as the waste near the drill string will be quickly depleted of its dissolved ammonia. Furthermore, the flammable gas monitors would stop the operations if high ammonia concentrations are detected at the exhauster. Ceasing the nitrogen flow will stop the ammonia release.

One of the purposes of the use of nitrogen is to remove the waste from the drill bit. The nitrogen carries the waste chips. The flutes on the drill string also help the transportation of waste chips. Because of nitrogen addition and aerosol created by drilling, an exhauster is required to be operated during RMCS operations. The exhauster operation will also remove the small amounts of waste gas that may be entrained into the dome during nitrogen purging. It is believed nitrogen remaining trapped in the waste and subsequently triggering a large GRE is an unlikely occurrence.

The nitrogen addition can cause the dome to be pressurized if the exhauster fails. Thus, the nitrogen flow must be stopped upon exhauster failure.

M.5. REFERENCES

1. P. M. Francis, "Aerosol Study for the Rotary Mode Exhauster," Westinghouse Hanford Company report WHC-SD-WM-ES-225, Rev. 0 (1993).

2. L. H. Sullivan et al., "A Safety Assessment for the Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," Los Alamos National Laboratory report, LA-UR-92-3196, Rev. 14 (March 31, 1995).

3. K. O. Pasamehmetoglu, "Single Shell Tanks Dome Volume Calculations," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-086, (November 1995).

4. C. Unal, "Concerns with Uncontrolled Reactions Caused by Rapid Pressurization and Depressurization of the Voidmeter Sampler," Los Alamos National Laboratory Calc-Note, TSA6-CN-WT-SA-TH-044, (May, 1994).

5. A. N. Beris, J. A. Tsamopoulos, R. C. Armstrong, and R. A. Brown, "Creeping Motion of a Sphere through a Bingham Plastic," J. Fluid Mech. 158 (1985) pp. 219–244.

6. J. D. Hudson, B. J. Palmer, and C. W. Stewart, "The Potential for Flammable Concentrations of Ammonia Resulting from Core Drilling Operations," Pacific Northwest National Laboratory letter report PNL-WTS-112295 (November 1995).

APPENDIX N

STRUCTURAL ISSUES ASSOCIATED WITH ROTARY MODE CORE DRILLING OPERATIONS

N.1. INTRODUCTION

In this appendix we discuss structural issues associated with the operation of rotary-mode core sampling (RMCS). There are six different issues examined. Some of the issues are related to the ignition hazards, and others are breach of containment issues. They are not discussed in a particular order.

N.2. DOME LOADING

RMCS operations for single-shell tanks will impose an increase in the live weight over the tank dome. Section 2 describes all the equipment that is necessary to perform the sampling operation.

N.2.1. Static Dome Loading

In this section, we consider static and dynamic dome loading. Reference 1 indicates that dome loading must be controlled by the dome-loading limits for single-shell tanks (SSTs) as specified in OSD-T-151-00013 (Ref. 2). The RMCS System Weights Table N-1 lists the weights of the various components that possibly will be imposed simultaneously on the dome surface. This additional tank dome loading is considered to be a live load in the Westinghouse Hanford Company (WHC) evaluation of the tank structural integrity.

The static load capacity of the tank dome is monitored carefully, and an overload state that could precipitate a structural failure must be avoided. The equipment required on the surface of the tank to support RMCS sampling operations qualifies as a live load. The tank loads study permits a 50-ton concentrated live load over a 10-ft radius on the tank dome. Although all equipment listed in Table N-1 weighs more than 50 tons, not all of it is placed on top of the tank. The weight of the RMCS equipment on top of the tank is <50 tons; thus, this limit is not exceeded.

N.2.2. Dynamic Dome Loading

In case a truck were to fall on the tank dome, the dome would be subjected to dynamic dome loads. Reference 2 considers this scenario and analyzes the consequences of the dynamic loading caused by the truck dropping onto the dome. The truck weight is estimated to be 30,000 lb. The drop height for the truck was selected as 3 ft from the raised platform, and the truck is assumed to land on the minimum of 7 ft of fill.

TABLE N-1
RMCS COMPONENT WEIGHT BREAK-DOWN

Component	Weight (lb)
Core sample truck (includes grapple hoist assembly and shielded receiver assembly)	30,000
Truck platform	6,000
Universal sampler (11 @ 10.3 lb)	113
Drill String (50 ft @ 4 lb/ft)	200
Change-out assembly	45
Riser adapter and drill rod washer	280
Riser sleeve	200
Inlet breather filter stack	2,000
Support truck	7,000
Cask truck	8,000
Cask stand	300
Casks (5 @ 480 lb)	2,400
Mobile X-ray system	5,000
Exhauster and flammable gas detection systems	12,200
Light plants (2 @ 1000)	2,000
Video vehicle	5,000
Tent	7,000
Tent weights	33,000
People (10 total)	2,000
Total Potential Weight	122,738

The analysis examines the worst case in which the platform disappears and the truck lands on its tires,. which is conservative because this gives the smallest projected area. (The greater likelihood is that the truck would fall off the platform and land on its side, thereby affecting a greater area.)

The kinetic energy of the dropping mass is assumed to work by the resistance representing the impact. The work is estimated by integrating the load deflection diagram. (Details of calculations are available in Reference 3.) The deflection calculation considered the impact and static contributions. The dynamic load is calculated as 525,000 lb. Assuming that the load is spread over a 60° cone angle as it passes through the minimum 7 ft of soil until it reaches the dome, a projected bearing surface area on the dome is calculated as 29,860 in^2. The allowable load on the dome is given as 5540 lbf/ft^2 in Reference 4. Considering 3 in. of water vacuum in the dome, the net allowable dome load is estimated as 4,680 lbf/ft^2 when the dome pressure is atmospheric.

This conservative analysis shows that the dome will withstand the impact force of the 30,000-lb truck dropping on it from the 3-ft-high platform. The analysis in Reference 3 is conservative in that it uses the smallest conceivable projected area of the dome in the calculation. If the truck were to fall on its five jacks, or on its side, the projected reacting area of the dome would be greater, and the margin of safety larger. Further, it is not likely that the truck will fall at the same time the dome is subjected to a vacuum equivalent to 3 in. of water.

N.3. BUCKLING OF THE DRILL STRING

The failure of the drill string during drilling is evaluated as a fire hazard. The downward force is limited to prevent drill bit overheating. The other limit on the down force should be based on the buckling limit. In this section, we discuss the structural buckling limit under various boundary conditions.

The drill string has an outer diameter (o.d.) of 2.25 in. and an inner diameter (i.d.) of 1.91 in., and these dimensions will be used in all of the calculations discussed in this appendix. The effects of torsion on the drill string have not been considered, and the weakening effects of the multiple threaded joints have been ignored.

Three different cases have been considered. In each case, it is assumed that the upper end of the drill string is fixed. The lower end may be free, pinned, or fixed. The formulas for allowable buckling load for long columns in these three conditions are given in References 3 and 5. Calculated buckling limits are shown in Fig. N-1 as a function of drill string length.

It is difficult to predetermine which set of end conditions should be applied as bounding boundary conditions. There are two different cases to consider; (1) the drill bit entering the crust, and (2) the drill bit penetrating the crust or waste. Reference 6 documents the case of a drill-string failure at a length of 41.7 in. under a vertical load of 2,600 lb (the drill bit was in the waste). This falls exactly on the fixed-fixed curve of the above graph. However, it does not necessarily follow that waste entrance should be treated as such. It is conceivable that when a new drill first bites into the hard salt cake surface, the string will behave as fixed-fixed. It is also possible that the drill will wander along the salt cake, and behave as fixed-free.

The first core sampler has a centering spike attached to the bottom of the core sampler. The use of centering spike ensures that the drill bit does not wander along the salt cake as it tries to penetrate. Therefore, it is reasonable to assume that the boundary conditions are fixed-pined as the drill string penetrates the waste or when it is in the waste. We have establish a control requiring that the first core sampler must include the centering spike.

Based on the above discussion, the downward force during crust penetration should be evaluated from Figure N-1 using fixed-pinned boundary conditions. We could not put a limit that could bound all lengths. For drill string lengths less than 45 ft, the downward force limit is quite high. However, the downward force in this range is also limited with 750 lbf established by the envelope testing to eliminate the waste ignition hazard. Thus, the downward force will be set to 750 lbf when the drill-string length is less than 45 ft. For drill string lengths higher than 45 ft, this limit should be lowered to 650 lbf because of buckling concerns.

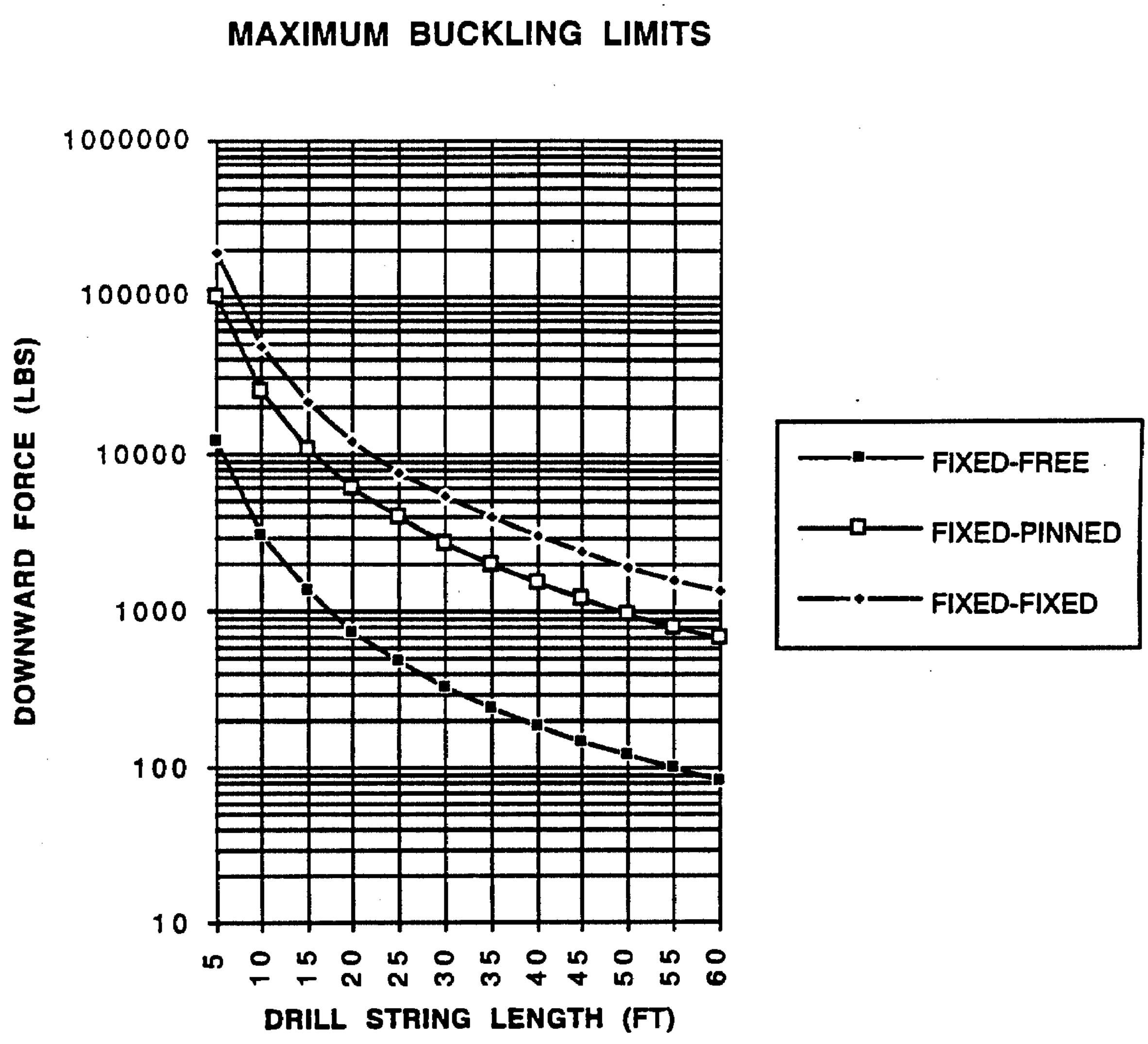


Fig. N-1. Buckling limits for drill strings considering three boundary conditions.

N.4. MAXIMUM BEARING FORCE CALCULATIONS OF DRILL STRING AGAINST SLEEVE

The major concern is the frictional spark when the drill string rotates in the sleeve and periodically bangs into flutes on the conductive sleeve. In this section, we determine the horizontal force that could be applied to the drill string during contact with the sleeve.

Figure N-2 is an illustration of the operation of the drill string in the conductive sleeve. The objective is to determine the absolute maximum force that the drill string could exert against the sleeve before the failure of the drill string. This maximum force can occur when the end of the sleeve is the shortest distance from the salt cake.

The following assumptions are proposed. The tube material is steel with an ultimate tensile strength of 90 ksi. The weakness caused by the threads is ignored in order to compute the highest possible bearing force. The sleeve is 15 ft long and is totally rigid. Among the tanks considered, Tank U-108 has the shortest distance from the bottom of the sleeve to the top of the salt cake. That distance is 80 in. Upon touching the waste, the drill experiences a lateral force, sufficient to fracture it at the point where it leaves the sleeve.

The bending moment required to fracture the drill string is given in Reference 5 as $M = s_u \times I/c = F \times 80$ in. From this equation, the bearing force is estimated as 610 lb

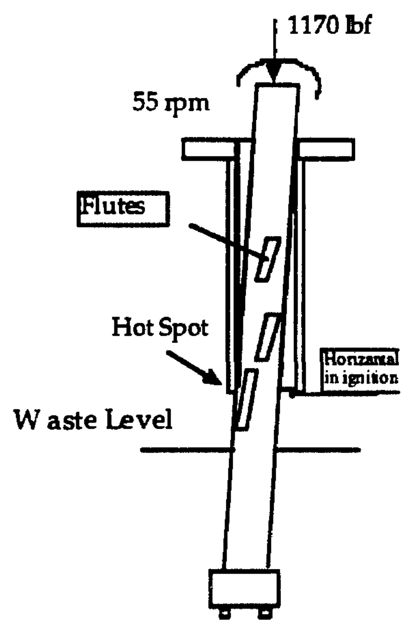


Fig. N-2. Sketch of a drill string in riser.

against the sleeve before the drill string fails. This particular case will develop the highest possible bearing force. The deflection at this force is found as 5.7 in. in Reference 3. It has been assumed that the sleeve is completely rigid. In reality, some deflection of the sleeve will occur, and the drill string may not necessarily fail where it leaves the sleeve. Furthermore, the particular tank chosen has the shortest distance between the sleeve and the salt cake. These two factors combine to give the maximum contact force of 610 lb. A deflection of 5.7 in. is used to conclude that the drill string could not damage the side walls. The contact load estimates are also used in designing the ignition testing discussed in Appendix T.

N.5. DRILL STRING DROP ACCIDENT

A potential hazard to the tank structural integrity exists if the RMCS drill string were to fall and impact the tank bottom. The drill string is restrained from falling and impacting the tank bottom by the pneumatic foot clamp. After numerous sections of the drill string have been added, the suspended weight will cause the drill string to fall if the clamp is released because the force of gravity exceeds the frictional forces. Initially, the frictional force developed at the riser seal interface exceeds the string weight. The frictional force is produced by the rubber seal that girths the outside diameter of the drill string shell. This constant force eventually is overcome by the column weight as the sections are added. The long drill string extending nominally halfway into the tank poses the largest hazard to the integrity of the tank bottom from an impact. We evaluated the impact force that would occur if the drill string were released.[3]

Among the tanks considered, Tank AX-103 has been chosen as a worst case because the low level of waste (42 in.) is insufficient to absorb a significant amount of energy from the falling drill string. Consequently, the effects of drag and buoyancy will be ignored.

Assumptions made in evaluating the drop accidents are as follows. The tank has a cylindrical height of 390 in. and is topped by an elliptical dome that is 144 in. high. The minimum waste level is 42 in. (Ref. 7). There are 84 in. of fill on top of the tank. The first rod section of drill weighs 6.3 lb (Ref. 8).

The methodology is based on the ballistic impact on the tank bottom. The drop distance from the ground to the tank bottom is 618 in. (Ref. 8). The impact velocity is 17.6 m/s (57.6 ft/s). This velocity is conservative because the drag force decelerating the motion is not considered. The maximum impact kinetic energy for one drill rod of 6.3 lb becomes 325 ft-lbf. Conservatively, no credit was taken for the concrete beneath the steel liner because over the years the concrete could be displaced.

If the steel bottom corroded 4.5 mils per year for 40 years (Ref. 9), the remaining thickness would be 0.195 in. (Ref. 9). From the analytical techniques of Reference 8, we found $t/D = 0.086 < 0.35$. The critical velocity at which 50% of the cases would have penetration is found to be 218 ft/s. This is greater than the 57.6 ft/s calculated above; therefore, penetration is not likely for the single section of drill string.

As another check, it has been customary to convert a body that does not have a ballistic shape to an equivalent body by solving for an effective diameter. This has been considered as discussed in Reference 3 and the same conclusion is found; penetration is not likely if a single drill rod is dropped.

However, if we examine the case where the drill string is 340 in. long, the weight becomes 113 lb. The drop distance then becomes 278 in. Using the same ballistic impact analysis for higher weights, we found the critical velocity at which 50% of the cases would have penetration as 34.6 ft/s. It appears likely that the base would be penetrated if the whole drill string were to be dropped.

Another method is based on stresses induced in the steel liner from the impact as it was done in Reference 8. We equate the work done by the liner in absorbing the kinetic energy of the dropped drill string to the kinetic energy.

The impact velocity of the drill string is expressed as a function of the number of the drill rod ($V = (2gh)^{0.5} = [(2\,g\,(618 - 19n)]^{0.5}$, where n = the number of 19-in. drill sections). The kinetic energy becomes ($324n - 10n^2$) (Ref. 3). The kinetic energy peaks at 16 sections for a string length of 16 x 19 = 304 in.

Taking Poisson's ratio as 0.25 and the radius of the bottom plate that responds to the impact as 60 in., the equivalent spring constant for the plate is found as 6,370 lb per in. The impact force is calculated as 20,100 lb. The deflection at this load is found at 3.15 in. The developed moment can be calculated as 8164 in. lb. This results in a stress level of 1.3E6 psi. It is clear that this is more than an order of magnitude higher than the ultimate strength of the material. Thus, bottom liner penetration could occur if the drill string were dropped.

N.6. STRUCTURAL FAILURE OF THE ROTARY CORE DRILL STRING UNDER PURE TORSION

If the drill string becomes embedded in the waste because of debris in the waste, torque will continue to be applied to the drill string at a constant rate. If such a condition occurs, there is a possibility that the drill string will partially fail. Partial failure of the drill string will then result in a nitrogen flow bypass through the area that is partially failed with a leak path. Providing the necessary nitrogen flow to the drill bit protects the drill bit from overheating. Thus, waste or flammable-gas ignition is prevented. The flow rate is measured in the nitrogen instrumentation box. If a partial drill-string failure occurs because of applied torque, this condition will never be detected. Therefore, the likelihood of ignition in the waste becomes uncertain. In other words, providing nitrogen flow if there is a leak path on the drill string would not prevent the drill bit from overheating.

In this section we examine the scenario in which the drill string is considered to be torque from the upper end while the rotation of the lower end is not allowed. If the drill string fails in a short period of time under the over-torque conditions, we can conclude that the drill bit does not have enough time to overheat itself. Thus, the purpose of this section is to examine whether or not the drill string will fail in the short period of time when a torque is applied.

This issue is examined in Reference 10. The method applied and results will be briefly summarized here. An analysis in Reference 10 assumes that the drill string is jammed in the waste while torque is applied at a maximum rate of 55 rpm. Linear elastic methods are applied as a first approximation to obtain the lower bound failure estimate. Secondly, strain energy methods are used to upper bound the solution by assuming that the ultimate shear strain in the drill rod is proportional to the shear modulus. This is a very conservative approximation but will provide the upper limit of failure and will estimate the maximum time-to-failure.

Material is manufactured from ASTM A-518 carbon steel (its properties are given in Reference 10). Linear elasticity analysis estimates the shear stress as Tc/J (where T = torque, c = distance from the point of rotation to the maximum outer fiber on the cylinder under shear, and J = polar moment of inertia). The torque results in an angle of rotation for pure torsion as given by $\theta = TL/JG$ where, G = shear modulus, θ = angle of rotation, and L = length. The shear modules are calculated as 11.2E6 psi using a Poisson's ratio of 0.3. Assuming the shear stress developed under torsion is brought to the limit of the material, that is, the shear ultimate strength of the pipe, then the maximum angle of rotation can be determined. This is conservative because the theory is applicable to linear elastic bodies, and obviously this assumption does not account for the ductility of the material. The angle of rotation is calculated as 126° in Reference 10. This corresponds to about one-third of a full revolution. In terms of a time-to-failure determination, the rod will fail in 0.38 seconds for a rotational speed of 55 rpm. The time period to failure becomes 2.1 seconds for a rotational speed of 10 rpm and 4.2 seconds for 5 rpm. The lower speeds are not usually selected because sampling becomes poor. However, even in the case of low rotational speed, the drill rod will fail in a few seconds.

The second method that upper-bounds the torsional resistance is based on the strain energy method. Shear failure is assumed to occur when the materials' total strain energy equals the work done by the applied torque. Then, the strain energy can be written in terms of the shear stress and shear strain. However, in this case, the assumption is that the shear strain is the "ultimate" shear strain capacity of the material based on a linear elastic relationship. Using this method, the angular rotation to cause failure is estimated as 5208°. For a rotational speed of 50 rpm, this corresponds to a time period of 15.8 seconds. The time becomes 43.4 seconds for a rotational speed of 20 rpm. This second method is only provided to show an upper bound, and by no means will this be a reasonable failure angle or time-to-failure of the drill string under pure torsion. Because linear-elastic methods do not account for ductility or the strain hardening/softening of materials, the strain energy calculated is grossly conservative. Furthermore, the ultimate strain used in the calculations is also overly conservative because for this specific material, typically, there is virtually no ductility.

In reality, the drill string will fail somewhere between 0.5 and 2 seconds for a drill bit rotational speed of 55 rpm and between 2 to 8 seconds for a rotational speed of 20 rpm. The most important notion to consider is that this material does not have much ductility, as evidenced by the lack of strain hardening. The fact that the yield strength is only 10 ksi lower than the ultimate strength shows negligible strain hardening capability. In fact, one may consider this material somewhat brittle. Therefore, the assumption that the material attains 15% ultimate shear strain at failure is very conservative. In addition, no stress concentration factor (or effective area) is considered for threads between the drill rods. The threaded rods allow the drill string to fail in much smaller time periods.

N.7. DRILL-STRING RESONANCE

A torque and axial load will be applied to the drill string during drilling. Excitation of the drill string with a natural frequency is of concern. In this section, we evaluate the resonance rotational speeds under various boundary conditions. However, the weakening effects of the multiple threaded joints have been ignored.

Consider first the case of torsional resonance. The equation for the first mode of torsional resonance is given in Reference 3. Limiting rotational speed is plotted in Fig. N-3 as a function of the drill string length.

The maximum rotational speed is 55 rpm. From Fig. N-3, it is clear that the torsional resonance speed is extremely high. Figure N-4 plots the first- and second-mode resonance rotational speed as a function of the drill string length for the fixed-free, fixed-pinned, and fixed-fixed boundary conditions. Curves with fixed-pinned boundary conditions are suggested for the cases where the drill bit penetrates the waste and where the drill bit is in the waste. We tabulated the suggested range of speeds in Table N-2.

When the drill string is in the waste, a rotational speed of up to a maximum of 55 rpm can be used when the drill string length is less than 45 ft. Above 45 ft, the speed should be either 40 rpm. The second excitation frequency is much higher than the maximum allowable speed of 55 rpm.

N.8. DRILLING THROUGH THE BOTTOM OF THE TANK

Buckling of steel liner bottom plates in underground single-shell tanks (SSTs) and double-shell tanks (DSTs) has been observed in about three instances and documented in one specific case that we are aware of. DST SY-101 has a known buckle that extends inwardly about 4.5 to 5.0 inches, which was caused by the stress-relieving operations immediately after heat-treating the shell liner to 1100°F. Documentation of this specific case is extensive, also providing contour maps of the actual buckled shape.

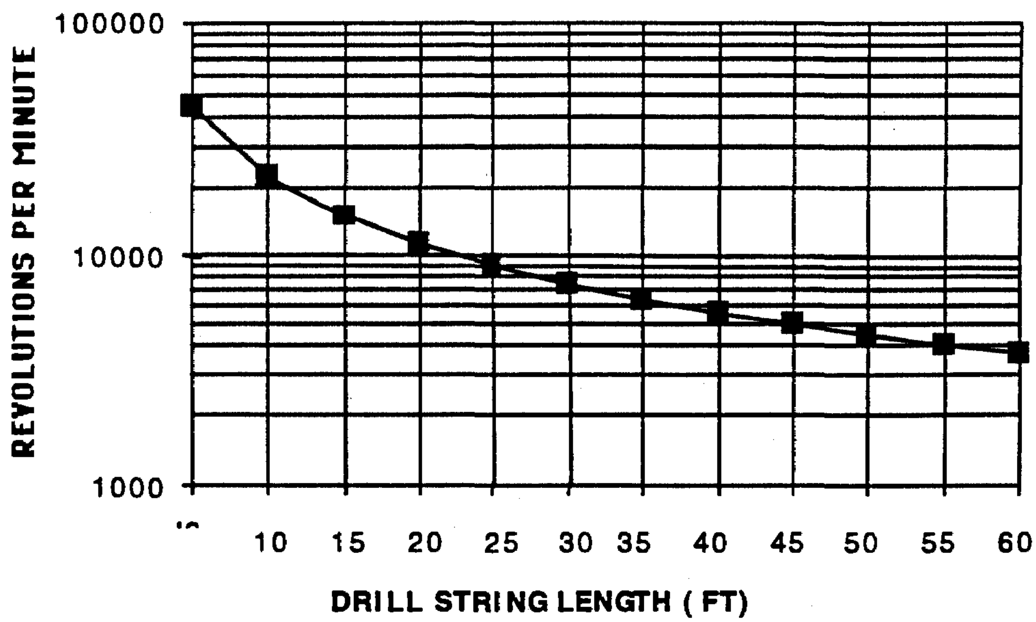


Fig. N-3. Resonance speed caused by torsional load.

Other cases in SSTs that are known to exist but have not been documented pose a potential concern when installing equipment through the risers that extend to near the bottom of the tank. The inward deflection created by the buckles may prevent equipment from fully seating on the riser. Other more important concerns are with RMCS equipment, which is required to obtain samples from the complete depth of tank waste. The potential for drilling through the steel liner is evident if the steel bottom plate has a deformation from lateral buckling. Therefore, limiting the drill string height to a safe distance above the bottom plate is justified.

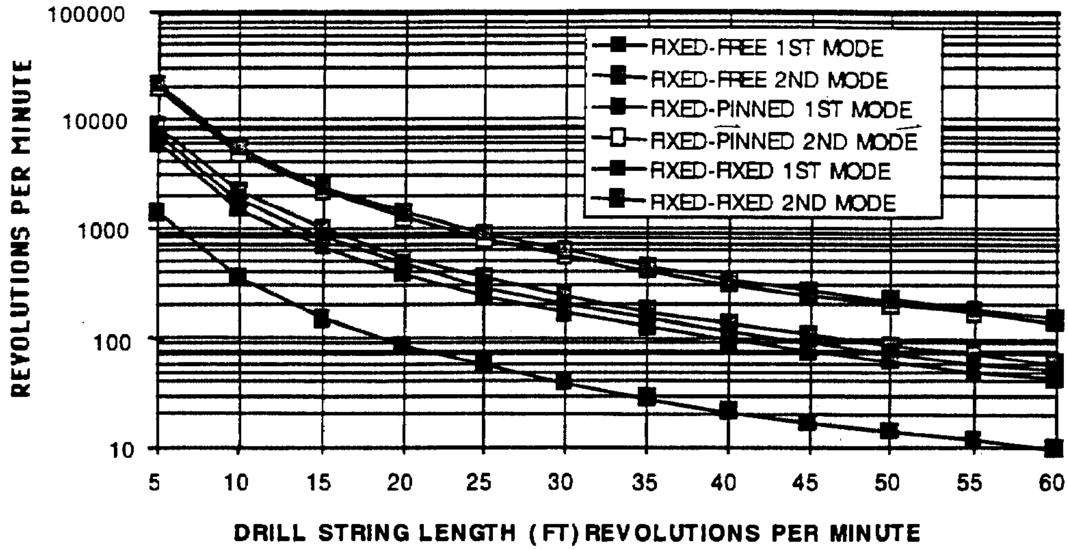


Fig. N-4. Transverse resonance rotation speed as a function of the drill string length.

TABLE N-2
ROTATIONAL SPEED LIMITS

Drill String Length (ft)	Force (lbf)	Rotational Speed (rpm)
L<45	<750	<55
45<L	<650	<40

This analysis evaluates nominal deformations in the bottom plate caused from effects related to tank construction practices. Because very little is known about the post-fabrication condition of some SSTs, one can only depend on the structural deformation created from the construction phase, such as the loads imposed on the tank walls after soil backfilling and shrinkage loads created during the curing period of the reinforced concrete shell.

N.8.1. Analysis

Using dimensions of Tank A-101 for the typical SST, Figure N-5 shows the approximate soil depth and tank characteristics. The tank liner is 3/8-in. thick carbon steel with a 75-ft diameter and the depth of soil to the tank bottom plate is approximately 54.5-ft. The waste temperature currently is taken as 135°F.

Th- lateral soil pressure is assumed as the "at-rest" soil pressure fo: retaining-type ·tures. The hydrostatic load at the base of the wall is shown[11,12] as

$$P = \gamma H K_0$$

where, γ = Soil density (lb/ft^3),

H = Depth of soil (ft), and

K_0 = Coefficient of soil pressure at rest.

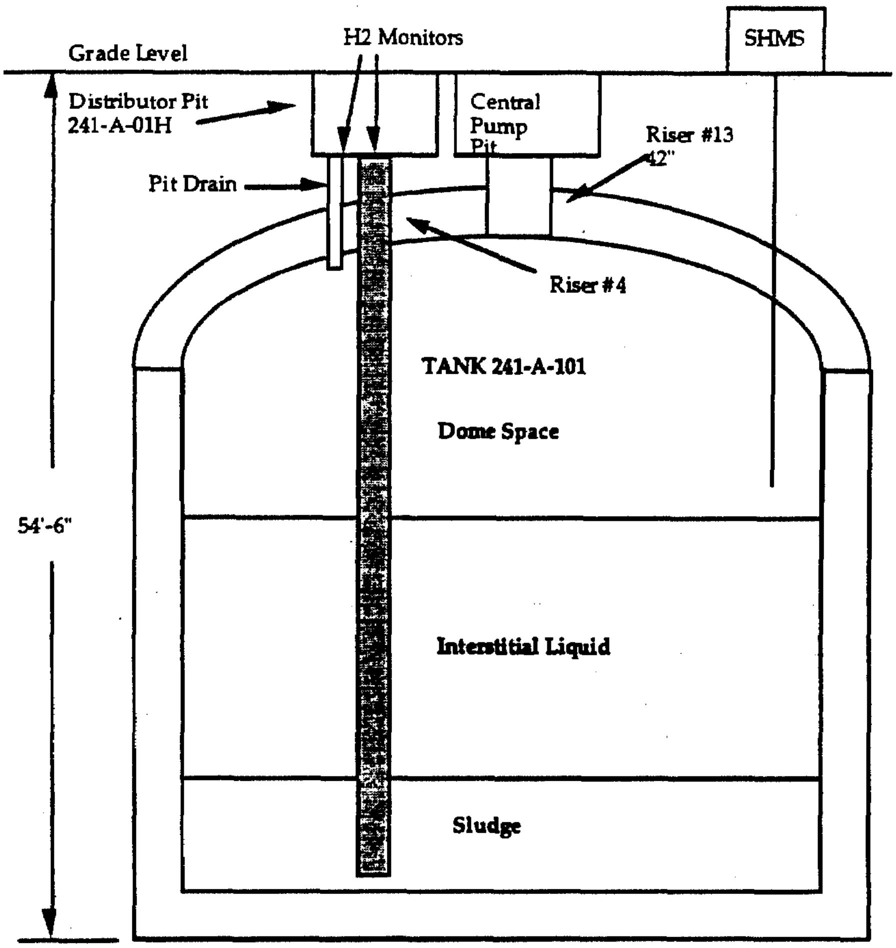


Fig. N-5. Cross-sectional view of A-101.

The maximum soil pressure, assuming a moist, dense soil, typical of the Hanford Tank Farm region is

$$P = 6500\ lb/ft^2 \qquad \text{or} \qquad P = 45\ psi\,.$$

The lateral soil force per unit circumference on the 3/8-in. bottom plate is

$F_S = 17$ lb/in.

Concrete shrinkage and creep is very common, and design practices allow for some shrinkage; however, structures are often slightly deformed because a small margin was allowed for deformation-type strains. For 3000 psi compressive strength concrete, typical of A-101 construction, Ferguson[13] provides the nominal shrinkage to be approximately 2.0E-4 in./in.

Obviously, there is some appreciable gap between the concrete and the steel liner after construction before shrinkage begins. This gap cannot be fully quantified. Thus, nominally, a 1/4 in. gap is assumed to exist between the steel and concrete immediately after construction.

The bottom plate radial deformation, based on a concrete shrinkage coefficient of 2.0E-4 in./in. is

$$\Delta R = \alpha R \,,$$

where, α = 2.0E-4 in/in.,

R = 450 in., and

ΔR = 0.09 in.

Thermal expansion deformations of the tank bottom, caused by heat loads from the waste, will comprise about

$$\Delta R_{th} = \alpha_{stl} R \Delta T \,,$$

where, α_{stl} = 6.5E-6 in/in/°F,

and the temperature difference is from 75°F to the current waste temperature of 135°F, or ΔT = 65°F. The 75°F temperature is assumed to exist at the time of construction with no appreciable deformations. The maximum thermal expansion of the tank bottom is

$$\Delta R_{th} = 0.175\text{-in.}$$

Accounting for the 1/4-in. initial gap between the steel and concrete, the maximum lateral deflection of the plate after concrete shrinkage and thermal expansion, would be 0.015 inches. The difference between the radial gap and the concrete shrinkage plus thermal expansion is an interference fit, that is, the radial contraction imposed on the tank plate. Thus, there exists a radial force per unit of circumference such that the proportionality of the following relationship must hold true in the elastic region

$$\frac{\Delta R}{\alpha R} = \frac{\sigma}{\alpha E},$$

where, σ = Stress, (psi)

E = Modulus of elasticity, (psi)

or, $$\Delta R = \frac{\sigma R}{E}$$

The applied stress from the shrinkage and thermal effects is

$$\sigma = 1000\text{-psi},$$

or a radial force per unit circumference of

$$F_{cs} = 375\text{-lb/in.}$$

Comparing this value to the critical buckling load of the 450-in. diameter plate assuming a clamped condition is[14,15]

$$\sigma_c = 1.22\frac{E}{1-\nu^2}\left(\frac{t}{a}\right)^2, \text{ and}$$

the critical stress is

$$\sigma_c = 28\text{-psi} \quad \text{or a radial load of} \quad F_{cs} = 10.5\text{-lb/in.}$$

The compressive load from the concrete shrinkage and thermal expansion is much greater than the critical buckling load of the plate. Given these large loads, the plate would have undergone local plastic deformation and therefore would never achieve such high radial forces. Obviously, the actual gaps and conditions are unknown, and any other assumption as to the actual state of construction is an estimate.

Therefore, in order to achieve a physical meaning, a conservatively critical buckling load representative of the circular plate plus additional load from the lateral soil pressure is used in calculating the maximum deflection of the buckled form.

This rationale assumes that soil pressure will always be present on the tank walls, and that thermal and concrete shrinkage loads will cause local plasticity, thus allowing for relieving of strains. Thus, the maximum load is taken as

$$F_t = 27\text{-lb/in.}$$

The out-of-plane deformation of the bottom plate for the compressive load shown above is approximated using a differential strip element of plate along its diameter.

This is a conservative assumption because it assumes a rectangular strip of length L and not a radial segment of a circular plate. In order to obtain a buckled shape deformation with a compressive radial load, a very small out-of-plane perturbation load is applied to initiate buckling, where the perturbation load is Q. Let Q equal 1% of the compressive load, and the deformation is found as[14]

$$w = \frac{Q}{2Pk}\left(\tan\frac{kL}{2} - \frac{kL}{2}\right),$$

where, w = Deflection (in.),

P = Lateral compressive force (lb),

$k = \sqrt{\frac{P}{EI}}$,

L = Elemental strip length (diameter), and

I = Moment of inertia ($in.^4$)

The solution to the maximum deflection is

$$w = 2.2 \text{ in.}$$

It should be understood that this calculation only provides an "estimate" of the buckling deformation. It presents a simplistic argument for a complex condition and makes assumptions on the state of construction. There are numerous unknown conditions that may exist, which if conservative assumptions are used, would yield unreasonable results of the buckling deformation. Furthermore, because actual observations of DST buckling are documented (e.g., SY-101) with maximum heights of about 4 to 5 inches, this calculation provides a basis for the order of magnitude.

N.8.2. Conclusions

A 3-in. minimum distance is recommended for limiting the lowering of the drill string to the tank bottom. This limit is established from the best-estimate analyses provided above. One may estimate larger deformations using more conservative assumptions that those used in this analysis. Obviously, the 3-in. limit does not guarantee that the drill bit will never contact the tank bottom. However, it reduces the probability of drilling through the bottom without sacrificing valuable sample data near the bottom of the tanks. As mentioned before, one documented case of bottom buckling is for 101-SY. For that case, the peak deflection is measured as ~4 in., which covers less than a few percent of the total surface area.

N.9. REFERENCES

1. N. Milliken, "Safety Analysis for the Push Mode and Rotary Mode Core Sampling," Westinghouse Hanford Company report WHC-SD-WM-SARR-031, Rev. 1 (June, 1995).

2. V. C. Boyles, "Operating Specifications for Single-Shell Waste Storage Tanks," Westinghouse Hanford Company report OSD-T-151-00013, Rev. D-4 (1994).

3. B. Weinstein, "Structural Analysis of Rotary-Mode Core Sampling Operations," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-ST-086 (December, 1995).

4. K. J. Lawrance, "Dome Analysis," Los Alamos National Laboratory Calc-Note N6-CN-WT-SA-ST-024 (August, 1992).

5. R. J. Roark and W. C. Young, Formulas for Stress and Strain, 3rd edition, (McGraw Hill Co., New York, New York, 1975).

6. H. H. Ziada, "Axial Failure Food Estimates for Push Mode Drill String," Westinghouse Hanford Company memorandum H5-52 (October 18, 1995).

7. K. O. Pasamehmetoglu, "Single-Shell Tanks Dome Volume Calculations," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-086 (December 1995).

8. W. O. Miller, "Retained-Gas Sampler Drill-String Drop Analysis," Los Alamos National Laboratory Calc-Note TSA6-CN-WT-SA-075 (November 30, 1994).

9. J. P. Strehlow, "Drill-Bit Punch Through Single-Shell Tank Liner," Westinghouse Hanford Company memorandum CSA:JPS:ggb:92/32 (1992).

10. E. Rodriguez, "Structural Failure of the Rotary-Core Drill String Under Pure Torsion," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-ST-085 (December 1995).

11. G. B. Sowers and G. F. Sowers, Introduction to Soil Mechanics, 3rd Edition (Macmillan Publishing Co., New York, New York, 1970).

12. J. E. Bowels, Foundations Analysis and Design, 3rd Edition (McGraw-Hill Book Co., New York, New York, 1982).

13. P. M. Ferguson, Reinforced Concrete Fundamentals, 3rd Edition (John Wiley & Sons, Inc., New York, New York, 1973).

14. S. P. Timoshenko and J. M. Gere, Theory of Elastic Stability, 2nd Edition (McGraw-Hill Book Co., New York, New York, 1961).

15. R. J. Roark and W. C. Young, Formulas for Stress and Strain, 5th Edition (McGraw-Hill Book Co., New York, New York, 1975).

APPENDIX O

ENERGY AND WATER ADDITIONS/REMOVALS

O.1. INTRODUCTION

In this appendix, the issues associated with energy and water addition to the tank during sampling are addressed.

O.2. WATER ADDITIONS

These accidents address the possibility of excessive water additions to the tank that would cause the level to rise above that allowed by safety controls. In the limit, flooding could result from the release of tank materials into the environment caused by hydrostatic failure of the tank. This appendix also addresses the effect of the water addition on the waste temperature and gas releases.

The maximum quantity of water available for decontamination during operation and removal is 5.7 m^3 (1500 gal.), which is physically controlled by the size of the water supply. Adding this quantity of water increases the tank level by a maximum of 1.4 cm (0.55 in.). Per activity, water additions are limited to 0.95 m^3 (250 gal.). Flooding of the tank by adding a maximum 1500 gal. of water is impossible. Numerous 1500-gal. tanks of water would have to be added in violation of the 1500-gal. total addition limit. The maximum quantity of water available for decontamination during operation and removal is 250 gal., which physically is controlled by the size of the water supply. The water addition to an assumed leaky single-shell tank (SST) must be reduced to 100 gal.

One of the reasons for keeping the water addition to minimum amounts is the danger of interim-stabilized tanks jeopardizing the interim-stabilized status. A tank must contain less than 50,000 gal. of drainable interstitial liquid and less than 5000 gal. of supernatant liquid in order to maintain its interim-stabilized status.

These numbers are predicated on the flow rate, duration of operation of the decontamination system, and maximum number of anticipated decontamination operations. Any addition of water beyond this total level must be approved by the test review group (TRG) with consideration for overall effects on the tank waste. To ensure that the water is sufficiently provided to the check valve for the purpose of cleaning, the water level in the water supply tank will be monitored.

Water addition has several more effects: (a) changes the waste temperature, (b) releases gases, (c) changes the waste pH level, and (d) increases the activity of radiolysis.

Farley[1] investigated the water addition effect. Roughly, unit change in waste pH would require an order-of-magnitude change in volume to sufficiently affect the hydronium ion concentration. Assuming water will affect a 1-ft radius, the minimum waste volume can be found as 82 gal. that are calculated for Tank AX-103 that has a minimum waste level of 42 in. A unit change in pH for this tank would require 820 gal. of water. The water addition is limited to 250 or 100 gal. per activity. The small amount of water added to the tank will dissolve salts and will be saturated. The pH change is not expected. The water-addition limit is 100 gal. for assumed leaky tanks to minimize the release to the environment.

Hydrogen is generated by the radiolysis of water. The water addition would reduce radioisotope concentration. However, the volume would be increased by water addition. Therefore, hydrogen generation per unit volume would not be affected with water addition. Small amount of water addition in comparison to the total volume would imply insignificant effects. Generation of other gases would be affected in the same way. Water addition, however, may cause gas release, reducing the gas retention capability. During rotary-mode core sampling operations, water will be added at the waste surface, and a gas release triggered by water addition is not expected.

O.3. STEAM GENERATION CAUSED BY ENERGY ADDITION

In Reference 2, a steam-release accident is postulated for high-heat tanks. High heat was considered to generate and retain steam in the waste. However, an analysis specific to high-heat Tank C-106 demonstrated that the condition of this tank is not sufficient to initiate a steam-release event. This was believed because there is sufficient heat transport to cool or condense the steam bubbles, and the sludge-shear strength was not enough to retain steam bubbles in the saturated region. The steam generation caused by heat generation is not a concern in the single-shell flammable-gas tanks having waste temperatures less than 93°C, and the waste level does not significantly change to indicate a great deal of accumulation.

In this safety assessment (SA), the concern is the generation of steam caused by drill bit frictional heating that could remove moisture from the tank. The energy addition to the tanks is discussed above for two limiting cases: frictional heating with no penetration and efficient cutting with penetration.

The bounding energy input caused by drilling is estimated as 8.66×10^6 J for frictional heating and 5.6×10^7 J for smooth penetrating drilling operations. Reference 3 gives the amount of water that can be evaporated for the tanks that are on the Flammable Gas Watch List. The maximum amount of water is estimated as 27.3 kg. These results are very conservative because all the drilling energy is assumed to result in evaporation. Nonetheless, the amount of evaporation is negligible and will not change the moisture content and waste level significantly in any of tanks listed in the table. The vapor volume is 22.84 m^3 (807 ft^3). Considering that the minimum dome volume is 1416 m^3 (50,000 ft^3) and that the steam will be generated over hours of operation, the temperature increase in the dome will not be significant.

O.4. WATER REMOVAL CAUSED BY EXHAUSTER

Another way to remove the moisture in the tank is by operating the exhauster. Among the original Flammable Gas Watch List tanks, the maximum tank dome temperature is found to be 37°C (98°F) in Tank 101-A. This temperature is used to calculate a conservative moisture removal. The exhauster has a relative humidity requirement of 70%. Above this value, normal exhauster operation is not allowed unless there is a gas-release event.

Reference 3 calculates the time of operation necessary to observe a noticeable waste-level decrease, 0.5 in., as ~15 days if the relative humidity in the dome were 70%. These results are very conservative because they do not account for the water vapor partial pressure suppression in highly concentrated salt solutions. In reality, the waste (especially if the surface is dry) is likely to act like a desiccant and absorbs moisture from the dome. Nevertheless, the rotary-mode core sampling (RMCS) operation is assumed to involve roughly about 10 days per year per tank in this SA (App. E). This period considers two full samplings each, including 10 to 11 samples. Note that each full sampling may occur at different times. Thus, during RMCS, water removal as a result of continuous ventilation is not a safety concern.

O.5. REFERENCES

1. W. G. Farley, "Safety Assessment for Thermocouple Tree System Installation and Operation in Ferrocyanide Waste Tanks," Westinghouse Hanford Company report WHC-SD-WM-SAD-014, Rev. 3 (November 1993).

2. N. Milliken, "Safety Analysis for Push-Mode and Rotary Mode Core Sampling," Westinghouse Hanford Company report WHC-SD-WM-SARR-031 (July 1995).

3. C. Unal, "Calculation of Water Removal From Single Shell Tanks Due to Exhauster Operation," Los Alamos National Laboratory Calc-Note, TSA10-CN-WT-SA-TH-092 (December 1995).

APPENDIX P

ANALYSIS OF FRICTIONAL HEATING IN ROTARY-MODE CORE SAMPLING

P.1. INTRODUCTION

It is possible that the rotating drill string may contact the conducting sleeve during drilling operations. Because this contact involves potentially high horizontal loads and dry metal-to-metal sliding, an analysis of the temperature rise caused by frictional heating was performed. In addition, a scoping analysis of frictional heating in the event of exhauster-fan-to-case contact was performed, as discussed in Section P-8 of this appendix. The analyses presented in this appendix should be viewed in light of statements in the literature such as

> *"The actual surface temperatures achieved during dry friction are virtually impossible to measure, and both the temperatures themselves and the methods used to obtain them are matters of continuous controversy."*[1]

Rabinowicz[2] notes that

> *"...In consequence of the difficulties involved in this situation, hardly anyone ever tries to calculate the temperature rise produced in sliding. Instead, if the author's experience is typical, reliance is generally placed on one or another of two widely established but mutually exclusive maxims:*
>
> 1. *The flash temperature at a sliding surface is usually only a little greater than the average temperature of the contacting surfaces.*
>
> 2. *The flash temperature is usually the melting temperature of the lower melting of the two sliding materials."*

Because reliance on either of the statements above provides a poor basis for a safety case, an attempt was made to develop a defensible calculation.

The concept of "flash temperature" mentioned by Rabinowicz is important to understanding the phenomenon of frictional heating and the analyses presented in this appendix. In sliding situations, contact is not made over the whole of the apparent contact area, A_a, but over a few isolated junctions (which together form the real contact area, A_r). Because these junctions are small and they receive substantial thermal energy, their temperatures may be much higher than that of neighboring

1

surface regions (that is, the local macroscopic surface temperature). The flash temperature is defined as the hot-spot temperature associated with these junctions. During sliding, junctions continue to be made and broken, and the "hot spots" on the surfaces shift their location throughout the apparent contact area. There seems to be general agreement, however, that the flash temperature reached at any of these hot spots tends to be reasonably constant under constant sliding conditions. Figure P-1 provides a schematic view of an interface, showing the apparent and real areas of contact.

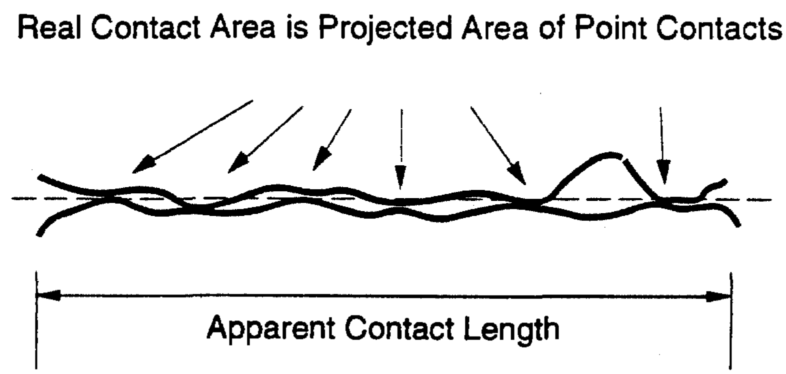


Fig. P-1. Schematic view of a sliding interface between real materials, showing the apparent and real areas of contact.

For a given dry-sliding problem, estimation of peak temperatures is, therefore, the combined problem of calculating the nominal surface temperature distribution resulting from frictional heating over the entire apparent contact area, and the "flash temperature rise," which are then added together. The first difficulties arise in determining appropriate areas and in estimating the flash temperature rise.

The real contact area depends on the characteristics of the surfaces in contact, namely the size and shape of the apparent area of contact, the surface roughness of the two materials, and the way they are placed together. Fortunately, it is possible to estimate the real contact area based on simple limit analyses assuming ideally plastic deformation. If the surfaces that are placed in contact are rough (not prepared bearing surfaces), the contact area of a localized region of material under an imposed load will depend on the stress that such a region can carry without plastic yielding. This property is known as the penetration hardness, and is about three times the yield stress. This argument is plausible based on the similarity between the load carried by a surface high point (called an asperity in the friction literature) and the load imposed by the indenter used in performing the surface hardness test. It also yields results consistent with experimental measurements, such as electrical contact resistance measurements with precious metals. The simple limiting values obtained by this approach are often modified to account for shear forces (always present in sliding) and surface energy considerations.

The apparent contact area consists of the real contact area of the junctions and the area of those regions that appears as if contact might have been made there (but was not). Again, this can be very difficult to estimate for other than simpie (for example, planar) geometry. It can be conservatively estimated from the real contact area estimate, based on the generalization in the literature that "the real contact area is *no more than* 10% of the apparent contact area" (emphasis added).

When surfaces slide together, almost all of the energy dissipated in friction appears in the form of heat at (or near) the interface. Historically, it was a friction experiment that proved the equivalence of mechanical energy and heat. As implied above, some of this energy can be deposited just below the surface because the plastic and elastic deformations occur throughout a volume. The material properties and characteristics of the surfaces can change as a result of this surface "working," changing the subsequent frictional characteristics, including heating. Several formulas for use in estimating the *expected* flash temperature rise have been developed based on simplified assumptions. The expected flash temperature rise results from distributed contact over many contact points. The limiting case of a single asperity with an area equal to A_r yields the *worst-case* flash temperature rise.

P.2. DRILL-STRING-TO-SLEEVE FRICTIONAL HEATING

As described in Section 4, the drill string moves within a conducting sleeve placed in the tank penetration. Information provided indicates that the drill string is 1100-series carbon steel and the sleeve is stainless steel. The sleeve is a Schedule 80S 3-in. nominal pipe,[3] which has an i.d. of 2.90 in. with a wall thickness of 0.3 in. and is nominally 15 ft long. The drill string has a 2.25 in. o.d. and a 1.906 in. i.d. The drill sections themselves are fluted on the o.d. and are nickel plated. It has been reported that the portion of the string not penetrating the waste is not fluted, and it is not assumed to be plated. A scale drawing of the drill-string-in-sleeve cross section is shown in Fig. P-2. Coolant nitrogen for the drill bit is fed through the drill string at a nominal rate of 30 scfm. A nitrogen purge flow is introduced into the annulus between the sleeve i.d. and the drill-string o.d. at a nominal rate of 5 scfm.

Contact between the drill string and sleeve is possible. An analysis provided in Appendix N determined that a horizontal load of up to 610 lbf could be applied before the drill string would break at the point where the string exits the sleeve. The figure in Appendix N illustrating this situation is greatly exaggerated, however. Because the nominal clearance between the drill string and sleeve is small compared to the 15 ft sleeve length, the contact angle is quite shallow (see Fig. P-3). The bounding frictional heating analysis presented here assumes the limiting load of 610 lbf is applied horizontally (incipient drill-string failure). It further assumes a drill rotational speed of 55 rpm and initial temperatures of 38°C. This analysis conservatively assumes contact at only one region (sleeve exit) and that the contact region remains stationary on the sleeve. It would be expected, in reality, that bending would cause the drill string to rotate eccentrically, sweeping the contact region around the sleeve periphery. Bending might distribute real horizontal loads over two regions of contact. Also, a minimum penetration rate must be maintained for continued drilling, which would "feed" colder drill-string material into the contact region.

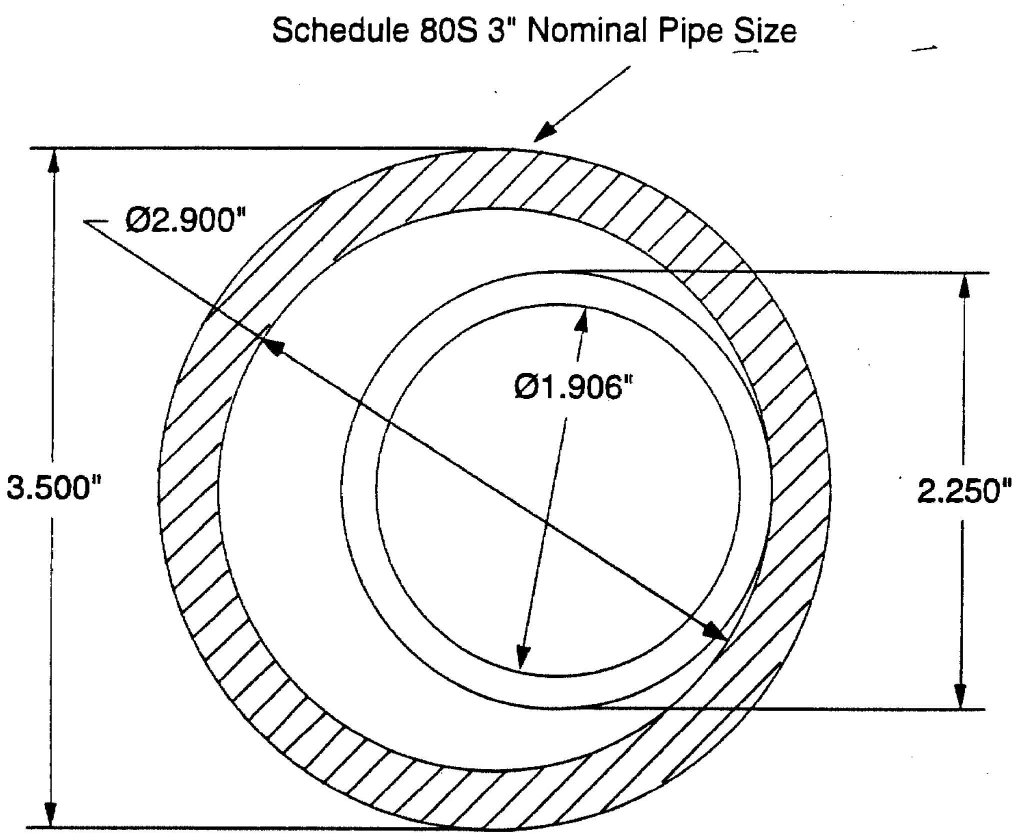


Fig. P-2. Cross-sectional view of the drill string in the conducting sleeve (to scale).

P.3. ESTIMATING CONTACT AREAS

Rabinowicz[2] suggests estimating the real contact area from the following relationship based on a limiting plastic-deformation analysis,

$$A_r = \frac{L}{p} , \qquad \text{(P-1)}$$

where L is the applied load acting normally and p is the penetration hardness. Because sliding applies shear forces at the surface, the limiting value obtained by Eq. (P-1) is usually modified to account for shear as

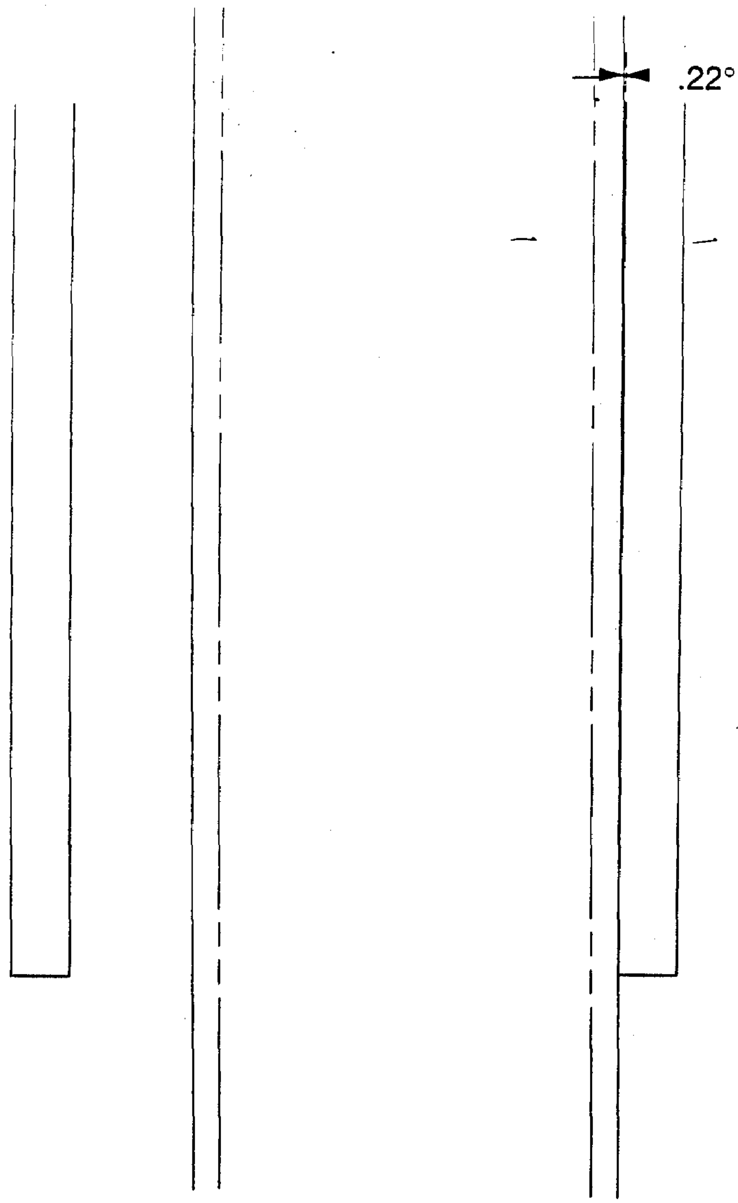


Fig. P-3. Vertical section of the drill string in the conducting sleeve (to scale).

$$A_r = \frac{L}{P}\sqrt{1+\alpha f^2}, \qquad \text{(P-2)}$$

where f is the coefficient of friction and α is an empirical constant.[4] When applied to the problem conditions described in Section P-2 above, the real contact area A_r is estimated to be 13.1 mm^2 (see Reference 5 for calculation details).

The apparent contact area is needed to specify the area over which frictional heating occurs to enable calculation of the nominal surface temperature distribution.

Because the problem geometry involves both curved and straight surfaces (see Figs. P-2 and P-3), determination of the apparent area is not straightforward, and a conservative approximation of ten times the real contact area is used (131 mm^2). The contact area in the problem considered here is probably elliptical.[6] To convert the area above to an ellipse, the major axis length is assumed to be four times the minor axis height. The resulting elliptical area has a major axis length of 12.9 m m and a minor axis height of 3.2 mm.

P.4. FLASH TEMPERATURE RISE

Rabinowicz[2] summarizes the state of the art in estimating the flash temperature rise, and offers the following choices:

$$\theta = \frac{v}{2} \pm (\text{a factor of } 3), \qquad \text{(P-3)}$$

described as "an order of magnitude realistic" method, where θ is the flash temperature rise (°C) and v is the sliding velocity in cm/s. For our problem, this method yields an estimate of 8°C, with a range of 0°C to 33°C.

For the simplification of one circular junction of diameter $2r_j$ sliding on another material at moderate speed v, the interface attains an equilibrium mean temperature rise θ_m above the nominal surface temperature of

$$\theta_m = \frac{f\Delta L v}{4r_j(k_1 + k_2)}, \qquad \text{(P-4)}$$

where r_j is the junction radius taken from the literature for dry steel on steel, and L is the applied load per junction, where the number of junctions is obtained by dividing the area of one junction of radius r_j into the real contact area A_r. The thermal conductivities of the two materials in contact are denoted k_1 and k_2. For this problem, θ_m is estimated by Eq. (P-4) to be 3°C.

Finally, a method is presented based on surface energy considerations, yielding "an order of magnitude" estimate for θ_m of

$$\theta_m = \frac{7800 f W_{ab} v}{(k_1 + k_2)}, \qquad \text{(P-5)}$$

where W_{ab} is the surface energy of adhesion. For our problem, this method yields the most conservative estimate of 46°C. This value was added to the maximum value calculated for the nominal surface temperature to estimate the peak surface temperature.

P.5. PEAK SURFACE TEMPERATURE CALCULATION

P.5.1. Nominal Surface Temperature Scoping Calculation

A scoping calculation was performed earlier, based on two semi-infinite bodies subjected to a sudden heat flux at the surface. This calculation used a different set of assumptions (fluted drill geometry in contact with the sleeve and a lower horizontal loading), but the results are qualitatively interesting. The calculation, described in Reference 5, concluded that a surface temperature rise on the order of several hundred degrees centigrade would require approximately 200 s. A corresponding steady-state interface temperature was calculated, with some general assumptions about convective heat transfer to the nitrogen drill-bit cooling and sleeve purge flow, at about 350°C.

P.5.2. Detailed Numerical Calculation of Nominal Surface Temperature

A detailed numerical model, with a two-dimensional drill string in contact with a three-dimensional sleeve was developed and applied. The string was modeled in two dimensions because the rotation smears any instantaneous azimuthal differences. The sleeve was modeled in three dimensions to account for the considerable heat capacity of the relatively thick wall and the extended area for convective heat transfer. Axial meshing was the same for both the string and the sleeve in the upper part of the model (through the contact region), and the drill string model extended below the sleeve. Approximately 1.45 m of overall drill string length was modeled, with the sleeve model just over half that length. The model axial ends were assumed adiabatic. Although the outer surface of the sleeve would be cooled by natural convection and could radiate heat to the cold tank interior, the outer surface of the sleeve and the outer surface of the drill string below the sleeve were conservatively considered to be adiabatic.

The finite-difference meshing can be varied, depending on the problem definition and expected thermal gradients. The axial meshing used to date is quite fine in the region of contact, being about one-fourth the thermal diffusion length for one revolution of the string. The axial nodes get courser as they get farther from the contact region. Both the drill string and the sleeve had three radial nodes for the calculations discussed here, with the outer drill-string-node thickness and the inner sleeve-node thickness kept equal. The azimuthal noding of the sleeve was relatively fine, as can be seen in Fig. P-4. The resulting model had 903 separate nodes. Frictional heating was applied to the contact region based on the elliptical contact area described earlier. Because frictional heating occurs throughout the volume "worked" in sliding contact and because the material properties of the sleeve and drill string are similar, half of the heat was applied to each component. The contact region was coupled with a conduction model with contact resistance, allowing heat to flow across the interface in either direction as dictated by the instantaneous temperature distribution. Convective cooling (or heating farther down the string interior) was included in both the drill string and the sleeve-to-drill annulus. The annulus convection model included the effect of ten different temperature surfaces (nine azimuthal sleeve nodes and the drill string outer surface).

The model was developed and solved within the architecture of the Los Alamos Systems Analysis (LASAN) code package.[7] LASAN materials properties and convective cooling routines were applied directly. The resulting model had 903 nonlinear ordinary differential equations that were solved simultaneously with a fully implicit integration algorithm. Temperature-dependent material properties were used throughout. The maximum surface temperature and its location were saved at each time step along with user-defined list variables and plot variables. Details of the model can be found in Reference 5.

P.5.3. Peak Surface Temperature Estimates

Figure P-5 presents the estimate for the peak surface temperature as a function of time after initial contact. The lower curve is the maximum temperature calculated with the numerical model described above. The conservative flash temperature rise from Eq. P-5 is added to yield the estimated peak surface temperature as a function of time. This is the peak surface temperature calculated with very conservative assumptions, which should bound the "expected" temperatures. The conservative estimate of the maximum possible "worst-case" surface temperature can be found in the following section.

P.6. WORST-CASE HOT-SPOT TEMPERATURE, AREA, AND LIFETIME

The literature presents an equation for the "worst-case temperature rise." This equation results from applying Eq. (P-4) with a *single* asperity of area A_r.

Application to our problem results in an estimated worst-case temperature rise above the nominal surface temperature of 577°C. The area of the hot spot is the real contact area, A_r, or 13.1 mm². This small volume would be expected to cool rapidly to the nominal surface temperature. Because the "single asperity" would be plastically deformed in sliding while carrying the *entire* applied load, it is reasonable to assume that this condition could only occur early in the dry sliding contact of two surfaces.

To determine the lifetime, or time-temperature history, of this hot spot, a numerical calculation was performed. It was assumed that the spot was formed on the first revolution in contact, so the nominal surface temperature was the initial temperature (assumed to be 38°C). When this 13.1 mm² spot is swept out from under the contact area, heating stops and cooling begins. Because conduction is expected to dominate, convective and radiative heat removal were ignored.

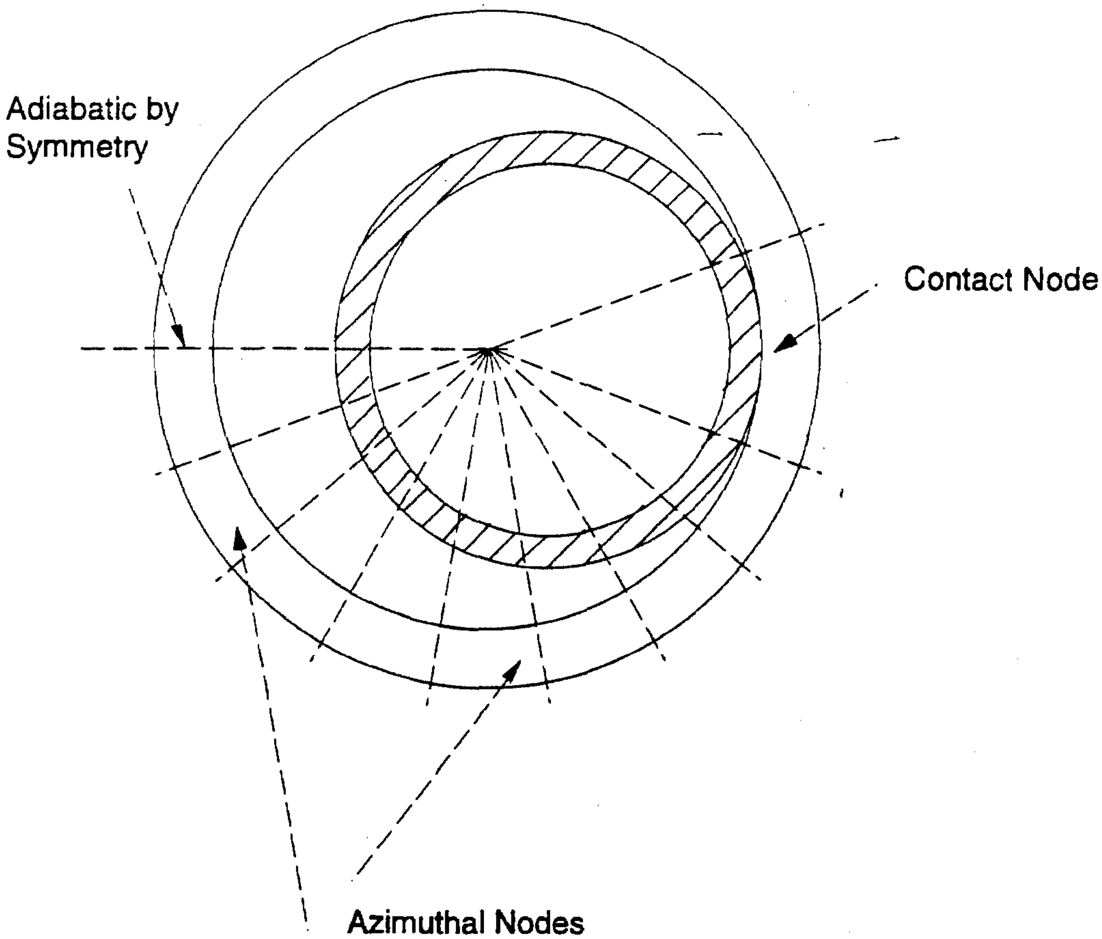


Fig. P-4. Azimuthal noding of the sleeve. Nine azimuthal nodes are actually calculated (symmetry gives the effect of 17 nodes with an adiabatic boundary opposite the contact region).

The average surface roughness (from ANSI B46.1-1978) for cold rolled or drawn materials ranges from about 1-10 μm.[1] The asperity height chosen for this analysis (100 μm) ensures that the contact point is well above the nominal surface. The analysis is quite sensitive to the assumed height of the contacting asperity, because the volume of the hot spot and the conduction length to the cooler surface both depend directly on the height. Using temperature-dependent material properties and the LASAN solver described above, the profile shown in Fig. P-6 was calculated. It can be seen that the hot spot drops below 400°C within 0.6 ms.

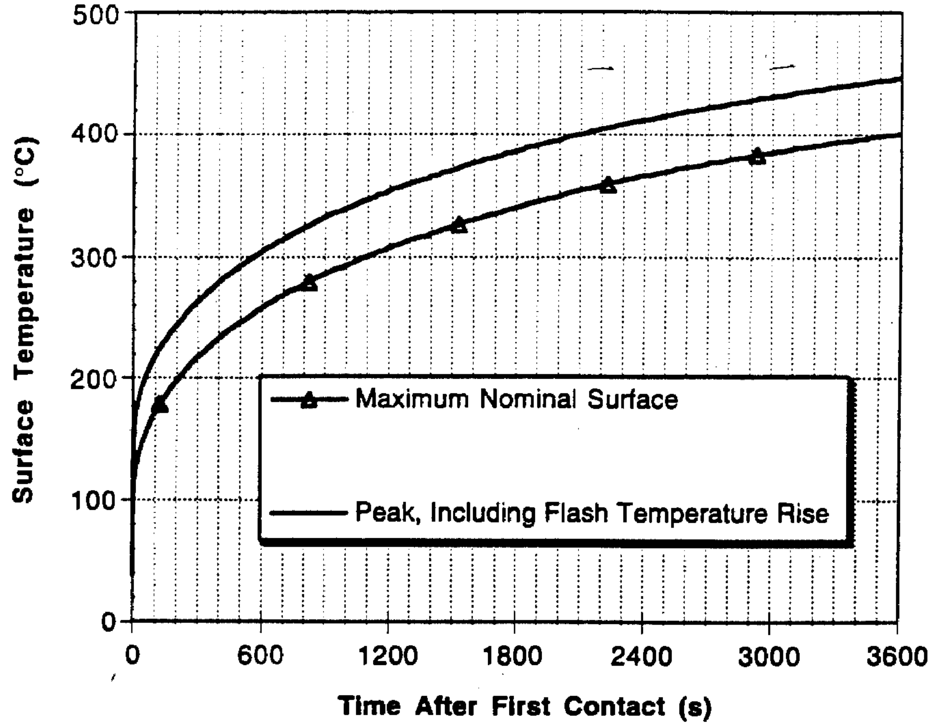


Fig. P-5 Estimated peak surface temperature as a function of time after initial contact. The lower curve is calculated with the numerical model described. The upper curve results when the conservative "flash temperature rise" is added to the numerical results.

P.7. CONCLUSIONS FOR DRILL-STRING-TO-SLEEVE CONTACT

The analyses above show that frictional ignition from a drill-string-to-sleeve contact event is unlikely. Even for a very conservative set of boundary conditions and loading assumptions (which probably could not be physically sustained for a long period), it takes on the order of 2100 seconds to reach surface temperatures of 400°C (500°C is not reached in 1 hour of contact). Although the possibility of a worst-case hot spot with a rapid, higher temperature rise cannot be precluded, analysis has shown the lifetime above 400°C to be very short, and the area is very small. With the nitrogen purge between the sleeve and the drill string, the presence of a combustible mixture in the vicinity of the hot spot is not likely. Consideration of the minimum surface temperature and the necessary area and induction time for ignition indicate that ignition is not expected even if a combustible mixture happens to be present.

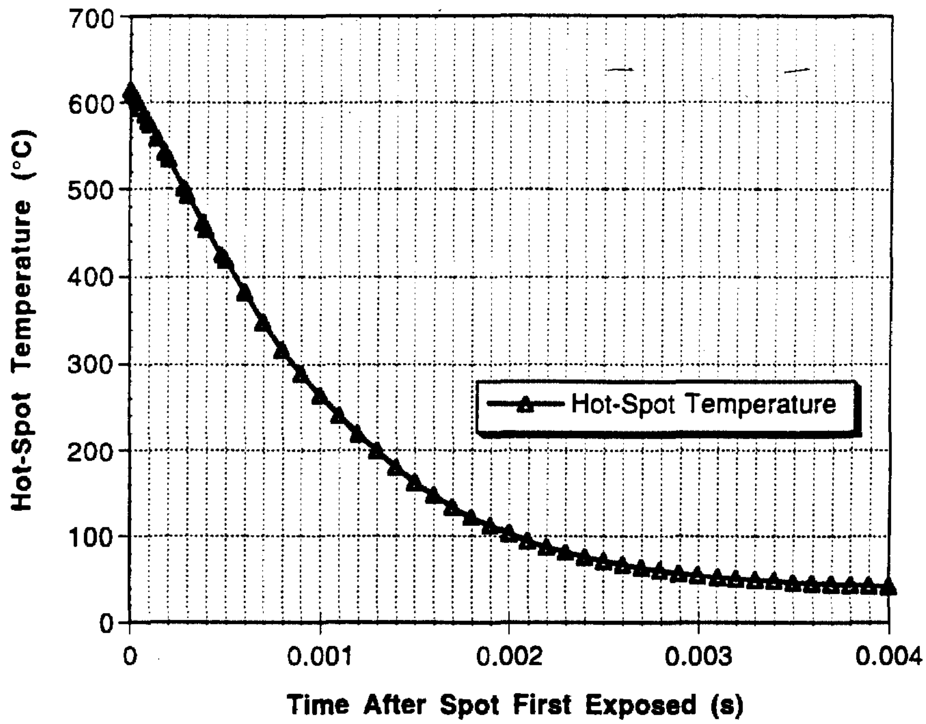


Fig. P-6. Transient cooling curve for a "worst-case" hot spot. It can be seen that the very small (13.1 mm^2) hot spot cools to below 400°C in less than 0.6 ms when exposed from under the contact area.

An experimental and theoretical study of the ignition of hydrogen/oxygen/nitrogen mixtures by hot surfaces, done for Canadian (CANDU) reactor licensing, provides methods for estimating both the minimum ignition surface temperature (MIST) and the induction time for ignition by surfaces with temperatures above the MIST.[8] For "20% and 30% hydrogen in air," the MIST was determined to be 916.2 K (643°C), which is higher than any of the temperatures calculated above. For temperatures below the MIST, the induction time is infinite (that is, ignition is not expected to occur, and did not occur in the experimental program).

However, as noted in the introduction to this appendix, there is considerable controversy about the ability to estimate the temperatures arising from dry metal-to-metal sliding. In order to conclude that ignition caused by drill string frictional contact with the sleeve is not likely with a high degree of confidence, it is necessary to obtain experimental verification by performing prototypical ignition testing. As test results are factored in, the predictive capability of the analysis will improve and the associated uncertainty will be reduced.

P.8. FRICTIONAL HEATING IN FAN-TO-CASE CONTACT

P.8.1. Scoping Calculation

A question has been raised about the possibility of frictional ignition by the exhauster fan during rotary-mode core sampling operations. The fan and its case are both made of aluminum. It is possible, using surface energy methods, to estimate the flash temperature rise above the nominal surface temperature resulting from dry metal-to-metal sliding as a function of sliding velocity.

Rabinowicz[2] develops an equation for the flash temperature rise based on surface energy considerations, presented earlier as Eq. (P-5). It can be noted that all parameters in this expression are material constants, with the exception of the sliding velocity. It is, therefore, particularly attractive for scoping estimates where a specific "event sequence" has not been postulated.

For aluminum, Table 2.1 of Reference 2 gives a value for the surface energy, γ, of 900 mJ/m^2 ($0.9\ J/m^2$). The surface energy of adhesion for two materials in contact, W_{ab}, is defined as[2]

$$W_{ab} = c_m \left(\gamma_a + \gamma_b\right), \qquad \text{(P-6)}$$

where the compatibility parameter, c_m, is 1.0 for identical metals, yielding a value for W_{ab} of $1.8\ J/m^2$. The coefficient of friction, f, for dry sliding of aluminum on aluminum is quite high. Marks' Handbook[3] gives a value of 1.4, confirmed by Figure 4.16 in Reference 2. The thermal conductivity for "generic" aluminum[9] is about 200 W/m °C.

Using the values listed above, Eq. (P-5) yields a unit-velocity flash temperature rise of about 49°C per m/s of sliding velocity. This value is only one-sixth of the comparable value for the drill-string-to-sleeve (carbon-steel/stainless-steel) problem above of 288°C per m/s of sliding velocity, but the potential sliding speeds in fan-to-case contact are much higher. Assuming an initial temperature of 38°C, any sliding velocity above about 12.7 m/s will produce melting using this simple model. (The drill-string-to-sleeve contact has a surface sliding velocity of only 0.16 m/s).

The exhauster ventilation fan has a 0.381-m (15-in.) o.d. and a maximum rotational speed of about 2400 rpm (estimated at the 60% power limit, 4.5 hp point — typical operating point is 28% power).[10] These fan characteristics give a tip speed of almost 48 m/s. Together with the unit-velocity flash temperature rise calculated above, this sliding speed gives a temperature well above the melting point of aluminum (conservatively 660°C, reported values for different material specifications range from 643°C to 657°C). In such cases, the temperature rise is limited to the melt temperature by the phenomenon of melt lubrication, which greatly reduces the coefficient of friction. This reduction in friction reduces the subsequent heating rate and limits the total quantity of material melted.

P.8.2. Discussion of Exhauster Fan-to-Case Frictional Heating

The first thing to remember is that the above estimate is an order of magnitude estimate for the mean flash temperature rise in equilibrium. Here equilibrium presumably means contact and constant sliding speed and because heat capacity does not appear in Eq. (P-5), thermal equilibrium of the "junctions" is expected. However, the junctions involved in the flash temperature *rise* (above the nominal surface) are *very* small and will reach thermal equilibrium quickly (assumed instantaneously in the friction and wear literature). But, a short duration "impact" could be different. Also, Eq. (P-5) gave the highest temperatures, by far, of three methods used in the drill-string-to-sleeve problem.

A second, and perhaps more important, consideration is what conditions are required for ignition of a hydrogen/air mixture by a hot surface. As mentioned in Section P-7 above, an experimental and theoretical study of ignition of hydrogen/oxygen/nitrogen mixtures by hot surfaces, done for Canadian reactor licensing, provides methods for estimating both the minimum ignition surface temperature and the induction time for ignition by surfaces with temperatures above the MIST.[8] For "20% and 30% hydrogen in air," the MIST was determined to be 916.2 K (643°C), or very close to the melt temperature of aluminum. For temperatures below the MIST, the induction time is infinite (that is, ignition is not expected to occur, and did not occur in the experimental program).

The relationship between the surface temperature, T_s, and induction time, t^*, was given as

$$T_S = T_{S\infty} e^{A/t^*}, \qquad \textbf{(P-7)}$$

where $T_{s\infty}$ is the MIST and A is an empirical characteristic time constant. For "20% and 30% hydrogen in air," A was reported to be 5.08e-5 s.

Rearranging Eq. (P-7) to solve for t^* given T_s,

$$t^* = \frac{A}{\ln\left(\frac{T_S}{T_{S\infty}}\right)}. \qquad \textbf{(P-8)}$$

For T_s at the melting point of aluminum, the induction time t^* calculated with Eq. (P-8) is 2.77 ms.

To determine the hot-spot lifetime above the MIST, a simple 1D transient heat transfer calculation was performed. The hot-spot thickness was taken to be 20 μm, as measured in experimental studies of methane ignition by a molten metal smear produced by worn coal-mining bits.[11] In a one-dimensional calculation, the area drops out if the calculation is based on the enthalpy per unit area (the time derivative is the heat flux). Because conduction was expected to dominate, other heat-transfer mechanisms such as convection to the ventilation flow and radiation to the ambient-temperature environment were ignored. The system was assumed to be initially at 38°C. The thermal conductivity and heat capacity of the melt were assumed to be equal to that of solid aluminum. The simple model was solved numerically with the LASAN code package.[7]

Figure P-7 displays the transient cooling of the melt smear to the ambient temperature surface. The plateau represents the time required to remove the heat of fusion from the melt. It can be readily seen that the hot smear is very short lived, with the time above the MIST temperature less than 4 μs and the time above 400°C less than 7 μs. This transient cooling is quite sensitive to the assumed melt-smear thickness, because both the volume of hot material and conduction length to the cooler surface depend directly on the assumed thickness. To assess the sensitivity, the problem was rerun with the assumed melt-smear thickness increased by a factor of 10 to 200 μm. Results for this parametric sensitivity calculation are shown in Fig. P-8. While the lifetimes are much longer than the base case, they are still short compared to the calculated induction time of 2.77 ms. Examination of Fig. P-8 shows the time above the MIST temperature is less than 0.4 ms, and the time above 400°C is less than 0.65 ms. At a sliding velocity of 48 m/s, this 0.65 ms lifetime would produce a smear above 400°C about 3 cm long (width depends on geometry of contact).

P.8.3. Conclusions for Exhauster Fan-to-Case Frictional Heating

Based on the simple analysis above, it appears unlikely that ignition would result from short-term contact between the exhauster fan and case, even though quite high local temperatures can be generated. The question of surface temperatures resulting from long-term rubbing is more difficult and would require detailed modeling of the fan and case to address. However, it requires a mechanical failure for fan-to-case contact to occur; therefore, sustained powered fan operation with contact is unlikely. If sustained rubbing is determined to be possible, the high thermal conductivity of aluminum provides some time to sense contact and interrupt fan power. Because the hot spots are quite localized, but at high temperatures, an optical temperature measurement (for example infrared) might be possible (depending on case geometry and "view factors"). This analysis is further documented in Reference 12.

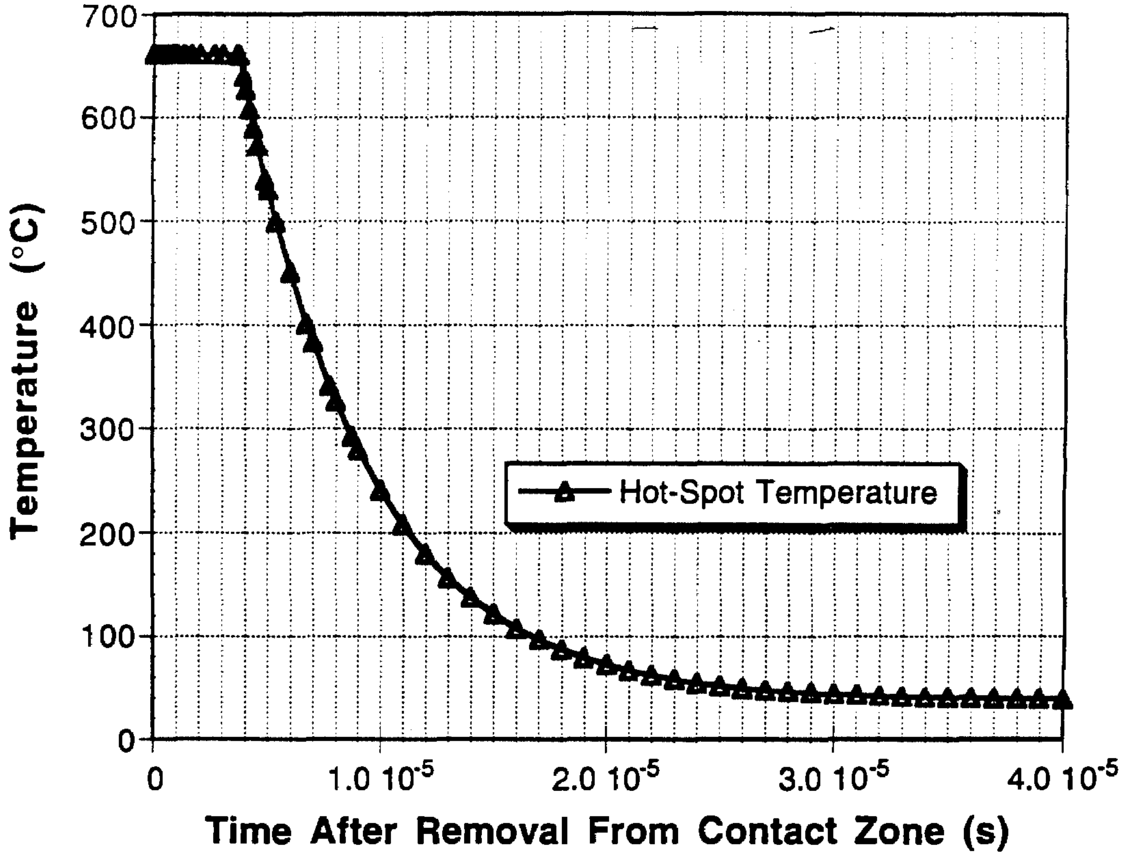


Fig. P-7. **Transient cooling curve for a 20-μm-thick hot-melt smear as a function of time after the melt is swept out of the contact zone. At that point, heating stops and conduction to the cool surface begins. The plateau represents the time required to remove the heat of fusion from the melt.**

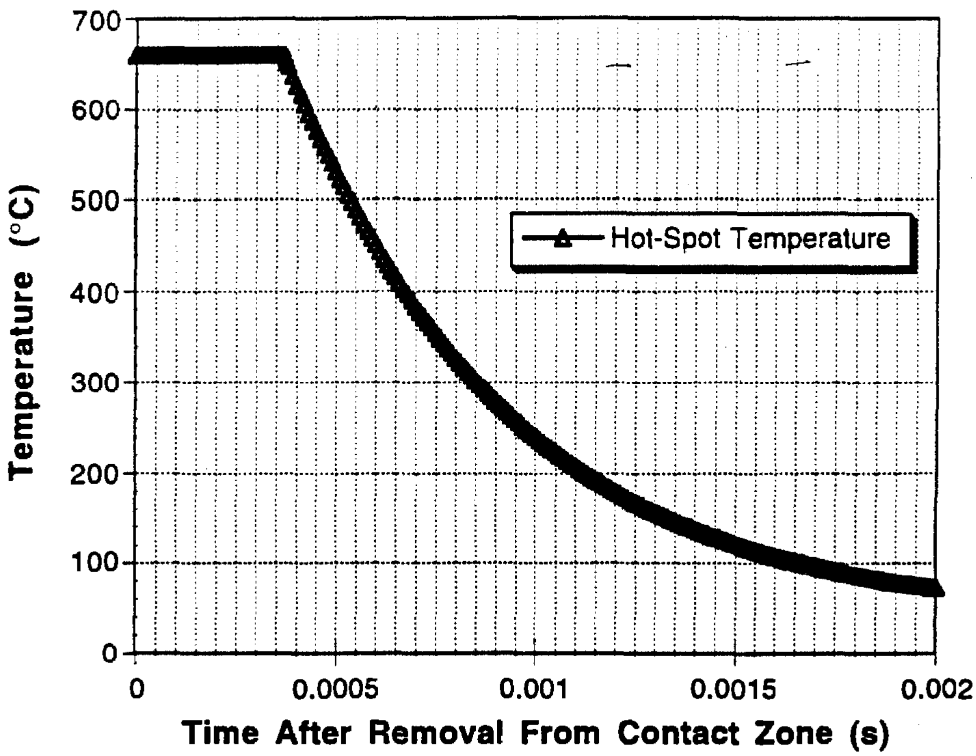


Fig. P-8. **Transient cooling curve for a 200-µm-thick (10 x expected) hot-melt smear as a function of time after the melt is swept out of the contact zone. At that point, heating stops and conduction to the cool surface begins. The plateau represents the time required to remove the heat of fusion from the melt.**

P.9. REFERENCES

1. H. E. Boyer and T. L. Gall, editors, *Metals Handbook Desk Edition*, (American Society for Metals, Metals Park, Ohio, 1985).

2. E. Rabinowicz, *Friction and Wear of Materials*, 2nd ed., (John Wiley and Sons, New York,New York, 1995).

3. T. Baumeister and L. S. Marks, editors, *Standard Handbook for Mechanical Engineers*, 7th ed., (McGraw-Hill, New York, New York, 1978).

4. J. S. Courtney-Pratt and E. Eisner, "The Effect of a Tangential Force on the Contact of Metallic Bodies," *Proc. Royal Soc.* **A**, Vol. 238, 529-550 (August 1956).

5. K. R. Stroh, "Analysis of Frictional Heating in Drill-String-to-Sleeve Contact," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-ST-092, (March 1996).

6. J. Bos and H. Moes, "Frictional Heating of Tribological Contacts," Journal of Tribology, Vol. 117, 171-177, (January 1995).

7. K. R. Stroh, G. J. Willcutt, Jr., M. L. Walsh, and A. G. Barker-Wohletz, "LASAN-3 - A General Purpose Code for the Simulation of Large-Scale Complex Systems," Los Alamos National Laboratory report, DRAFT November 1992.

8. R. K. Kumar and G. W. Koroll, "Ignitability of Hydrogen/Oxygen/Diluent Mixtures in the Presence of Hot Surfaces," *Nuclear Safety*, Vol. 36, No. 1, (January-June 1995).

9. J. P. Holman, *Heat Transfer*, 3rd Ed., (McGraw-Hill, New York, New York, 1972).

10. J. Robinson, Westinghouse Hanford Company, personal communication, February 22, 1996.

11. R. Blickensderfer, "Methane Ignition by Frictional Impact Heating," *Combustion and Flame*, Vol. 25, 143-152, (1975).

12. K. R. Stroh, "Analysis of Frictional Heating in Exhauster-Fan-to-Case Contact," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-ST-093, (March 1996).

APPENDIX Q

SAMPLE PROBLEM FOR THE COMPUTATION OF THE SITE-WIDE RISK

Q.1. INTRODUCTION

Rotary-mode core sampling (RMCS) operations will be performed in a number of tanks during the course of the year. In this safety assessment (SA), the bounding accident consequences and frequencies are computed. In doing so, a bounding tank was chosen in such a way that both the consequences and frequencies of a given accident were computed conservatively. For instance, for the dome collapse accident (App. I), the maximum drop height that corresponds to a tank that is less than half full is chosen. Likewise, the "super tank" source term that bounds all the single-shell tanks (SSTs) in the tank farm is used in quantifying the radiological consequences (App. R). The major accident scenario that leads to dome collapse is a deflagration in the dome space. In computing the accident frequency, large gas-release volumes that would normally be observed in full tanks (App. L) are used. Likewise, the minimum dome space volume is used in computing the dome concentrations (App. L), assuming a worse-case gas compositions (App. C). The bounding accident consequences are compared with the risk guidelines (RGs) (see Section 5) using the frequencies computed per year per tank basis.

However, it has been suggested that the frequency should be multiplied by the number of tanks that would be sampled during the year. There are reasons to question the validity of this approach. Simply multiplying "super tank" worse case accident frequencies by the number of sampling operations in the farm does not provide a reasonable estimate of the RMCS risk. At best, it provides a bound on the risk. The usefulness of this bound depends on its intended use.

The first reason to question whether this multiplication yields a reasonable estimate is the conservative nature of the assumptions used in deriving the bounding consequences computed in this SA. There is not a one tank that is represented by the super tank, hence there is no idea of how far removed the super tank is from a representative tank in accident frequencies and consequences. Because of the conservative nature of the SA results, no estimate of tank specific accidents frequencies has been made. Without further analysis, it is unknown, how representative the frequencies are to realistic tank conditions. In a similar vein, consequences based on a super tank are only meant to provide an upper bound. Again, it is unclear how far removed tank specific realistic consequences are from the bounding super tank consequences.

The second reason to question whether simple frequency multiplication is reasonable has to do with risk guidelines (RGs) in general, and WHC RGs in particular. Generally speaking, RG arose in the context of Probabilistic Risk Assessment (PRA). The RGs are intended to be used with PRA results, which include conservative assumptions when warranted. However, the PRA results are not considered worse-case or bounding. Hence, RG would not normally be used with bounding results. The fact that bounding analyses yields results below the RGs means only that the realistic case is bounded. It does not provide information what the actual risk really is. More specifically, WHC RGs are not cumulative in nature. In other words, following the WHC RGs, all frequency/consequence point representing accident sequences are compared individually to the RG. It can be seen that any differences between a real tank and the super tank will manifest themselves as different points in frequency/consequence space.

Based on these discussions, we do not believe that the proposed approach of multiplying the frequencies by the number of tanks may not be adequate in obtaining a realistic risk for the RMCS operations. Such an approach may grossly overestimate the risk and result in slowing down progress in the characterization program.

In this appendix, an example problem is provided. In this sample problem, bounding SA consequences acquired using SA methodology are compared with the risk of performing the same activity in a collection of tanks. The 19 single-shell tanks (SSTs) that are on the original Flammable Gas Watch List (FGWL) are chosen as the collection of tanks in this example.

Before the quantitative evaluation of the sample problem is started, the reader must be warned that the objective is not to provide a total realistic site-wide risk for the RMCS operations. The sole objective is to demonstrate that multiplying the risk of a bounding accident obtained using the SA methodology by the number of tanks may grossly overestimate the risk. In the process, an attempt was made to use realistic assumptions and input parameters while linearizing many of the mechanistic models for simplicity.

Q.2. DESCRIPTION OF SAMPLE PROBLEM

For the sample problem, the dome collapse accident is considered. In the following subsections, the mechanistic models used for consequence and frequency analysis are discussed.

Q.2.1. Consequence Model

The model used in Appendix I shows that the respirable solid waste material (M) that becomes aerosol as a result of dome collapse is directly proportional to the impact energy of collapsing concrete and soil. Assuming a constant concrete and soil weight on each tank, the impact energy is proportional to the drop height (D).

The radiological consequences (C) of the release is proportional to the amount of respirable material (M), the atmospheric dispersion coefficient (χ/Q), and the unit dose associated with the waste material(S). Thus,

$$C \propto M \times S \times \left(\frac{\chi}{Q}\right) \propto D \times S \times \left(\frac{\chi}{Q}\right) \quad \text{(Q-1)}$$

For simplicity, the off-site consequences are considered using the approximation that the offsite receptor is at a constant distance and direction from each tank. Thus, the χ/Q for each tank is constant. However, for the bounding consequence analysis, 95% weather conditions are used. But, the tanks will be sampled at different times during the year, and the assumption that 5% weather conditions exist each time is overly conservative in assessing the risk. Assuming that the sampling activities are randomly spread over the year, the use of 50% meteorology is more appropriate for risk assessment. Thus, the ratio of individual tank consequence and the bounding consequence may be computed as

$$\frac{C_i}{C_{max}} = \frac{D_i}{D_{max}} \times \frac{S_i}{S_{max}} \times \frac{(\chi / Q)_{50\%}}{(\chi / Q)_{95\%}} \quad \text{(Q-2)}$$

Q.2.2. Frequency Model

For this sample problem, it is assumed that the dome collapse scenario is a dome space deflagration caused by a lightning strike when flammable gases exist in the dome space. Each tank has the same cross-sectional area. Assuming that each tank has equal lightning protection, the lightning strike frequency per tank per year is constant. Thus, the frequency of dome deflagration caused by lightning is directly proportional to time-at-risk (T), which is defined as the time period during which the dome concentration is above flammable conditions. Thus,

$$F \propto T$$

Note that, for the purpose of this sample problem, lightning may be replaced with any other spark source which randomly occurs in time. To further simplify the problem, the following assumptions are introduced:

- Intrusion by the RMCS device causes a gas-release event (GRE) in each tank; and
- The volume of gas released is directly proportional to the volume of waste in the tank:

$$Q \propto V_w = a \times V_w . \quad \text{(Q-3)}$$

where Q is the gas-release volume, a is the proportionality constant and W_w is the waste volume. This assumption may be challenged as not being applicable to all tanks depending upon the waste properties in each tank. On the other hand, it can be argued that (based on the current knowledge of the overall SST waste properties and gas release mechanisms discussed in App. L), releasing a gas volume of 5 volume percent of the waste volume in each RMCS operations conservatively bounds all the tanks.

Assuming homogeneous mixing in the dome, the dome space concentration (X) as a result of the GRE is given by

$$X(t) = \begin{cases} 1 - \exp\left(-\frac{q}{V} t_o\right) & \text{if } 0 \leq t \leq t_o \\ \left[1 - \exp\left(-\frac{q}{V} t_o\right)\right] \exp\left[-\frac{w}{V}(t - t_o)\right] & \text{if } t > t_o \end{cases} , \quad \text{(Q-4)}$$

where q is the gas-release rate, V is the dome volume, t is the time after the GRE, t_o is the release period, and w is the ventilation flow rate. Assuming an instantaneous release and linearizing the concentration decay curve, Equation (Q-4) yields:

$$X(t) = \frac{Q}{V}\left(1 - \frac{w}{V} t\right) \quad wt < V \ . \quad \text{(Q-5)}$$

Defining the lean flammability of the gas mixture as the Low Flammability Limit (LFL), the time-at-risk (T) may be obtained as

$$T = \begin{cases} 0, & \text{if } \ a \times V_w / V \leq LFL \\ \frac{V}{w}\left(1 - \frac{LFL \times V}{a \times V_w}\right), & \text{if } \ a \times V_w / V > LFL \end{cases} \quad \text{(Q-6)}$$

Thus, the ratio of accident frequency for individual tanks to the bounding accident frequency can be computed as

$$\frac{T_i}{T_{max}} = \frac{V_i}{V_{max}} \frac{\left(1 - \frac{LFL \times V,i}{a \times V_{w,i}}\right)}{\left(1 - \frac{LFL \times V_{max}}{a \times V_{w,max}}\right)} \ . \quad \text{(Q-7)}$$

Two additional assumptions were introduced in deriving Eq. (Q-7):

- The same ventilation flow rate is used in all the tanks; and
- LFL is the same for all tanks and is equal to 0.04. One could introduce more details into this problem by using individual gas compositions and corresponding LFL values as discussed in Appendix C. However, such an exercise would be academic at best for the purpose of this calculation.

Q.3. RESULTS

For the bounding accident, we use the following parameters,

V_{max}	= 50000 ft^3 (App. C),
D_{max}	= 30 ft (App. I),
S_{max}	= 2.4×10^5 Sv/L (App. R),
$(\chi/Q)_{95\%}$	= 1.9×10^{-5} s/m^3 (App. R),
$V_{w,max}$	= 130,000 ft^3 (App. C), and
a	= 0.05 (conservative estimate based on discussions in App. L).

The 50% atmospheric dispersion coefficient is obtained from Reference 1 as approximately 10% of $(\chi/Q)_{95\%}$. The individual tank data are obtained from Appendix C and listed in Table Q-1. Also shown in Table Q-1 are the individual tank source terms [denoted as (S_a) obtained from Agnew's database].[2] This database includes only the ^{137}Sr, ^{137}Cs, and Pu. These nuclides make up ~70% of the bounding source term given in Appendix R. Thus, when using Agnew's data the comparable bounding source term would be S_{max} = 1.6×10^5 Sv/L (Ref. 2). The estimates by Agnew are based on historical fill records and a set of defined waste types that are based on many factors. Agnew defines a tank layer model (TLM), supernate mixing model (SMM) and total inventory (TI). In this sample problem, we use the TLM values because they are more representative of the total tank waste, and we used the bounding value where the maximum dose for each nuclide is chosen among the TLM, SMM and TI values. This is similar to the "super tank" approach used for the source terms in Appendix R. Instead of choosing the maximum nuclide for the entire tank farm, the maximum nuclide for a given tank is used. This source term is denoted as $S_{a,max}$ in Table Q-1.

Another alternative to using Agnew's data would be to use the SST flammable gas subset source term developed in Reference 3 for all the tanks. It can be argued that, because the database is small, this subset does not necessarily bound all the flammable-gas tanks. However, for the purpose of this sample problem, a realistic source term for each tank rather than a bounding source term for all the tanks is of interest. The SST flammable-gas subset given in Reference 3 is possibly still conservative for these purposes. The bounding SST flammable-gas source term is given as 6.1×10^3 Sv/L (Ref. 3).

Details of the calculations are given in Reference 4. The results are summarized in Table Q-2.

TABLE Q-1
INDIVIDUAL TANK DATA

TANK	V (ft^3)	V_w (ft^3)	D (ft)	S_a (Sv/L)	$S_{a,max}$ (Sv/L)
A-101	51,900	127,000	16	800	20,910
AX-101	76,600	102,400	21	1460	38,500
AX-103	163,500	15,600	41	5260	39,350
S-102	65,200	75,500	20	400	2740
S-111	65,200	75,500	20	1360	3950
S-112	68,100	72,500	20	1170	6900
SX-101	115,600	63,300	30	1580	2040
SX-102	103,500	75,500	27	730	2820
SX-103	88,700	90,200	24	1110	1510
SX-104	91,600	87,300	25	1110	2200
SX-105	84,300	94,600	23	1300	4750
SX-106	102,700	76,200	27	660	1370
SX-109	144,000	35,000	37	2710	2710
T-110	57,600	54,500	16	60	60
U-103	50,600	61,500	15	710	820
U-105	56,900	55,200	16	920	960

TABLE Q-1 (cont)
INDIVIDUAL TANK DATA

TANK	V (ft^3)	V_w (ft^3)	D (ft)	S_a (Sv/L)	$S_{a,max}$ (Sv/L)
U-107	50,200	61,900	15	2690	11,270
U-108	51,300	60,780	15	1570	17,500
U-109	58,700	53,400	17	1780	6080

In Table Q-2, c represent the consequence from individual tanks as a percent of the bounding consequence (C_{max}). Thus,

$$c = 100 \frac{C_i}{C_{max}} \quad . \tag{Q-8}$$

The individual accident frequencies (f) for the tanks are expressed as percent of the accident frequency for the bounding case (F_{max}). Thus,

$$f = 100 \frac{F_i}{F_{max}} \quad . \tag{Q-9}$$

We define the risk as the product of frequency and consequences. The term r in Table Q-2 is defined as the percent fraction of the bounding risk. Thus,

$$r = 100 \frac{R_i}{R_{max}} = 100 \frac{F_i C_i}{F_{max} C_{max}} \quad . \tag{Q-10}$$

As shown in Table Q-2, the total consequences range between 1.4 and 8.4% of the bounding consequences using different source terms. The lowest cumulative consequence is obtained using Agnew's best-estimate source term. The highest consequence results from Agnew's bounding source term. These results suggest that, using conservative tank specific models, the offsite consequences of 19 consecutive dome collapses in a year is less than 10% of the bounding dome collapse consequences computed in this SA.

The major contribution to the overall consequences (>30%) is from Tank AX-103 which has a very small waste volume and a large dome volume. Thus, the deflagration frequency for this tank is 0 resulting in a 0% contribution to the overall risk.

TABLE Q-2
SAMPLE PROBLEM RESULTS

TANK	c_1 (%)	c_2 (%)	c_3 (%)	f (%)	r_1 (%)	r_2 (%)	r_3 (%)
A-101	0.14	0.03	0.69	100	0.14	0.03	0.70
AX-101	0.18	0.06	1.66	89	0.16	0.06	1.48
AX-103	0.35	0.44	3.32	0	0.00	0.00	0.00
S-102	0.17	0.02	0.11	58	0.10	0.01	0.07
S-111	0.17	0.06	0.16	58	0.10	0.03	0.10
S-112	0.17	0.05	0.28	49	0.08	0.02	0.14
SX-101	0.25	0.10	0.13	0	0.00	0.00	0.00
SX-102	0.24	0.04	0.16	0	0.00	0.00	0.00
SX-103	0.20	0.05	0.07	55	0.11	0.03	0.04
SX-104	0.21	0.06	0.11	43	0.09	0.02	0.05
SX-105	0.20	0.06	0.22	70	0.14	0.04	0.16
SX-106	0.23	0.04	0.08	0	0.00	0.00	0.00
SX-109	0.31	0.21	0.21	0	0.00	0.00	0.00
T-110	0.14	0.00	0.00	26	0.04	0.00	0.00
U-103	0.13	0.02	0.03	50	0.06	0.01	0.01
U-105	0.14	0.03	0.03	29	0.04	0.01	0.01
U-107	0.13	0.08	0.35	51	0.07	0.04	0.18
U-108	0.13	0.05	0.54	48	0.06	0.02	0.26
U-109	0.14	0.06	0.21	21	0.03	0.01	0.04
TOTAL	3.6%	1.5%	8.4%	746%	1.2%	0.3%	3.2%

Subscripts (1) Flammable Gas Source Term (Ref. 3)
(2) Agnew's Best-estimate Source Term S_a (Ref. 2)
(3) Agnew's Bounding Source Term $S_{a,max}$ (Ref. 2)

The total relative frequency may be obtained as 7.5 (750% of the bounding tank frequency). The major contributors are tanks A-101 (100%) and AX-101 (~90%) because they have a large waste volume to dome volume ratio compared to other tanks. Thus, for this sample problem, doing RMCS activities in 19 tanks increases the frequency by a factor of 7.5 instead of a factor of 19 that the conservative approach would require.

Finally, this sample problem shows that, using conservative tank-specific parameters, RMCS operations in 19 FGWL tanks would result in a total risk to an off-site individual, which is only 1.2% of the bounding risk computed in this SA (using the flammable-gas source term). Using Agnew's upper-bound source terms for each tank, the total risk becomes 3.2% of the risk obtained from bounding analysis. For the conservative case, nearly 70% of the total risk is from Tanks A-101 and AX-101 whereas the remaining 17 tanks only contribute 30% of the total risk. The maximum risk from an individual tank is from Tank AX-101, which is only 1.5% of the bounding risk.

Q.4. SUMMARY AND CONCLUSIONS

The sample problem discussed in this appendix clearly illustrates that in obtaining the total risk associated with the RMCS operations in multiple tanks over a year, we should not take either the consequences or frequencies obtained for one tank and multiply it by the number of tanks. This approach would be overly conservative. The above sample problem demonstrates that using tank-specific yet conservative estimates, the total risk of dome collapse risk in running the RMCS device in 19 FGWL SSTs is ~3.2% of the bounding risk calculated in this SA per tank. Three big factors that reduce the total risk are as follow:

- The use of tank-specific source terms,
- The use of 50% meteorology in computing the atmospheric dispersion factors, and
- The use of tank-specific gas-release volume and time-at-risk magnitudes derived from a simple scale model.

Based on the analysis provided in Section 5 of this SA, the radiological offsite consequences of a dome collapse accident is < 10 rem. The mitigated frequency of the dome collapse accident for a bounding tank is shown to be < 1.0E-6/yr in this SA. Assuming a frequency of 1.0E-06/yr, the risk is equal to 1.0E-5 rem/yr.

As shown in this sample problem, the worse case consequence among the 19 FGWL tanks analyzed is 0.3 rem. In order to exceed the radiological offsite RGs, the accident frequency must be > 1.0E-2/yr.

In a typical risk assessment, one would complement the above calculations with an uncertainty analysis. The purpose in this appendix is not to provide a full risk assessment. First, a conservative source term is used even for tank specific conditions. Further, the orders of magnitude differences between the proposed approaches demonstrate the point, and further analysis using these linearized simple models will be at most academic at this stage.

If one were interested in obtaining the site-wide risk associated with running the RMCS in all the flammable-gas tanks, an approach similar to the one shown here can be used. The use of the bounding accident consequences and frequencies as being applicable to each tank to estimate the site-wide risk will greatly overestimate the risk and unnecessarily slow down the progress in the tank characterization program.

Q.5. REFERENCES

1. C. Unal, "Evaluation of Atmospheric Dispersion Coefficients at Elevated Discharge Temperatures, Velocities, Diameters and Release Heights by Using AI-RISK Computer Program," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-078 (August 1995).

2. R. T. Perry, "Bounding Radioactive Source Term for Hanford Tanks," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-RAD-009 (November 1995).

3. R. J. Van Vleet, "Radionuclide and Chemical Inventories for the Single-Shell Tanks," Westinghouse Hanford Company report WHC-SD-WM-TI-543 (1993).

4. K. P. Pasamehmetoglu, "Computation of the Site-Wide Risk," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-113 (February 1996).

APPENDIX R

SOURCE TERM, CRITICALITY, RADIATION EXPOSURES AND CONSEQUENCE CALCULATION METHODOLOGY

R.1. INTRODUCTION

In this appendix, the following issues are addressed:

Section 2.0: Bounding source terms applicable to single-shell tank (SST) waste are summarized. The inhalation doses resulting from the bounding source term also are included in this section.

Section 3.0: The criticality issues associated with the rotary-mode core sampling (RMCS) operations are discussed.

Section 4.0: The high-efficiency particulate air (HEPA) filter loading and resulting radiation exposure doses are estimated. Radiation doses from the shielded receiver and the drill unit also are discussed in this section.

Section 5.0: This section summarizes the methodology used for estimating the receptor doses from material releases.

R.2. SST SOURCE TERM

The radionuclides used in this safety assessment (SA) for the source term are based on an evaluation of the data characterizing the tank waste made by Westinghouse Hanford Corporation (WHC) engineers. The results are based upon the information contained in References 1 through 6. In addition, files of sample data collected by the Tank Characterization Program, Tank Characterization Report, and the Tank Contents Database maintained by Pacific Northwest Laboratories for WHC were also used. Scatter plots of activities versus tank and tables containing very high and very low activities were prepared from the reports and data noted. The results are given in Reference 7.

Eleven radionuclides that account for 99.9% of the total dose based on the data from References 1 and 2 were plotted. On each plot, a line was drawn that represented the maximum activity concentrations obtained. When an experimental sample point higher than the line was found, it was reviewed by a panel. If the panel could not technically justify eliminating the point, it was used. Conversely, the panel would lower a point on the line if it could be justified.

After the maximum sample activity concentrations were established, a maximum sample activity composite was developed for nine tank groupings based on the recommended maximum activity concentrations for each of the nuclides. A nuclide is listed if it contributes to 0.1% or more of the activity. These source terms for SST solids and SST liquids are listed in Table R-1. These activities would be used for external exposure calculations.

The unit-liter-dose values that are used to calculate exposure from inhalation are based on the source terms described above and dose conversion factors. The dose conversions factors are those found in Reference 8. Multiplying the dose conversion factors for each nuclide by the source term for each nuclide results in a committed effective dose equivalent (CEDE). These CEDEs are summed for each composite for a total CEDE. The CEDEs summed with effective dose equivalent (EDE) caused by external dose radiation result in a total effective dose equivalent (TEDE). Here, however, the EDEs are negligible for all accident scenarios except for those involving a liquid pool. The results here assume that the TEDE is equal to the CEDE. The CEDE for SST liquids and SST solids based on the maximum activities per liter for SST tanks are also given in Table R-1.

R.3. CRITICALITY CAUSED BY RMCS OPERATIONS

The purpose of this section is to address the criticality issues associated with the RMCS operations. It presents calculations and the reasoning made to determine if the single-shell Flammable Gas Watch List tanks are criticality safe under all conditions for the proposed rotary-core drilling.

The maximum plutonium content found in any experimental sample in SST analysis forms the basis for the ^{239}Pu content. This value is given in Table R-1, which has the maximum value of plutonium found in any sample for SSTs.

For solids in single-shell tanks, the plutonium concentration is given as 4.4e+08 Bq/L. This value contains both the contribution from ^{239}Pu and ^{240}Pu. Plutonium-240 is not fissionable. However, assuming all activity is caused by the fissionable ^{239}Pu, this translates to 0.191 g/L, a bounding value for ^{239}Pu in single-shell tanks. The plutonium concentration demonstrated to be criticality safe has been calculated and reported in References 9 and 10.

The minimum critical plutonium concentration calculated by Rogers[9] was 2.6 g/L with a 95% confidence level. He used a reasonably conservative mixture of high-level tank waste, which did not include some significant neutron absorbers known to be in the waste. This analysis is discussed and accepted in Reference 11.

The minimum critical plutonium concentration calculated by Carter[10] was 3 g/L. He states that as long as the concentration in waste remains under this value, criticality will not occur for any conditions of moderation or reflection. This analysis is discussed and accepted in Reference 12.

TABLE R-1
ACCIDENT SOURCE TERM ACTIVITY CONCENTRATIONS AND UNIT-LITER-DOSE VALUES FOR ACCIDENTS INVOLVING RELEASE OF SOLID OR LIQUID TANK WASTE

Nuclide	SST Liquid Source-Bq/L	SST Solid Source-Bq/L	Conversion Factor	SST Liquid CEDE-Sv/L	SST Solid CEDE-Sv/L
^{14}C	1.0e+05	1.2e+05	5.64e-10	5.9e-05	7.0e-05
^{60}Co	1.2e+07	5.3e+08	5.91e-08	7.1e-01	3.1e+01
^{79}Se	*	1.7e+04	2.66e-09	*	4.5e-05
^{90}Sr	1.1e+10	1.7e+12	6.47e-08	7.2e+02	1.1e+05
^{90}Y	1.1e+10	1.7e+12	2.28e-09	2.5e+01	3.9e+03
^{99}Tc	1.7e+07	1.2e+10	2.77e-10	4.7e-03	3.4e+00
^{106}Ru	3.3e+03	2.4e+05	1.29e-07	4.3e-04	3.1e-02
^{125}Sb	5.3e+04	2.8e+08	3.30e-09	1.8e-04	9.2e-01
^{129}I	1.0e+04	6.4e+08	4.69e-08	4.7e-04	3.0e-01
^{134}Cs	2.1e+05	2.6e+06	1.25e-08	2.6e-03	3.2e-02
^{137}Cs	2.3e+10	7.5e+10	8.63e-09	2.0e+02	6.5e+02
^{144}Ce	4.3e+01	1.6e+03	1.01e-07	4.3e-06	1.6e-04
^{154}Eu	2.7e+09	6.6e+09	7.73e-08	2.1e+02	5.1e+02
^{155}Eu	7.5e+07	6.4e+06	1.12e-08	8.4e-01	7.1e-02
^{237}Np	*	3.0e+07	1.46e-04	*	4.7e+03
^{238}Pu	9.3e+04	1.9e+08	1.06e-04	9.8e+00	2.0e+04

TABLE R-1 (cont)
ACCIDENT SOURCE TERM ACTIVITY CONCENTRATIONS AND
UNIT-LITER-DOSE VALUES FOR ACCIDENTS
INVOLVING RELEASE OF SOLID OR LIQUID TANK WASTE

Nuclide	SST Liquid Source-Bq/L	SST Solid Source-Bq/L	Conversion Factor	SST Liquid CEDE-Sv/L	SST Solid CEDE-Sv/L
239Pu**	3.6e+07	4.4e+08	1.16e-04	4.2e+03	5.2e+04
241Pu	2.8e+08	3.5e+09	2.23e-06	6.3e+02	7.8e+03
241Am	3.7e+07	3.6e+08	1.20e-04	4.4e+03	4.4e+04
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ULD				1.0e+04	2.4e+05

*No Data Available. These radionuclides have a negligible impact on the radiological dose evaluations because of their low activity concentrations.

**The ^{239}Pu nuclide dose contribution also includes ^{240}Pu.

ULD - unit-liter dose. ULD values are given for each composite in terms of committed effective dose equivalent (Sv) per unit-liter of waste inhaled at the location of the maximum on-site/off-site individual.

Because the bounding value of ^{239}Pu concentration in the tanks is 0.191 g/L, the tanks are currently criticality safe because this value is at least an order of magnitude less than the minimum critical plutonium concentration. The question then is whether there is a possible mechanism resulting from the rotary-core drilling that could concentrate the plutonium into a critical configuration.

The rotary-core drilling will not add any fissionable material to the tank, and in fact, will be removing some material during the process as the drill penetrates the salt cake. Pockets of possible high concentration would not be forced into smaller volumes; they would be removed as the drill passes through. The process should actually decrease the multiplication factor by removing material.

If the drill enters a liquid layer, the material would be displaced without concentration. The plutonium concentration in liquid is less than that found in solids by an order of magnitude or more, according to Table R-1. If the liquid were forced into the salt or sludge, it would serve as a diluent, resulting again in a decrease in the multiplication factor.

If the drill enters the sludge in the bottom of the tank, the sludge would be mixed if the sampling is assumed to cause a local rollover or tank rollover through a gas-release mechanism, resulting in a mixture with a layer with less concentration of Pu, again acting as a diluent.

The above analysis and facts provide assurance that nuclear criticality within the single-shell Flammable Gas Watch List tanks will not occur as a result of RMCS.

R.4. RADIATION EXPOSURE CALCULATIONS

In this section we estimate the radiation exposure from the HEPA filters, shielded receiver, and the drill string. Only gamma exposure is calculated. The gamma source strength in the solid is from the column labeled "SST Solid" in Table R-1. The only gamma emitter of importance is ^{137m}Ba, a daughter of the decay of ^{137}Cs. The source strength of ^{137}Cs from the column "SST Solid" is 7.5e10 Bq/L. The ^{137}Cs is in secular equilibrium with ^{137m}Ba, and 94.6% of the decay from ^{137}Cs produces ^{137m}Ba. Using a salt density of 2.2 grams/cm^3, the ^{137m}Ba source strength is 8.71e-04 Ci/g.

R.4.1. HEPA Filter Loading and Radiation Exposure

The HEPA filter is designed to trap the particle escaping the tank during the drilling operations. This note gives an estimate of the exposure from the filter caused by the capture of the radioactive particles during drilling operations.

In Table 2 of Ref. 13, the total mass out of the riser and to the HEPA filter is 901 g, a value based on continuous operation of the exhauster, a total drilling depth of 266 inches, and a schedule of 40 minutes of drilling (19 inches) followed by a 60-minute delay before starting the next drilling period. Only particles greater than 5.5 μm were assumed to have been carried up the stack. The total exhaust flow for the case used here is 250 ft^3/min. These results were calculated using the TRAC-TE code. This code and the results are discussed in Reference 13. The results take into account the settling of the aerosol created. The time required to reach an equilibrium concentration was not given; however, the time required to reach an equilibrium condition for a 700 scfm with continuous exhauster flow case was given as 400 minutes. For this 700-ft^3/min case, the mass flow rate out the stack for the first 100 minutes was 90% of the average mass flow rate. Thus, for the calculations in this note, it is not unreasonable to use an average exhaust rate of 901g/1400 minutes, i.e., 64.4 grams captured in the filter in 100 minutes of operation. This would be one drilling period and one hour's wait. The filter would have 64.4 grams x 8.71E-4 Ci/g loading.

Using the code MicroShield,[14] a filter geometry of 24 in. x 24 in. x 11.5 in. containing SiO_2 at a density of 0.1 g/cm^3, we find the exposure at 1 cm from the surface is about 300 mR/h at the end of 100 minutes of operation. This exposure may be scaled with units of 100 minutes of time because it is based on an average mass flow rate.

The maximum allowable dose for a worker is 300 mrem/week. These calculations indicate that there may be cases in which this limit could be exceeded. It is necessary then that health and safety personnel monitor the filter during operation.

Also, the size of the exposure seems to require a prefilter in the limiting cases when the source term is of this size.

R.4.2. Radiation Exposure From Shielded Receiver and Drill Unit

Shielded Receiver. The receiver is modeled as a series of concentric cylinders 19 inches long. The dimensions and materials are given in Table R-2.

The source-containing material is modeled as $NaNO_3$. The ^{137m}Ba source contained in the $NaNO_3$ is 0.596 curies (7.0874e+07 Bq/cm^3). Using the code MicroShield,[14] we find the exposure at 1 cm from the surface is 211 mR/h. The bounding value of exposure calculated is 211 mR/h at 1 cm from the surface of the receiver. It would be expected that there would be no samples that would actually produce this value because the samples would contain liquid that have a lower source strength. In addition, the source strength used here is the maximum found in any sample. However, this value could cause a worker to exceed the limit of 300 mrem/week. It is necessary then that health and safety personnel monitor the receiver during operation.

TABLE R-2
MATERIALS, DIMENSIONS, AND DENSITY OF THE SAMPLE RECEIVER

Material	Density, (g/cm^3)	Maximum Radius (in.)
$NaNO_3$	2.2	0.564
Steel	7.93	0.75
Air	0.00122	1.0335
Steel	7.93	1.1875
Lead	11.34	2.013
Steel	7.93	2.25

Contaminated Pintle Rod. In this section, the exposure rate from a contaminated pintle rod is determined. The exposures determined are results from the MicroShield code. In these calculations, the equivalent volume of waste that would be found on a contaminated pintle rod is modeled in the center of the quill rod. These approximations are conservative.

The volumes of waste placed in the center of the quill rod are based on a 1-mm and a 3-mm-thick contamination on the pintle rod. The pintle rod is 92.48 cm long with a radius of 0.237 cm. A 1-mm contamination gives an equivalent radius of 0.24 cm of contamination in the center of the quill rod and a 3-mm contamination gives an equivalent radius of 0.482 cm. Using the bounding value of ^{137}Cs found in solid waste, the two source strengths are 0.0338 and .137 Ci.

The steel quill rod has an inside radius of 2.42 cm and an outside radius of 2.875 cm. The exposure as determined using MicroShield at 1 cm from the surface of the quill rod for the 1-mm contamination is 0.72 R/h, and for the 3-mm contamination, the exposure at 1 cm for the surface of the quill rod is 2.84 R/h. At 1 meter from the surface of the quill rod, the exposure is 8.6 mR/h for the 1-mm contamination and 35 mR/h for the 3-mm contamination.

The magnitude of these exposures indicates that radiation monitoring of the quill rod is necessary to prevent unnecessary exposure to personnel in the event that the rod becomes contaminated.

R.5. RECEPTOR DOSE CALCULATIONS

In this section, the radiological dose calculation methodology is discussed. The methodology is adopted from Reference 15 for consistency with other safety basis documents employed at the Hanford Site. In Reference 16, this methodology is compared with the AI-RISK methodology[17] previously used in the Tank 101-SY Mixer Pump SA.[18] The receptor dose is calculated as

$$D = Q \times \frac{\chi}{Q'} \times R \times ULD \qquad \textbf{(R-1)}$$

where

- D is the dose in Sv,
- Q is the material release volume (L),
- χ/Q' is the atmospheric dispersion coefficient (see Tables R-3 and R-4),
- R is the breathing rate

  = 3.3×10^{-4} m^3/s typical acute breathing rate (light activity)

= 2.7×10^{-4} m^3/s typical chronic breathing rate (24 h average), and

ULD is the unit liter dose in Sv/L obtained from Table R-1.

The atmospheric dispersion coefficients are obtained using the computer code GXQ, which uses the methods in the Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145 (Ref. 19). The atmospheric dispersion coefficient is the time-integrated normalized air concentration at the receptor for radiological releases and continuous chemical releases. For puff chemical releases the atmospheric dispersion coefficient is the instantaneous maximum concentration at the receptor. Only the plume meander correction was used in the calculations. The coefficients used to calculate dose or concentration are presented in Tables R-3 through Table R-4. The acute release values were developed for weather conditions that result in downwind concentrations exceeded only 0.5% of the time in the maximum sector (16 sectors) or 5% of the time for the overall site. The larger of the two values was used as the integrated bounding value for the on-site and off-site individuals. The chronic annual average χ/Q' values were obtained by calculating chronic annual average values for each sector and using the highest value for calculation purposes. This value is suitable for long-term releases but not for accidents.

TABLE R-3
DISPERSION COEFFICIENTS

RECEPTOR	χ/Q' (s/m^3)	χ/Q' with PM* (s/m^3)	CAA** χ/Q' (s/m^3)
Onsite	3.44 E-02	1.13 E-02	4.03 E-04
Offsite	1.88 E-05	1.49 E-05	9.16 E-08

*PM: plume meander correction applied
** CAA: chronic annual average

For a release duration of less than 1 h, the χ/Q' (first column) is used. For a release duration between 1 and 2 h, the plume meander correction is applied, and the χ/Q' with PM (second column) is used. For a release duration greater than 8760 h (1 yr), the CCA χ/Q' (third column) is used. For a release duration between 2 h and 8760 h, a logarithmic interpolation between values in column 2 and column 3 is used. The offsite receptor distances for the 200-Area tank farms obtained from Reference 15 are shown in Table R-4.

TABLE R-4
SITE BOUNDARY DISTANCES FOR THE TANK FARMS[15]

Direction	Distance (km)
S	16.650
SSW	16.650
SW	13.875
WSW	11.100
W	11.100
WNW	11.100
NW	14.800
NNW	14.800
N	16.650
NNE	23.125
NE	19.425
ENE	15.725
E	15.725
ESE	21.275
SE	24.975
SSE	21.275

One case referred to in this SA requires the evaluation of the dispersion coefficient for a 1-wk (168-hr) duration release. Applying the logarithmic interpolation, the on-site and off-site dispersion coefficients may be obtained as

$$\frac{\log(1.13\times10^{-2})-\log\left(\frac{\chi}{Q'}\right)}{\log(1.13\times10^{-2})-\log(4.03\times10^{-4})}=\frac{\log(2h)-\log(168h)}{\log(2h)-\log(8760h)}=\frac{\chi}{Q'}=1.94\times10^{-3}$$

and

$$\frac{\log(1.49\times10^{-5})-\log\left(\frac{\chi}{Q'}\right)}{\log(1.49\times10^{-5})-\log(9.16\times10^{-8})}=\frac{\log(2h)-\log(168h)}{\log(2h)-\log(8760h)}=\frac{\chi}{Q'}=1.01\times10^{-6}$$

respectively.

Table R-5 provides the receptor doses for a 1-L release.

TABLE R-5
RECEPTOR DOSES FOR A 1-LITER RELEASE

	ONSITE		OFFSITE	
	SST Solid	SST Liquid	SST Solid	SST Liquid
Prompt (< 1h)	2.76E+00 Sv 2.76E+02 rem	1.15E-01 Sv 1.15E+01 rem	1.49E-03 Sv 1.49E-01 rem	6.20E-05 6.20E-03 rem
1 week	1.54E-01 Sv 1.54E+01 rem	6.40E-03 Sv 6.40E-01 rem	8.00E-05 Sv 8.00E-03 rem	3.33E-06 Sv 3.33E-04 rem
1 month	8.65E-03 Sv 8.65E-01 rem	3.60e-05 Sv 3.60E-02 rem	3.31E-05 Sv 3.31E-03 rem	1.38E-06 Sv 1.38E-04 rem
1 year	3.20E-03 Sv 3.20E-01 rem	1.33E-05 Sv 1.33E-02 rem	7.26E-06 Sv 7.26E-04 rem	3.02E-07 Sv 3.02E-05 rem

R.6. REFERENCES

1. R. J. Van Vleet, "Radionuclide and Chemical Inventories for the Double Shell Tanks," Westinghouse Hanford Company report WHC-SD-WM-TI-543 (1993).

2. R. J. Van Vleet, "Radionuclide and Chemical Inventories for the Single Shell Tanks," Westinghouse Hanford Company report WHC-SD-WM-TI-565 (1993).

3. D. J. Braun, et al., "High-Level Waste Tank Subcriticality Safety Assessment," Westinghouse Hanford Company report WHC-SC-WM-SARR-003 (1994).

4. F. M. Jungfleisch, "TRAC: Preliminary Estimation of the Waste Inventories in Hanford Tanks Through 1980," Westinghouse Hanford Company report WHC-SD-WM-TI-057 (1984).

5. S. R. Agnew, "Estimated Chemical and Radiochemical Inventories Spreadsheet: NE Quadrant, A, AX, B, BX, BY, C Farms," Westinghouse Hanford Company report WHC-SD-WM-TI-628, Rev. 0, (1994).

6. S. R. Agnew, "Estimated Chemical and Radiochemical Inventories Spreadsheet: SW Quadrant, S, SX, U Farms," Westinghouse Hanford Company report WHC-SD-WM-TI-631, Rev. 0 (1994).

7. W. L. Cowley, "Tank Waste Source Term Inventory Validation," Westinghouse Hanford Company report WHC-SD-WM-ER-400, Rev. 0 (1995).

8. K. F. Eckerman, et al., "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," Federal Guidance Report No. 11 (DE89-011065) Office of Radiation Programs, US Environmental Protection Agency (1988).

9. C. A. Rogers, "An Analytical Model for Evaluating Subcritical Limits for Waste in Hanford Site Storage Tanks," Westinghouse Hanford Company report WHC-SD-SQA-CSA-20356 (1993).

10. R. D. Carter, "CSAR 79-007 Underground Waste Storage Tanks and Associated Equipment," Westinghouse Hanford Company report SD-SQA-CSA-20108 (1979).

11. D. J. Braun et al., "High-Level Waste Tank Subcriticality Safety Assessment," Westinghouse Hanford Company report WHC-SD-WM-SARR-003 (1994).

12. T. S. Vail, "Justification for Continued Operation of Hanford High-level Waste Tanks Resulting from the Criticality" Westinghouse Hanford Company report USQ, 492-CRITSAF, WHC-SD-WM-JCO-001 Rev. 3 (1993).

13. P. M. Francis, "Aerosol Study for the Rotary Mode Exhauster," Westinghouse Hanford Company report WHC-SD-WM-ES-225 REV 0 (1993).

14. C. A. Engine and G. Work, Micro Shield Version 4, (Grove Engineering, Inc., Rockville, Maryland, 1992).

15. "Tank Waste Composition and Atmospheric Dispersion Coefficients for Use in Accelerated Safety Analysis Consequence Assessment," Westinghouse Hanford Company report WHC-SD-WM-SARR-016, Rev. 1 (October 1995).

16. K. O. Pasamehmetoglu, "Comparison of the Radiological Consequence Analysis Used in the Mixer Pump SA with the ASA Analysis," Los Alamos National Laboratory Calc-Note TSA10-CN-WT-SA-TH-073 (October 1995).

17. Y. Y. Chien, and D. MacFarlane, "AI-RISK: A Computer Program for Calculating Doses and Health Risk from Accidental Release of Radioactive Materials," Los Alamos National Laboratory report LA-UR-92-2636, (July 1992).

18. L. H. Sullivan et al., "A Safety Assessment for the Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," Los Alamos National Laboratory report, LA-UR-92-3196, Rev. 14 (March 31, 1995).

19. "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," Regulatory Guide 1.145, US Nuclear Regulatory Commission, (1982)

APPENDIX S

SPILL RELEASE FRACTIONS

S.1. INTRODUCTION

Several spill scenarios are identified in the hazards evaluation. One of the most important scenarios is a spill from the core barrel when the core barrel is flooded. The other one is a spill from the core sampler.

If waste collects inside the core barrel or the drill rods, handling could cause a release. Even though accumulated waste may be discovered by radiological monitoring, this would only aid workers in preparing to catch the spill that could follow removal.

The length of the core barrel is 1.1 m (40 in.), and the inside diameter is 5.08 cm (2 in.). Thus, the core barrel could contain 2.2 L (0.07 ft^3) of waste. Using a waste density of 1.6 kg/L (100 lb/ft^3), the corresponding mass is obtained as 3.5 kg (7.8 lb).

The sampler is 48 cm (19 in.) long and has a 1-in. (2.54-cm) diameter. The volume of the sampler is 0.25 L (15 $in.^3$) and would contain 0.4 kg (0.9 lb) of waste.

S.2. ANALYSIS

In order to estimate the aerosol fraction during a spill, the waste may be modeled as liquid or solid.

The airborne material (source term) released from a liquid spill can be evaluated from the following equation, as suggested in the Department of Energy (DOE) Handbook:[1]

$$\text{source term} = MAR \times DR \times F \times RF \times LPF, \qquad \text{(S-1)}$$

where

MAR = material at risk,

DR = damage ratio = 1,

F = airborne release fraction,

RF = respirable fraction, and

LPF = leak path factor = 1.

The LPF and DR are conservatively assumed as 1.

S.2.1. Respirable Aerosol Fraction for Liquid Spills

Reference 2 (Sec. 4.4.2.2, p. 4.74) summarizes the experimental release fraction from liquid spills. Most of the experimental data are obtained at Pacific Northwest Laboratory (PNL)[3] and are for viscous liquids and slurries. The spill height was 3 m (10 ft) in PNL's experiments. Other parameters such as the diameter of particles, densities of liquids and solids, and the viscosity of slurry and liquids were varied. Also included in the database was a slurry containing important species of 101-SY waste. The resulting correlation is given as

$$F = 6.31 \times 10^{-6} Ar^{0.45} \left(\frac{\rho_{air}}{\rho_{liq}} \right)^{2.2} Fr^{0.35} \quad , \qquad \text{(S-2)}$$

where

F = fraction airborne,

ρ_{air} = air density,

ρ_{liq} = solution density,

Fr = Froud number, and

Ar = Archimedes number.

Froud and Archimedes numbers are defined as

$$Fr = \frac{V^2}{gR} \quad \text{and} \quad Ar = \frac{\rho_{liq}^2 h^3 g}{\mu^2} \quad , \qquad \text{(S-3)}$$

where

h = spill height,

g = gravitational constant,

μ = viscosity of solution,

V = impact velocity, $(2gh)^{1/2}$,

R = radius of liquid drop, $(3/4\ Vol/\pi)^{1/3}$, and

Vol = volume of solution.

Equation (S-2) shows that the respirable fraction is proportional to the drop height and drop velocity and inversely proportional to the volume of the material and viscosity. Using a bounding drop height of 5 m (15 ft), a minimum liquid volume of 0.25 L (7.1×10^{-6} ft^3), a liquid density of 1000 kg/m^3 (62.4 lb/ft^3), and a liquid viscosity of 1 cP, the respirable fraction (F) is obtained as 1.0×10^{-4}. Note that the liquid density and viscosity used in this calculation correspond to water density and viscosity, which is very conservative for the waste supernate.

S.2.2. Respirable Aerosol Fraction for Solid Waste Spills

To estimate the respirable aerosol fraction of a solid waste spill, we use the formula provided by MacDougall et al.4 given by the following simple relationship:

$$F = 2 \times 10^{-10} \frac{E}{Vol} \quad , \tag{S-4}$$

where E is the impact energy in joules and Vol is the material volume in m^3.

Equation (S-4) was derived from Argonne National Laboratory experiments (Refs. 5, 6, and 7) involving the brittle fracture of small samples of glass, ceramics, uranium dioxide pellets, and concrete. A test consisted of placing a single cylindrical specimen on its side between two hardened tool steel plates inside a sealed chamber. Each specimen received a dynamic diametrical impact by a weight dropped from a preselected height onto the upper plate. The impact energy is dissipated by disintegration, and some aerosol particulate is formed. The net respirable fraction of the brittle material (particulates with a diameter of less than 10 μm) is given by F, which is found to be linearly proportional to the impact energy. If the energy is set equal to the impact energy of the material being spilled, Eq. (S-4) reduces to

$$F = 2 \times 10^{-10} (\rho g h) \quad , \tag{S-5}$$

where ρ is the waste density taken as 1600 kg/m^3 (100 lb/ft^3) and h is the drop height bounded by 5 m (15 ft). Thus, the respirable fraction becomes 1.6×10^{-5}.

S.3. CONCLUSIONS

In this safety assessment, a conservative value of 2×10^{-4} (Ref. 8) is used for the respirable fraction during a spill accident. The analysis provided in Section 2 of this appendix shows that a release fraction of 2×10^{-4} is bounding for liquid and solid waste spills of interest.

S.4. REFERENCES

1. "Airborne Release Fractions/Rates and Respirable Fractions For Nonreactor Nuclear Facilities" DOE Handbook 3010-94 (October 1994).

2. J. E. Ayer et al. "Nuclear Fuel Cycle Facility Accident Analysis Handbook," NUREG-1320, Nuclear Regulatory Commission (April 1988).

3. M. Y. Ballinger and W. H. Hodgson, "Aerosols Generated By Spills of Viscous Solutions and Slurries," PNL-5910, NUREG/CR-4658, Nuclear Regulatory Commission (November 1986).

4. H. R. MacDougall, L. W. Scully, and J. R. Tillerson, "Preliminary Preclosure Radiological Safety Analysis," Appendix F in "Site Characterization Plan Conceptual Design Report," Sandia National Laboratory report SAND84-2641 (1987).

5. W. J. Mecham, L. J. Jardine, R. H. Pelto, G. T. Reedy, and M. J. Steindler, "Interim Report of Brittle-Fracture Impact Studies: Development of Methodology," Argonne National Laboratory report ANL-81-27 (October 1981).

6. L. J. Jardine, W. J. Mecham, G. T. Reedy, and M. J. Steindler, "Final Report of Experimental Laboratory-Scale Brittle Fracture Studies of Glasses and Ceramics," Argonne National Laboratory report ANL-82-39 (October 1982).

7. W. J. Mecham, L. J. Jardine, G. T. Reedy, and M. J. Steindler, "General Statistical Description of the Fracture Particulates Formed by Mechanical Impacts of Brittle Materials," Ind. Eng. Chem. Fundam., 22, 384-391 (1983).

8. R. M. Marusich, "Safety Assessment for Push Mode Core Sampling in Tank 101-SY," Westinghouse Hanford Company report WHC-SD-WM-SAD-008, Rev. 0-A (May 10, 1991).

APPENDIX T

BUREAU OF MINES IGNITION TEST PROGRAM FUNCTIONAL REQUIREMENTS AND ACCEPTANCE CRITERIA

T.1. INTRODUCTION

The hazard identification process presented in Section 3 of this safety assessment (SA) resulted in numerous burn initiators in the dome, in the drill string, in the waste and aboveground. Section 4 discusses these accidents and their possible initiators. Some of these burn accidents are postulated to occur as a result of mechanical sparks during rotary-mode core sampling (RMCS) normal operations or accidental conditions. The frequencies of these accidents are determined in Appendix E and summarized in Section 4. The discussion in Section 4 shows that, without additional experimental studies, the consequences and frequencies of the burn accidents caused by mechanical sparks are not acceptable.

The key reason to do experiments with prototypical atmospheres is the need for a database to support safety and engineering decisions on a technical basis. Unless there is a reliable and experimentally tested theoretical basis for predicting behavior, one will be reduced to making ad hoc decisions in the absence of experimental data. There is no general and reliable theory of frictional ignition that will enable test results with one mixture and frictional ignition situation to be extrapolated to a very different mixture or frictional stimulus. In the multicomponent mixtures characteristic of the flammable gases in the Hanford tanks, the interactions of the various components are a key aspect of behavior that can only be conclusively resolved in experimental studies.

Table T-1 summarizes the accident scenarios in which the mechanical sparks are initiators for a burn accident and the experimental results are necessary to conclude that the risk is bounded by the guidelines. Also included in Table T-1 is the section number where the bounding tests for each accident is discussed. Note that a separate series of tests for each accident is not needed, and a number of accidents (mainly the drop accidents) in Table T-1 may be bounded by one set of tests.

As a requirement of this SA, an experimental test program is implemented to demonstrate that no sparks capable of igniting a bounding flammable-gas mixture under bounding operating conditions can be generated as a result of the accidents listed above. These experiments are being performed at the U.S. Bureau of Mines (BOM) In some cases, a bounding set of tests are used to cover more than one accident scenario shown in Table T-1. In this appendix, the necessary BOM ignition tests required by this SA, their functional design requirements, and acceptance criteria are described for each ignition test. The results of the tests performed at the BOM is also discussed in this appendix.

TABLE T-1
SUMMARY OF ACCIDENT CASES FOR WHICH TEST RESULTS ARE NEEDED

Ignition Scenario	Description	Section
Ignition caused by frictional sparks as a result of the drill bit penetration	During the drill-bit penetration through the crust or waste sludge, a frictional spark can ignite the flammable gas in the vicinity of drill bit.	2.0
Ignition under the waste surface caused by frictional sparks by the drill bit	The ignition of the flammable gas in the waste by the frictional sparks created by the drill bit is of concern if the drill bit strikes hard materials such as rocks, metals, or hard waste layers.	2.0
Ignition in the riser caused by a frictional spark	If the conductive sleeve-nitrogen purge system fails, ignition of flammable gases is possible. Another case considered is the ignition of hydrogen in the riser (between the conductive sleeve and riser).	3.0
Ignition in the drill string caused by assembly/disassembly of drill strings or drill rod-quill rod adapter impact	The ignition of the flammable gas in the drill string caused by impacts that could be created during drill string or drill string quill rod assembly or disassembly are possible.	4.0, 6.0
Ignition in the riser caused by the drill string, equipment, or tool drop	The flammable gas in the riser/dome can be ignited if equipment, drill string, or tools are dropped into or onto the riser during the installation or removal phase.	4.0 and 6.0
Ignition caused by the drill string or tool drop on crust	Dropping the drill string or other tools on the crust may ignite the flammable gas in the vicinity of the crust.	4.0, 5.0, and 6.0
Ignition in the drill string caused by drops	Ignition in the drill string as a result of frictional sparks, dropping core sampler are possible.	4.0, 5.0, and 6.0
Ignition in X-ray or cask	The ignition source is the drop of the sampler into the X-ray container or the cask. Low-impact energies and velocities are involved.	5.0
Ignition in the shielded receiver	The drop of core sampler in the shielded receiver could cause spark. Low-impact energies and velocities are involved.	5.0

T.2. DRILL BIT FRICTIONAL IGNITION TESTS

One of the safety concerns of sampling with rotary mode in single-shell flammable-gas tanks is the ignition of the flammable gases retained in the waste. The ignition of flammable gas may occur in several different ways:

- The waste may be hard enough to create a frictional spark as the drill bit penetrates the salt cake or any other hard layer in the waste;
- The drill bit may also strike metal debris and cause a metal-to-metal friction resulting in a spark; and

- Friction on hard debris may cause local hot spot generation during which the temperature exceeds the autoignition temperature of the gas mixture.

The objective of drill bit frictional ignition tests is to demonstrate that the operation of rotary core drilling in a bounding frictional environment and bounding gas composition does not cause an ignition. The following are the sections in which the test parameters for the ignition tests are discussed:

- Downforce (Section 2.1.)
- Rotational Speed (Section 2.2.)
- Nitrogen flow rate (Section 2.3.)
- Gas Temperature (Section 2.4.)
- Gas Composition (Section 2.5.)
- Debris Material and Configuration (Section 2.6.)
- Drill Bit Type (Section 2.8.)
- Number and Duration of Tests (Section 2.7.)
- Autoignition Temperatures (Section 2.9.)

T.2.1. Downforce

The downforce used during tests must be at least 120% of the nominal downforce that will be used during drilling in the actual waste. Currently, the analysis provided in Appendixes F and N determine the maximum allowable downforce. In ignition testing, the downward force must be ≥120% of the limiting value defined by the envelope tests or structural analysis.

T.2.2. Rotational Speed

Like the downforce, the rotational speed (rpm) must be set higher than the nominal rotational speed that will be used during actual sampling operations, which is 55 rpm. For the tests, the rotational speed must be ≥120% of the limiting value defined by the envelope tests or structural analysis (approximately 65 rpm). This margin is believed to be sufficient for protection against accidentally exceeding the nominal speed, considering the other conservative features of the test.

T.2.3. Nitrogen Purge Flow Rate

During ignition tests, the nitrogen purge system will not be used.

T.2.4. Gas Temperature

To bound the maximum waste temperatures in all the flammable-gas tanks (including the measurement uncertainties), the gas mixture must be ≥100°C.

T.2.5. Gas Composition

The initial analyses of the limited data show that the gas composition varies in each tank (App. C). Thus, the frictional ignition testing using actual drill bits must be performed in a bounding gas composition and bounding contact configuration.

It is very difficult to determine a realistic gas composition that bounds all possible combination of species mentioned above for all single-shell tanks. Using the current database, one can only determine major flammable-gas species that may be assumed to exist in all of the single-shell tanks. Based on the analysis provided in Appendix C, the major flammable-gas species are hydrogen (H_2), nitrous oxide (N_2O) which is an energetic oxidizer and NH_3. Based on observation of waste simulants, free oxygen (O_2) is not expected in the waste gas. However, air addition to the waste is possible during the RMCS operation.

In summary, the important gas species to consider are H_2, NH_3, N_2O, O_2, (used to conservatively bound the effect of entrained air). Instead of trying to determine a realistic gas composition that may bound all tanks, the stoichiometric mixtures are chosen. In determining the stoichiometric mixtures, the findings of the previous studies are used.

Krok and Shepherd[1] were unable to ignite a typical Tank 101-SY gas mixture (without ammonia and air) by striking two bars together or creating sparks by grinding. They were able to ignite the 101-SY gas mixture with a grinder striking on a metal piece when it is mixed with air fractions between 75% and 90%. It is concluded that, in the gas mixtures tested, N_2O acts as an ignition inhibitor. References 2 and 3 also confirm that a typical 101-SY gas mixture cannot be ignited with the frictional operation of the drill bit in a simulated waste crust or on a steel plate. Based on these findings, it appears that a stoichiometric H_2-O_2 mixture would be bounding for mechanical sparks.

The evidence about the ability of bronze and brass strikers to cause frictional ignition is controversial. Powell[4] cites evidence for ignition with hydrogen and methane but not with gasoline fumes in an enriched oxygen atmosphere. The phenomena of frictional ignition is sensitive to surface phenomena such as the oxidation state of the metal and contaminants such as aluminum. Very small amounts of aluminum or an aluminum-containing compound on a surface can produce frictional ignition in situations that otherwise would be considered absolutely safe. Ammonia is known to be chemically reactive with copper and other base metals containing compounds and will alter the state of the surface. This clearly raises the issue that the frictional ignition characteristics of a surface may be affected by ammonia. There have been no studies on frictional ignition in the presence of ammonia. Although one may suspect that frictional ignition of ammonia will be difficult because of the low flame speed of ammonia-air mixtures, that is really not a valid reason to rule out ammonia as playing a role in frictional ignition in multi-component mixtures. Thus, a stoichiometric mixture is introduced (keeping the hydrogen-to-ammonia ratio as 1) of H_2-NH_3 and O_2 in the test matrix.

Finally, although the earlier studies[1-3] show that mechanical sparks are not expected to ignite H_2-N_2O mixtures, the addition of ammonia to this mixture has not been tested. References 5 and 6 indicate that ammonia may be very explosive in a nitrous oxide atmosphere. The studies documented in References 5 and 6 do not include mechanical sparks. However, because of the high explosiveness of this mixture, a stoichiometric mixture of H_2-NH_3 and N_2O also must be tested.

Thus, as part of the acceptance criteria, three gas mixtures must be tested. These mixtures are summarized in Table T-2.

TABLE T-2
GAS MIXTURES

Species	Mixture #1	Mixture #2	Mixture #3
Hydrogen	66%	30%	20%
Oxygen	34%	40%	-
Ammonia	-	30%	20%
Nitrous Oxide	-	-	60%

T.2.6. Debris Material and Configuration

The condition of waste in terms of hardness is not known before operation. There exists a possibility of penetrating a very hard waste layer in a tank. In addition, there may exist some metal debris lost or dropped from the riser in the past. Hard materials such as rocks also may exist in the waste. Thus, it is likely that the drill bit may strike against metal and other hard objects during the operation.

The possibility of ignition is higher if the drill bit strikes on harder materials such as carbon or stainless steel rather than hard salt cake or crust. Because of this, the use of a simulant to model the frictional sparks during the waste penetration in the proposed testing is not necessary. Instead, the bounding spark initiating contact condition, i.e., striking metal objects or rocks are considered.

The conditions of the metal or hard object and geometry of the contact is another key parameter for ignition testing. The metal objects may already be corroded and may have a rough surface. The drill bit may strike wedge-shaped objects, a flat metal surface, or the edge of an inclined metal sheet or pipe. The configuration of drill bit-to-metal contact may play a role in generating a frictional spark that is capable of igniting the flammable-gas mixture. The metal object may be made of soft carbon steel as well as hard carbon steel. Thus, the selection of a bounding drill bit contact configuration and material needs to be addressed by testing.

Two bounding materials are selected for the frictional ignition tests;

1. 4140 hardened tool steel shapes, and

2. rocks found in the area of the Hanford Tank Farms.

The basis for the selection of 4140 hardened alloy steel is because of its relative incendivity and radiance properties. The relative radiance indicates the ability to create a spark (Ref. 7). Relative incendivity is the parameter to describe the ability to ignite hydrogen-air mixture in an ignition test. Both parameters are defined relative to the properties of pure iron.

Relative incendivity is defined as the inverse of the time to ignition in a given ignition test as described in Reference 7. This parameter is found to be a function of the applied loading pressure and surface speed. The relative incendivity of the hardened 4140 steel was found to be much higher than mild steel, structural steel, and stainless steel.

Relative radiance (as quantified by the measured radiant flux) for 4140 hardened tool steel is also much higher than the carbon steel (1018, 1096, 1030, 1080, 1040, 1060, etc.).

Figure T-1 shows the three sharp-edge shape made of 4140 hardened tool-steel piece before the ignition test. This contact geometry is believed to be bounding to cause frictional sparks. Figure T-2 illustrates the drilling process onto these sharp-edged steel pieces. Figure T-3 is the photograph of the drill bit after drilling on these pieces. As shown, the drill bit surface is quite damaged.

T.2.7. Duration and Number of Tests

For each gas mixture #1 (stoichiometric H_2-O_2) shown in Table T-2 and for each material (metal and rocks as described previously), a minimum of five tests must be conducted. If there are uncertainties in the bounding configurations, multiple configurations may be tried as part of the minimum number of tests required.
The number of tests for the other two gas mixtures shown in Table T-2 must be ≥ 3 for each material and each gas mixture tested. Different configurations may be used to count towards the requirement of the minimum number of tests for each material.

In the accident analysis, the operators are credited for a few minutes response time in case the penetration rate control is violated. For consistency with that credited control, each test must be run for a duration ≥ 3 minutes.

Tests must be conducted in well-mixed mixtures at elevated temperatures. The test chamber must be purged sufficiently before the flammable gas is introduced into the chamber. The flammable gas must be introduced into the chamber for a sufficient period. The gas composition in the chamber must be verified. To verify that well-mixed flammable gases existed during the test, the gases must be ignited with an alternate ignitor at the end of each test if a frictional ignition does not occur during the test.

T.2.8. Drill Bit Type

The drill bit cutting teeth are made of a sintered bronze with tungsten chips in the bronze matrix. This material can wear down easily when the drill bit strikes metal objects or hard materials. The core sample drill bits used in RMCS are Longyear (trademark of Longyear Incorporated) Parts Numbers 100IVD/8 (currently used) and 9505-15E (new prototype bit). BOM ignition testing also considers a new drill bit (Longyear part number 9505-15E).[5] This new drill bit is not used during testing to determine the safe operating parameters to prevent waste ignition (Appendix F); therefore, it is not considered in this SA. The purpose of specifying the drill bit is not exactly to indicate that no other drill bit can be used in an RMCS operation. This appendix summarizes the requirements of tests. However, any drill bit that is to be used in RMCS operations must pass both ignition and envelope testing requirements. The safe operating parameters (envelope tests) are obtained from experiments performed with the current drill bit. Therefore, the drill bit model number is specified to indicate that this type is the only one tested in ignition and envelope tests. When the drill bit model is changed or a new one is developed, it must pass the requirements of ignition and safe envelope testing, before it can be used in RMCS operations.

The current and new drill bits, current and new one, include carbon steel pins in the base of the drill teeth. Westinghouse Hanford Company (WHC)[5] currently is performing ignition tests for both bits to demonstrate that both drill bits do not ignite a flammable-gas mixture that may bound all possible combinations of flammable gases in single-shell Flammable Gas Watch List tanks (SSFGWLT). Tests are designed to simulate the action of a drill bit striking a hard object in the waste, such as a piece of structural steel or a rock, and determine what, if any, core drilling conditions exist that could ignite the flammable-gas mixtures. Tests were conducted in a bounding stoichiometric hydrogen oxygen and ammonia nitrous oxide mixture as required by this SA.

Tests to date with different structurally sharp carbon-steel objects consistently showed no ignition in the H_2-O_2 mixture. However, drilling on a hard rock resulted in ignition of the hydrogen oxygen mixture when the new bit was used. Examination of the new drill bit after the ignition indicated that the teeth were worn and carbon-steel pins were exposed to the rock.

The conclusion of testing is that the ignition of bounding mixtures of hydrogen and oxygen is likely if carbon-steel pins contact steel or rock targets. Because ignition is observed and the reason was proven to be the carbon-steel pins, this SA requires that the carbon steel pins or carbon steel components must be removed from the tooth region of the bit before using them in the tanks. A control also is implemented to replace the drill bit if a trip signal is received on the penetration rate four times with a cumulative penetration of 0.3 in. This control and the requirement to pass the tests listed in this appendix control the spark sources in the drill bit.

When the drill bit is redesigned to include pins with different materials such as stainless steel or brass, a series of ignition testing could be set up. In these tests, ignition tests with 3-min. drilling periods should be performed until the hydrogen-oxygen mixture is ignited. After each 3-min period, a waiting period must be implemented to make sure the starting temperatures were the same. The number of tests that give the ignition should be higher than 4; otherwise, control must be changed to half of this new number. If ignition occurs in the first or second test, the material must be re-evaluated.

T.2.9. Autoignition Temperatures

During one of the rock-drilling tests that was run for more than 5 minutes, the hydrogen oxygen mixture was ignited after 6 minutes of testing. It was postulated that the ignition occurred because the autoignition temperature at the teeth surface was reached. The test was repeated, and the ignition was observed at almost the same time. The bit teeth were not worn sufficiently to cause the carbon steel blanks to be exposed. Additional tests without flammable gas were performed to determine the interface temperature. In one of the tests, a thermocouple was placed 1/8 in. beneath the assorted rock. The rock was not worn significantly; therefore, the temperature just beneath the rock could be measured. The rock temperature 1/8 in. beneath the surface was 236°C after 6 minutes of testing. An infrared temperature probe was also used to determine the surface temperature of the teeth. After 4 minutes of testing, temperatures up to 400°C were observed. All of this evidence indicates that the autoignition temperature can be reached if the drilling lasts more than 5 minutes.

To ensure that, during drilling into the rock without purge gas and minimal insertion rate, the temperatures will not reach autoignition temperatures, the following tests must be performed. Ten runs shall be performed while drilling into a rock with gas mixture #1, and with the downforce and rotational speed specified above. The run period shall be 3 minutes. After each 3-minute run, the bit and the rock shall be allowed to cool to approximately ambient temperature. The bit face and the rock surface shall be photographed after each run. Ignition during any of the runs shall be sufficient cause to disqualify the tested bit design from FG/RMCS.

Envelope Testing

The possibility of causing an exothermic waste reaction exits if the drill bit-waste interface temperature exceeds 160°C. The operating parameters such as downward force, rotational speed, and nitrogen purge flow are necessary to be controlled not to cause unacceptable drill bit/waste temperature during drilling. Appendix F describes the testing requirements for thermal performance of the drill bit in addition to requirements in this appendix for frictional spark issue.

T.3. CONTACT BETWEEN DRILL STRING AND TANK RISER MATERIAL

Upon loss of nitrogen purge flow to the riser (annulus between the drill string and conductive sleeve), frictional sparks can be generated through the drill string and conductive sleeve contact. In order to demonstrate that sparks cannot be generated from drill string and sleeve contact, ignition tests must performed by the BOM. Four different sets of tests must be conducted in a stoichiometric hydrogen-oxygen mixture. A prototype drill rod was rotated within a test chamber with a side load, 200 lbf, pressed against it. The side load acts against the drill string itself and not against the drill bit. The following materials must be used for the drill string:

1. A standard uncoated steel drill string rubbing against carbon steel;
2. A standard steel drill string with a pipe joint compound on it rubbing against a carbon steel
3. A nickel plated and fluted drill string rubbing against carbon steel;
4. A fluted drill string with the nickel coating ground off rubbing against carbon steel.

Note that these test parameters are conservative because the conductive sleeve is made of a stainless-steel pipe and if flammable gas exists in the riser, it is a hydrogen-air mixture. The rotational speed is 65 revolutions per minute (rpm). A total number of 12 tests are conducted (three repeat tests for each material discussed above).

The steel selected was 4140 carbon-steel. The 4140 carbon-steel is bounding as discussed previously. If tests are performed with actual configuration (drill string is inside of the sleeve), the annulus must be purged with the well mixed gas mixture. If the drill string is rubbing on the outside surface of a pipe or a flat steel surface, only adequate mixing in the vicinity of the contact point must be provided. The temperature of the well mixed hydrogen-oxygen should be ~100°C. The purge flow rate should be minimized to provide well-mixed flammable-gas mixture.

The test period must be longer for these tests. The maximum period must be 26 minutes. This number is obtained by dividing the average drill rod length, 19 in., with the minimum penetration rate of 0.75 in./min.

These tests must show that the rotational motion of a carbon-steel drill string or a nickel-plated fluted drill string cannot create the ignition of a stoichiometric hydrogen oxygen mixture when the rotational speed and normal force are controlled.

T.4. DROP OF A NINETEEN-INCH DRILL STRING SECTION

A spark during disconnecting the quill rod from the drill string has been observed in the field. The quill rod adapter and the drill string were made of carbon steel. Any misalignment between the drill string and the quill rod caused by undesired platform movement or operator errors could create a relatively fast impact between the quill rod and the drill string when the drill string is disconnected. There is no instrument to detect the misalignment or any stress level on the drill string or quill rod adapter. Therefore, it is very difficult to evaluate the condition of drill string-quill rod adapter before disconnecting the drill string. Because a spark is observed in the field operation, this event must be assumed to have a high likelihood.

The DS is assembled by adding the drill rods. The addition of a drill rod could be performed as follows:

1. Manual installation by an operator; or

2. Manual installation using the lifting bail.

During both modes, drill-rod-to-drill-string impact also is possible. Impact can be caused by a drop of the drill rod or by an operator error. This accident is likely because the drill rods are made of carbon steel and assembling/disassembling is performed for each sample. The cable spray washer is installed after the DS is disconnected from the quill rod adapter. The change out assembly is installed after cable spray washer. If dropped on the DS, the change-out assembly also may cause a spark.

Ignition tests are designed to simulate the impact of dropping a 19-in. drill rod on a vertically oriented DS from a height of 3 feet. A height of 3 feet corresponds to an impact velocity of 14 ft/s. These tests must be performed 30 times because the expectation is that carbon-steel pieces could create sparks when impacted. Provided that these tests conducted with realistic conditions result in no ignition of stoichiometric hydrogen-air mixture, the probability of ignition may be estimated using binomial theorem. For 30 tests with no ignition, the probability of ignition is ~2.0×10^{-2}. Considering this probability, the accident frequency becomes on the order of ~10^{-7}.

A well-mixed gas mixture must be provided to the impact point. This is a key issue in these drop tests. To achieve mixing, the gas mixture must be provided with a minimum flow rate so as not to cause significant convective effects inside the stationary drill string. The purge time and flow rate must account for the volume of the test chamber as well as the drill string volume. Appropriate mixing in the test chamber also must be provided. The gas temperature must be ≥ 100°C, and the gas mixture must be a stoichiometric mixture of hydrogen-air for these tests.

Tests must not induce ignition the of the stoichiometric hydrogen-air mixture.

T.5. DROP TEST OF A ROTARY MODE SAMPLER ON TO A ROTARY BIT

Drop tests simulating the drop of the core sampler on the drill bit were performed in the following fashion. A prototype core sampler must be dropped from a height of 60 feet through a prototype drill string on the drill bit attached to the lower end of the drill string. The section of the core barrel containing the grooves, or serrated edges, where the quadralatch fingers latch, and the quadralatch fingers and body must be made of 304 stainless steel to reduce the likelihood of a spark. The test chamber and drill string must be filled with a stoichiometric hydrogen-air mixture. Ignition is not expected because the bottom of the core sampler is made of stainless steel. Tests must be repeated ten times to confirm this expectation.

A well-mixed gas mixture at the impact point must be provided. Note that the 60-foot DS may require significantly larger purge periods. The gas mixture must be purged with a minimum flow inside of the stationary DS in all tests. The purge time and flow rate must account for the volume of the test chamber as well as the long DS volume. Mixing in the test chamber should also be provided. The gas temperature must be ≥100°C.

If there are pins inside the current drill bit, they need to be scratched so that the core sampler can impact on carbon steel pins. For this experiment, you must use the current drill bit (Longyear, trademark of Longyear Incorporated) Part Number 1OOIVD/8). The number of tests must not be less than 10.

These tests must conclude that no ignition of stoichiometric hydrogen-air mixtures is observed in ten core sampler drop tests performed under these conditions.

T.6. QUILL ROD ADAPTOR-DRILL STRING IMPACT TESTS

A misalignment between the quill rod adapter and drill string could cause sparks when the drill string is disconnected from the quill rod adapter. This event can occur during both RMCS. The quill rod adapter impact test used a section of the same type of stainless-steel pipe dropped on its end onto the end of a section of carbon drill string. Calculations (Ref. 8) showed that the maximum kinetic energy during drill-string/quill-rod misalignment is 115 in.-lb. A safety factor of 2 was employed, raising the kinetic energy to 230 in.-lb. A 5.22-lb piece was dropped 44 in. onto the carbon-steel pipe to simulate this impact.

A well-mixed gas mixture of stoichiometric hydrogen and either oxygen or air (66%/34%) with a minimum flow rate must be provided to the impact point. The purge time and flow rate must account for the volume of the test chamber as well as the long DS volume. The gas temperature must be ≥100°C. The gas mixture needs to be supplied both to the drop tube and the test chamber.

These tests must be repeated 10 times and must show no ignition.

T.7. RESULTS OF IGNITION TESTING PERFORMED AT BUREU OF MINES

Witwer[8] performed the ignition testing required by this appendix at the BOM. The procedure and test setup, including the recipes of the flammable gas described by Witwer in his report, are reviewed and found to be consistent with the requirements of this appendix. Results of each test described in this appendix did not show an ignition of the flammable mixtures of hydrogen-oxygen, hydrogen-ammonia-oxygen and hydrogen-ammonia-nitrous oxide, as reported by Witwer.[8] Therefore, the accident scenarios, including the ignition of flammable gases caused by mechanical sparks (frictional sparks, sparks resulting from impact), are considered to be not credible for RMCS operations.

T.8. SUMMARY AND CONCLUSIONS

All of the required tests described in this appendix were performed at BOM by Witwer.[8] All the test procedures and results are documented in Ref. 8. The test procedure and findings of this report have been reviewed, and they were found to be consistent with descriptions given in this appendix. Results showed no ignition in all of the tests described in this appendix. The conclusion of ignition testing therefore is used to address the postulated fire accidents caused by mechanical sparks discussed in Section 4.

The core sample drill bits used in BOM tests were Longyear (trademark of Longyear Incorporated) part numbers 1OOIVD/8 (currently used) and 9505-15E (new prototype bit). These drill bits are qualified for FG/RMCS based on BOM test results. However, there are no envelope tests for the new prototype bit, Number 9505-15E.

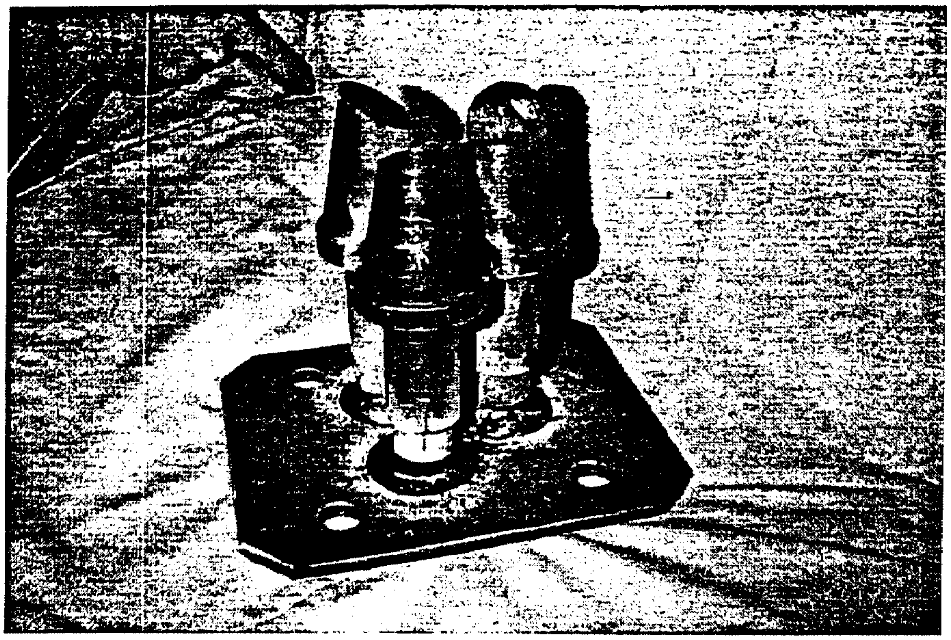


Fig. T-1. The photograph of three sharp, hardened 4140-tool steel shapes before drilling.

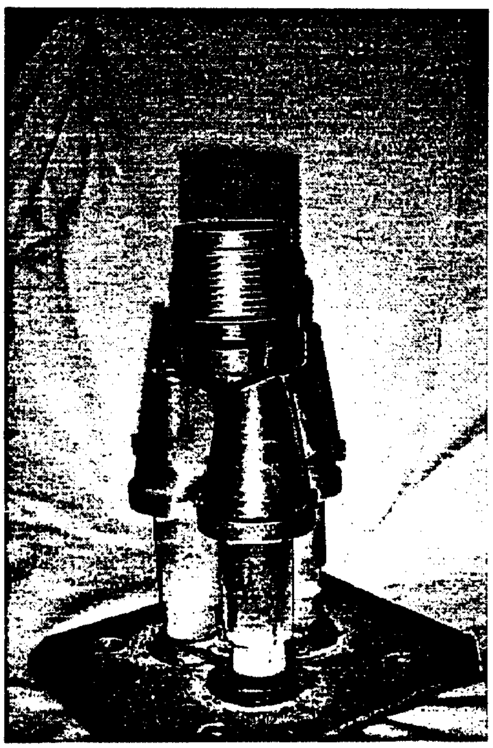


Fig. T-2. The photograph illustrating the three sharp, hardened 4140-tool steel shapes during drilling.

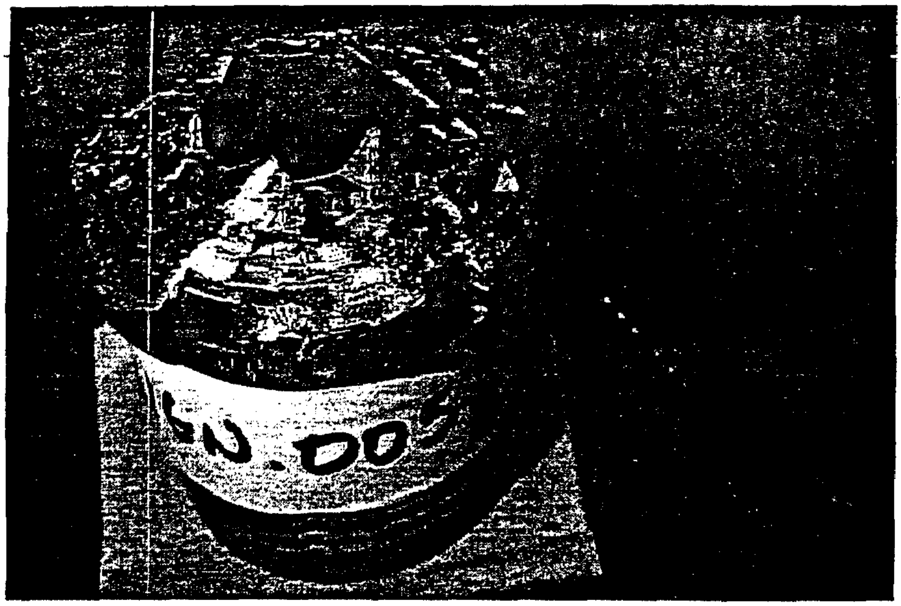


Fig. T-3. The photograph of the drill bit after drilling on a hardened 4140-tool steel shape.

The FG/RMCS equipment may be modified in the future. Any modifications made in drill bits, core samplers, drill rods or operating conditions specified in this appendix must be assessed against ignition test results given in this appendix. Proposed design or operating parameter changes which are not bounded by the results of ignition testing discussed in this appendix will require performance of additional bounding tests. The USQ process will be applied to ensure that any design or operational parameter changes are bounded by the results of the ignition testing in this SA.

T.9. REFERENCES

1. J. C. Krok and J. E. Shepherd, "Electrical and Frictional Spark Ignition of N_2O-H_2-N_2-air Mixtures," Los Alamos National Laboratory report, LANL-WT-800, (June 1993).

2. K. L. Cashdollar, K. S. Witwer, A. Furno, G. M. Green, R. A. Thomas "Ignitability Testing for Core Drilling Systems," Westinghouse Hanford Company report WHC-SD-WM-TRP-224 (March 1995).

3. K. L. Cashdollar, M. Herzberg, I. A. Zlochower, C. E. Lucci, G. M. Green, and R. A. Thomas, "Laboratory Flammability Studies of Mixtures of Hydrogen, Nitrous Oxide, and Air, " Westinghouse Hanford Company report WHC-SD-WM-ES-219, Rev. 0 (August 1992).

4. M. Hertzberg and I. A. Zlochower, "Explosibility of Nitrous Oxide: The Effect of H-Atom Bearing Impurities," Twenty-Fifth International Symposium on Combustion, University of California, Irvine (July 31–August 5, 1994).

5. E. Jones and J. C. Kerr, "Inflammability Limits of Ammonia, Nitrous Oxide and Air," J.S.C.I., Vol. 68 (January 1949), pp. 31–34.

6. F. Powell "Ignition of Gases and Vapors," Industrial and Engineering Chemistry, Vol. 61, No. 12, p. 29 (1969).

7. R. Blickensderfer, J.E. Kelley, D.K. Deardorff, and M.I. Copeland, "Testing of Coal-Cutter Materials for Incendivity and Radiance of Sparks," Bureau of Mines Report of Investigation, RI-7715 (1972).

8. K. S. Witwer, "Test Report for Ignitability Testing," Westinghouse Hanford Company report WHC-SD-WM-TRP-257 (June 1996).

APPENDIX U

FUNCTIONAL REQUIREMENTS FOR FLAMMABLE AND TOXIC GAS (HYDROGEN AND AMMONIA) SENSORS

U.1. INTRODUCTION

The purpose of the sensors is to provide signals that can be used as safety shut-down indicators for both flammability (mainly hydrogen and ammonia) and toxic (mainly ammonia) hazards during rotary-mode core sampling (RMCS) operations. The primary flammability hazard is the release of hydrogen gas, and the primary toxicity hazard is the release of ammonia gas (which is also flammable). The signal will be used to shut down the drill truck and to alert personnel to evacuate the tank farm as a protection against toxic-gas exposure. The objective of this appendix is to specify the functional requirements of the chosen sensors for this applications.

U.2. EVALUATION OF THE SENSOR

At the time of the submittal of this safety assessment (SA), two sensors have been identified and are being designed as part of the ventilation system. The first is a Wittaker Cell hydrogen detection system and the second is an SMC combustible gas sensor.

The Wittaker Cell is an electrochemical cell with a membrane placed between the sample gas and the active element. It is very selective for hydrogen and responds directly to the partial pressure of hydrogen on the other side of the membrane. It is configured with a calibration port that can be used to flood the sensor region with a calibration or zero gas during operation conditions. For the sensor to read out concentration it is essential that the pressure in the sensor region be within the expected tank pressure range during the calibration.

The Sierra Monitor Corp. (SMC) combustible gas sensor uses a catalyst to "burn" the gas and detects the resulting heat release. To increase sensitivity and decrease drift, the heat detection is done by comparing the temperature of a reference (uncatalyzed bead) to that of a signal (catalyzed) bead. The beads are imbedded in a sintered metal housing which prevents the combustion energy from igniting a flammable mixture. It has the advantage of responding to both ammonia and hydrogen.

Westinghouse Hanford Company has considerable experience with the Wittaker Cell, which has been shown to have an adequate response time as given in App. B. The Wittaker cell has been shown to have adequate sensitivity, and experience has shown that it is very reliable and stable in the current tank farm applications. Calibration is required only every three months.

The SMC detector has not been used in the tank farm environment before, but it has re·ently been tested as described in a report by Straalsund.[1] The key points of this report were the following:

- The output is noisy, which can be rectified by electrical processing but still is barely adequate for this application.
- The response of the system was very sensitive to the flow rate of the gas by the sensor.
- The response was sensitive to the orientation of the device.
- The sensor responded to ammonia as well as hydrogen with the ammonia response factor being approximately 40% of the hydrogen response.

Based on the information provided, the sensors, if implemented properly, should provide the required protection against flammability and toxicity hazards during a gas-release event (GRE). The SMC sensor, if set to trip at 5000 ppm hydrogen equivalent, should sense both a 5000 ppm hydrogen concentration and a 12000 ppm ammonia concentration for alarm purposes if the gas was purely hydrogen or ammonia, respectively.

U.3. FUNCTIONAL REQUIREMENTS FOR THE SENSORS

The requirements for the Wittaker Cell sensor deployment will be a slightly less stringent than the SMC sensor because the Wittaker cell has better sensitivity and has been demonstrated to be stable and reliable in the tank farm environment.

U.3.1. Wittaker Cell Requirements

- The system must be rated to sample from a Class-I, Division-1, Group-B environment.
- The deployment system must retain the response time requirement of reaching 90% of full scale in less than 2 minutes.
- The configuration must allow for the system to be calibrated in a manner that ensures that zero and calibration gas are within the expected tank pressure range during the calibration. The system must be able to be operated during pressure transients caused by a potential GRE.
- The calibration should be performed at initial deployment and every three months after that point. The calibration should consist of setting the zero with pure air or nitrogen and calibration with a nominal 6000 ppm hydrogen. The calibration procedure with a nominal 6000 ppm

hydrogen should test the shutoff electronics as well as the sensor reading.

U.3.2. SMC Combustible Gas Sensor Requirements

The requirements for the SMC combustible gas sensor are more stringent for several reasons:

- The sensor is sensitive to both flow and pressure.
- The signal-to-noise and lower detection limit seem to be marginal for the application.
- There is no operational history for exposure to tank farm gases.

The following are the functional requirements for the SMC combustible gas sensor:

- The system must be rated to operate in a Class-I, Division-1, Group-B environment.
- In addition to the electrical qualification, it must be documented that the sensor element itself will not ignite a flammable mixture.
- The deployment system must retain the response time requirement of reaching 90% of full scale in less than 2 minutes.
- The design must assure that the system conservatively responds to a pressure or flow rate transient anticipated during a GRE.
- Configuration of both sensors must allow the system to be calibrated in a manner that the pressure in the sensor region is within the expected tank pressure range during the calibration.
- The initial sensor must be calibrated with both hydrogen and ammonia.
- The functional test should be performed at initial setup at each location and every day the system is used after that point. The functional test must consist of setting the zero with pure air or nitrogen and calibration with a nominal 6000 ppm hydrogen. The functional test procedure with a nominal 6000 ppm hydrogen should test the shutoff electronics as well as the sensor reading.
- The sensor must be replaced at least once per month with a new sensor that has been calibrated with both hydrogen and ammonia.

U.4. REVIEW OF FINAL DESIGN, FUNCTIONAL REQUIREMENTS, PERFORMANCE, AND CALIBRATION OF FLAMMABLE GAS DETECTION SYSTEM

The final design and calibration of the sensors are summarized in Ref. 2 The description of the system is given in Section 2. A brief summary of the system design is given below.

The flammable-gas detection system consists of four primary components: (1) a spool piece with gas sensors to obtain gas samples from the exhaust stream, (2) and (3) two identical, separate, electronic packages, and (4) a power distribution skid with redundant shutoff contactors. The system is powered by the same source as the exhauster. The flexible duct from the waste tank is attached to the spool piece that is bolted directly to the exhauster heater. The ventilation stream passes through the spool piece and into the exhauster. Attached to the spool piece are two separate flammable-gas sensors; a Whittaker hydrogen detector cell and a SMC combustible gas detector. The use of SMC and Wittaker sensors provides a redundancy in hydrogen detection. The detection of ammonia can only be performed by the SMC sensor and therefore is not redundant.

The purpose of the gas sensors on the spool piece is to provide safety shut-down signals for both flammability and toxic hazards during core sampling operations. Out-of-tolerance conditions include concentrations of hydrogen equivalent flammable gas greater than 5000 ppm, or concentration rate increases greater than 100 ppm/s. Upon detection of out-of-tolerance conditions, the interlock will initiate drill rig shutdown and alert personnel to evacuate the tank farm.

Review of Ref. 2 indicates that both the Wittaker cell and SMC combustible gas sensors are qualified to be operated in Class-I, Div.-1, Group-B environments.

The calibration of both sensors consisted of setting the zero with pure air or nitrogen and calibrating with a nominal 6000 ppm of hydrogen. Calibration involved hydrogen concentrations from zero to a nominal 6000 ppm with a step increase in concentration. No unexpected nonlinearity was observed, and calibration results were acceptable.

The response time of the SMC combustible gas sensor was experimentally measured using the orientation of the prototype. These tests are performed with calibrated sensors. The hydrogen concentration was increased from 0 to a nominal 6000 ppm. Both sensors meet the requirement of reaching 90% of the full scale (a nominal 6000 ppm) in less than 2 minutes, which was used in determining the trip set point of the flammable-gas detector.

Configuration of both sensors allows the system to be calibrated in a manner that zero and calibration gas are exposed to sensors within the expected pressure as during the operation mode.

Pressure and flow transient tests simulating a GRE are performed. Results confirm that the sensors adequately operate under an anticipated transient condition.

Both sensors themselves do not ignite a flammable mixture when they are operational.

SMC sensor, if set to trip at a 5000-ppm hydrogen equivalent, should sense both a 5000-ppm hydrogen concentration and a 12000-ppm ammonia concentration for alarm purposes if the gas were purely hydrogen or ammonia, respectively. The set point for a rate of increase of concentration is 100 ppm/s for 10 seconds.

Wittaker cell, if set to trip at a 5000-ppm hydrogen equivalent, should sense a 5000-ppm hydrogen concentration for alarm purposes if the gas were purely hydrogen. The set point for a rate of increase of concentration is also 100 ppm/s for 10 seconds.

A control is established for an SMC sensor to be initially calibrated with hydrogen and ammonia and an SMC sensor to be replaced at least once per month with a new sensor that has been calibrated with both hydrogen and ammonia. A control is also established for the SMC sensor to be calibrated in the following fashion. A functional test shall be performed at the initial setup at each location and every day the system is used after that point. The functional test shall consist of setting the zero with pure air or nitrogen and calibration with a nominal 6000-ppm hydrogen. The functional test procedure with a nominal 6000-ppm hydrogen shall test the shutoff electronics as well as the sensor readings. A functional calibration test shall be performed once every three months for the Whittaker cell.

U.5. CONCLUSIONS

This appendix presents the functional requirements of flammable-gas sensors used in RMCS operations. A reliable, fast, accurate, and redundant flammable-gas detector system is designed to be operated in steady-state exhauster operating conditions as well as during rapid transient surges. They are located in a spool piece upstream of the preheater in the exhauster. Flammable-gas sensors consist of a Wittaker cell and an SMC combustible gas sensor.

Review of the design and results of calibration of both sensors and how the design meets the requirements given in this appendix reveal that the flammable-gas detection system will function as desired to detect GRE and flammability on the tank dome and shut down the drill engine. Requirements listed in this appendix for both Wittaker and SMC combustible gas sensors are concluded as being fulfilled.

The following controls are established for the flammable-gas detection system:

- SMC sensors shall be replaced at least once each month with new sensors,
- New SMC sensors shall be initially calibrated in a laboratory environment using hydrogen and ammonia,

- A functional calibration test shall be performed in the field at the initial setup and then every day for the SMC sensor,

- A functional calibration test shall be performed once every three months for the Whittaker cell,

- The functional calibration test shall consist of setting the zero with pure air or nitrogen and calibration with a nominal 6000-ppm hydrogen for both sensors,

- The functional calibration test procedure with a nominal 6000 ppm hydrogen shall test the shutoff electronics as well as the sensor reading for both sensors.

- The set point for tripping both sensors shall be a 5000-ppm hydrogen equivalent.

The set point for a rate of increase in hydrogen equivalent concentration is 100 ppm/s for 10 seconds.

U.6. REFERENCES

1. E. Straalsund, "Combustible Gas Sensor Interference Report," Westinghouse Hanford Company report WHC-SO-WM-TRP-249 (January 1996).

2. E. K. Straalsund, Flammable Gas-Detection System and Calibration " Mid-Columbia Engineering report MCE-RPT-001 (June 1996).

96/3861

ENGINEERING CHANGE NOTICE

Page 1 of 2

1. ECN 609990

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	3a. USQ Required?	4. Date
Supplemental [X] Direct Revision [] Change ECN [] 9-3-96 pc Temporary [] Standby [] Supersedure [] Cancel/Void []	R. E. Raymond, 75200, S7-12	[] Yes [X] No	4/30/96
	5. Project Title/No./Work Order No. Rotary Mode Core Sampling System (RMCS)	6. Bldg./Sys./Fac. No. Tank Farm Facilities	7. Approval Designator SQD
	8. Document Numbers Changed by this ECN (includes sheet no. and rev.) WHC-SD-WM-OSR-005, Rev. ~~0~~ 0 WHC-SD-WM-ISB-001, Rev. ~~0~~ ~~WHC-IP-0954, Rev. 5~~ KmB 5/2/96	9. Related ECN No(s). N/A	10. Related PO No. N/A

11a. Modification Work	11b. Work Package No.	11c. Modification Work Complete	11d. Restored to Original Condition (Temp. or Standby ECN only)
[] Yes (fill out Blk. 11b) [X] No (NA Blks. 11b, 11c, 11d)	N/A	N/A Cog. Engineer Signature & Date	N/A Cog. Engineer Signature & Date

12. Description of Change

1. WHC-SD-WM-ISB-001, Rev. 0-~~X~~, Vol. 1, on page 6-9, a fourth table line shall be added. The control topic shall be: Rotary Mode Core Sampling

The affected facilities shall be: Flammable Gas Watch List Tanks and SST's specified in Requirement Source

The requirement sources shall be: WHC-SD-WM-OSR-005, latest revision and WHC-SD-WM-SAD-035, latest revision.
The ISB requirement shall be: "Rotary Mode Core Sampling Activities shall be controlled by Sections 3.7 and 5.31 of WHC-SD-WM-OSR-005, latest revision."

REFERENCE ~~2~~. WHC-IP-0954, Rev. 5, "Tank Farms Interim Operational Safety Requirements Compliance Implementation Plan," Rev. 5, shall have the following statement added to page 2, the Executive Summary.

"The IOSR's for Rotary Mode Core Sampling (RMCS) will be fully implemented prior to deployment of the RMCS in flammable gas tanks. A readiness assessment/review will verify implementation of this IOSR.

2. ~~3~~. LCO 3.7.1, 3.7.2, 3.7.3, 3.7.4, 3.7.5, and Administrative Controls 5.31.1, 5.31.2, 5.31.3, 5.31.4, 5.31.5, 5.31.6, 5.31.7, 5.31.8, 5.31.9, 5.31.10, 5.31.11, and 5.31.12 (SEE ATTACHED PAGES) will be added to Sections 3 and 5 of WHC-SD-WM-OSR-005, Rev. 0 and the Table of Contents (TOC) will be modified to reflect these additional requirements.

13a. Justification (mark one)

Criteria Change	[]	Design Improvement	[X]	Environmental	[]	Facility Deactivation	[]
As-Found	[]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

13b. Justification Details

The IOSR requires revision to implement the level 1 controls established in the Safety Assessment "A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks, Hanford Site, Richland, Washington," WHC-SD-WM-SAD-035, Rev. 0

14. Distribution (include name, MSIN, and no. of copies)

Unclassified Document Control, Kelli S. Lenz (N4-18)

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15. Design Verification Required	16. Cost Impact				17. Schedule Impact (days)	
	ENGINEERING		CONSTRUCTION			
[] Yes	Additional	[] $ None	Additional	[] $	Improvement	[] None
[X] No	Savings	[] $	Savings	[] $	Delay	[]

18. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 12. Enter the affected document number in Block 19.

SDD/DD	[]	Seismic/Stress Analysis	[]	Tank Calibration Manual	[]
Functional Design Criteria	[]	Stress/Design Report	[]	Health Physics Procedure	[]
Operating Specification	[]	Interface Control Drawing	[]	Spares Multiple Unit Listing	[]
Criticality Specification	[]	Calibration Procedure	[X]	Test Procedures/Specification	[]
Conceptual Design Report	[]	Installation Procedure	[]	Component Index	[]
Equipment Spec.	[]	Maintenance Procedure	[]	ASME Coded Item	[]
Const. Spec.	[]	Engineering Procedure	[]	Human Factor Consideration	[]
Procurement Spec.	[]	Operating Instruction	[]	Computer Software	[]
Vendor Information	[]	Operating Procedure	[X]	Electric Circuit Schedule	[]
OM Manual	[]	Operational Safety Requirement	[X]	ICRS Procedure	[]
FSAR/SAR	[]	IEFD Drawing	[]	Process Control Manual/Plan	[]
Safety Equipment List	[]	Cell Arrangement Drawing	[]	Process Flow Chart	[]
Radiation Work Permit	[]	Essential Material Specification	[]	Purchase Requisition	[]
Environmental Impact Statement	[]	Fac. Proc. Samp. Schedule	[]	Tickler File	[]
Environmental Report	[]	Inspection Plan	[]		[]
Environmental Permit	[]	Inventory Adjustment Request	[]		[]

19. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision

Specific Operating Procedures and Calibration Procedures to be determined.

20. Approvals

	Signature	Date
OPERATIONS AND ENGINEERING		
Cog. Eng.	J. S. Schofield *John Schofield*	5/1/96
Cog. Mgr.	D. W. Hamilton *[signature]*	4/30/96
QA	M. L. McElroy *M. L. McElroy*	5/1/96
Safety	M. N. Islam *[signature]*	5/1/96
Environ.		
Other		
WT Plant Eng. Mgr.		
TWRS Safety Program	J. W. Lentsch *[signature]*	4/25/96
TFTP Deputy Dir.	J. E. Truax *[signature]*	5/2/96
SEAC	R. M. Marusich *RM Marusich for JL Deichman*	5/2/96
Auth. Basis	J. J. Klos *[signature]*	5/2/96
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A-7900-013-3 (11/94) GEF096

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IMPLEMENTATION NOTICE

6.0, Rev. 0-K, "ISB Requirements for Single Shell Tanks"

This page implements the controls established by A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks.

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RECORD OF REVISION

(1) Document Number WHC-SD-WM-ISB-001, Vol. 1

Page 1

(2) Title
Hanford Site Tank Farm Facilities Interim Safety Basis

CHANGE CONTROL RECORD

(3) Revision	(4) Description of Change - Replace, Add, and Delete Pages	Authorized for Release (5) Cog. Engr.	(6) Cog. Mgr. Date
0-K	(7) A fourth line added to table to implement rotary mode core sampling requirements	J. S. Schofield John Schofield 7/1/96	D. W. Hamilton [signature]

Hanford Site Tank Farm Facilities Interim Safety Basis

J. W. Lentsch
Westinghouse Hanford Company, Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-87RL10930

EDT/ECN: 609990 UC:
Org Code: W75230 Charge Code: N4HBB
B&R Code: Total Pages: 2

Key Words: rotary mode, sample truck, flammable gas tank, hydrogen

Abstract: This page implements the controls established by A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks.

Release Approval Date Release Stamp

Approved for Public Release

ISB REQUIREMENTS FOR SINGLE-SHELL TANKS

CONTROL TOPIC(S)	AFFECTED FACILITIES	REQUIREMENT SOURCE	ISB REQUIREMENT
Interim Operational Safety Requirements	All SSTs	WHC-SD-WM-OSR-005, Latest Revision	The Single Shell Tank Interim Operational Safety Requirements are adopted in their entirety as ISB Requirements.
Overground Transfer Lines	All SSTs	WHC-SD-WM-SAR-034, Revision 0-A	The Operational Safety Requirements from Chapter 11.0 of the "Overground Transfer Line Addendum to the Single-Shell Tank Safety Analysis Report," WHC-SD-WM-SAR-034, Revision O-A are adopted in their entirety as ISB Requirements.
Nuclear Criticality	SSTs	WHC-SD-WM-OSR-005, AC 5.12, Latest Revision DOE-HQ Memo, T.P. Grumbly, HQ, to Manager, RL dated March 14, 1994	The criticality USQ was approved for closure via the Requirement Source Memo. Refer to WHC-SD-WM-OSR-005, Administrative Control (AC) 5.12 for requirements.
Rotary Mode Core Sampling	Flammable Gas Watch List SSTs specified in Requirement Source	WHC-SD-WM-OSR-005, Latest Revision WHC-SD-WM-SAD-035, Latest Revision	Rotary Mode Core Sampling shall be controlled by Sections 3.7 and 5.31 of WHC-SD-WM-OSR-005, Latest Revision

RECORD OF REVISION	(1) Document Number WHC-SD-WM-OSR-005	Page 1

(2) Title
Single Shell Tank Interim Operational Safety Requirements

CHANGE CONTROL RECORD

(3) Revision	(4) Description of Change - Replace, Add, and Delete Pages	Authorized for Release (5) Cog. Engr.	Authorized for Release (6) Cog. Mgr. Date
0-E	(7) LCO 3.7 and Administrative Controls 5.31. Rotary Mode Core Sampling....	J. S. Schofield 7/18/96	D. W. Hamilton

A-7320-005 (08/91) WEF168

Single Shell Tank Interim Operational Safety Requirements

J. W. Lentsch
Westinghouse Hanford Company, Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-87RL10930

EDT/ECN: 609990 UC:
Org Code: W75230 Charge Code: N4HBB
B&R Code: Total Pages: 53

Key Words: rotary mode, sample truck, flammable gas tank, hydrogen

Abstract: These pages implement the controls established by A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks.

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3.7 ROTARY MODE CORE SAMPLING SYSTEM

3.7.1 Flammable Gas Detection System

LCO 3.7.1 The flammable gas detection system shall be operable with trip setpoints at 5000 ppm hydrogen concentration equivalent and > 100 ppm/s rate of equivalent hydrogen concentration increase over a 10 sec period.

APPLICABILITY: OPERATION (RMCS waste intrusive operations in Flammable Gas Watch List (FGWL) Tanks or those tanks recommended by the contractor to be included on the FGWL).

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Automatic trip occurs.	A.1 Stop RMCS activities and evacuate all personnel within a 100-meter radius from the edge of tank.	Immediately
	AND	
	A.2 Re-enter within 100 meter radius in accordance with the Tank Farm Health and Safety Plan WHC-SD-WM-HSP-002	In accordance with the Tank Farm Health and Safety Plan WHC-SD-WM-HSP-002
B. Flammable Gas Detection System Inoperable	B.1 Stop RMCS waste intrusive operations	Immediately
	AND	
	B.2 Restore Flammable Gas Detection System Operability	Prior to resuming RMCS Waste Intrusive Operations

SURVEILLANCE REQUIREMENTS

		SURVEILLANCE	FREQUENCY
SR	3.7.1.1	Two redundant channels shall be operable. Calibration shall be checked per required frequency and a trip test performed.	6 months
SR	3.7.1.2	**Hydrogen Detector** (Whittaker Cell Sensor)	
		• The system must retain the response time requirement of reaching 90% of full scale in less than 2 min.	Initial setup and every three months thereafter
SR	3.7.1.3	**Flammability Detector** (SMC Sensor)	
		• The functional test shall be performed at the specified frequency. The test procedure shall test the shutoff electronics as well as the sensor readings.	Initial setup and daily thereafter
		• The system must retain the response time requirement of reaching 90% of full scale in less than 2 min.	monthly
		• The sensor must be replaced at the required frequency with a new sensor that has been calibrated.	monthly

3.7 ROTARY MODE CORE SAMPLING SYSTEM

3.7.2 Tank Gas Pressure Detection System

LCO 3.7.2 — The gas pressure detection system shall be operable and capable of detecting an increase in tank pressure greater than 2 in. w.g. in any 5 min period.

APPLICABILITY: OPERATION (RMCS waste intrusive operations in Flammable Gas Watch List (FGWL) Tanks or those tanks recommended by the contractor to be included on the FGWL).

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Automatic trip occurs.	A.1 Stop RMCS activities and evaluate all personnel within a 100-m radius from the edge of tank.	Immediately
	AND	
	A.2 Re-enter within 100 m radius in accordance with the Tank Farm Health and Safety Plan WHC-SD-WM-HSP-002.	In accordance with the Tank Farm Health & Safety Plan WHC-SD-WM-HSP-002
	AND	
	A.3 A minimum 10 minute wait period shall be imposed following an automatic drill rig shut down due to GRE or other event prior to resuming operations.	> 10 min
B. Pressure Detection System Inoperable	B.1 Stop RMCS Waste Intrusive Operations	Immediately
	AND	
	B.2 Restore Pressure Detection System Operability	Prior to resuming RMCS waste intrusive operations

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.7.2.1	Two redundant channels shall be operable. Calibration shall be checked per required frequency and a functional test performed.	6 months

3.7 ROTARY MODE CORE SAMPLING SYSTEM

3.7.3 Exhauster Induced Tank Pressure

LCO 3.7.3 Exhauster shall be operable and shall maintain tank pressure less than atmospheric pressure and greater or equal to a negative 3 in. w.g.

APPLICABILITY: OPERATION (one hour prior, during, and sixteen hours following waste intrusive operations in Flammable Gas Watch List (FGWL) Tanks or those tanks recommended by the contractor to be included on the FGWL).

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Tank pressure exceeds limits.	A.1 Restore pressure to acceptable limits. If pressure cannot be restored, shut down drill rig engine.	Immediately
B. Exhauster shutdown due to automatic trip.	B.1 Cease RMCS operations.	Immediately
	AND	
	B.2 A 10 min minimum waiting period is required prior to resuming operations.	> 10 min
C. Exhauster inoperable.	C.1 Stop RMCS Waste Intrusive Operations.	Immediately
	AND	
	C.2 Restore Exhauster operability.	Prior to resuming RMCS waste intrusive operations

SURVEILLANCE REQUIREMENTS

SURVEILLANCE			FREQUENCY
SR	3.7.3.1	The exhauster pressure switch shall be calibrated periodically.	6 months

SURVEILLANCE REQUIREMENTS

		SURVEILLANCE	FREQUENCY
SR	3.7.3.2	Prior to initiating RMCS operations and periodically during exhauster operations, the pressure shall be verified to be in limits.	Prior to initiating operations and then once every 24 hours.
SR	3.7.3.3	All exhauster shutdown indication elements shall be calibrated with independent verification and tested with indication of all failures.	6 months

3.7 ROTARY MODE CORE SAMPLING SYSTEM

3.7.4 Nitrogen Purge System

LCO 3.7.4 The Nitrogen Purge System shall be operable and able to:

a. supply the drill string at a rate of ≥ 30 scfm.

b. supply nitrogen to the drill string at a temperature > 10°F and < 140°F.

APPLICABILITY: OPERATION (RMCS waste intrusive operations in Flammable Gas Watch List (FGWL) Tanks or those tanks recommended by the contractor to be included on the FGWL).

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Automatic trip occurs.	A.1 Cease RMCS operations.	Immediately
	AND	
	A.2 A 10 min minimum waiting period is required prior to resuming operations.	> 10 min
B. Nitrogen temperature out of range alarm.	B.1 Stop drill rig engine.	Immediately
	AND	
	B.2 Continue nitrogen purge.	Immediately
	AND	
	B.3 Do not resume drilling until temperature is within normal range.	> 10 min
C. Nitrogen purge system inoperable.	C.1 Stop RMCS waste intrusive operations.	Immediately
	AND	
	C.2 Restore Nitrogen Purge System Operability	Prior to resuming RMCS operating

D. Nitrogen temperature monitor inoperable.	D.1 Stop RMCS waste intrusive operations.	Immediately
	AND	
	D.2 Restore Nitrogen temperature monitor operability.	Prior to resuming RMCS operating

SURVEILLANCE REQUIREMENTS

SURVEILLANCE			FREQUENCY
SR	3.7.4.1	The purge system shall be tested for bypass leakage periodically. Testing shall be independently verified with indication of failures. Leak rate shall be limited to the uncertainty of the system or less than 2% of the required flow.	6 months
SR	3.7.4.2	Flow monitoring and automatic shutdown system will be calibrated periodically and verified as capable of automatically sending a shutdown signal to the drill rig engine immediately upon receipt of a valid shutdown signal of detecting nitrogen flow less than the required flow (2 of 3 control channels).	6 months
SR	3.7.4.3	Temperature indicator and alarm shall be calibrated periodically.	6 months

3.7 ROTARY MODE CORE SAMPLING SYSTEM

3.7.5 Rotary Drilling Parameters

LCO 3.7.5 The RMCS equipment shall be operable and shall:

a. not be operated with a down force on the drill bit > 750 lbf.

b. not operate at a drill string rotation > 55 rpm.

c. not be operated when the penetration rate is <0.75 in/min for a cumulative time of 60 sec in any 3 min period.

APPLICABILITY: OPERATION (RMCS waste intrusive operations in Flammable Gas Watch List (FGWL) Tanks or those tanks recommended by the contractor to be included on the FGWL).

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Automatic trip.	A.1 A minimum 10 min waiting period shall be imposed following an automatic trip due to down force, rpm, or penetration rate prior to resumption of RMCS operations.	> 10 min
B. Walkdown Function, hydraulic bottom detector, Down Force, Rotary RPM Measurement, or penetration rate system inoperable.	B.1 Stop RMCS waste intrusive operations.	Immediately
	<u>AND</u>	
	B.2 Restore system operability.	Prior to resuming RMCS operations
C. Grapple load exceeds 250 lb.	C.1 Stop electric motor driving the grapple hoist (or verify automatic stop).	Immediately

SURVEILLANCE REQUIREMENTS

		SURVEILLANCE	FREQUENCY
SR	3.7.5.1	RPM measurement and alarm trip equipment shall be calibrated and functionally tested on the stated frequency.	6 months
		There shall be dual RPM measurement sensors, both of which shall be operable when rotating the drill bit below the waste surface. The drill string rotation and penetration shall cease upon alarm or failure of either sensor circuits.	
		Penetration rate measurement system and alarm trip equipment shall be calibrated and functionally tested on the stated frequency.	6 months
		Down force measurement system and alarm trip equipment shall be calibrated and functionally tested on the stated frequency.	6 months
		Down force and alarm trip equipment shall be operable when rotating the drill bit below the waste surface.	
		Upon a valid high RPM, high penetration rate or high down force alarm, the system shall be capable of ceasing drill string rotation and penetration immediately.	
		The walkdown function and hydraulic bottom detector shall be verified operational.	6 months
		The walkdown function shall be operable for all samples except the last, when the hydraulic bottom detector shall be used.	
		Grapple hoist cable shall be inspected periodically.	6 months
		Grapple load cell shall be calibrated.	6 months

B 3.7 ROTARY MODE CORE SAMPLING SYSTEM

B 3.7.1 Flammable Gas Detection System

BASES	
BACKGROUND	The flammable gas detection system is connected between the riser and exhauster housing with local system readouts and alarmed setpoints. During drilling exceeding the setpoints will trip the drill rig engine and close the nitrogen purge flow solenoid operated valve.
APPLICABLE SAFETY ANALYSES	Analysis performed in Section 4 and Appendix B of Reference 1 to allow safe operation of the RMCS sets two limits to protect against a GRE and possible fire or explosion. This mitigates unacceptable consequences resulting from a dome collapse.
LCO	A trip setpoint of 5000 ppm hydrogen concentration equivalent assures that the tank in question does not exceed 25% of Lower Flammability Limit (LFL) during a GRE. An addition rate trip of 100 ppm hydrogen concentration equivalent increase over a 10 sec. period protects against exceeding the 25% LFL and gives sufficient notice of an impending GRE to allow proper precautions to be taken.
APPLICABILITY	OPERATION (RMCS waste intrusive operations in Flammable Gas Tanks).

BASES

ACTIONS	A.1 These actions were established in Reference 1 as the minimum personnel requirements to protect plant personnel upon exceeding the setpoints established. A.2 Re-entry into the 100 meter will be in accordance with the Tank Farm Health and Safety Plan, WHC-SD-WM-HSP-002. B.1 RMCS waste intrusive operations are not allowed without an operable Flammable Gas Detection System. B.2 Flammable Gas Detection System operability must be restored prior to resuming RMCS waste intrusive operations.
SURVEILLANCE REQUIREMENTS	SR 3.7.1.1 A 6-month trip test and calibration of the redundant trip circuitry provides assurance that system performance has not degraded.
SURVEILLANCE REQUIREMENTS	SR 3.7.1.2 Initial and 3 month check required by Reference 1 for Whittaker Cell. The calibration should be performed at initial setup at each location and every 3 months after that point. The calibration should consist of setting the zero with pure air or nitrogen and calibration with 6000 ppm hydrogen. The calibration procedure with 6000 ppm hydrogen should test the shutoff electronics as well as the sensor reading.
SURVEILLANCE REQUIREMENTS	SR 3.7.1.3 Initial and daily check required by Reference 1 for SMC Sensor.

BASES

REFERENCES	1.	LANL, 1996, *A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks, Hanford Site, Washington*, WHC-SD-WM-SAD-035, Rev. 0-a, Los Alamos National Laboratory, Los Alamos, New Mexico.

B 3.7 ROTARY MODE CORE SAMPLING SYSTEM

B 3.7.2 Tank Gas Pressure Detection System

BASES	
BACKGROUND	The purpose of this system is to prevent burn in and out of dome by detecting gas release rates > 1000 ft^3/min. It also provides protection for fire and toxic hazards, reduces the likelihood of spark in flammable gas atmosphere, and provides protection for exposure to toxic gas releases. This mitigates unacceptable offsite consequences resulting from a dome collapse.
APPLICABLE SAFETY ANALYSES	Safety analyses were performed in Sections 4, 4.2, and Appendix B of Reference 1.
LCO	A pressure pulse of 50.8 mm (2 in.) w.g. would correspond to a 0.5% increase in the dome pressure. Using a dome volume of 1416 m^3 (50,000 ft^3), the ideal gas law and adiabatic compression, a 5.1 m^3 (180 ft^3) sudden release into the dome is sufficient to generate a 2-in. w.g. pressure pulse. The purpose of the 2" w.g. trip is to protect against a release rate of > 1000 ft^3/min.
APPLICABILITY	OPERATION (RMCS waste intrusive operations in Flammable Gas Tanks).

BASES

ACTIONS	<u>A.1</u> These actions were established in Reference 1 as the minimum personnel requirements to protect plant personnel upon exceeding the pressure setpoint. <u>A.2</u> Re-entry into the 100 meter will be in accordance with approved Tank Farm procedures. <u>A.3</u> The 10 min wait allows sufficient time for the drill bit and associated waste to adequately cool down. <u>B.1</u> Waste intrusive operation are not allowed without an operable pressure detection system. <u>B.2</u> Pressure detection system operability must be restored prior to resuming RMCS waste intrusive operations.
SURVEILLANCE REQUIREMENTS	<u>SR 3.7.2.1</u> A 6-month trip test and calibration is necessary to ensure that the equipment will perform as required by the safety assessment. A channel is considered to be the sensor and associated circuitry and components up to the input to the alarm and trip circuit.
REFERENCES	1. LANL, 1996. *A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks, Hanford Site, Washington*, WHC-SD-WM-SAD-035, Rev. 0-a, Los Alamos National Laboratory, Los Alamos, New Mexico.

B 3.7 ROTARY MODE CORE SAMPLING

B 3.7.3 Exhauster Induced Tank Pressure

BASES	
BACKGROUND	Excessive vacuum in the dome is another accident identified in Reference 1 as a result of exhauster operations. The exhauster design prevents the occurrence of excessive vacuum because the shutoff head is -14 in. w.g. A dome collapse would not occur until -15 in. w.g. Also, the inlet high-efficiency particulate air (HEPA) filter has a vacuum breaker to mitigate excessive negative tank pressure. The vacuum breaker is set at about -4 in. w.g.
APPLICABLE SAFETY ANALYSES	The analysis was performed in Section 4.6.1 of Reference 1.
LCO	The range established by the LCO assures that tank pressure is less than atmospheric and greater than that which would open the vacuum breaker or collapse the tank dome.
APPLICABILITY	OPERATION (RMCS waste intrusive operations in Flammable Gas Tanks).

BASES

ACTIONS

A.1

Pressure change during exhauster operation is relatively slow. In any case cessation of RMCS operations will restore a serious negative pressure condition.

B.1

RMCS operations are not allowed without the exhauster in operation.

B.2

The minimum 10 min waiting period upon an exhauster automatic trip is required to ensure adequate cool down time for the drill bit and associated waste.

C.1

RMCS waste intrusive operations are not allowed without an operable exhauster.

C.2

Exhauster operability must be restored prior to resuming RMCS waste intrusive operations.

SURVEILLANCE REQUIREMENTS

SR 3.7.3.1

A 6-month system test and calibration will assure that the exhauster is performing as designed and meeting the requirements assumed in the safety assessment.

SURVEILLANCE REQUIREMENTS

SR 3.7.3.2

The pressure switch requires periodic surveillance to ensure that pressure requirements are met.

SURVEILLANCE REQUIREMENTS

SR 3.7.3.3

A test of all exhauster shutdown system elements ensures system reliability.

B 3.7 ROTARY MODE CORE SAMPLING SYSTEM

B 3.7.4 Nitrogen Purge System

BASES	
BACKGROUND	Nitrogen is supplied for five different functions during RMCS operations: (1) the Drill String purge gas system used during RMCS drilling; (2) the purge through the riser sleeve annulus, (3) the hydrostatic head in the drill string and (4) in the shielded receiver, and (5) the Z-purge (NFPA 496) in the SR weather cover. The systems provide: (1) drill bit cooling and cleaning during rotary drilling, (2) help prevent waste flooding in the drill string, and (3) prevent gas accumulation.
APPLICABLE SAFETY ANALYSES	Through use of the purge system, drill bit overheating and waste ignition is prevented. Control prevents local exothermic chemical reactions as well as a possible ignition of flammable gas in the waste. Analyses to establish this LCO were performed in Sections 4.4.1, 4.4.4, and 4.6.3 of Reference 1.

BASES

LCO	Envelope testing determined that 30 scfm was the minimum flow which, in combination with other parameters, would provide adequate cooling when coupled with a limit on nitrogen inlet temperature. The two-second requirement for a trip to occur is based on the safety assessment assumption that the determination of a valid alarm signal requires approximately 2 seconds. Immediately is used as a special completion time. In this case, the Required Action is to be commenced without delay and continuously pursued in a controlled manner until complete. While the minimum purge flow must be greater than 30 scfm; however, it is possible that necessary cooling to the drill bit would not be provided if there were a leak from the nitrogen purge system between the flow measurement location and the drill bit. WHC determined that the leak from the truck is within the uncertainty range of instrumentation. As indicated in Table 4.12 of Reference 1, the leak rate from the nitrogen system must be measured once every 6 months. This control requires that the leak rate must be within the uncertainty range of instrumentation or < 2% of the nominal flow.
APPLICABILITY	OPERATION (RMCS waste intrusive operations in Flammable Gas Tanks).

BASES

ACTIONS

A.1

RMCS operations are not allowed without an Nitrogen Purge System in operation.

A.2

Provided that the drill string rotation is not re-started for a minimum period of 10 min, it is possible to resume RMCS operations. This is the minimum time to allow drill bit and waste cooling.

B.1

RMCS operations are not allowed with the Nitrogen temperature out of range.

B.2

A continued purge is required to assist drill bit cool down.

B.3

A temperature outside the bounds of the safety assessment must be corrected prior to resuming operations.

C.1

RMCS waste intrusive operations are not allowed without an operable nitrogen purge system.

C.2

Nitrogen purge system must be restored prior to resuming RMCS waste intrusive operations.

D.1

RMCS waste intrusive operations are not allowed without an operable nitrogen temperature monitor.

D.2

Nitrogen temperature monitor must be restored prior to resuming RMCS operations.

BASES

SURVEILLANCE REQUIREMENTS	<u>SR 3.7.4.1</u> The 6-month testing and calibration requirement was established in Reference 1 to ensure equipment reliability and operability.
SURVEILLANCE REQUIREMENTS	<u>SR 3.7.4.2</u> The 6-month testing and calibration requirement was established in Reference 1 to ensure equipment reliability and operability. A channel is considered to be the sensor and associated circuitry and components up to the input to the alarm and trip circuit. Two of the three channels must alarm in order for the trip to occur. If one channel is taken out of service then it shall be tripped and one more channel alarm will cause a trip condition.
SURVEILLANCE REQUIREMENTS	<u>SR 3.7.4.3</u> Temperature sensor calibration and alarm test assures proper operator response to out of normal condition.
REFERENCES	1. LANL, 1996, *A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks, Hanford Site, Washington*, WHC-SD-WM-SAD-035, Rev. 0-a, Los Alamos National Laboratory, Los Alamos, New Mexico.

B 3.7 ROTARY MODE CORE SAMPLING SYSTEM

B 3.7.5 Rotary Drilling Parameters

BASES

BACKGROUND	Behavior of the drill string and, in particular the drill bit, was a high focus area in the safety assessment (Reference 1). Many accident scenarios were analyzed to determine performance requirements. All the requirements established were to limit the heat generating capacity of the drilling operation.
APPLICABLE SAFETY ANALYSES	Wastes including mixtures of sodium nitrate and sodium nitrite with organic compounds can produce violent exothermic reactions (Appendix G Reference 1). Increasing the temperature of the waste in the vicinity of the drill bit can cause a thermal runaway. There are several hazards that are associated with a local thermal runaway, and they are discussed in Appendix G of Reference 1. Two major important hazards are the ignition of the flammable gas and the ignition of a self-propagating exothermic reaction in the waste. Reactions in mixtures containing relatively small amounts of organic compounds can result in temperatures greater than the autoignition temperature of hydrogen mixtures, so the ignition of flammable gases is the more limiting condition. Because the possibility of flammable-gas mixture cannot be eliminated, the approach used is to take all practical measures to eliminate ignition sources. A local runaway reaction is a potential ignition source, so the requirement that there be no local runaway reaction is consistent with the philosophy used. Preventing a local thermal runaway is also protection against a propagating exothermic reaction, and it eliminates the possibility of generating additional flammable gas as a result of elevated temperatures. Appendix G of Reference 1 discusses runaway reactions and waste ignition in great detail. Basic conclusions of Appendix G of Reference 1 are that local runaway reactions can be prevented by establishing waste temperature limits. The following temperature limits are established: • The temperature of small waste fragments produced at the drill tip must not exceed 180°C. • The temperature of the drill bit and the average temperature of the waste affected by drilling must not exceed 160°C for more than 10 min.

BASES

APPLICABLE SAFETY ANALYSES (continued)	New envelope testing has been performed by WHC to determine the operating parameters, rotational speed, down forces, and nitrogen purge flow to comply with the safety criteria given above. Appendix F of Reference 1 discusses the details of testing and the results obtained. As a summary, results of envelope testing and their analysis showed that the drill bit surface temperature and the waste substrate temperature can be kept below 160°C, including an uncertainty of 10°C, if the following limits are applied: Down force < 750 lbf, rotational speed < 55 rpm, minimum nitrogen flow > 30 scfm, and penetration rate > 0.75 in./min. The chip temperatures under these conditions are also limited to 180°C as required. If a trip is initiated when one of the set points for these four parameters is exceeded, drilling must be stopped. After a shutdown there must be a waiting period of 10 min before drilling can continue. The waiting period of 10 min is based on the experimentally determined cooling time. The testing and the analysis included plugged holes on the drill bit. The drill bit shall be replaced if drilling is shut down four times consecutively as a result of low penetration rate and if the cumulative penetration is < 0.3 in. for the last three attempts.
LCO	The requirements of 3.7.5 (a), (b), and (c) were established by envelope testing documented in Reference 1. The time requirement in the action statement is based on the approximate time it takes to establish a valid trip signal determination.
APPLICABILITY	OPERATION (RMCS waste intrusive operations in Flammable Gas Tanks).

BASES

ACTIONS

A.1

The minimum 10 min waiting period is to provide adequate drill bit and associated waste cool down.

B.1

RMCS waste intrusive operations are not allowed without an operable Down Force, Rotary RPM Measurement, penetration rate system, walkdown function, and hydraulic bottom detector.

B.2

Operability must be restored prior to resuming RMCS waste intrusive operations.

C.1

Action statement prevents load exceeding those specified in Reference 1.

SURVEILLANCE REQUIREMENTS

SR 3.7.5.1

A 6-month test and calibration was required by Reference 1 to ensure system reliability and performance.

Controlled loads on the grapple hoist prevent grapple drop consequences and potential for fire (Sections 4.3.2 and 4.3.6 of Reference 1).

REFERENCES

1. LANL, 1996, *A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks, Hanford Site, Washington*, WHC-SD-WM-SAD-035, Rev. 0-a, Los Alamos National Laboratory, Los Alamos, New Mexico.

Section 5 ADMINISTRATIVE CONTROLS (ACs)

5.31 ROTARY MODE CORE SAMPLING

5.31.1 Control Applicability

For single-shell tanks (SSTs) on the flammable Gas Watch List (FGWL), or those tanks recommended to be on the watch list, an evaluation checklist shall be completed per Section 7.0 of Reference 1.

Checklist items will include:

(1) Tank Specific Hazards / Other Watch lists
(2) Flammable Gas Composition
(3) Toxic Gas Composition
(4) Waste Temperature
(5) Waste Energetics
(6) Likelihood of Gas Release Event (GRE)

Successful completion of the checklist is required for RMCS operations to proceed. This means that no adverse items remain unresolved.

5.31.2 Ignition and Envelope Testing

Ignition and envelope test requirements and acceptance criteria shall be used to verify drill bit and material performance. Required testing has been completed.

5.31.3 Flammable Gas Detection System Verification

Functional requirements and performance acceptance criteria provided in Reference 1 shall be used to verify the performance of the flammable gas detection system. This is a one time check for the Whittaker Cell and the SMC sensor and need not be repeated. Should a new sensor be selected for use, its performance shall be verified against Appendix U of Reference 1.

5.31.4 Tank Dome Activities

Controls shall be in place that prevent other activities on a specific tank during RMCS waste intrusive activities.

These controls will allow simultaneous dome-intrusive activities if:

- the equipment is qualified for operation in a Class I, Division 1, Group B environment, and,
- operation is based on its own safety assessment, and,
- operation does not physically interact with the drill string, and is not waste-intrusive.

5.31.5 Gas Leak Paths

A formal tank walkdown procedure shall be developed and implemented prior to waste-intrusive activities that:

- assesses the general condition of risers,
- identifies observable leaks,
- as a minimum, documents identified leaks ≥ 1 in. (equivalent diameter), and,
- as a minimum, seals or adds deflectors to identified leaks with an equivalent leak diameter ≥ 1 in. (equivalent diameter).

5.31.6 Open Riser Exclusion Zone

An exclusion zone shall be established with a radius of 36-riser-diameters around any open riser during waste-intrusive RMCS activities.

5.31.7 Energized Equipment in the Dome and Open Riser Exclusion Zones

During waste-intrusive operations, all energized equipment exposed to the tank dome vapor space being sampled (as defined in approved contractor safety documentation) shall be rated for operations in Class I, Division 1, Group B environment or Class I, Division 2, Group B environment with automatic shut down for flammable gas concentrations ≥ 25% LFL.

All existing energized equipment not meeting the above control shall be de-energized.

This also applies to open riser exclusion zones (exclusion zone is defined as an area with a radius of 36-riser-diameters around open risers during waste-intrusive activities).

5.31.8 Tank Loading

Loading on each tank shall comply with IOSR requirements for simultaneous static and dynamic loading for each specific FG/RMCS tank.

5.31.9 Truck Position

A procedure shall be developed and implemented that, prior to waste-intrusive operations:

- prevents positioning the sampling truck over an open riser, and
- seals any risers under the truck, and

- raises the truck a minimum of 36 in. between any potential ignition source on the truck and the top of any riser or pit over which the truck is positioned.

5.31.10 Portable Inlet Stack

Prior to waste-intrusive activities, it shall be verified the inlet breather filter effluent (in the event of tank pressurization) is directed vertically to a height of at least 15 ft. above ground level.

5.31.11 Drill Bit, Core Barrel, and Drill Rods

The FG/RMCS drill bit, core barrel, and drill rods shall be of the configuration and material tested by the Bureau of Mines and performance evaluated in Reference 1.

5.31.12 RMCS Operations

It shall be verified that the exhauster is fully operational:

- 1 hr before the nitrogen purge flow to the Drill String is established ≥ 30 scfm.
- the flammable gas concentration in the tank vapor space shall be <1000 ppm before starting RMCS operations to obtain the initial segment in any core in a given riser.
- during all rotary drilling operations, and
- for a cumulative 16 hrs following termination of nitrogen purge flow to the Drill String.

When rotary drilling operations are resumed within any 16-hr waiting period, a new 16-hr period will be initiated following termination of Drill String nitrogen purge flow of ≥ 30 scfm.

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31 Rotary Mode Core Sampling

BASES

BACKGROUND	Reference 1 addresses each of the required elements associated with the installation, operation, and removal of a rotary-mode core sampling (RMCS) device in flammable-gas single-shell tanks (SSTs). The RMCS operations are needed in order to retrieve waste samples from SSTs with hard layers of waste for which push-mode sampling is not adequate for sampling. In Reference 1, potential hazards associated with the proposed action were identified and evaluated systematically. Several potential accident cases that could result in radiological or toxicological gas releases were identified and analyzed and their consequences assessed. Administrative controls, procedures and design changes required to eliminate or reduce the potential of hazards were identified.
APPLICABLE SAFETY ANALYSES	Results of the safety assessment performed in Reference 1 have been incorporated into this document. Specific analyses are as follows: (1) B 5.31.1 Control Applicability (2) B 5.31.2 Ignition and Envelope Testing (3) B 5.31.3 Flammable Gas Detection System Verification (4) B 5.31.4 Tank Dome Activities (5) B 5.31.5 Gas Leak Paths (6) B 5.31.6 Open Riser Exclusion Zone (7) B 5.31.7 Energized Equipment in the Dome and Open Riser Exclusion Zones (8) B 5.31.8 Tank Loading (9) B 5.31.9 Truck Position (10) B 5.31.10 Portable Inlet Stack (11) B 5.31.11 Drill Bit, Core Barrel, and Drill Rods (12) B 5.31.12 RMCS Operations

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.1 Control Applicability

BASES	
BACKGROUND	The Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks: Hanford Site, Richland, Washington, WHC-SD-WM-SAD-035, Rev. 0-a, June 7, 1996, hereafter designated as Reference 1 was developed using bounding assumptions. However, these assumptions are not verified against each one of the existing or potential flammable gas tanks (see Section 1 of Reference 1). Thereafter the following applies to RMCS waste intrusive operations in flammable gas tanks (FGT's).

BASES

APPLICABLE SAFETY ANALYSES

The following assumptions must be verified before RMCS waste intrusive operations in any FGT.

CHECKLIST ITEMS

Tank Specific Hazards / Other Watch lists

If a given tank has a specific hazard or accident initiator that is not analyzed in Sections 3 and 4 of Reference 1, the analysis must be supplemented to cover the tank specific conditions. For instance, Reference 1 does not address ferrocyanide issues even though some of the FGTs may also be on the ferrocyanide watch list. This checklist item is especially important for tanks that are on multiple watch lists (in addition to flammable gas watch list.

Flammable Gas Composition

Reference 1 assumes that 25% of the LFL is greater than 5000 ppm hydrogen based on the analysis provided in Appendix C of Reference 1. The only flammable gas species considered are hydrogen and ammonia with small amounts of methane. If new information (information that is not cited in Appendix C of Reference 1) reveals that, for a given tank, there are other flammable gas species and/or the assumed value of the LFL is not conservative, the analysis in Appendix C must be revised to incorporate the new data.

Toxic Gas Composition

For toxic effects, the gas composition in a given GRE is assumed to be 60% ammonia or 75% nitrous oxide. If any evidence before the FG/RMCS operation exists to indicate that these values (especially the ammonia fraction) may be exceeded in one of the SSTs as a result of new analysis or data, or if they are not conservative, the consequence that these values (especially the ammonia fraction) may be exceeded in one of the SSTs as a result of new analysis or data, or if they are not conservative, the consequence analysis must be re-evaluated.

Also, the results of vapor space sampling program were reviewed. Major toxic gases that are found in the dome

BASES

(continued)

space of the presently defined flammable-gas tanks are ammonia and nitrous oxide. Other gases are found in trace quantities and do not pose a concern. However, it was recognized that the existing data are limited and all tanks of interest are not covered. Thus, if new data reveal that toxic gases in excess of the hazardous limits are detected in a given tank, the consequence analysis must be reevaluated. The reevaluation may be done by simply scaling the toxic gas fraction and the guidelines against the ammonia fraction and the associated RGs.

Waste Temperature

The best available tank temperature data must show that the peak waste temperature (considering uncertainties) must be < 90°C. If the peak waste temperature is ≥ 90°C, the envelope testing results discussed in Appendix F of Reference 1 must be re-evaluated.

Waste Energetics

The Safety Assessment assumption in regard to tank specific parameters such as gas and waste composition, gas release probability etc. may become non-conservative by a new analysis or data for a specific tank considered to be sampled by RMCS prior operations.

See Section 7.0 and Appendix G of Reference 1.

BASES

(continued)

Likelihood of Gas Release Events

The GRE probability includes statistical distributions for gas-release amounts and rates that are based on limited data and expert judgment. If additional data or analyses exist for a specific tank to indicate that the GRE probabilities used in Reference 1 are not conservative, the accident frequencies need to be re-evaluated for that tank.

In general, before the RMCS operation starts on a given tank, the best available tank specific data for gas inventory and gas release evidence must be evaluated to confirm that the statistical model for gas-release amounts and rates used in Reference 1 are still conservative. In general, if one or more of the following conditions are observed for a given tank, the GRE probability model given in Appendix L must be re-evaluated.

- Periodic level drops and level swells in excess of ± 3 in.
- Level drop ≥ 3 in. during or after an intrusive event
- Dome concentration measurements ≥ 25% of the LFL before, during or after a waste intrusive event.
- A well defined nonconvective layer (parabolic temperature profile) below a supernate or convective layer (flat temperature profile) that would be indicative of potential rollovers.
- Retained gas inventory estimates (via level swell, fill history, etc) is > 20% of the available dome space volume.

If the re-evaluation indicates that the existing GRE model is not conservative for a given tank, a revision to the Safety Assessment will be necessary.

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.2 Ignition and Envelope Testing

BASES

BACKGROUND	Fire hazards, a significant part of the safety assessment, are considered to be beyond an extremely unlikely event based on ignition testing.
APPLICABLE SAFETY ANALYSES	
	Appendix F "Thermal Analysis of Rotary Drilling", Appendix G "Waste and Crust Ignition", and Appendix T "Bureau of Mines Ignition Test Program Functional Requirements and Acceptance Criteria, all located in Reference 1 shall be used to verify drill bit and material performance. The material cited above provides a safety basis for RMCS operations. The summary report required by Appendix T must be reviewed and approved by the PRC and verification of same must be acknowledged as a prerequisite to RMCS operations. Any subsequent change in drill bit or material would require revalidation per Appendix T requirements.

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.3 Flammable Gas Detection System Verification

BASES	
BACKGROUND	The purpose of the sensors is to provide signals that can be used as safety shutdown indicators for both flammability and toxic hazards during rotary-mode core sampling (RMCS) waste intrusive operations. The primary flammability hazard is the release of hydrogen gas. and the primary toxicity hazard is the release of ammonia gas (which is also flammable). The signal will be used to shut down the drill truck and to alert personnel to evacuate the tank farm as a protection against toxic-gas exposure.
APPLICABLE SAFETY ANALYSES	

BASES

The use of a redundant and adequate flammable gas detector is a key assumption to provide safe shutdown of RMCS operations during a GRE. This reduces the likelihood of a spark in flammable gas atmosphere and also provides protection for toxic gas exposures. This mitigates unacceptable offsite consequences resulting from a dome collapse.

Two sensors have been identified and are being designed as part of the ventilation system. The first is a Whittaker Cell hydrogen detection system and the second is an SMC combustible gas sensor.

The Whittaker Cell is an electrochemical cell with a membrane placed between the sample gas and the active element. It is very selective for hydrogen and responds directly to the partial pressure of hydrogen on the other side of the membrane. It is configured with a calibration port that can be used to flood the sensor region with a calibration zero gas during operation conditions. For the sensor to read out concentration it is essential that the pressure in the sensor region be identical during the calibration as it is during actual operations.

The SMC combustible gas sensor uses a catalyst to "burn" the gas and detects the resulting heat release. To increase sensitivity and decrease drift, the heat detection is done by comparing the temperature of a reference (uncatalyzed bead) to that of a signal (catalyzed) bead. The beads are imbedded in a sintered metal housing which prevents the combustion energy from igniting a flammable mixture. It has the advantage of responding to both ammonia and hydrogen.

Westinghouse Hanford Company has considerable experience with the Whittaker Cell, which has been shown to have an adequate response time (Appendix C Reference 1). The Whittaker Cell has been shown to have adequate sensitivity, and experience has shown that it is very reliable and stable in the current tank farm applications. Calibration is required only every three months.

The SMC sensor has recently been tested and should provide the required protection against flammability and toxicity hazards during a gas-release event (GRE).

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.4 Tank Dome Activities

BASES

BACKGROUND

The tank dome is considered to be Class I, Division 1, Group B environment because RMCS can induce a GRE. Sparks in the dome or volumes having a connecting path to the tank dome must be controlled. Control prevents ignition of flammable gas by non-FG/RMCS-related ignition sources.

This mitigates unacceptable offsite consequences resulting from a dome collapse.

APPLICABLE SAFETY ANALYSES

This event considers the possibility of an ignition caused by the existence of energized equipment in the dome or domes of connected tanks or connecting ventilation systems. Any activity in the connecting tanks may initiate a fire that may propagate into the tank being sampled. Therefore, it is required that all equipment in the dome be rated for operations in a Class-I, Division-1, Group-B environment or a Class-I, Division-2, Group-B environment with automatic shutdown. Any equipment that does not meet this requirement must be deenergized during RMCS operations. No other activities in the connecting tanks or on the same tank are allowed during RMCS operations. These controls reduce the likelihood of ignition caused by existing equipment in the tank dome and the domes of connecting tanks. Violation of this control may result in an unanalyzed initiator.

Class-I, Division-2, Group-B equipment is capable of sparking upon single failure. Consequently, such equipment must be protected by a reliable shut-down circuit. Furthermore, the background concentrations of flammable gases must be measured and shown to be less than 25% of the lower flammability limit (LFL) before energizing this equipment. In order to cause a spark, a sequence of double independent failures are necessary (the shut-down circuit must fail, and the Class-I, Division-2, Group-B equipment must also fail simultaneously).

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.5 Gas Leak Paths

BASES	
BACKGROUND	Above ground fires that could propagate into the dome are managed by controlling position of the non-qualified equipment. Since sparks from non-qualified equipment can not be eliminated, a safe distance criteria is developed. This criteria requires that possible leak diameter is to be known and controlled. This mitigates unacceptable offsite consequences resulting from a dome collapse.
APPLICABLE SAFETY ANALYSES	

BASES

(continued)

Flammable-Gas Release Through Open Riser (Or Possible Leak Paths) Driven By Gas Release Event And Burn (Operation and Removal)

This event postulates that a large GRE occurs, releasing flammable gas from openings in the tank, exposing the flammable gas to equipment with possible spark sources, resulting in a fire on top of the tank. This event is of concern during operation and removal phases of RMCS waste intrusive operations. None of the auxiliary support equipment on top of the tank is qualified to operate in a flammable-gas environment.

Preventing flammable-gas exposure to this equipment is managed by inspection of the tank top for leaks and the repair of all leaks with an effective diameter of ≥ 1 in. Open paths from the tank dome to the tank top include the exhauster stack, the breather inlet riser, open risers, drill string riser, and other possible tank leak sources (unsealed risers, pits, etc.). It is assumed that inspection of tank top penetrations for potential leak paths will find leak paths with nominal leak diameters > 1 in. It is assumed that undetected leak paths with a nominal 1-in. diameter could go undetected. Therefore, the top of the tank must be examined to identify leaks, and when identified, the leaks must be ≤ 1 in equivalent diameter (reference paragraph 4.1.2.1 of WHC-SD-WM-SAD-035, revision 0-A).

A portable stack over the breather inlet HEPA system will be used during waste-intrusive operations. The portable stack is 15 ft tall, has an upper 4-in. diameter, is sealed at the ground level, and is grounded. The purpose of using a portable stack over the breather inlet is two-fold:

- The gas release would be released through stack, resulting in increased atmospheric dilution and reducing the toxicological consequences of a GRE.
- Any non-qualified equipment on the top of the tank around the breather inlet HEPA system would be protected from flammable-gas exposures.

It is required that any non-qualified electrical equipment

BASES

(continued)

riser during waste-intrusive operations. If a GRE occurs, immediate personnel evacuation is required.

Another control also requires that when the drill truck needs to be parked over a riser or pit, the riser or pit must be sealed. Note that the riser or pit considered here is not the riser being sampled, but the one that the front part of the truck is parked on. If the truck is parked over an unused riser or pit, the potential spark location is not considered random, and no credit can be taken for the probability of a random placement. However, the leak size from pit or riser is assumed to be no bigger than 1 in. There is at least 3 ft between the top of the pit/riser and any potential ignition sources on the truck. A control was established to make sure the distance between potential ignition sources on the truck and the top of the pit/riser is ≥ 36 in. Combining the failure probability to seal the riser/pit and violate the 36-in. distance criteria and the GRE probability that makes the dome pressure positive, the accident frequency is determined as 2.1E-8/yr. This frequency is low. However, the unmitigated frequency becomes 1.4E-4/yr. if the control to seal the riser/pit and 36-in. distance criteria are not implemented.

The flammable-gas release could occur from other unused risers if they have undetected leak paths. The control requiring the examination of risers before operations reduces the probability of have an unknown open path. It is assumed that leaks from threaded junctions, flanges, and cover plates could be identified with an equivalent leak diameter > 1 in. If a GRE occurs and non-qualified equipment is located close to these unknown openings, the accident frequency of a above-tank fire becomes 1.8E-7/yr. This frequency includes the probability of a GRE based on exposure time (Appendix L of Reference 1) and the probability of a temporal random spark. It also assumes that 50% of all risers on the top the tank leak after the initial inspection is performed. The existence of a spark on the equipment located around risers is also assumed. The unmitigated accident frequency is 2.8E-5/yr for this accident scenario; therefore, the control requiring limiting the leaks before the RMCS operation is important.

The last accident scenario includes the ignition of a flammable

BASES

(continued)

not to place any non-qualified equipment within 36 diameters of the riser being opened during waste-intrusive operations. Considering this control and a GRE probability based on exposure time including a temporal random spark, the mitigated accident frequency becomes 4.2E-8/yr. This number is conservative because it was not considered that the riser may be open for only a fraction of the mission time. The unmitigated accident frequency is 1.4E-5/yr.

The combined mitigated frequency of these three events is 2.4E-7/yr. Note that the fire propagation into the dome conservatively is assumed to be 1.0. This number is conservative because it is assumed that non-qualified equipment does include a spark source and the probability of a random spark in time is based on a conservative dome concentration.

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.6 Open Riser Exclusion Zone

BASES

BACKGROUND	Minimizes ignition sources in proximity with flammable gas. Minimizes gas leakage in proximity with ignition sources or unqualified equipment. This mitigates unacceptable offsite consequences resulting from a dome collapse.
APPLICABLE SAFETY ANALYSES	
	See B 5.31.5

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.7 Energized Equipment in the Dome and Open Riser Exclusion Zones

BASES	
BACKGROUND	This control prevents ignition sources in proximity with flammable gases. This mitigates unacceptable offsite consequences resulting from a dome collapse.
APPLICABLE SAFETY ANALYSES	
	See B 5.31.5

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.8 Tank Loading

BASES

BACKGROUND	An administrative limit on tank dome loading can prevent collapse. This mitigates unacceptable offsite consequences resulting from a dome collapse.
APPLICABLE SAFETY ANALYSES	
	The static load capacity of the tank dome is monitored carefully and an overload state that could collapse the dome must be avoided. The equipment required on the surface of the tank to support FG/RMCS sampling operations qualifies as a live load (see Appendix N of Reference 1). The tank loads study permits a 50-ton live load on the tank dome. Even though the weight of all FG/RMCS equipment exceeds 50 tons, not all of the equipment is placed on the tank dome at one time. Therefore, the dome loading must be controlled by the dome loading limits for SSTs as specified in OSD-T-151-00013. The dome would be subjected to dynamic dome loads if a truck were to fall from the hydraulic jack or from a platform. Appendix N considers this scenario and analyzes the consequences of the dynamic loading caused by dropping the truck. It is concluded that the dome could withstand the impact force of the 30,000-lb truck dropping on it from the 3-ft-high platform.

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.9 Truck Position

BASES

BACKGROUND	The RMCS truck when parked over an unused riser must be protected from flammable gas releases. This requires controlling the distance between the leak source and truck, reducing above tank fire frequencies by mitigating human error and minimizing ignition sources.
APPLICABLE SAFETY ANALYSES	
	It is important that when the RMCS truck needs to be parked over an unused, closed riser or pit, the riser or pit must be sealed. Note that the riser or pit considered here is not the riser being sampled, but the one that the front part of the truck is parked on. If the truck is parked over an unused riser or pit, the potential spark location is not considered random, and no credit can be taken for the probability of a random placement. However, the leak size from pit or riser is assumed to be no bigger than 1 in. There is a least 3 ft between the top of the pit/riser and any potential ignition sources on the truck. A control was established to make sure the distance between potential ignition sources on the truck and the top of the pit/riser is ≥ 36 in. Combining the failure probability to seal the riser/pit and violate the 36-in. distance criteria and the GRE probability that makes the dome pressure positive, the accident frequency is determined as 2.1E-8/yr. This frequency is low. However, the unmitigated frequency becomes 1.4E-4/yr if the control to seal the riser/pit and 36-in. distance criteria are not implemented.

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.10 Portable Inlet Stack

BASES

BACKGROUND

Directing the breather inlet HEPA effluent 15 ft vertically:

- allows atmospheric dispersion coefficients to decrease so that toxicological acceptance guidelines at the onsite boundary can be met.
- prevents electrically unqualified equipment in proximity with flammable gas.

APPLICABLE SAFETY ANALYSES

A portable stack over the breather inlet HEPA system will be used during waste-intrusive FG/RMCS operations. The portable stack is at least 15 ft tall, has an upper 4-in. diameter, is sealed at the ground level, and is grounded. The purpose of using a portable stack over the breather inlet is two-fold:

- The gas release would be released through stack, resulting in increased atmospheric dilution and reducing the toxicological consequences of a GRE.
- Any non-qualified equipment on the top of the tank around the breather inlet HEPA system would be protected from flammable-gas exposures.

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.11 Drill Bit, Core Barrel, and Drill Rods

BASES

BACKGROUND	Results from envelope testing and ignition testing are only valid for equipment of the design tested. This mitigates unacceptable offsite consequences resulting from a dome collapse.
APPLICABLE SAFETY ANALYSES	

BASES

One of the safety concerns of sampling with the rotary-mode drill in flammable gas tanks is the ignition of the flammable gas in the waste by the frictional sparks created by the drill bit. The condition of waste in terms of hardness is not known before the operation. A possibility of penetrating a very hard waste layer in a tank exists. In addition, there may be some metal debris lost or dropped from the riser in the past. Hard materials such as rocks or metals can also exist in the waste. Thus, it is likely that the drill bit may strike against metal and other hard objects during drilling.

Ignition caused by frictional sparks is evaluated by performing ignition testing in bounding conditions. Appendix T (Reference 1) discusses the ignition testing requirements and acceptance criteria. The objective of the tests is to demonstrate that the operation of rotary core drilling in a bounding frictional environment with bounding gas composition does not cause an ignition. Testing is being performed by the WHC and BOM personnel.

The conditional frequencies of a fire accident resulting from exceeding the rotational speed and down force are estimated as 1.4E-5 and 9.4E-5/yr as indicated in Table 4.12. Controls are established to trip the drilling operation when the rotational speed and down force exceed 55 rpm and 750 lbf. There is no delay time for the trip except the delay time from the data acquisition system. If needed, the alarm points will be set at lower values. However, drilling must stop when the trip value is reached. The RMCS operations must use only the drill-bit type tested according to the requirements listed in Appendix T (Reference 1).

B 5.0 ADMINISTRATIVE CONTROLS (ACs) - GENERAL

B 5.31.12 RMCS Operations

BASES

BACKGROUND	Flammable gas concentrations are mixed, dispersed, and reduced with exhauster preparation. Accumulation of aerosols, particulates, and flammable gases following waste intrusive activities must be minimized. This mitigates unacceptable offsite consequences resulting from a dome collapse.

BASES

APPLICABLE SAFETY ANALYSES

Wastes including mixtures of sodium nitrate and sodium nitrite with organic compounds can produce violent exothermic reactions. Increasing the temperature of the waste in the vicinity of the drill bit can cause a thermal runaway. There are several hazards that are associated with a local thermal runaway, and they are discussed in Appendix G (Reference 1). Two major important hazards are in ignition of the flammable gas and the initiation of a self-propagating exothermic reaction in the waste. Reactions in mixtures containing relatively small amounts of organic compounds can result in temperatures greater than the autoignition temperature of hydrogen mixtures, so the ignition of flammable gases is the more limiting condition. However, a self-propagating reaction would produce very high temperatures, which would cause structural damage to the tank. The consequences of a self-propagating reaction could be severe.

Because the possibility of flammable-gas mixture cannot be eliminated, the approach used is to take all practical measures to eliminate ignition sources. A local runaway reaction is a potential ignition source, so the requirement that there be no local runaway reaction is consistent. Preventing a local thermal runaway is also protection against a propagating exothermic reaction, and it eliminates the possibility of generating additional flammable gas as a result of elevated temperatures. Appendix G of Reference 1 discusses runaway reactions and waste ignition in great detail. Basic conclusions of Appendix G are that local runaway reactions can be prevented by establishing waste temperature limits. The following temperature limits are established:

- The temperature of small waste fragments produced at the drill tip must not exceed 180°C.
- The temperature of the drill bit and the average temperature of the waste affected by drilling must not exceed 160°C for more than 10 min.

Because the consequences of a propagating exothermic reaction are severe, FG/RMCS should not be performed in tanks in which a propagating exothermic reaction may occur.

BASES

(continued)

force, and nitrogen purge flow to comply with the safety criteria given above. Appendix F (Reference 1) discusses the details of testing and the results obtained.

As a summary, results of envelope testing and their analysis showed that the drill bit surface temperature correspondingly the waste substrate temperature can be kept below 160°C, including an uncertainty of 10°C, if the following limits are applied: Down force < 750 lbf, rotational speed < 55 rpm, minimum nitrogen flow > 30 scfm, and penetration rate > 0.75 in./min. The chip temperatures under these conditions are also limited to 180°C as required. If a trip is initiated when one of the set points for these four parameters is exceeded, drilling must be stopped. After a shutdown there must be a waiting period of 10 min before drilling can continue. The waiting period of 10 min. is based on the experimentally determined cooling time. The testing and the analysis included plugged holes on the drill bit.

The minimum purge flow must be > 30 scfm; however, it is possible that necessary cooling to the drill bit would not be provided if there were a leak from the nitrogen purge system between the flow measurement location and the drill bit. WHC determined that the leak from the truck is within the uncertainty range of instrumentation. This control requires that the leak rate must be within the uncertainty range of instrumentation or < 2% of the nominal flow.

Drill rods are threaded to each other. An O-ring is used to provide a seal. The leaks are possible if the O-rings are left out. WHC determined the possible leak rates could not be higher than 0.3 scfm when the O-rings are not used. This is < 1% of a nominal flow of 30 scfm and negligible. With the use of O-rings, the leak rate also was measured and was shown to be negligible. Therefore, O-rings on the drill rod are not required, and the nitrogen purge flow for drill bit cooling is sufficient when set to a minimum of 30 scfm.

There is one event that would include an unknown leak path as a result of failure of the drill string during drilling. If the drill bit or string becomes embedded in the waste momentarily because of debris in the waste,

BASES

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torque could continue to be applied to the drill string at a constant rate. If such a condition occurs, there is a possibility that the drill string could partially fail. Continuing to operate with a partially failed drill string could result in nitrogen flow bypass through the failed area. This concern is assessed below.

Appendix N (Reference 1) examines the possibility of over-torquing the drill string. The drill string is considered as having torque applied from the upper end, but the rotation of the lower end is not allowed. Appendix N presents two methods to determine the time necessary to break the drill string. Linear elastic methods are applied as a first approximation to obtain the lower bound failure estimate. Second, strain-energy methods are used to determine an upper bound by assuming that the ultimate shear strain in the drill rod is proportional to the shear modules. It is estimated that failure would occur in less than 15 sec for all rotational speeds. Note that Appendix N did not take any credit for the threaded drill rods. Experience shows that the drill string always fails at the threaded sections. The real failure time is expected to be in a few seconds because of the stress concentration factor for threaded sections. Therefore, it is concluded that a drill string tear without a break is very unlikely.

Envelope testing measured the rate of increase in the drill-bit surface temperature when nitrogen flow is terminated at steady-state operating conditions. The test results are summarized in Appendix F (Reference 1). Results showed that an average heat-up rate of 2°C/s is observed in the time period of 0 to 20 sec after the nitrogen flow is shut down. This rate corresponds to a temperature increase of 30°C in 15 sec in which the drill string would be broken when overtorqued. Envelope testing established the operating parameters so that the drill bit and waste temperature is less than 150°C. Considering a 30°C heat-up of the drill bit for this accident, the drill bit/waste temperature would be 180°C. Appendix G (Reference 1) argues that the waste temperature would be allowed to be at the minimum exothermic-reaction temperature of 180°C for a short period of time because the induction time of reaction is expected to be much larger than 10 to 20 sec. Therefore, it is concluded that if the drill fails because it is over-torqued, it would

BASES

(continued)

vicinity of the drill bit would not experience runaway reactions.

- RMCS operations must be shut down if the dome flammable gas concentration is above 5000 ppm hydrogen equivalent. Based on currently available calibration data, this set point gives protection for ammonia concentrations of ~10,000 ppm if the gas is purely ammonia.

- Evacuation is necessary if a gas release occurs.

REFERENCES

1. LANL, 1996, *A Safety Assessment of Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks, Hanford Site*, WHC-SD-WM-SAD-035, Rev. 0-a, Los Alamos National Laboratory, Los Alamos, New Mexico.

FAX COVER SHEET

Page 1 of: 54
(Coversheet Included)

Included Draft Ignition ...

CHARACTERIZATION EQUIPMENT ENGINEERING
Characterization Field Engineering
Characterization Equipment Design

To: N. Morcos

From: Dennis Hamilton

Phone #:

Phone #: (509) 372-1130

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Fax #: (509) 373-4238

Location: Idaho

Location: Richland, WA

MESSAGE:

REVISIONS MADE TO ROTARY-MODE CORE SAMPLING SAFETY ASSESSMENT REVISION-0a AS A RESULT OF INEL REVIEW

Changes are underlined.

Page 1-2, Section 1.2, 1st paragraph

.... parameters of interest. The total waste stored in Tank A-101 is 953 Kgal and is mostly consisted of salt cake (950 Kgal). Tank A-101 waste is classified as double-shell slurry feed (DSSF). Estimated radionuclides in Tank A-101 are Cesium (Cs-137), Strontium (S-90), Plutonium (Pu), and Uranium (U).

Page 2.2, Section 2.2.1

The DOE Orders cited in Table 2-1, are presently applicable to the design of the rotary-mode core sampling equipment. They are helpful in developing the criteria outlined in Sections 2.1.2, 2.1.3, 2.1.4, and 2. The risk criteria are given in Section 5 of this SA.

Page 2-4, Section 2.1.4.

... The safety criteria are based on a set of tests in which dry sodium acetate nitrate/nitrite mixtures exhibited propagating behavior at about 300°C (572°F) with a TOC value greater than 6 wt%. Appendix G evaluates this criteria in detail for each SST.

Page 2-8, Section 2.3

.... Of the three possible tank configurations, the 1,000,000-gal.-capacity tank used in Farms A, AX, and SX is schematically shown in Fig. 2-1. The other tank configurations are similar to that of given in Fig. 2-1. The BY-, TX- and S-Tank Farm has tanks with 758,000-gal. capacity, but tanks in Farms B, BX, C, T and U have a capacity of 530,000 gallons.

Page 2-13, Section 2.4.1.4, 1st component

Drill Bit. The drill bit rotationally bores into the waste to produce a nominal 1-in.-diameter core sample, and acts as the leading tip of the drill string. The bit has a hollow-cored center section surrounded by cutting teeth and holes on the drilling surface for nitrogen purge flow. The commercially available unit (nominally 2.5-in. o.d.) is made of copper-based (sintered bronze) material with teeth designed to "smear" when they come into contact with the bottom of the tank to prevent penetration. Appendices T and F addresses the safety concerns in regard to material properties.

Page ˙ 20, Section 2.4.2, 3rd item

....Vendor information indicates that the HEPA filter performance is undetermined at a differential pressure of 10 in. w.g. after 15 minutes, but there are no relief valves or vacuum breakers installed to protect the HEPA from excessive delta pressure. In order to protect against filter collapse, the blower is limited to 9 inches of water static pressure.

Page 2-31, Section 2.5.3

Heading of 2.5.4 is eliminated and the remaining of text is renumbered.

Page 5-10, Section 5.4.1, 4th paragraph

The dome peak ammonia and nitrous oxide concentrations then become 1.2%, 6%, and 12% for the anticipated, very unlikely, and extremely unlikely gas-release events defined based on frequency ranges and expected gas release amounts and marked as GRE-1, GRE-2 and GRE-3 in Table 5-7. These three GRE, GRE-1, GRE-2, and GRE-3, categories will be used in Tables given in the rest of this section.....

TABLE 5-1
ANTICIPATED AND UNLIKELY GAS-RELEASE EVENTS

Event Probability	Event Category	Q-Prompt Release, (ft^3)	Peak NH_3 Conc. (%)
≥1.0 E-2	GRE-1	≤1000	1.2
≥1.0 E-4	GRE-2	≤ 5000	6
≥1.0 E-6	GRE-3	≤ 10,000	12

TABLE 5-2
SUMMARY OF GAS-RELEASE ACCIDENTS

Accident Condition	Frequency (yr)	Gas Concentration & Release Rate
1-GRE-1 and open riser (removal)	1.1E-3 (0.01x5.6E-2x2)	1.2% NH_3 in the dome, 66 scfm*
2-GRE-2 and open riser (removal)	1.1E-5 (1E-4x5.6E-2x2)	6% NH_3 in the dome, 333 scfm*

3-GRE-3 and open riser (removal)	1.1E-7 (1E-6x5.6E-2x2) Beyond extremely unlikely	12% NH_3 in the dome, 666 scfm*
4-GRE-1 and open frisbee (operation)(nitrogen purge to riser sleeve fails)	3.2E-6 (2x0.01x1.6E-4)	1.2% NH_3 in the dome, 66 scfm*
5-GRE-2 and open frisbee (operation) (nitrogen purge to riser sleeve fails)	3.2E-8 (2x1.0E-4x1.6E-4) beyond extremely unlikely event	6% NH_3 in the dome, 333 scfm*
6-GRE-3 and open frisbee (operation) (nitrogen purge to riser sleeve fails)	3.2E-10 (2x1.0E-6x1.6E-4) beyond extremely unlikely event	12% NH_3 in the dome, 666 scfm*
7-GRE-1 and drill string open at the top with sampler in the drill string	2.6E-5 (2x0.01x1.3E-3)	1.2% NH_3 in the dome, 66 scfm*
8-GRE-2 and drill string open at the top with sampler in the drill string	2.0E-7 (2x1.0E-4x1.3E-3) beyond extremely unlikely event	6% NH_3 in the dome, 333 scfm*
9-GRE-2 and drill string open at the top with sampler in the drill string	2.0E-9 (2x1.0E-6x1.3E-3) beyond extremely unlikely event	12% NH_3 in the dome, 666 scfm*
10- GRE-1 from exhaust and inlet stack (operation)	0.02 (2x0.01)	1.2% NH_3 in the dome, 66 scfm*

TABLE 5-8 (cont)
GAS-RELEASE ACCIDENTS

Accident Condition	Frequency (yr)	Gas Concentration & Release Rate
11-GRE-2 from exhaust and inlet stack (operation)	2.0E-4 (2x1.0E-4)	6% NH_3 in the dome, 333 scfm*
12-GRE-3 from exhaust and inlet stack (operation)	2.0E-6 (2x1.0E-6)	12% NH_3 in the dome, 666 scfm*
13-Continuous releases from exhauster after an GRE-1	0.02 (2x0.01)	1.2% NH_3 in the dome, 250 scfm**
14-Continuous releases from exhauster after an GRE-2	2.0E-4 (2x1.0E-4)	6% NH_3 in the dome, 250 scfm**

15-Continuous releases from exhauster after an GRE-3	2.0E-6 (2x1.0E-6)	12% NH_3 in the dome, 250 scfm**

* Averaged over 15-minute period
Page 6-1

(Note that all tables in Section 5 are updated).

Page 6-1, Section 6.1, 2nd paragraph and reference 4

Westinghouse Hanford Company (WHC) standard controls include a series of WHC documents that define the safety envelope for the tank farm, waste transfer activities, and waste storage activities. The primary document is the WHC Health and Safety Plan[1]although other documents include the Safety Assessment for Push- and Rotary-Mode Core Sampling in Ferrocyanide Tank,[2] Safety Analysis for the Push Mode and Rotary Mode Core Sampling[3]and the Interim Operational Safety Requirements for Rotary Mode Core Sampling in Flammable Gas Single Shell Tanks.[4] During the development of the procedures for each of the activities, the current operational safety requirements (OSRs), interim operational Safety requirements (IOSRs), and operational safety documents (OSDs) must be considered (refer IOSR[4] for restart requirements). The safety envelope established by the analyses shall not be changed unless approved by the Department of Energy (DOE). The controls provided in this section can be modified if the appropriate organization grants approval

Ref. 4. WHC-SD-WM-OSR-005 Rev 0, "Single Shell Tank Interim Operational Safety Requirements," Author L.F. Dougherty

Page C-4

...This model is based on the assumption that the species ratios obtained from the dome space measurements are the same for the gas bubbles that exist in the waste. Thus, it is assumed that

- The mass transfer (including the molecular diffusion out of the waste) from the waste surface is negligible, and
- The species ratios are established by equilibrium in the waste prior initiation of GRE.

Page C-6, last paragraph

Based on this analysis, the composition obtained for Tank AX-101 results in the maximum equivalent fuel being 103% H_2 and appears to be the limiting composition for the flammability analysis at the conditions prior GRE.

Page C-11, 2nd paragraph

... Thus, even small volumes of gas burned in the dome space may result in catastrophic dome failure. Note that the gas release volume of 96 m^3 is not 100% hydrogen. It was assumed that there is 60% ammonia in the released gas. Remaining 40% includes 88.1% hydrogen (Tank AX-101) as indicated in Table C-3. Thus, the hydrogen concentration becomes 35% in the released gas. This results in 2/4% hydrogen concentration in the dome.

Page G-5, Section G.4 definitions

U	= heat transfer coefficient for the fragment,
T_o	= initial temperature of the fragment,
T_s	= temperature surrounding the fragment,
r	= density of the fragment,
c_p	= heat capacity of the fragment, and
D	= diameter of the fragment,
k	= thermal conductivity.

Page G-15, Section G.5.2.3

Summary

The second method of analysis is more restrictive than the event-tree analysis given in Section 5.2.1

Page J-11, 2nd paragraph

Hydrogen and air mixtures near stoichiometric (~ 29.5% hydrogen) are known to be detonable. Mixtures departing from stoichiometric, either in the hydrogen-lean or hydrogen-rich direction are increasingly more difficult to detonate. It has been generally believed that hydrogen-air mixtures with mixture ratios of <18% or >58% hydrogen, could not be detonated. As shown in Section 2 of this appendix, the hydrogen concentration in the drill string reaches 30% in 16 minutes at 2 ft above the rotary drill. One operation of drilling takes about 30 minutes. By that time, the hydrogen concentration is already above 18%. Therefore, some burn in the drill string may detonate.

Page J-11, Section J.3.3

Conclusions

From the above analysis, the overpressure and the rate-of-pressure rise during a burn in the drill string are 630 kPa and 2279.5 bar/s, respectively.

During a detonation in the drill string, the overpressure and the rate-of-pressure rise are 15 bars (1.5×10^6 Pa) and 3×10^6 bar/s, respectively. A DDT may occur in the drill string. Therefore, any burn in the drill string may result in a detonation because the rate of pressure rise is very high (3×10^6 bar/s) during the detonation. Consequently, the structure of the drill string is conservatively assumed to fail

Page L-1, Section L.1, 3rd bullet

The probabilistic GRE model discussed in this appendix was introduced only after the completion of these first two steps in order to obtain realistic accident frequencies.

Page L-4, 5th paragraph

It can be stated that 2 out of 87 activities resulted in a detectable GRE, suggesting a frequency of 2.3×10^{-2}. Accounting only for the activities in the SSTs, the probability becomes 2 out of 77 (2.6×10^{-2}). Also subtracting the activities in which the level data were inconclusive, the probability becomes 2 out of 58 (3.4×10^{-2}). However, this approach does not apply to a bounding tank, and at best it provides an overall probability of a GRE in the flammable-gas tanks. The LOWs are installed in A-101 (waste level ~345 in.) and AX-101 (waste level 278 in.), which have the largest waste volumes in the SSTs that are on the original FGWL. Tank A-103, which showed a 2.4 in. level drop between March 25 and March 26, 1986, also has a large waste volume (waste level ~370 in.). The other possible 2-to 3-in. level drop corresponds to Tank SX-104 that has less than 240 in. of waste.

Page L-8, Section L.3, 2nd paragraph

First, the discussion provided in the previous section is cast into a qualitative model. The qualitative likelihood matrix is provided in Table L-1. In Table L-1 qualitative likelihood definitions included following frequencies: a-Range 1 is defined as an event with a frequency of 1, b-Range 2 is defined as an event with a frequency of 10^{-1}, c-Range 3 is defined as an event with a frequency of 10^{-2}, d-Range 4 is defined as event with a frequency of 10^{-3}, e-Range 5 is defined as an event with a frequency less than 10^{-3}.

TABLE L-1
QUALITATIVE LIKELIHOOD MATRIX FOR GAS-RELEASE VOLUMES AND RATES

	Volume (ft^3)			
Rate (ft^3/min)	100	500	2500	10,000

1	Range 1	Range 2	Range 3	Range 4
10	Range 2	Range 2	Range 3	Range 4
100	Range 3	Range 4	Range 4	Range 4
1000	Range 4	Range 4	Range 5	Range 5

Page L-9, 2-4th paragraph

For release volumes that are never observed in the SSTs, a qualifier of "Range 3" is assigned. The existing models do not predict release volumes corresponding to Range 3 and less likely categories, except for a rollover and seismic event that can liquefy the waste by vigorous shaking. Even for these Range 3 events the release volume is limited by the fraction of total retained gas. The maximum values shown in Table L-1 (10,000 ft^3) corresponds to the largest GRE volume observed in Tank 101-SY before mitigation. Similar events have not been observed in any of the SSTs.

The rate range shown in Table L-1 is obtained by considering the orders-of-magnitude, based on the discussions provided in the previous section. Only rollovers and seismic shaking may result in release rates on the order of 100 ft^3/min or greater, while resulting in large release volumes. There is a remote possibility of tapping into a high pressure gas region which may result in large release rates but a very small volume. Thus, while small volume releases at high releases rates are believed to be Range 4 events, large volumes with large releases rates are in Range 5 event category.

The qualitative matrix may be quantified for the gas-release volume and gas releases rates assuming that these two are independent parameters. In the quantification process, the following probabilities were assigned: a probability of 1 for Range 1 event, 10^{-1} for Range 2 event, 10^{-2} for Range 3 event and 10^{-3} for Range 4 event. Thus, the quantitative results may be approximated as a logarithmic distribution given by....

Page R-5, Section R.4.1, 2nd paragraph

.. containing SiO_2 at a density of 0.1 g/cm^3, we find the exposure at 1 cm from the surface is about 300 mR/h at the end of 100 minutes of operation. This exposure may be scaled with units of 100 minutes of time because it is based on an average mass flow rate.

Page U-1, Section U-1

APPENDIX U
FUNCTIONAL REQUIREMENTS FOR FLAMMABLE AND TOXIC GAS (HYDROGEN AND AMMONIA) SENSORS

INTRODUCTION

The purpose of the sensors is to provide signals that can be used as safety shut-down indicators for both flammability (mainly hydrogen and ammonia) and toxic (mainly ammonia) hazards during

Page U-2, Section U-2, 2nd paragraph

.... operation conditions. For the sensor to read out concentration it is essential that the pressure in the sensor region be within the expected tank pressure range during the calibration.

Page U-2, Section U.3.1, 3rd and 4th bullets

The configuration must allow for the system to be calibrated in a manner that ensures that zero and calibration gas are within the expected tank pressure range during the calibration. The system must be able to be operated during pressure transients caused by a potential GRE.

The calibration should be performed at initial deployment and every three months after that point. The calibration should consist of setting the zero with pure air or nitrogen and calibration with a nominal 6000 ppm hydrogen. The calibration procedure with a nominal 6000 ppm hydrogen should test the shutoff electronics as well as the sensor reading.

Page U-3, Section U.3.2., 5th and 8th bullets

•In addition to the electrical qualification, it must be documented that the sensor element itself will not ignite a flammable mixture.

•Configuration of both sensors must allow the system to be calibrated in a manner that the pressure in the sensor region is within the expected tank pressure range during the calibration

Page U-4, Section U.4

...; a Whittaker hydrogen detector cell and a SMC combustible gas detector. The use of SMC and Wittaker sensors provides a redundancy in hydrogen detection. The detection of ammonia can only be performed by the SMC sensor and therefore is not redundant.

.....Both sensors themselves do not ignite a flammable mixture when they are operational.

SMC sensor, if set to trip at a 5000-ppm hydrogen equivalent, should sense both a 5000-ppm hydrogen concentration and a 12000-ppm ammonia concentration for alarm purposes if the gas were purely hydrogen or ammonia, respectively. The set point for a rate of increase of concentration is 100 ppm/s.

Wittaker cell, if set to trip at a 5000-ppm hydrogen equivalent, should sense a 5000-ppm hydrogen concentration for alarm purposes if the gas were purely hydrogen. The set point for a rate of increase of concentration is also 100 ppm/s.

A control is established for an SMC sensor to be initially calibrated with hydrogen and ammonia and an SMC sensor to be replaced at least once per month with a new sensor that has been calibrated with both hydrogen and ammonia. A control is also established for the SMC sensor to be calibrated in the following fashion. A functional test shall be performed at the initial setup at each location and every day the system is used after that point. The functional test shall consist of setting the zero with pure air or nitrogen and calibration with a nominal 6000-ppm hydrogen. The functional test procedure with a nominal 6000-ppm hydrogen shall test the shutoff electronics as well as the sensor readings. A functional calibration test shall be performed once every three months for the Whittaker cell.

Page U-5, 3rd paragraph

The following controls are established for the flammable-gas detection system:

- SMC sensors shall be replaced at least once each month with new sensors,
- New SMC sensors shall be initially calibrated in a laboratory environment using hydrogen and ammonia,
- A functional calibration test shall be performed in the field at the initial setup and then every day for the SMC sensor,
- A functional calibration test shall be performed once every three months for the Whittaker cell.

- The functional calibration test shall consist of setting the zero with pure air or nitrogen and calibration with a nominal 6000-ppm hydrogen for both sensors,

Appendix A

The second column of Table A-5 named as Hazard. We agreed to change this title as Hazard/Accident. It, however, is very difficult to revise this table because it is scanned from a MS-DOS based-document. Therefore, we suggest that we make this change in Revision 1 if INEL agrees.

96/3861

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INEL
Idaho National Engineering Laboratory

Mr. R.R.McNulty, ESQ
DOE-RL TWRS
Management System Division
P.O.Box 550
Richland, WA 99352

Date: July 18, 1996
From: N. Morcos, MS 2114
Subject: Third Tier Review Safety Evaluation Report of the Safety Assessment document titled "A SAFETY ASSESSMENT OF ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON."

Attached is the Third Tier Independent Review Team's (IRT) Safety Evaluation Report (SER) for the Hanford Safety Assessment (SA) for the document titled "A SAFETY ASSESSMENT OF ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON" (RMCS). The SA review was performed in response to a request from the DOE-RL Management Systems Division (MSD) independent review coordinator (April 26, 1996). The review was performed in accordance with DOE-RL's **DOCUMENT REVIEW PLAN FOR SAFETY ASSESSMENTS FOR SAT-WELL PUMPING AND ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS TANKS** (Appendix 1 of SER). The IRT members were selected in accordance with directions in the review charter and submitted for approval by DOE-RL TWRS MSD on the basis of their qualifications and their expertise. The list of approved reviewers is shown in Appendix 2 of the SER.

Based on the independent review, the IRT recommends approval of the SA titled "A SAFETY ASSESSMENT OF ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON" together with it's attached ISORs (contained in engineering change notice, ECN 609990) without any conditions or limitations except for the provision that any changes made to the operations or associated equipment as described in the SA should be followed by a careful USQ assessment process

The independent review process is summarized in the Executive Summary in the SER. The associated details and documentation are available in the RMCS SA file as submitted to DOE-RL TWRS MSD.

Please do note hesitate to call me at 208-526-4926 if I can be of any additional assistance

Sincerely,

N. Morcos, Ph.D.
IRT Chairman.

RMCS SAFETY EVALUATION REPORT

RMCS (SA)

SAFETY EVALUATION REPORT

Prepared for:

U.S. Department of Energy
Richland Operations Office
Tank Waste Remediation System

Prepared by:

The INEL Independent Review Team

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Work Order MSIDL DOE 1

ABSTRACT

This Safety Evaluation Report (SER) documents the INEL Independent Review Team's (IRT's) assessment of the (SA) A SAFETY ASSESSMENT of ROTARY MODE CORE SAMPLING in FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON" (RMCS)

The SA addresses each of the required elements associated with the installation, operation and removal of the rotary mode core sampling (RMCS) device in Flammable Gas Watch List (FGWL) Single-Shell tanks (SSTs) located within the 200 Area in the Hanford Site, Richland, Washington. The RMCS operations are needed to retrieve waste samples from SSTs with hard layers of waste for which push-mode sampling is not adequate for sampling. Potential hazards associated with the proposed activities were identified and evaluated systematically. Potential accident cases that could result in radiological or toxicological gas releases were identified and analyzed, and their consequences analyzed. Administrative controls, procedures, and necessary design changes to eliminate or reduce the potential hazards were also identified.

The SA was prepared using the "Interim Guidance for Preparing Safety Assessments", (rev 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Len Duffy in a memorandum dated May 6, 1992 which included in Appendix 3. The SA addresses most of the elements required in the Department of Energy (DOE) Standard DOE-STD-3011-94 "Guidance for preparation and Submittal of Basis Interim Operation (BIO) for DOE Nonreactor Nuclear Facilities." DOE Standard DOE-STD-3009-94 "Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports" was used as guidance to perform the Hazard Analysis.

The independent review was performed in accordance with a DOE-RL charter and is intended to assess compliance of the RMCS SA with applicable safety-related statutes, rules, DOE Orders, and Standards and, in particular with the requirements of DOE Order 5480.23 as delineated in related DOE standards. Additional clarification and guidance regarding these requirements were obtained from DOE-STD-1027-92, "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis", DOE-STD-3009-94, "Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports", DOE-STD-3011-94 "Guidance for preparation and Submittal of Basis Interim Operation (BIO) for DOE Nonreactor Nuclear Facilities", and the DOE-RL approved Quality Assurance Plan. The review was also performed on the basis of six broad standards of performance: accuracy, completeness, traceability, consistency, readability, and functionality.

The IRT members were selected in accordance with the review charter submitted for approval by DOE-RL TWRS PRI.

The review was conducted in two stages. The first stage was initiated upon receipt of the document on May 6, 1996. The INEL review comments were forwarded to DOE-RL on May 10, 1996 for evaluation by DOE and WHC. Responses to our comments were received from WHC on June 10, 1996. The response were evaluated and formally returned to DOE-RL on June 17, 1996 requesting incorporation of the changes agreed upon to resolve the open issues. Finally, a meeting was held with WHC, Los Alamos staff, and DOE-RL on July 2 and 3, 1996 to review the final document draft and resolve/close all remaining open issues. The final draft of the ISORs was also reviewed on July 15, 1996.

This document summarizes the evaluation of the revised revision 0 of the RMCS SA and the final draft of the IOSRs as received from WHC. The evaluation entailed assessment of the modifications to the documents as agreed upon during the July 2 and 3, 1996 meeting to resolve the identified IRT concerns. All open issues and areas of concern have been clarified, addressed and resolved. There remains no open issues of concern to the IRT after reviewing the changes incorporated into the final document revision as reviewed. A copy the Review Comment Record sheets used in the July 2-3, 1996 meeting for closing all open issues is included as Appendix 4.

The DOE-RL, TWRS recommends approval of the SA titled "A SAFETY ASSESSMENT of ROTARY MODE CORE SAMPLING in FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON" (WHC-SD-WM-SAD-035, Rev. 0-a); with the provision that any changes to the operations or the equipment as described in the document should be followed by a careful USQ assessment process. This SA is a stand-alone safety analysis supporting a temporary activity. It systematically identifies the hazards of the RMCS operations, describes and analyzes measures taken to eliminate, control and mitigate identified hazards, and analyzes potential accidents together with their associated risks.

The SA is organized in accordance with the "Interim Guidance for Preparing Safety Assessments", (rev 2, March 6, 1992), as shown in Appendix 3.

The authorization basis consists of this SER, the Safety Assessment # WHC-SD-SAD-035, Rev 0-a; the WHC letter # 9653662 R2, dated August 30, 1996, and the IOSRs identified in ECN # 609990. Rotary mode core sampling will be limited to the following four (4) tanks: AX-101, AX-103, BX-110, and TY-102.

Paul Hernandez

Paul Hernandez, DOE-RL, TWRS

TABLE OF CONTENTS

APPENDICES

EXECUTIVE SUMMARY

Description

This Safety Evaluation Report (SER) documents the results of a third tier independent review of the Safety Assessment (SA) document titled "A SAFETY ASSESSMENT OF ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON " (RMCS) for the Hanford Tank Waste Remediation System (TWRS) Program tank farms. The independent review was performed to assess compliance of the RMCS SA with the requirements of DOE Order 5480.23, DOE-STD-3009-94, DOE-STD-3011-94, "Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3), and DOE-STD-1027-92.

The SA is intended to address the safety basis for each of the required elements associated with the installation, operation, and removal of a rotary mode core sampling (RMCS) device in Flammable Gas Watch List (FGWL) Single-Shell tanks (SSTs) located within the 200 Area in the Hanford Site, Richland, Washington. Potential hazards associated with the proposed activities are identified and evaluated systematically. Potential accident cases that could result in radiological or toxicological gas releases are identified and analyzed, and their consequences analyzed. Administrative controls, procedures, and necessary design changes to eliminate or reduce the potential hazards are also identified.

The review was performed by an Independent Review Team (IRT) at the Idaho National Engineering Laboratory (INEL) and in accordance with a charter issued by DOE-RL (Appendix 1). The charter specified the review criteria and the rules of independence and qualifications of the reviewers. The list of qualified reviewers is shown in Appendix 2 together with their respective qualifications.

Evaluation Criteria

The independent review team used the following six broad performance standards to guide their review: accuracy, completeness, traceability, consistency, readability, and functionality. The primary focus of the review was to compare the draft document against the governing requirements documents:

DOE Order 5480.23, Nuclear Safety Analysis.

DOE-STD-1027-92, "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis."

DOE- STD-3009-94, "Preparation Guide for U.S. Department of Energy Non-reactor Nuclear Facility Safety Analysis Reports."

DOE-STD-3011-94 "Guidance for preparation and Submittal of Basis Interim Operation (BIO) for DOE Nonreactor Nuclear Facilities."

"Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3).

Evaluation Findings

An evaluation summary of the final version of revision 0 of the RMCS SA and the final draft of the IOSRs as received from WHC is presented. The evaluation entailed assessment of the modifications to the documents as agreed upon during the July 2, 1996 meeting to resolve the identified IRT concerns. All open issues and areas of concern have been clarified, addressed and resolved for both the SA and associated IOSR documents. There remains no open issues of concern to the IRT after reviewing the changes incorporated into the final document revision as reviewed. A copy the Review Comment Record sheets used in the July 2, 1996 meeting for closing all open issues is included as Appendix 4.

Conclusions

The IRT recommends approval of the SA titled "A SAFETY ASSESSMENT OF ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS: HANFORD SITE, RICHLAND, WASHINGTON " (RMCS) with the provision that any changes to the operations or the equipment as described in the document should be followed by a careful USQ assessment process.

1.0 SECTION 1 - SCOPE

1.1 Description

Section 1 describes the action that requires the SA. It provides a discussion of the activity, and the action required by the purpose of the SA. The action for Rotary Mode Core Sampling is well described together with it's identified needs. Alternative courses for sampling and the consequences of "no action" are described and assessed.

1.2 Evaluation Criteria

"Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3).

1.3 Evaluation Findings

There are no open issues with respect to the RMCS SA SECTION 1

1.4 Conclusions

This section adequately describes Rotary Mode Core Sampling, alternative methods, and consequences of "no action".

2.0 SECTION 2 - DESCRIPTION OF ACTION

2.1 Description

Section 2 identifies feasible alternatives to implement Rotary Mode Core Sampling, and establishes the criteria for evaluating alternative modes. The alternative modes are assessed, and the RMCS is justified. Maps, layouts, drawings and procedures are provided to identify hazard elements that may be encountered during RMCS.

2.2 Evaluation Criteria

DOE- STD-3009-94, DOE-STD-3011-94, "Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3), and DOE Order 5480.23

2.3 Evaluation Findings

There are no open issues with respect to the SA Section 2

2.4 Conclusions

Section 2 of the RMCS adequately meets the requirements of the evaluation criteria.

3.0 SECTION 3 - IDENTIFICATION OF HAZARDS

3.1 Description

Section 3 of the SA clearly identifies all potential hazards related to the RMCS activities. The functional analysis of the RMCS activities, environmental materials fabrication, degradation processes are addressed. This section also addresses inspection and monitoring consideration of equipment and facilities used in RMCS processes. Hazards identification is based on task analyses related to the installation, operation, and removal of equipment and materials required for RMCS.

3.2 Evaluation Criteria

DOE- STD-3009-94, DOE-STD-3011-94, "Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3), and DOE Order 5480.23

3.3 Evaluation Findings

There are no open issues with respect to the SA Section 3

3.4 Conclusions

Section 2 of the RMCS adequately meets the requirements of the evaluation criteria.

4.0 SECTION 4 - HAZARD ANALYSIS

4.1 Description

Section 4 provides hazards analyses for hazards identified in Section 3 as related to their potential severity including potential for occurrence. Environmental, materials, fabrication, degradation processes, inspection and monitoring practices as they could impact failure modes of system components are considered.

4.2 Evaluation Criteria

DOE- STD-3009-94, DOE-STD-3011-94, "Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3), and DOE Order 5480.23

4.3 Evaluation Findings

There are no open issues with respect to the SA Section 4

4.4 Conclusions

Section 4 of the SA adequately meets the requirements of the criteria listed above.

5.0 SECTION 5 - CONSEQUENCES OF ACCIDENTS

5.1 Description

Section 5 describes accident consequences and considers safety and system effects. It also describes radiological and toxicological consequences of accidents to both the workers and the public.

5.2 Evaluation Criteria

DOE- STD-3009-94, DOE-STD-3011-94, "Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3), and DOE Order 5480.23

5.3 Evaluation Findings

There are no open issues with respect to the SA Section 5

5.4 Conclusions

Section 5 of the SA adequately meets the requirements of the criteria listed above.

6.0 SECTION 6 - CONTROLS

6.1 Description

Section 6 provides the identified and necessary controls required to perform the operations required by RMCS while ensuring that the risk acceptance guidelines are maintained.

6.2 Evaluation Criteria

DOE- STD-3009-94, DOE-STD-3011-94, "Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3), and DOE Order 5480.23

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6.3 Evaluation Findings

There are no open issues with respect to the SA Section 6

6.4 Conclusions

Section 6 of the SA adequately meets the requirements of the criteria listed above.

7.0 SECTION 7 - CHECKLIST ITEMS

Section 7 of the RMCS SA provides a checklist of assumptions used as basis for developing the SA. Therefore, any parameters and/or limits that vary from the checklist should trigger re-evaluation of the conclusions made in this SA, probably via a USQ process.

5.3 Evaluation Findings

There are no open issues with respect to the SA Section 5

5.4 Conclusions

Section 5 of the SA adequately meets the requirements of the criteria listed above.

6.0 SECTION 6 - CONTROLS

6.1 Description

Section 6 provides the identified and necessary controls required to perform the operations required by RMCS while ensuring that the risk acceptance guidelines are maintained.

6.2 Evaluation Criteria

DOE-STD-3009-94, DOE-STD-3011-94, "Interim Guidance for Preparing Safety Assessments", (REV 2, March 6, 1992), developed by SAIC for DOE as directed by a letter from Leo Duffy in a memorandum dated May 6, 1992 (Appendix 3), and DOE Order 5480.23

6.3 Evaluation Findings

There are no open issues with respect to the SA Section 6. Rotary Mode Core Sampling activities will be initially limited to the following four tanks BX-110, AX-101, AX-103 and TY-102 with the proviso that the requirements of the checklist in Section 7 of the SA are met.

6.4 Conclusions

Section 6 of the SA adequately meets the requirements of the criteria listed above.

7.0 SECTION 7 - CHECKLIST ITEMS

Section 7 of the RMCS SA provides a checklist of assumptions used as basis for developing the SA. Therefore, any parameters and/or limits that vary from the checklist should trigger re-evaluation of the conclusions made in the SA, probably via a USQ process.

APPENDIX 1

DOE-RL REVIEW CHARTER

DOCUMENT REVIEW PLAN

for

SAFETY ASSESSMENTS

for

SALT-WELL PUMPING AND ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS TANKS

DOCUMENT REVIEW PLAN

SALT-WELL PUMPING AND RMCS IN FLAMMABLE GAS TANKS

SAFETY ASSESSMENTS

PURPOSE

The purpose of this Document Review Plan is to establish requirements and responsibilities for the Independent (3rd tier) review of the Safety Assessments for Salt-well Pumping and Rotary Mode Core Sampling (RMCS) in Flammable Gas Tanks per *Tank Waste Remediation Systems Procedure*, TWRS 08-01, "Safety Documentation Review and Approval".

BACKGROUND

A major safety issue at Hanford has been the generation, retention and sudden release of flammable gases in large waste tanks (500,000 gallons and larger) containing substantial amounts of sludge and saltcake. An Unreviewed Safety Question was declared and various double shell (DSTs) and single shell (SSTs) tanks were put on a "Watch List". Restrictions were placed on activities involving intrusion into the dome space and waste in tanks on the Flammable Gas Watch List (FGWL). As a result, neither Rotary Mode Core Sampling (RMCS) for characterization nor Salt-well pumping for interim stabilization is currently within the Authorization Basis for tanks on the FGWL. Several Tri-Party Agreement (TPA) milestones are affected by the restrictions on activities in FGWL tanks. Additionally, the potential exists for any SST to leak and contaminate the soil around the tank unless the tank is interim stabilized, since most SSTs are beyond their design life. In view of the fact that more than 60 SSTs are known or suspected to be leaking, there is substantial risk in delaying interim stabilization. Characterization also needs to be performed, especially to facilitate Privatization.

The purpose of the two SAs to be reviewed is to establish a sound technical basis for authorizing waste-intrusive activities for tanks on the FGWL, without undue risk to the public, workers and the environment. The immediate risk of a deflagration or detonation accident caused by waste-intrusive activities needs to be balanced against the long-term risk of large quantities of liquid waste releases to the environment, with the potential for reaching the surface and causing harm to workers and the public.

Substantial progress has been made in the study and understanding of the physical and chemical phenomena associated with the retention of flammable gases and their sudden release ("burp") since the declaration of a USQ and establishment of the FGWL. However, as evidenced by the recent imposition of controls related to flammable gases on all 177 tanks, understanding of the phenomena is not complete. Analyses are currently being performed with a view to removing controls for flammable gases on tanks which are not on the FGWL.

In view of the foregoing, the question of whether waste-intrusive activities should be authorized in FGWL tanks is a serious one. An Independent (3rd tier) Review by recognized experts not associated with RL-TWRS is, therefore, considered necessary, even though the activities under consideration do not involve permanent changes to the tank configuration and are of a short duration per tank.

REVIEW PLAN

SCOPE

The primary objective of this review is to ensure that the document complies with the criteria and guidelines established in DOE Order 4700.1, Project Management System, DOE Order 5400.5, Radiation Protection of the Public and the Environment, 40 CFR 835, Occupational Radiation Protection, DOE Order 6430.1A, General Design Criteria, and DOE Order 5480.23, Nuclear Safety Analysis Reports (as augmented by DOE STD 3009) as applicable to the grading designated below. The review will determine if the criteria and guidelines for these limited duration activities have been followed; and, if the conclusion that the salt-well pumping and RMCS activities can be performed without undue risk to public, workers and the environment, is well supported and presented.

LIMITATIONS

This review covers all sections of the Safety Assessment. The activities for which authorization is being sought, viz., Salt-Well Pumping and RMCS, involve the introduction of equipment into the tank waste for a sort duration, and their removal at the conclusion of the activity. Due to the short-term nature of the proposed activities, only the following sections of a Safety Analysis Report (SAR) are included in this SA (deviation authority is Leo Duffy letter dated May 6, 1992):

- Executive Summary
- Description of Activity
- Hazard Identification
- Hazards Analysis
- Accident Analysis
- Required Controls

REVIEW TEAM

The DOE-RL TWRS Management Systems Division (MSD) with the concurrence of the Environmental, Safety and Health Division of the Richland Operations Office (ES&H) will commission, coordinate, and support the Independent Review Team (IRT) review of the SAs. The IRT shall report to the MSD through the IRT Chairman. The MSD, as an independent oversight division of TWRS, has no responsibility for tank farm operations and did not draft any portion of the SAs.

IRT members must be experienced in one or more of the safety related subject matters addressed in the SAs. They must have sufficient experience with safety analyses similar to the SAs to be considered industry experts. Members are qualified for the panel based on their industry experience and backgrounds. In particular, the following specific experience is required in the IRT (though not required of each IRT member):

- hazard identification, methodology, and assessment, including event trees
- hazard classification as described in DOE Order 5480.23, "Safety Analysis Reports"

- hazard and accident analysis format and content, as stipulated in DOE Order 5480.23, "Safety Analysis Reports", and DOE-STD-3009.

- accident selection from hazard analysis

- radiological and toxicological accident assessment and methodology.

- knowledge of hazards associated with the storage and transportation of radioactive and mixed wastes at Defense nuclear facilities

Each IRT member participating in review of the SAs should have the following minimum qualifications:

- Minimum Bachelor of Science degree in engineering/physical science (preferably Masters)

- Ten to Twenty years experience in the commercial or federal nuclear industry or non-reactor nuclear industry. A minimum of 5 years involvement with deterministic and/or probabilistic accident safety analyses.

- Knowledge in one or more of the following areas:

- Heat transfer
- Chemistry/chemical reactions
- Thermodynamics
- HVAC
- Criticality
- Source term dispersion mechanisms, including airborne release fractions, release rates, respirable fractions, etc.
- structural analysis (concrete/steel), including seismic

A chairman of the IRT review team will be appointed by MSD with the concurrence of DOE-RL ES&H.

Proposed members of the IRT may be suggested by DOE-RL or DOE-HQ. However, the IRT chairman is under no obligation to follow these suggestions. Selection of review team members are subject to the concurrence of MSD and DOE-RL ES&H. The review chairman shall submit individual qualification statements for each team member to the MSD for DOE-RL review and concurrence.

The IRT chairman shall insure that each reviewer is independent of:

- project activities sponsoring the document;

- project activities that result in direct involvement with document development, and;

- other reviews of the document

REVIEW ASSIGNMENTS

The IRT chairman shall identify the scope and extent of each individual reviewer's review assignment(s).

SCHEDULE

The substantive independent review shall be completed and all review comments shall be transmitted to MSD within two weeks following actual receipt of the document by the IRT chairman. For planning purposes, the Salt Well Pumping SA will be available for third tier review on or about April 15th. The RMCS SA will be available on or about March 20th. The IRT chairman shall be allowed 10 working days from the receipt of the revised SA to verify final comment closure and issue a draft Safety Evaluation Report (SER) to MSD for administrative review. The final SER shall be provided to MSD within two working days of receipt of MSD's administrative concurrence with the draft SER.

GENERAL REQUIREMENTS

All review comments are to be documented on the Review Comment Record (RCR) Form (Attachment A or electronic Form WEF 011 on HLAN). Satisfactory disposition of each individual reviewer's comments shall be confirmed independently by the individual reviewer's signature or initials on the disposition record.

The IRT shall conduct one round of comment closure reviews following submission of the initial IRT review comments. This review shall evaluate the acceptability and adequacy of each proposed comment closure. A written response shall be provided MSD identifying all disposition comments found to be unacceptable by the IRT and the technical basis for reject. Final closure of comment responses which require a modification of SA text shall not occur until the IRT chairman verifies that the required text modification(s) have been incorporated into the SA and have been found acceptable (redline/strikeout verification of SA is allowed).

The IRT chairman shall submit a final SER, which at a minimum, shall include the material content identified in attachment B. A separate SER shall be produced for each SA reviewed. Additionally, each SER shall include one copy of the SA as last reviewed by the IRT for the purpose of establishing a baseline document control.

The IRT chairman shall submit a quality assurance plan to MSD which details the method of review, conflict/comment resolution process, reviewer qualifications and review assignment(s), administrative controls, and review criteria (see Safety Assessment Checklist below).

REVIEW CRITERIA

The review criteria have been established by the guidance and requirements provided in the aforementioned DOE Orders (see SCOPE SECTION), DOE guidance, and related federal environmental, safety, and health laws. A Safety Assessment Checklist (Attachment C) has been developed for optional use to aid in addressing the applicable criteria . Major elements of the established criteria consist of description of the safety analysis/evaluation process, description of the hazard categorization, accident analysis and risk acceptance, safety equipment and features, safety classification, and general document quality. The IRT chairman may modify Attachment C or develop an independent checklist as part of the IRT quality assurance plan.

REFERENCES

1. Tank Waste Remediation System Procedure 08-01, Safety Documentation Review and Approval, November 1995.

2. DOE Order 4700.1, Project Management System.

3. DOE Order 6430.1A, General Design Criteria.

4. WHC-CM-4-46, Nonreactor Nuclear Facility Safety Manual.

REVIEW COMMENT RECORD (RCR)

1. Date	2. Review No.
3. Project No.	4. Page 1 of 1

5. Document Number(s)/Title(s)	6. Program/Project/ Building Number	7. Reviewer	8. Organization/Group	9. Location/Phone

17. Comment Submittal Approval:

Organization Manager (Optional)

10. Agreement with indicated comment disposition(s)

Date

Reviewer/Point of Contact

Author/Originator

11. CLOSED

Date

Reviewer/Point of Contact

Author/Originator

12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/ resolve the discrepancy/problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT accepted.)	16. Status

A-6400-090.1 (03/92) WEF011

EXHIBIT 8.1
- Recommended Format and Content of SERs -

Overall content of the SER shall be based on a graded approach as described in DOE 5480.23. An SER being written in response to an individual phase or stage of SAR development, USQ, or JCO shall be commensurate with the scope of the related Safety Documentation. An SER may be in the form of a formal report, an attachment to a formal DOE transmittal, or may be part of the text of a formal DOE transmittal.

In general, an SER is expected to follow the format and content provided below:

a. COVER/CONCURRENCE PAGES - Title of document and concurrence signatures. Non-concurrence or differing professional opinion by review team members should be indicated (non-concurrences and/or differing opinions should be documented in an Appendix to the SER).

b. EXECUTIVE SUMMARY (optional) - This section is intended to provide an overall summary of the facility and the associated risks. As such, this section is a crucial part of the SER in presenting the results of the DOE review and therefore should be largely self contained. If the SER is of relatively short and of limited complexity, an executive summary may not be warranted.

   - Reason for change, revision, or new document
   - Brief description of facility, including history if pertinent
   - Description of DOE review process
   - Important findings and conclusions
   - Description of additional controls, conditions for approval, and any restrictions on operations
   - A statement of adequacy. Include discussion of any team member non-concurrence or differing professional opinion
   - Recommendations of acceptability, including a statement that the Facility can operate safely, without undue risk to the health and safety of the public, workers, and the environment.

c. Table of Contents

d. Remaining sections of the SER should be based on format determined by author of SER, typically reflecting the chapters/sections of the subject Safety Document. Description of the review methodology and review team is typically presented as part of the discussion of the first chapter/topic. The following should be addressed for each chapter/topic:

   - Brief description of intent and content of the chapter/topic
   - Presentation and discussion of findings
   - Conclusions and conditions for approval (acceptability of the activity or operation in terms of risk to the health and safety of facility workers, co-located workers, and the public).

- Recommended Format and Content of SERs (Cont'd) -

Include any non-concurrence or differing professional opinion by review team members (non-concurrences and/or differing opinions should be documented in an Appendix).

e. Summary of any conditions for approval, including:

- Clarification of the safety basis as described in the Safety Document;
- Requirement for preparation and submittal of additional analyses or data;
- Commitment to system design changes or additional operational limitations;
- Additional programmatic or institutional commitments to certain administrative controls, including maintenance, testing, surveillance, and training provisions;
- Changes and/or additions to OSR/TSR.

f. Appendices

- Acronyms
- Review team members and resumes or biographies
- Review plan/review basis
- Team member concurrence/non-concurrence sheets (team members who have differing professional opinion are expected to document concerns and disagreements; these should be acknowledged in the conclusions section of the SER and in the Executive Summary).

g. Attachments

- Review comments and resolutions (RCRs are adequate).

SAFETY ASSESSMENT CHECKLIST

Some General Considerations, Merits, and Reservations

The attached checklist, developed by the Department of Energy (DOE) Richland Operations Office (RL) Tank Waste Remediation System (TWRS) Program Integration Division (PRI), and Westinghouse Hanford Company (WHC) Safety Analysis and Engineering (SA&E) is intended to be used as an aid in preparing and reviewing Safety Assessments (SAs) prepared by TWRS contractor/participants pursuant to criteria and guidelines established in DOE Order 4700.1, *Project Management System*, DOE Orders 6430.1A, *General Design Criteria*, and WHC-CM-4-46, *Nonreactor Nuclear Facility Safety Manual*, and are based on many DOE Orders, DOE guidance, and related federal environmental, safety, and health laws.

The checklist provides columns for "yes," "no," and not applicable ("N/A") responses. If desired, notes on document adequacy and other comments can also be entered. Generally, the questions are phrased so that a "yes" answer is preferable to a "no" answer. Note that not all questions will apply to all SAs; the questions should be adapted to the particular circumstances presented by the proposed action. Consider also the use of the "graded approach"- depending on the extent and potential hazard of a given facility, some reduction in coverage under each area or combination of subjects may be acceptable in the SA.

In providing this product, RL-TWRS recognized that a document checklist, while it may have value to the contractor/participants, will also have limitations. A carefully applied checklist may help experienced preparers and reviewers avoid overlooking required or recommended items. It may help preparers and reviewers identify needed analyses and discussions. It may provide a record of an internal review. On the other hand, each DOE proposal presents unique circumstances and potential impacts, and the preparation and review of SAs does not reduce to a single formula or checklist. No document checklist can be universally comprehensive or complete. No document checklist should be relied upon as the only way to build quality into a DOE safety analysis process. No checklist can be a substitute for the original laws, regulations, and guidance documents. No checklist can ensure that the SA will be adequate under, and in full compliance with, DOE Order 5480.23 and associated standards. The RL-TWRS contractors/participants should also bear in mind that addressing generic items on a checklist alone may not lead to a sufficiently rigorous analysis of potential impacts for a specific safety issue. Further, checklist items are not always of equal importance or weight. If a known, obvious hazard is not addressed, a SA is generally inadequate; however, if full accident analyses are omitted, it is not a critical matter in terms of document adequacy. In short, a checklist should not be a replacement for good judgment.

Finally, this SA checklist is not intended to promote the rote generation of standardized documentation, nor promote an ethic focused on minimal compliance with DOE Orders and standards. It cannot induce or measure whether the methods of safety analysis are systematically applied or whether resources are appropriately allocated, or whether management/decision-makers utilized SA results in decisions and whether those decisions result in the protection of the worker, public, and environment. Generation of safety documents will not by itself foster daily excellence in worker, public, and environmental safety. In the long run, the focus should be on the ultimate "product" of the safety analysis process: quality decisions, stewardship of resources, and safety to the total community.

DOE RL-TWRS February 16, 1996

SAFETY ASSESSMENT CHECKLIST

Document Title:	Reviewed By:
Document Number:	Office/Phone:
Document Date:	Date:

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
SUMMARY					
Does the summary address the entire SA? (Consideration by the reviewers must be given to status in the project life cycle - DOE Order 4700.1)					
Does the summary discuss the design basis accidents (DBAs), and risk-dominant accident scenarios that have been analyzed, and the measures taken to eliminate, control, or mitigate the consequences of these accidents? (Does this include a discussion or statement specific to criticality?)					
Does the summary describe the potential hazards that have been addressed?					
Does the summary clearly define the facility, including its physical and institutional boundaries, distinguishing it from other DOE facilities or operations outside the scope of the analysis and clearly define those external functions, such as utilities or external support organizations.					
In projects which modify or interface with existing facilities, does the statement of purpose and need discuss: any new types of accidents which were not possible before?					
any synergistic effects?					
any increased probabilities or consequences, or otherwise, alter the scenario for accidents previously analyzed?					

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
DESCRIPTION OF THE SAFETY ANALYSIS/EVALUATION PROCESS					
The safety analysis process is iterative and is used to establish and maintain the safety basis throughout the project life cycle. Does the safety analysis process used: describe the design to systematically identify necessary systems, structures, and components (SSCs) that prevent or mitigate unacceptable releases of radioactive and/or hazardous material;					
analyze a new or existing facility to verify that the design adequately performs the identified safety functions during normal and accident conditions;					
systematically determine the safety function(s) of SSCs; and					
identify as non-binding, preliminary technical safety requirements and/or administrative controls as possible mitigations to consequences					
Does the SA aid management in insuring that major safety considerations (technical and compliance) are incorporated early into the project life cycle?					
Does the SA evaluate the functional design criteria (FDC) and is it issued concurrently with the conceptual design report (CDR) as part of the budget validation package for the project?					
Is the need for new safety documentation and modifications to the existing safety documentation identified in the SA?					
DESCRIPTION OF THE HAZARDS					
Was the operation broken down into components or modes to be analyzed? This can be SSCs, processes, operating modes, etc.					
Were proposed non-binding safety class SSCs and their basis for designation determined? (i.e., SEL)					
Were the hazards and/or hazardous conditions present described? The following descriptions should be considered:					

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
Energy sources (these sources include energy forms which could contribute to the release and exposure of radiological and/or otherwise hazardous materials resulting in biological damage) - natural phenomenon, electrical, gravitational, pressure, ionizing radiation, non-ionizing radiation, linear, rotational, potential, kinetic, radiant, fire/explosion, criticality, airborne acoustic radiation, noise, static magnetic fields, subfrequency static electric fields, etc.)					
Hazardous Materials - those materials that are toxic, explosive, flammable, corrosive, or otherwise physically or biologically threatening.					
Typical Classes of Hazards - fire/explosion, loss of containment/confinement, injury to personnel, criticality, interfaces between steps, components, systems, and nearby facilities, maintenance, natural phenomena, exposure to radiation and/or other hazardous materials, operational failures and their impact on the facility.					
Consequence - state in qualitative terms, the impacts to the health and safety of the workers, members of the public, and the environment.					
Engineered Features and Administrative Controls - identify and document any engineered features (providing safety function) and/or administrative controls for which credit may be taken to detect, prevent, reduce the frequency of, control, and/or mitigate the stated consequences.					
Does the SA identify the need for additional, detailed analysis for each item identified in the hazards identification process above using the following: Designate scenarios that have an annual probability of less than 10^{-6} as "beyond extremely likely".					
Identify events with programmatic impact only or with no significant safety consequence.					

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
Identify credible accident scenarios which must be evaluated to assure that risks presented are adequately analyzed and managed.					
Segregate the remaining event sequences according to the frequency range. Within each category, group common types of events. Select the scenarios which are expected to result in the most significant consequences. These scenarios are selected for further evaluation in the accident analysis. NOTE: The methods selected depend upon the stage of facility design, and the types of hazards being analyzed.					
ACCIDENT ANALYSIS AND RISK ACCEPTANCE					
For each event sequence:					
Have all postulated sequences of events which could lead to the most significant consequences been evaluated?					
Have bounding consequence values been identified?					
Have the quantity and characteristic of radionuclides and hazardous materials available for release been defined to acceptable standards and guidelines?					
Have all assumptions for the mechanisms and extent of release through the mitigating barriers been defined?					
Have the potential consequences to onsite and offsite receptors been determined?					
Have the frequencies of the stated scenario event sequences been evaluated?					
Have the environmental impacts been determined?					
Has the adequacy of the design to effectively perform the identified function(s) been demonstrated?					
Has the acceptability of the risks (consequences) been evaluated?					

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
Has the accident analysis process, basis, and assumptions and conclusions been appropriately critiqued to ensure that the project is representative of the work to be performed?					
SAFETY EQUIPMENT AND FEATURES					
Does the SA refer to safety class items and their design to withstand the effect and be compatible with, the environmental conditions associated with operation, maintenance, shutdown, testing, and accidents?					
Does the SA demonstrate how the design of the facility shall reduce the consequences of normal and DBA events by incorporating ALARA design concepts?					
Does the SA provide an assessment of the design against potential nuclear criticality?					
SAFETY CLASSIFICATION[1]					
Have safety class designations been made in conjunction with the analysis of consequences from hazards, natural phenomena, and postulated accident scenarios?					
Have the safety class designations been assigned the highest applicable safety class?					
Has the safety classification criteria determination (at the system and major-structure level) been included in the preliminary safety documentation (e.g., the SA)?					
Have determinations for safety classification been based on the nature of the safety or environmental protection function?					
Have determinations for safety classification been based on the requirements of DOE Order 6430.1A Section 1300-3.2 Safety Class Items?					

[1] Applicable only as determined by current preliminary design requirements.

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
Safety class items are systems, components, and structures, including portions of process systems, whose failure could adversely affect the environment or the safety and health of the public. Specifically, safety class items are those SSCs, with the following characteristics: Those whose failure would produce exposure consequences that would exceed the guidelines in DOE Order 6430.1A, Section 1300-1.4, Guidance on Limiting Exposure of the Public, at the site boundary or nearest point of public access					
Those required to maintain operating parameters within the safety limits specified in the Operational Safety Requirements (OSR), Interim Safety Basis (ISB), Interim OSR (IOSR) during normal operations and anticipated operational occurrences					
Those required for nuclear criticality safety					
Those required to monitor the release of radioactive materials to the environment during and after a DBA					
Those required to achieve and maintain the facility in a safe shutdown condition					
Those that control the safety class items described above					
DOE/TIC 11603, Rev. 1, presents examples of safety classification of plant systems, structures, and components in its appendices; however, for comparable sections in DOE/TIC 11603, Rev. 1, and DOE 6430.1A, the design criteria in DOE 6430.1A shall govern.					
Are the Safety class items subject to appropriately higher-quality design, fabrication, and industrial test standards and codes such as those specified in Section 0106, Regulatory Requirements, and Section 0109, Reference Standards and Guides, to increase the reliability of the item and allow credit to be taken for its capabilities in a safety analysis. Safety class items shall be designed to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Section III) or to other comparable safety-related codes and standards that are appropriate for the system being designed.					

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
Safety class and non-safety class items shall comply with Section 0140, Quality Assurance. The design of systems, components and structures that are not safety class items shall, as a minimum, be subject to conventional industrial design standards, codes, and quality standards. Failure of these items shall not adversely affect the environment or the safety and health of the public. In addition, their failure shall not prevent safety class items from performing their required functions.					
Does the design ensure that a single failure does not result in the loss of capability of a safety class system to accomplish its required safety functions ? To protect against single failures, the design shall include appropriate redundancy and shall consider diversity to minimize the possibility of concurrent common-mode failures of redundant items.					
Safety class items shall be designed to withstand the effects of, and be compatible with, the environmental conditions associated with operation, maintenance, shutdown, testing, and accidents. The environmental capability of equipment shall be demonstrated by appropriate testing, analysis, and operating experience, or other methods that can be supported by auditable documentation, or a combination of these methods.					
Equipment qualification shall provide assurance that safety class items will be capable of performing required safety functions under DBA conditions. The qualification shall demonstrate that the equipment can at least perform for the period of time that its safety functions are required. Subsequent equipment failure, after its safety function is no longer required, may be allowable.					
Safety class items shall be designed to allow inspection, maintenance, and testing to ensure their continued functioning, readiness for operation, and accuracy. Ancillary equipment, such as pumps, blowers, motors, compressors, gear trains, and controls, shall be located in an area least likely to be contaminated.					
The design shall include provisions for periodic testing of monitoring, surveillance, and alarm systems. In addition, the design shall provide the capability to test periodically, under simulated emergency conditions, safety class items that are required to function under emergency conditions.					

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
All systems for which credit is taken to meet the criteria of DOE Order 6430.1A, Section 1300-1.4.2, Accidental Releases, shall be in-place testable in terms of pressure, filtration or removal efficiency, alarm capability, leak resistance, and the like. Safety class items shall be designed to be testable on a regular schedule.					
Structures, systems, and components that provide for nuclear criticality safety shall be designed as safety class systems and be capable of performing their criticality safety functions during and following design basis accidents and events.					
Risk and vulnerability analyses can be used to identify targets that are essential to ensure the operability of safety-class items and the security of critical programs or facilities. In addition, cost-benefit analyses can be conducted to identify efficient and cost-effective measures to meet site-specific safeguards and security requirements. Targets shall be prioritized so as to determine those to be afforded the greatest level of security in accordance with the graded safeguards and security approach.					
FORMAT, GENERAL DOCUMENT QUALITY, USER-FRIENDLINESS					
Is the SA written precisely and concisely, using plain language, and without jargon?					
Is the SI system of units used (with English units in parentheses) to the extent possible?					
If scientific notation is used, is an explanation provided?					
Does the SA use appropriate significant figures?					
Are the units consistent throughout the document?					
If regulatory terms are used, are they consistent with their regulatory definitions?					
Are visual aids used whenever possible to simplify the SA?					
Are technical terms defined?					
Is the SA grammatically correct?					
Are abbreviations and acronyms defined the first time they are used?					
Is the use of abbreviations minimized to the extent practical?					

	Yes	No	N/A	Page	Adequacy Evaluation and Comments
Do the appendices support the content and conclusions contained in the main body of the SA? Is information in the appendix consistent with information in the main body of the SA?					
Is information in tables and figures consistent with information in the text and appendices?					
OVERALL CONSIDERATIONS/INCORPORATION OF SA VALUES					
If the Environmental Assessment (EA) adopts, in whole or in part, this SA document prepared by Westinghouse Hanford Company, has DOE independently evaluated the information used?					
Does the SA appropriately use incorporation by reference? Is/are the incorporated document(s) up-to-date?					
Do the conclusions regarding potential impacts support the information and analyses presented in the EA?					
Although not required, will there be follow-up to determine if the analyses were accurate and that the mitigation measure are implemented?					
PROCEDURAL CONSIDERATIONS					
Does the SA make reference to a more comprehensive safety assessment/analysis as more definitive design information is available?					

APPENDIX 2
SA IRT Members

DOE: R. McNulty, DOE-RL, and C. Noble, DOE-ID

ID	NAME	QUALIFICATION & AREA OF EXPERTISE
BEI	G. A. Beitel	Ph.D Physics, Explosives, Waste Management
din	G. A. Dinneen	MS Mechanical Engineering/Nuclear Science, Safety Analysis
GUZ	R. C. Guenzler	MS Civil Engineering, Structural Analysis
NM	N. Morcos	Ph.D Radiochemistry, Nuclear Chemistry, Radiological Risk Assessment, Safety Analysis, Commercial Nuclear Power, Commercial Radioisotope Production.
WJP	W.J. Prendergast	BS Chemical Engineering; Diplomat in Environmental Engineering; Professional Engineer; Plant Design and Operations Analysis.
KSM	K.S. Moor	MS Zoology; Environmental Monitoring and Assessment

APPENDIX 3

GUIDANCE FOR PREPARATION OF SAFETY ASSESSMENTS

DOE F 1325.8
(8-89)
EFG (07-90)

United States Government — HANFORD — Department of Energy

memorandum

RL COMMITMENT CONTROL PHONE 6-8537
CONTROL NO: 921008.01
ASSIGNED TO: TFDn
DISTRIBUTION: MLok, EAP, ERD, OCC, TSD, WMD, DEP

CC: RFCV, REG

DATE: MAY 6 1992

REPLY TO ATTN OF: EM-36:Calley:FTS 233-7417

SUBJECT: Guidance for Preparation of Safety Assessments

TO: Manager, DOE Richland Field Office

Attached for your use is interim guidance for the preparation of safety assessments to support proposed actions to address unreviewed safety questions (USQs) and other priority safety issues related to high-level radioactive waste storage.

Historically, these safety assessments have been untimely and of inconsistent quality. In an effort to improve them, the EM staff has prepared the attached "Interim Guidance for Preparing Safety Assessments," Revision [2], dated March 6, 1992. This guidance was originally prepared in draft form in September 1991, and reviewed by the DOE Richland Field Office (RL), Westinghouse Hanford Company (WHC); Office of Environmental, Safety and Health (EH); and the Office of Nuclear Safety (NS). The views and comments of those organizations have been incorporated into the interim guidance. We view this as a dynamic document and plan to make whatever future changes are necessary to make it compatible with our experience in applying the guidance to the safety assessment preparation and approval process.

It is our intent that this guidance will provide the needed continuity in the preparation and review of safety assessments. You are directed to use this guidance in the preparation of all safety assessments related to high-level waste tank safety. My staff contact for this action is Harry Calley (FTS 233-7417).

Leo P. Duffy
Assistant Secretary for Environmental
Restoration and Waste Management

Attachment

cc w/attachment:
J.R. Gerton, DOE-RL

RL Commitment Control
MAY 12 1992
Richland Operations Office

INTERIM GUIDANCE

FOR

PREPARING SAFETY ASSESSMENTS

Developed for U. S. Department of Energy
High-Level Radioactive Waste Tanks Task Force

Revision [2]

March 6, 1992

C. C. Herrington
J. R. Fearring

Science Applications International Corporation

INTERIM GUIDANCE FOR PREPARING A SAFETY ASSESSMENT

INTRODUCTION

As is indicated by the title, development of this paper, has continued toward improving the guidance for Safety Assessments. This revision of the "INTERIM GUIDANCE" incorporates new thinking that has developed and addresses the expectations of the SA reviewers who are ultimately responsible for concurrence or approval of the assessments. In addition past guidance related to addressing the Scope of the action addressed by the SA, has been expanded to more fully treat the need for completing an Engineering Evaluation of Alternatives prior to beginning the preparation of a SA.

The guidance information presented below is organized as follows:

1. "General Guidance" related to the overall document

2. "Specific Guidance" organized according to the SA content topics which remain unchanged. They are:

   1.0 SCOPE
   2.0 DESCRIPTION OF ACTION
   3.0 IDENTIFICATION OF HAZARDS
   4.0 HAZARD ANALYSIS
   5.0 CONSEQUENCE OF ACCIDENTS
   6.0 CONTROLS

GENERAL GUIDANCE

In addition to being technically accurate and complete, the SA must be written with the audience in mind. The purpose of the SA is to convince the decision makers that the proposed course of action is necessary, and that you have logically and systematically identified and addressed the safety issues involved.

A Safety Assessment is not intended to convince the reviewer that the subject situation is the best action, activity or modification to accomplish its goals whether the goals be economic, production related or improving safety. Nor is a Safety Assessment intended to be an engineering study where various options are evaluated and the best selected. The engineering study addressing the options and the selection of the action, activity, or modification best suited to meet the needs of the program is entitled, an Engineering Evaluation of Alternatives. It is usually completed prior to the SA and referenced in the SA. A Safety Assessment is a safety analysis to support a temporary activity or to cover a small situation until the safety analysis/SAR is updated to envelop it. As such, a Safety Assessment has similar goals and should utilize an approach similar to that of a safety analysis/SAR. The goal is to systematically identify the hazards of a situation, describe and analyze measures taken to eliminate, control or mitigate identified hazards and to analyze potential accidents and their associated risks (DOE Order 5480.5 (1)).

When possible, the SA should be developed as a stand-alone document. When using references, avoid the use of internal memos which are not readily available to the reader. When possible, information necessary to support the conclusions presented should be attached as appendices.

SPECIFIC GUIDANCE

1.0 SCOPE

The section on SCOPE describes the action that requires the safety assessment (SA) to be written. The section is prefaced by a brief discussion of the BACKGROUND of the activity, telling why this particular subject requires attention [e.g., HLW tanks are generating hydrogen] and the action to be addressed by this SA [e.g., Means should be in place to ensure that the concentration of hydrogen in the tank remains lower than the lower flammability limit].

All of the information that identifies the need for the specific proposed action and defines the action itself, should be included in order to provide the full scope of consideration needed by reviewers in evaluating the SA. Alternative courses of action to accomplish the desired result must be considered. The alternative of no action should be considered and addressed as appropriate. The methodology used in identifying alternatives and the bases for selecting the preferred course of action to be proposed in the SA should be documented at the time that an Engineering Evaluation of Alternatives (EEA) is prepared.

Ideally, the EEA should be completed prior to the preparation of the SA. The various sections of the EEA can then be used in developing related sections of the SA and the Environmental Assessment (EA) (See Attachment 1). An effective EEA will contain information that is needed by the SA reviewers to judge the adequacy of the total SA. It will identify the problem to be addressed by the proposed action. It will demonstrate that the basic safety mechanisms related to the problem are understood and that specific safety mechanisms requiring controls have been identified. An effective EEA will present criteria for choosing among alternatives. Criteria related to the areas of Safety, Environmental, Schedule, and Technology considerations and constraints should be included as appropriate. All viable alternatives for action as presented by the problem should be identified. The identified alternatives should be analyzed to determine the potential for hazards which could lead to the release of radioactive material, containment degradation, or toxic gas releases. Finally an effective EEA will demonstrate that the comparison of alternatives was based upon consideration of the identified criteria.

2.0 DESCRIPTION OF ACTION

The section on DESCRIPTION OF ACTION identifies feasible alternatives to implement the selected course of action, and establishes the criteria for evaluating alternatives.

The SA should then evaluate the implementing alternatives and justify the one selected . This section should detail the steps necessary to accomplish the selected implementing alternative, including preparation, execution, and recovery. Factors to consider in the description include program and process requirements and the physical and schedule constraints likely to be met.

The degree of detail in this section must be sufficient to identify all of the elements of any potential hazard that is described in Section 3.0. Maps, layouts, drawings and procedures should be used to clarify items described in this section.

3.0 IDENTIFICATION OF HAZARDS

The section on IDENTIFICATION OF HAZARDS should clearly identify all potential hazards related to the proposed activity. The hazards should be based on a functional analysis of the processes involved, and on environmental, materials fabrication, degradation processes, and inspection and monitoring considerations related to equipment and facilities.

Identification of Hazards should be based on an analysis of the tasks involved in installation, operation, and removal (as appropriate) of equipment and/or material in the facility. The analysis should be started after reviewing the work plan and understanding the possible effects and interactions of the activities and the physical and chemical phenomena in the facility being analyzed. Hazards to be considered include:

- release of radioactive material due to a spill or pressurization
- generation or release of flammable gases with potential for ignition
- pressurization of portions of the facility caused by exothermic reactions or other means (e.g., steam explosions)
- breaching of a tank caused by corrosion, embrittlement, deformation, reopening leak pathways, or combinations of the above
- reduction of facility structural integrity impacting safety
- creating and releasing toxic gases
- application of external influences such as:
    - addition of energy to the tank systems, including impact, friction, agitation, ultrasound, ignition energy
    - creation of chemical or physical reaction by additions or intermixing of tank contents
    - seismic hazards, as appropriate
- changing the physical or chemical phenomena occurring in the tank to initiate any of the hazards identified

The hazard identification technique used and the results should be described. The hazards typically associated with high-level waste tank safety should be given extra consideration when identifying pertinent hazards. In doing so, consideration should be given to the following:

Tank contents

- burning flammable gases or organic vapors
- explosion of gas mixtures
- explosion caused by liquid chemical reactions, radiolytic reactions, and steam generation
- temperature excursions

Tank structural integrity

- corrosion, embrittlement, deformation, re-opening leak pathways, and multiple failure considerations.

Hazard-initiators

- addition of energy to the tank systems, including impact, friction, agitation, ultrasound, ignition energy
- creation of chemical or physical reaction by additions or intermixing of tank contents
- Seismic hazards, as appropriate

4.0 HAZARD ANALYSIS

The section on HAZARD ANALYSIS should address each of the hazards identified in Section 3.0 relative to their potential severity. Factors include potential for occurrence (probability and magnitude of threat and jeopardy of vital equipment). Consideration should be given to environmental, materials, fabrication, and degradation processes, and inspection and monitoring practices as they impact failure modes and fragility analyses of system components, and the total system.

5.0 CONSEQUENCE OF ACCIDENTS

The section on CONSEQUENCE OF ACCIDENTS should consider safety and system effects caused by accidents related to the potential hazards. Appropriate use may be made of computer codes which have been benchmarked, verified, and validated. The consequence evaluation addressing exposure of site workers and the public to radiation should be expressed in terms of committed effective dose equivalence. The consequence evaluation addressing toxic environments should be expressed in terms of immediate danger to life and health.

6.0 CONTROLS

The section on CONTROLS should specify the controls determined by the hazard analysis that are necessary and sufficient to eliminate or reduce the consequences of the hazard.

Controls should be described as follows:

- Give the basis for the selection of controls, including consideration of alternatives and the factors that resulted in the final decision. The Safety Assessment should document the analysis that demonstrates that the chosen controls are effective in controlling risk.

- Describe special operational requirements, the basis for special needs, and the means for their implementation. This category may include identification of hold points for administrative, safety, or quality assurance control.

- Describe any special equipment requirements identified by the assessment. Include design considerations to ensure its contribution to safety during the activity.

- For each potential hazard having significant consequences, indicate the means to be utilized to monitor the efficacy of the controls that are necessary for prevention and mitigation of the hazards associated with operation safety requirements with their associated safety limits and limiting conditions for operation.

- Provide a means for evaluating the status of parameters related to the control.

- Consider the potential for interaction between potential hazards and their individual means of control that may increase or decrease safety.

SA/EA DEVELOPMENT GUIDANCE
I - ENGINEERING EVALUATION OF ALTERNATIVES

1. Assess problem
2. Identify need for action
3. Identify alternatives
4. Identify hazards for alternatives
5. Develop selection criteria
6. Compare alternatives
7. Describe selected alternative

SA/EA DEVELOPMENT GUIDANCE
II - SAFETY ASSESSMENT

1. Identify scope (EEA 1,2,3)*
2. Describe action (EEA 7)
3. Identify hazards (EEA 4)
4. Perform hazard analysis
5. Analyze consequences
6. Identify Controls

(Parens identify relevant sections of the Engineering Evaluation of Alternatives (EEA) development)

SA/EA DEVELOPMENT GU DANCE
III - ENVIRONMENTAL AS ESSMENT

1. Prepare introduction EA 1, 3; SA 1)*

2. Identify need for act on (EEA 2)

3. Describe selected alt native (EEA 7)

4. Identify other alternatives considered (EEA 3)

5. Identify affected environment
(From Safety Analysis Report)

(Parens identify relevant sections of the Engineering Evaluation of Alternatives (EEA) and Safety Assessment (SA) development)

APPENDIX 4

IRT COMMENTS

(2)

PRELIMINARY FINAL

LANL AND DOE COMMENTS HAVE BEEN INCORPORATED

Received 5-24-96

Final Version used in Closure (7-2-96) of Hanford.

JUNE 7, 1996

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 1

A SAFETY ASSESSMENT OF ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS

HANFORD SITE, RICHLAND WASHINGTON

12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/ resolve the discrepancy /problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT required.)	16. Status
din 1 xvi gen E	Several of the Acronyms are not consistently presented or have editorial problems with them. These include the following; minimum ignition surface temperature permissible exposure limit time-weighted average *unreviewed* safety question		Accept - text will be scanned and acronyms made consistent.	

NOT CHANGED IN TEXT PGS XXVII - XXVIII

O.K.

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 2

NM 1 Gen S	The Accidents analysis section of this document is very well developed. However, key issues such as mitigating procedures, controls, and safety systems and components have not been developed. This approach at presenting a safety document for final approval and expecting the completion of its essential components through the USQ process primarily circumvents and defeats the purpose of developing and writing a Safety Analysis Document. As such, the SA is incomplete, and suggests an improper application of the USQ process. THE SSCs GERMANE TO THIS OPERATION SELECTED SC, IDENTIFIED IN THIS SA, CITED A REFERENCE TO THE SEL IS NOT SUFFICIENT SA should include a table of incompleted issues together with a commitment for "Closing Etc" O.K.		Administrative controls and mitigating procedural requirements necessary to meet guidelines are identified in Section 6.0. The purpose of the SA was to establish a proper authorization basis for RMCS operations. Design features necessary to meet risk guidelines are identified in Section 6.0. The Safety Equipment List (SEL), in WHC-SD-WM-SEL-032, reflects the requirements of Section 6.0 and identifies the safety classification of credited design features. The SEL (WHC-SD-WM-SEL-032) will be added as a reference to the SA. The SA itself states that adding a tank not currently considered per the approved list will require a revision to the SA. This does not make the SA incomplete nor does it improperly apply the USQ process.	O.K. M.M

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 3

NM 1 Gen S (continued)	NOTE: SER WILL INDICATE SAFETY SIGNIFICANT OPEN ITEMS.		For those tanks on the approved list in Appendix g, this SA is the authorization basis against which future operations, including USQ screening, will be based. The approach is top down, that is (1) perform a safety assessment that establishes all required necessary and sufficient controls and includes any unresolved or open issues, (2) implement Level 1 controls via change to the appropriate IOSR, (3) implement Level 2 and 3 controls in OSD's and procedures, (4) resolve all open or unresolved items per directions clearly stated in the SA, and (5) perform an Operational Readiness Review and (6) obtain DOE-RL approval prior to initiating operations.	

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No. —
	2. Project No.	4. Page 4

NM 2 Exec Summary GEN S	The SA must identify the mechanism(s) by which the open items such as undeveloped new procedures, unidentified Safety Systems and Components, and specific test results (Bureau of Mines) will be evaluated with respect to DOE Orders and Standards to become part of this SA and support the TWRS ISB. As such, the ASA is incomplete, and it is an improper application of the USQ process. See response to NM-1 by N Morros		Items 7.1 through 7.7 are now complete. Section 7.0 now consists only of a pre-operational evaluation checklist. Mechanisms are provided to verify adequacy. Actions are identified up to and including new analysis, evaluations, or revisions to the SA. Currently the Bureau of Mines (BOM) tests have been completed and the hydrogen monitors are qualified per SA requirements.	
NM 3 1-2 1.2 O See Text Change	This section states that a representative tank with bounding conditions was chosen by performing a preliminary screening process. The criteria for decision making should be included in this description. OK if "Waste Type" is more detailed than calling it SST & DST waste. Discuss parameters. See Text		Bounding tank selection is discussed in Appendix C. Brief mention of criteria will be added to 1.2. Following text added: "The screening process considered important tank parameters such as retained-gas amount, measured dome flammable- and toxic-gas concentrations, the observed or anticipated gas-release amount, and the waste type. Among the SSTs on the FGWL Tank A-101 was found to maximize the parameters of interest.	NEW

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 5

din 2 2-2 2.1.1 Tbl 2-1 O	DOE Orders 5480.7 and 6430.1A have been superseded by DOE Order 420.1. The SA should reflect the current DOE Orders even though they have not been incorporated in the new contract with the Contractor.		Excerpting from Interim Policy Statement DOE P 450.2 (9-29-95) "Policy Statement on the Identification Implementation and Compliance with Environment, Safety, and Health Requirements": "Transition To Rules And Revised Orders The Department is replacing a number of its Orders with new rules and revised Orders. The resulting transition must be managed so as to assure adequate protection throughout; consistent with maintaining adequate protection, costs and benefits should be considered appropriately. Even though many ES&H Orders will be canceled as corresponding rules and revised Orders are issued, cancellation of these Orders does not, by itself, modify or otherwise affect any contractual obligation based on the canceled Orders. Requirements in canceled Orders which are incorporated and implemented in a contract will remain in effect until the contract is modified to delete those requirements.	

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 6

din 2 2-2 2.1.1 Tbl 2-1 O (continued)	O.K. TEXT NOT MODIFIED. NO NEW SECTION 2.0.1		Also these are the DOE orders that were applicable to the design at the time. This will be clarified in the text. Section 2.0.2 was modified, including Table 2-1. NEW	
BEI 1 2-2 2.1.1 S See Text Change O.K.	A list of DOE Orders is NOT "principal health and safety criteria". They may contain design criteria, safety criteria, and so on, some relevant, some not. The principal health and safety criteria are those criteria which will be used in this document to determine which risks and consequences from normal, abnormal, and accident conditions are acceptable, and which require safety class (class 1, 2, or 3) fixes. NEED TO INCLUDE IN TEXT — "THE SAFETY REQUIREMENT INCLUDES DESIGNING TO THE RISK CRITERIA GIVEN IN WHC-CM-4-46 AS DISCUSSED IN SECTION 5.	O.K.	Accept - Retitle 2.1.1 as DOE Safety and Design Requirements and prior to Table 2-1 add the sentence. These orders were helpful in developing the criteria outlined in 2.1.2, 2.1.3, 2.1.4, and 2.2. The risk criteria are given in ~~WHC-CM-4-46 and~~ discussed in Section 5.0 of the SA. Modifying the title will avoid confusion.	
BEI 2 2-3 2.1.3 S	None of the bullets listed under the opening sentence are criteria. Please provide the criteria promised.	OK	Accept - The sentence will be revised to: "by qualitatively considering the following." Quantitative criteria are also given. In this section we present general criteria used by WHC. Some of these are used in the rest of the document as is, for example 25% of LFL to decide if there is a flammability concern.	

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 7

BEI 3 2-3 2.1.3 E	The first sentence in the second paragraph seems to be at odds with Tank Farm Safety Criteria. It is apparent from many other tank farm documents that one of the principal safety criteria is that the tank dome vapor space always have less than LEL for H_2 and I believe it is <2%. Anything higher is an off-normal or accident mode. This sentence says that the Safety criteria is that it have less than 25% H_2, which says that 24% H_2 is considered safe. Please fix this sentence.	OK	Accept - sentence should state less than 25% LFL hydrogen equivalent.	
BEI 4 2-4 2.1.3 E	The sentence at the top is a judgmental statement under a Criteria Section. Please delete.	OK	The observations were important in establishing the 25% LFL criteria and need to remain as explanatory text.	
BEI 5 2-4 2.1.4 S O.K. See Text Appendix	All of the material on page 2-4, including ¶2.1.3 and ¶2.1.4 have promised safety criteria, but the only thing that appears is criteria related to establishing a tank classification scheme. Whereas that is interesting, and of value somewhere else, it does not help with this document if one were to look for the principal health and safety criteria, which are missing.	No such sections in revised text. O.K.	This Section (now 2.0.3 and 2.0.4) have been revised. Criteria are now referenced but bulleted items at beginning of 2.0.3 are now considered "qualitative observations". As it exists it is still inconsistent	
din 3 2-5 2.2 Tbl 2-2 O	The safety criteria of organic watch list tanks specifies that the level 3 tanks (unsafe) are defined as not meeting level 2 requirements. This implies there are three variables that could be judged to define a level 3 tank which are: less than 5 wt% TOC, less than 17 wt% moisture, and greater than 90°C. I don't think that it is intended that all three criteria be used to judge the level 3 Watch List tanks. Level 1 tanks are defined as having less than 5 wt% TOC. The specific criteria used to define the level 3 tanks should be specifically defined.		Table cited was not germane and has been deleted. The safety criteria for organic watch list tanks should be provided in SA. O.K.	

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 8

BEI 6 2-5 2.2.1 O	These four categories have no category for tanks that exhibit episodic gas-release behavior.	ok	The third item considers tanks that potentially exhibit episodic gas release. There is only one SST in this category (A-101). There is no data to suggest that SSTs exhibit episodic releases. There is however a concern that they could. See Appendix L also.	
BEI 7 2-5 2.2.2 E	The first two sentences tell the reader that there is "some very scarce, limited." data available. That seems to have more qualifiers in a row than necessary.	ok	Accept - "Very scarce" will stay, "limited" will be deleted.	
BEI 8 2-6 2.2.3 E	"free-standing" liquid. This would imply an unsupported column of water, last seen when Moses crossed the Red Sea. I suspect that some term from the hydrologists, like "perched" supernatant would be more accurate and descriptive.	ok	Accept - The sentence will be reworded.	
BEI 9 2-7 2.2.4 E	On page 2.7, the heat of combustion is referred to as heat of combustion, on the next page it is called heat of reaction. The term heat of combustion is correct.	ok	Accept - heat of reaction on page 2-8 will be changed to heat of combustion.	
BEI 10 2-8 2.2.4 E	line 9 from top of page. It is not "potential hazards", but "potential consequences" which are increased.	ok	Accept - Hazard will be changed to consequences.	
BEI 11 2-8 2.3 E	Is it correct that 6.5 feet of earth covering was used for "Heat dissipation"???	ok	Accept - Yes. Primary Reason: shielding Secondary Reason: heat dissipation	

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 9

BEI 12 2-9 2.3 Fig. 2.1 E See Tank about other Tanks.	Please insert a drawing that an engineer could find acceptable. This tank is out of scale, lop-sided, and probably inaccurate. O.K. HOWEVER INFORMATION PROVIDED BY THE NEW FIGURES IS DIFFERENT FROM WHAT WAS ON OLD FIGURE —	OK	Note Figure 2-1 is a schematic. A schematic is a broad, diagrammatic presentation. A detailed civil engineering drawing was not intended. However, an improved schematic was added with representative dimensions. The engineering drawings are available for the reviewers.	
din 4 2-8 2.3 last 0	This section describes that the HEPA filters are protected by a small loop seal to protect against a plugged filter. This is also potential for an unmitigated release of radioactive and hazardous material if the loop seal is unintentionally voided of the seal material or needed to relieve the pressure from a plugged filter. This potential accident scenario should be included in the safety analysis of system operation.	O.K.	The loop filter seal is on the tank breather inlet HEPA. The presence of the RMCS does not increase the probability of loop seal failure and reduces the probability of unmitigated release (due to the presence of the exhauster) in the event of a loop seal failure.	

A FAILURE OF THE EXHAUSTER COINCIDENT WITH LOOP SEAL FAILURE ~~OF~~ SHOULD BE EVALUATED AS A POTENTIAL ACCIDENT.

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 10

din 5 2-9 2.4 gen S See Flue O.K	From the description of the various components associated with the core sampling operation, it is difficult to understand how the components of the drill string interacts with each other. This information is essential for the reviewer to determine the potential accident that can occur with the drilling operations. Detailed diagrams/drawings of the component interfaces should be provided. Examples of the interfaces needing further definitions include the quadralatch, the pintle rod, the pintle rod/rotary valve, the grapple clasp, the mechanical remote latch, etc. For example, it is not clear from the discussion/drawings, how the mechanical remote latch is used to interface with the sampler to insert/remove the new samplers as the drilling progresses or to retrieve the samplers following the completion of the core sample drilling. AWAITING RECEIPT OF DWG. SET.	O.K	The difficulty in understanding this system is understood. Section 2.0 and Appendix A provide some detailed drawings, however, without the use of video tape or direct field observation it is difficult to fully comprehend the operation of the RMCS system. WHC staff would welcome the opportunity to show the reviewer(s) how the system performs. Section 2.0 tries to give minimum design information and defines the system in a general sense. References and adequate WHC design documentation are available to the reviewer. WHC will assemble a drawing set for use by reviewers.	
BEI 13 2-11 2.4.1 E	"but" is an inappropriate conjunction. It should be a simple statement of fact - "and"	OK	Accept - 'but' will be changed to 'and'.	
BEI 14 2-11 2.4.1.2(3) E	The sentence that says the load cell is designed to shut off the motor with a "maximum load" of 250 lb. This is grammatically incorrect. That sentence says it would not shut it off with a load of say 300 lb. Recommend, "... if the load equals or exceeds 250 lb."	OK	Accept - will strike "with a maximum load of" and replace with "if the load equals or exceeds 250 lbs."	

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 11

BEI 15 2-12 2.4.1.4(3) S	The drill teeth are a safety feature of the system. However the teeth are "proprietary" NOT OK! This is the Safety Analysis document. If the Safety Analysts don't know what it is made of, I find it hard to believe that it is acceptable. Being proprietary does not mean that we should be commensurably ignorant! Provide either the composition of the material, proprietary or not, or a complete property data sheet, showing as a minimum hardness, tensile and compressive strength, melting point, and sparking potential.	O.K	The material is now identified in 2.4.13. NO SUCH SECTION IN REVISED REPORT — OPEN. NEED TO PROVIDE IN SA.	
BEI 16 2-13 2.4.1.4(4) S O.K	The description of the drill rods is unacceptable. The hydrogen burn and explosion are based on the volume and strength of the drill rod. Although the OD is given, the volume can not be calculated and neither can the burst strength. Please add also the ID, the nominal wall thickness, the minimum wall thickness (in the vicinity of the threads), and the tensile strength and fracture toughness.		Accept - The volume of the drill string is important but we always assumed that if there is a spark in the drill string no matter what the volume and gas composition is the flame will propagate into the waste. This is conservative. However, the requested data will be added (now Section 2.4.1.4).	

NO SUCH SECTION IN REPORT — REVIEW WHEN AVAILABLE STILL OPEN

Comment Coding
S Significant, O Optional, E Editorial

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din 6 2-19 2.4.2 2nd P S Add Text to 2.4.1 OK	This section describes the exhauster system which includes an air preheater to maintain the humidity of the air to be no greater than 80%. What controls are placed on the operation of the preheater for the operation of the exhauster system? If the preheater fails, does this imply that the exhauster must also be shutdown? The implications associated with a system failure should be described in this section or provide a reference to where the operational limitations are provided. Loss of preheater is not one of the items identified in Section 2.5.5.3 that would cause an automatic termination of the exhauster. A failure of the preheater could be either in leak of the HX to the filter system which could result in plugging the filter or a failure of the HX to operate that would result in excess tank humidity getting to the filter, thus causing the filter to plug. The controls for the preheater should be discussed. INCLUDE IN SA	O.K	Failure of the water tube preheater does not result in a hot spot and cannot cause ignition of flammable gases. Failure of the preheater could result in saturated HEPA filters. Airstream humidity is constantly monitored and an alarm is generated when the level exceeds 80%. To further protect against filter collapse, the blower is limited to nine inches of water static pressure. The HEPA filter manufacturer states that the filters will remain intact and maintain effectiveness at 10 inches of water pressure differential. No preheater controls are required.	
BEI 25 2-29 2.5.2 Bullet 1 0	After a detailed description of the equipment in Section 2.4x, there was no mention of a "bonded lifting bail." Is this "bonded" as in insured or guaranteed (to compensate for the proprietary drill bit) or is it bonded as in glued?, and if glued, what kind of glue. Or is it somehow electrically bonded? The statement obviously raises more questions than it answers.	OK	Accept - Clarification will be added that the electrically bonded lifting bail is a device that supports the drill string and never enters the tank.	

Comment Coding

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IN REVISED COPY SECTION 2.5.3 IS THE SAME AS 2.5.4

BEI 26 2-30 2.5.3.1 Bullet 1 S	A key component is the gas monitor. The system can not be operated without it. Later, (table 4-10), it is identified as a credited control. There is no mention of the gas monitor in the system description, or in the diagram (Fig 2-13) accompanying this paragraph.	OK	Accept - A brief description of the gas monitor will be added to Section 2.0 with reference to Appendix U (added as 2.3.3). The gas monitor design criteria are discussed in Appendix U.	
din 7 2-36 2.5.5.2.2 S	This section specifies the limits on the rotational speed of the drill at 55 rpm and the down force limit at 750 lbf. This is not consistent with the limits specified in Appendix N which specifies the rotational limit of 40 rpm and the down force limit of 650 lbf for drill strings of greater than 45 ft. The limits should be consistent throughout the report. This same comment applies to the information presented in Table 2-7.		These limits are for different problems. 55 rpm and 750 lbf in conjunction with purge gas flow are to control drill bit temperature (Level 1 Hardware Control 6.6.4.1). The 40 rpm and 650 lbf are to compensate for a potential buckling problem with a long drill string (Level 3 Administrative Control 6.9.12.4).	OK
NM 4 2-37 2.5.5.2.4 ~~2.5.5.2.5~~ S OK	The document should specify which procedures and controls will ensure implementation of the necessary actions outlined in these sections. where are PROCEDURES SPECIFIED.		The document specifies all necessary controls in Section 6.0.	
NM 5 2-38 2.5.6 S OK Refer only to IOSR's (?)	This section states that "Restart following off-normal incidents should be performed in a way consistent with the requirements of the Interim Safety Basis." Even though this is necessary, it is not a sufficient statement. The applicable and approved requirements in the ISB should be identified in the section in table format.	OK should BE SA. is	Applicable and approved requirements are identified in Section 6.0. This SA and IOSR's will be implemented via a revision to the ISB.	

Comment Coding

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BEI 17 3-2 Table 3-1 E	For chemistry consistency, recommend that Oxygen be added to the list of flammable gases, since it is abundantly present; then, under the right hand column group first the "flammable fuel gas" and then the oxidizers.	OK	Flammable gases, in the context of the safety assessment, are mixtures of H_2 and oxides. Oxygen will be added as an oxidizer.	
NM 6 3-3 (Methodology) S O.K.	See NM 1 Gen and NM 2 Exec Sum Gen Above. This approach circumvents the Safety Analysis Review process by omitting essential issues from the SA and leaving them for review at a later date under a USQ. As such, the SA is incomplete, and it is an improper application of the USQ process.	O.K. See NM-1 Table	No circumvention of Safety Analysis Review process is intended. See response to NM 1 GEN and NM 2 Exec Sum GEN.	
NM 7 3-4 S 3.2 O.K.	This section states that "the hazards associated with transportation of the rotary-core drilling unit or its auxiliary equipment from the tank farm or its ultimate decontamination and disposal are not considered. Transportation of the cask where core samples are stored is also not considered." The SA should identify which approved document evaluates these activities and conditions. Otherwise this presents a problem with "Interfacing" between activities and facilities, and consequently introduces non-evaluated scenarios and associated risks.	OK Reference to SA for transport of cask should be cited.	Accept - Appropriate reference documents will be cited. Transportation of this equipment outside the tank farm boundary is clearly outside the purview of the safety assessment.	
NM 8 3-5 3.2 S OK	First Paragraph, states ... "frequency determination did not include a detailed failure-rate evaluation, but qualitative frequency estimates are provided." This is a legitimate approach, however, the SA should provide a logical derivation of the values presented more than "engineering assessment".		Data used in the estimation of reliabilities are obtained from standard industry literature and documented in (Appendix D and E) and provide a logical derivation to the approach. They are available to the reviewer.	

MUST SHOW THAT STANDARD CONDITIONS & ENVIRONMENT DATA IS FOR THE [illegible] THIS PROPOSED APPLICABLE [illegible]

Comment Coding

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
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BEI 27 3-8 Table 3-3 Row 6 0	Comment BEI 15 was made in response to a failure to identify the drill bit material. In this table the teeth are incorrectly identified as (brass-based). Since brass is a generic name for a wide variety of copper-zinc alloys, it is non-scientific to refer to a brass-based alloy. This table refers to ¶ 4.2.6, which correctly refers to the drill bits as bronze (a correct and valid term) and also equally correctly as copper-based. It is recommended that a proper description (sintered bronze with tungsten bits) be incorporated into ¶2.4.2.4, and thereafter use either bronze or copper based unless more detail is warranted.	ok	Accept - It will be changed to copper-based.	
BEI 28 3-10 Table 3-4 Row 5, C3 E	"maintain continuous in contact" ? How should it read ?	OK	Accept - Sentence revised to "maintain continuous contact".	
din 8 4-6 4.1.1.3 0	This section specifies that the exhauster air stream is preheated with a hot water heat exchanger to preclude condensation from occurring on the HEPA exhaust filter. It is not apparent that the increased likelihood of the plugging of the HEPA filter due to leaks from the heat exchanger has been taken into consideration. (See comment din 6).	OK	Yes, this has been taken into consideration. The benefit of a non-electrical water heater far exceeds plugging the HEPA filter, which event would cause exhauster shutdown, an uncommon but anticipated event.	
din 9 4-10 4.1.3 E	This section specifies that leak size for pit to riser is assumed to be no bigger than 1 in. It should be clarified what is meant by 1 in. In Table 4-3, it states that "..less than 1 in.-effective leak diameter". If this is what is meant, then it should be used throughout the text.	OK	Accepted - text will be scanned for consistency and changed to 1" effective leak diameter.	

Comment Coding
S Significant O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 16

din 10 4-21 4.2.3 S O.K.	Several of the frequencies presented in this section are not supported by the logic or assumptions used to derive the frequency values. Differing frequency values can be found in some of the Appendices (D and E). It is recommended that the detailed information and assumptions be provided in the SA. Some of the probability numbers appear to be extremely small. Justification of these numbers needs to be provided.	OK	Accept - Appendix D and E will be reexamined and appropriate justification provided as necessary. REWORKED SECTION 4.2.3	
din 11 4-40 4.4.2 S O.K.	This section states that aluminum, bronze, and teflon are known to be incompatible with some of the wastes. In Section 4.2.6, it states that the drill bit is made of sintered bronze. What compatibility tests have been run to determine the compatibility between the waste and the drill bit? This information should be supplied in the SA. Chapter 2 should provide a description of material used for the construction of the various components so that the reviewer can determine the compatibility of components has been adequately addressed. PROVIDE BASIS/5 IN SA. SECTION 4.4.2 NEEDS TO BE CLARIFIED.		As stated on page 4-25 if the Bureau of Mines (BOM) tests indicate no ignition, then the accident frequency with this proprietary material is considered zero. BOM tests are now complete. Material compatibility has also been demonstrated by the evaluation of historical information.	
din 12 4-51 4.8.1 S	The assumptions used to determine the maximum release from a HEPA filter failure is based on the loading from the drilling operations associated with one tank. This implies that the exhaust HEPA filter must be changed out after each tank drilling operation to maintain the safety analysis within limits. This requirement should be incorporated into the administrative section of the IOSR to ensure that it is accomplished.	OK	As long as filter housing contact dose rate is less than the 100mR limit (specified in 6.9.6.5), the value for the maximum release as postulated in the SA would not be exceeded. There is no need to change out filters until the 100mR limit is reached or the pressure differential limit (5.9 inches w.g.) across the filter bank is exceeded.	

Comment Coding
S Significant O Optional, E Editorial

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BEI 29 4-46 4.6.2(1) O	"The rubber seal that girths" is not shown/discussed in the system description section ¶2.xx.	OK	Accept - It is described in 2.4.3 (page 2-21). The word 'seal' will be changed to 'frisbee'.	
BEI 30 4-46 4.6.2(2) E	The low frequency does not impact the hazard. Change in frequency changes the Risk.	OK	Accept - change hazards to risks.	
BEI 31 4-48 4.6.4(2) E	"The stress from this impact" can not trace the impact being addressed.	OK	Last sentence of previous paragraph discusses risers being driven into the tanks. The stress reference to is the result of these impacts.	
din 13 5-2 5.1.2 S b	This section specifies the Radiological Risk Guidelines that were used in the evaluation of the safety or the Core Drilling Operations. The most restrictive of the risk guidelines cited were used in the safety evaluation. However, some more restrictive limits are being proposed, primarily for the onsite workers. How much impact on the safety analysis results if the more stringent limits were imposed?	OK	As stated in 5.1.1. Revision 3 of the Risk Guidelines were used per the direction of DOE-RL. More stringent guidelines have not been analyzed. DOE HAS MADE A RULING ON WHICH RISK GUIDELINES MUST BE USED IN SARS.	

THIS SECTION SHOULD REFLECT CURRENT STATUS OF RISK GUIDELINES.

Comment Coding
S Significant   O Optional   E Editorial

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din 14 5-8 tbl 5-7 S	The selection of the size of the releases during drilling operations is based on event probability; smaller releases having a higher probability of occurrence. The event probability associated with the size of the release is provided in Table 5-7. However, in Table 5-8 the events are classified as "anticipated", "very unlikely", etc., that do not correspond to the calculated frequency of occurrence should be provided. An explanation of the event classification and how it corresponds with the calculated frequency of occurrence. One would expect that the classification and the calculated frequency of occurrence would be in direct correlation with one another. It is difficult to rationalize an anticipated event having a frequency of occurrence on the order of 2E-6/yr. See change in Table 5-7 O.K	The same terminology should not be used for classifying the releases and accidents	Frequency Category vs. Frequency Range was discussed on page 5-3. The words "anticipated", "unlikely" etc. are used to define the gas release event during the accident itself. There are other events that must occur to have a radiological release. These events are discussed in the text and their failure probabilities are given in the table.	
NM 9 7-1 7.0, 7.1, 7.2 S	See NM 1, NM 2, and NM 6 O.K.	See 111 7.1 incomplete Issues 2, Tabulation	See NM 1, NM 2.	
NM 10 7-2 7.7 S	This section requires that "If additional Level 1 Controls are found to be necessary as a result of actions needed to close the open items, the SA must be reviewed and approved prior to operations." 1) How will this be implemented, and which authority/expertise will make this determination ? 2) See NM 1, NM 2, and NM 6 above. This de facto makes this document incomplete for the planned activity. O.K		If changes to the SA are required, review and approval will be by DOE-RL. Implementing the Section 6.0 controls and completing the Chapter 7 items makes the SA complete for the tanks specified in Appendix G.	

Open items must be closed prior to approval of S.A. Approval can only be granted to open item if restrictions on operation/ hardware are imposed.

Comment Coding
S Significant O Optional E Editorial

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NM 11 7-3 7.8 S O.K.	Considering the checklist shown in this section, the reader can infer that an SA must be performed for each FG/RCMS activity on any other tank, or treat these activities as USQs. The mechanism for the intended approach should be clearly delineated. G. 5.2.3 HAS BEEN REVISED TO ELIMINATE THE REQUIREMENTS FOR ADDING ADDITIONAL TANKS.		The checklist itself will stipulate the mechanism for adding an additional tank. This mechanism is covered in 4.2.3 of Appendix G (page G-15) and Administrative Control 5.31.1 of the IOSR.	
NM 12 A-2 GEN (1st Para) S O.K.	See NM 1, NM 2, and NM 6. The SSCs, preventive and mitigative procedures should be an integral part of the SA. DOE ORDER 5480.23 REQUIRES THE SA SHOULD DOCUMENT PROCEDURES		See NM 1 and NM 2 (~~at a commercial operating nuclear power facility, abnormal operating and emergency response procedures are not in integral part of the safety assessment~~).	HOWEVER, DOE REQUIRES PER 5480.23
NM 13 A-3 1.2 S OK	First Bullet. The type and quantity of hazards are not shown in Table A-5. "Chemical Reactions" and "Tank Waste" do not describe type or quantity of a hazard.		Appendix A is used for screening purposes. Table 3-1 summarizes the hazards.	O.K.

Change Heading of 3rd Col. Table 5-1 HAZARD / Accidents

FOR THE CONDUCT OF NORMAL, ABNORMAL & EMERGENCY OPERATIONS. (ATTACH. 1 ITEM 13).

THE HAZARDS IDENTIFIED IN TABLE A-5 DO NOT FOLLOW THE DEFINITION OF HAZARD DEFINED IN SECTION A.1.2. NEITHER DOES TABLE 3-1 DEFINE THE SPECIFIC HAZARDS ASSOCIATED WITH "CHEMICAL REACTION" OR "TANK WASTE".

O.K.

Comment Coding

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NM 14 A-6 2.0 S	This section concludes that "bump drilling mode was eliminated from the operation." The SA should delineate the controls or procedures that implement this exclusion.		Bump drilling mode is outside the safety envelope established by the SA. These modes of operation were proposed. They are not physically possible due to design controls and administrative requirements. Section 2.0 intentionally does not mention bump mode or slow rotation modes that were identified during the initial hazards identification study. They are not going to be used. Therefore, they are not defined in Section 2.0. This SA only addresses the operations defined in Section 2.0.	ok
BEI 35 B-04 3.3(2) E	There appears to be either an error in this paragraph or it is simply unclear. If the definition of "diameters" remains constant, than it is impossible to have the concentration drop from 8% to 2.4% to 0.6% and then increase to 1.2% at distances of 0, 18, 2.2, and 36 source diameters, respectively. A sketch could solve most of the mis-understanding.		Accept - The centerline concentration drops from 2.4% to 1.2%. The concentration of 0.6% is at a radial distance at 18 D axial distance. The sentence will be revised to .."the concentration at the 18 D axial distance drops to 0.6% at a radial distance of 2.2D from the jet centerline."	ok

Comment Coding
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HOW ARE THOSE REQUIREMENTS CITED IN CHAP 4 IMPLEMENTED? MOST OF THE REQUIREMENT ARE NOT CITED IN CHAP 6.

NM 15 B-5 3.3 S O.K.	This section describes and calculates consequence to equipment exposed to a flammable atmosphere. The second paragraph on page B-5 stipulates positioning of equipment during the activity. This preventive approach is legitimate, however, the SA should also indicate the controls and procedures which will ensure and implement this preventive approach.	PLEASE PROVIDE RATIONALE	The appropriate requirements have been stated in Sections 6.0 and 4.0. Section 6.0 requirements will be added to the IOSR and then put into lower tier controls and procedures.	
NM 16 B-8 4.1 S	The SA should provide the rationale and basis for assuming that the releases from tank 101-SY are bounding for the FG/RMCS activities. O.K. No! They are not! Please provide rationale & basis		The rationale and basis for assuming that gas releases from Tank 101-SY are bounding are contained in Appendix L. The worst gas release is observed in tank 101-SY. As discussed in Appendix L, SST gas releases are expected to be much smaller and slower. Based on the data we have the bounding number is given in the appendix.	

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NEED DEFINITION OF "SLOW" DAYS, WEEKS, YEARS, etc.

NM 17 C-3 3.1 S O.K	The second bullet states " The species ratios do not change with time or bubble location in the waste." This is correct only under steady state conditions but not after a GRE since the production rate for each of these species is unique and different. Consequently, the added assumption that they are in at constant proportions is also not always true. The SA should address this concern. THERE IS NO INDICATION THAT AN EQUILIBRIUM CONDITION WILL EXIST!		Gas release event is relatively fast. Chemical processes effecting gas generation rates are slow. The gas released during a GRE is the gas that is stored in the waste prior to the GRE. Therefore, the composition of stored gas is a good measure of the composition of gas during a GRE. The composition prior to the GRE is the concern. During a GRE the release of the stored gas is the concern and not the gas as it is being generated. RMCS operations were not contemplated during transient events.	
NM 18 C-5 Table C-3 S O.K	The discussion, methodology, and results summarized in Table C-3 are based on Steady-State conditions. These do not necessarily represent conditions during and after a GRE. The SA should evaluate this concern.		See response to NM 17. The SST data are used conservatively to bound the composition of the gas that is stored in the waste for a long time.	
NM 19 C-6 3.1 S O.K	The last statement in this section concerning AX-101 should be re-evaluated in view of comment NM 18 above.		See response to NM 17 and 18 (also the verification step of assuring hydrogen equivalent gas concentration is < 1000 ppm prior to initial RMCS operations verifies this steady state).	

Comment Coding
S Significant O Optional, E Editorial

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BEI 36 C-10 4.0 S O.K.	Sustained reactions in a gas are a function of composition, pressure and temperature. The over-pressure is also a function of temperature. Please provide temperature information, initial and calculated final temperatures, and ignition temperatures. SEE ATTACHED TEXT AND CALS. THE TEXT INDICATES THAT THE IGNITION TEMPERATURE IS A FUNCTION OF PRESSURE 5 mm Hg CORRESPONDS TO IGNITION TEMP OF ~400°C. AT ATMOSPHERIC PRESSURE, THE IGNITION TEMP IS ~550°C. THIS INFORMATION SHOULD BE INCORPORATED INTO H_2 EVALUATION.		Calculations are based on conservative waste temperatures. Pressure does not effect the adiabatic burn calculation because specific heat of ideal gas is only function of temperature. The initial dome pressure was atmospheric. The ignition temperature is not used in this calculation. When a burn is assumed, a spark with an ability to ignite is considered regardless of its origin. Ignition temperature is only a concern when there is a hot spot somewhere in the system.	
BEI 37 C-10 4.0(3.4) S include in Text O.K.	The data in ¶ 3 and 4 can not be reconciled. In ¶ 4 it states that 96 m^3 of hydrogen is equivalent to 2.4%. In ¶ the dome volume is assumed to be 1415 m^3; but, 96/1415 = 6.78%. THE EXPLANATION OF THE AMOUNT OF H_2 IN THE RELEASE GAS COULD BE BETTER EXPLAINED IN THE SA TEXT. EVEN THE USE OF PIE CHARTS TO SHOW THE GAS COMPOSITION WOULD BE USEFUL.	OK	96 m3 is the released gas volume and is not 100% hydrogen. It was assumed that there is 60% ammonia in the released gas. Remaining 40% includes 88.1% hydrogen as indicated in AX-101. Thus, hydrogen concentration becomes 35%. If 96/1415.8 is multiplied by 35% we have 2.4% hydrogen in the dome. include in Text.	

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BEI 38 C-10 4.0(4) S O.K.	It is stated that the adiabatic burn will give a pressure of 35 psia in a 2.4% H_2 burn. Using 57.8 kcal/mole (241 kJ/mole as on page C-6, 8.8, 6.9, and 7.07 cal/mole•K for the specific heat of water, nitrogen, and oxygen, respectively, and 6.6% by volume hydrogen, and an initial dome air-space temperature of 50 C, this reviewer calculates a peak temperature of 590 C (the ignition temperature of hydrogen in air from the Handbook of Chemistry and Physics) and an final pressure of 37 psia. Using similar assumptions, a 4% mixture would result in a pressure of 30 psia, still enough to fail the tank. The issue is not whether or not an over-pressure sufficient to fail the dome is possible, but in reproducible and traceable statements in the text.		Section C.4 (page C-16) was largely rewritten. SEE ATTACHED TEXT AND CALCS. MAKE STATEMENTS IN S.A. TEXT DEFENSIBLE.	

Comment Coding
S. Significant O. Optional E. Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
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BEI 39 C-10 4.0(4)b S O.K.	Following the above comment, the flame/gas-explosion literature was revisited. It is very clear that the mathematics of flames and explosions is far more complicated that the description in Appendix C. Clearly, one must be careful in describing terms and conditions. And the state variables are pressure, volume (or mole-percent), and temperature. The resolution of the problem discussed in the previous comment is that ignition temperature is a function of pressure. At a pressure of about 5 torr, the ignition temperature is 400 C, that is the lowest temperature at which a hydrogen oxygen flame can propagate. At 1 atmosphere, the ignition temperature is 550 to 590 C. The 4% LEL is not energetic enough to raise the temperature to 550 C. Additional factors are the ignition temperature falls in an oxygen rich (air) atmosphere. The 4% and 400 C are safe limits under essentially any conditions. However, one can not use the minimum ignition temperature of 590 C, and the concentration that will produce that temperature to calculate an over-pressure and attribute it to an administratively low 2.4% hydrogen concentration. Please include a few standard graphs which show ignition temperature as a function of pressure and concentration, and computed temperatures and pressures as a function of hydrogen concentrations such that the document will be technically accurate. (See attached Reference Figure) THE 400°C AUTOIGNITION TEMPERATURE IS NOT CONSISTENT OR VALID FOR ATMOSPHERIC CONDITIONS.		In order to cause a burn we need three things, fuel, oxygen, and energy (spark) to ignite. Spark can be created by electrical, mechanical, etc. devices. In this SA we are mostly concerned with the frictional sparks, electrical sparks, impact related sparks, etc. These have enough energy to ignite hydrogen. One needs only 0.01 mJ (electrical device) to ignite H2. One other way to start combustion is to exceed autoignition temperature as the reviewer points out. The autoignition temperature is only concerned when there is a hot spot created by friction or something else. Autoignition temperature is pressure dependent but also changes with composition. Autoignition temperatures may be around 400°C ~~(see Appendix G) for H2 and N2O~~ mixtures. The pressure effect is somewhat irrelevant because we have always atmospheric pressures or slightly less than this value in the dome. The flame propagation after ignition is mostly concentration dependent. There are only a few accidents in the SA concerning the autoignition temperature (frictional heating of the riser	

Autoignition at 400°C occurs at a pressure of ~ 5 mm Hg,

Comment Coding
S Significant O Optional, E Editorial

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BEI 39 C-10 4.0(4)b S (continued) O.K.	See attached copies of pages from KUO, "Principles of Combustion" The conflict has ~~been~~ and remains that $T_i = 400°C$ @ Low pressure (5mm) $T_i = 580°C$ @ atmospheric.		hot spots are cooled and prototypical experiments showed no ignition due to both frictional sparks and autoignition temperature. Lower flammability limits is also different for mixtures. It goes down with addition of NH3. Additional clarity has been provided through a re-write of most of Appendix C. The information presented is accurate.	
NM 20 C-12 5.0 S O.K.	The next to last paragraph of this section assumes that "gas and water are homogeneously distributed." This assumption cannot be true since we know that the waste is stratified in the tanks, and that the gas is collected below a stratified layer and the supernatant liquid (water) is above this layer. Case in point is the "roll over" or GREs observed in tank 101-SY.	ADD TO SA TEXT	It is agreed that gas and water distributions are poorly understood. This section refers to the interstitial gas and liquid stored in the gas retaining layer, and does not address the macro stratification in the tank. This section estimates the total volume of gas available to burn	

and that flame propagation is a function of ~~both~~ Tinitial, ~~and~~ Concentration, and pressure

$PV = nRT$

Comment Coding
S Significant O Optional E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
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din 15 D-6 Tbl D-1 S	The results in this section specifies some results for the failure to trip drill string on excessive rpm. It is not clear if this includes the dual trip value of 55 rpm for less than 45 ft and 40 rpm for DS lengths greater than 45 ft. This should be clarified in the SA.	OK	55 rpm relates to temperature of drill bit (Level 1 Hardware Control 6.9.12.3). 40 rpm relates to drill string buckling (Level 3 Administrative Control 6.9.12.4). Structural limits are not controlled automatically but manually using by administrative controls as indicated in Sections 6.0 and 4.0.	
din 16 D&E gen E O.K	There are twelve items that were modeled to perform a systems reliability analysis. The results of the analysis is provided in Table D-1 for the frequency of the initiating event and the probability of subsequent failures. However, there are no details or assumptions used in deriving the results. For the SA reviewer to assess the results, these details are needed to be included in the SA description. Some of the results appears to be questionable on the low side and needs to be substantiated with more information. Appendix E just repeats the same results.	O-K THE ASSUMPTIONS ASSOCIATED WITH DERIVING THE RELIABILITY NUMBERS SHOULD BE SUMMARIZED IN SA TEXT.	Appendix D estimates reliability based on fault trees given in SA references. Appendix E uses the reliability numbers and estimates the frequency of accident using event trees per activity. Calculations are available to the reviewer and include all the necessary information.	
din 17 E-4 Tbl E-1 row 3 E	This row discusses the leaking riser penetration releases. Under the controls credited for mitigative action, it states "limit leakage from all unused risers/pits to less than 1 in". Is this a hole size, an area (units), or the amount of vacuum needed to be maintained? The control measure needs to be clarified.	OK	Accept - text will be amended to "less than 1" equivalent diameter."	

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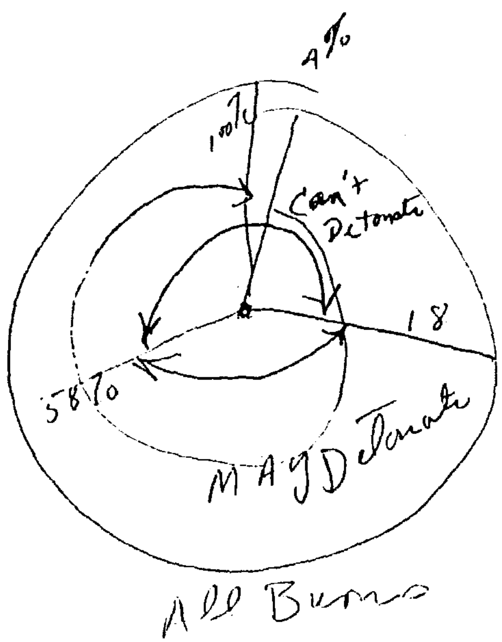
BEI 40 G-02 2.0 Bullet 2 S	As stated in Comment BEI 39, the auto-ignition temperature is a function of pressure. The 400 C temperature is applicable to about a 5 torr pressure system. The atmospheric pressure auto-ignition temperature is above 500 C.		See response to BEI 39. SEE RESPONSE TO BEI-39 FOR CORRECTIVE ACTION	O.K.
BEI 41 G-06 3.2 Eq G-4 S (add Ref def. k)	The paragraph following Eq-G4 is unsupported. Biot is undefined, k is undefined, and time constant is undefined. "K" & "TIME CONSTANT" ARE NOT DEFINED.	O.K	They are defined in the text.	
BEI 18 J-02 Para 3 E	This sentence needs help. "... the mole fraction ... be zero" is not good English. Elsewhere in this section "be" is used incorrectly.	OK	Accept - change " mole fraction be " to mole fraction is " and " be one " to " is one ".	
BEI 19 J-03 Para 3 E	Middle sentence "... hydrogen caused by thermal gradients ..." should have the word "diffusion" after "hydrogen"	OK	Accept.	
BEI 20 J-10 Para 3 O	Agree. Independent calculation by this reviewer confirms the calculated over-pressure.	OK	No action required.	
BEI 21 J-10 3.2(3) E	a problem with plural "distance"	OK	Accept - will change to singular.	
BEI 22 J-11 (2) E	"beyond" is a poor choice of preposition, since 20% is "beyond 18%" and that is not what is meant.	OK	Replace 'beyond' with 'greater than' and changed to < 18% and > 58%.	

Comment Coding
S Significant, O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 29

BEI 23 J-11 (2) S	The logic supporting the conclusion that "any burn in the drill string may detonate" is inadequate. There is a problem with an undistributed middle. The argument presented is: A- Concentrations between 18% and 58% hydrogen detonate. (agree) B - Hydrogen concentration can reach 18% in 30 minutes. (agree) Therefore, C - All burns will detonate. (disagree!) B has nothing to do with A. This faulty argument is then made the e conclusion of the Appendix - see ¶ 3.3 below (BEI 24).	*O.K*	Last sentence in paragraph states "therefore, any burn in the drill string may detonate." Detonable concentration is obtainable in the drill string if there is a waiting time. The minimum time to reach the minimum detonable concentration is determined, and a control is provided to eliminate the flammable gas from drill string. Therefore, there is a relation between the time and concentration.	



Some burns may Detonate

(NOT "ALL" BURNS MAY DETONATE.

Strictly a matter of logic

Suggested wording
Therefore, ~~[illegible]~~ some burns may lead to detonation.

Comment Coding
S Significant O Optional, E Editorial

MISSING IMAGE

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 30

BEI 24 J-11 3.3 S	The conclusion section contains 6 conclusions. The first four address over-pressure and rate of pressure rise. This reviewer has no argument with those conclusions. The fifth conclusion is that "any burn may detonate because the rate of pressure rise is very high during the detonation". That is an unsupported statement and is worse logic than made in the body of the Appendix (see comment BEI 23 above. The final conclusion is totally unsupported and appears for the first time in the conclusion paragraph - Consequently, the structure of the drill string may fail ~~and cause partial dome failure~~ ! The document should present facts and documents to support the statement that a 15 bar over-pressure in a confined volume of approximately 20 liters in a 4 Ml chamber would collapse the dome // It has not even been shown. in this appendix that a hydrogen detonation would cause failure of the drill string // This is the portion of the comment that should be addressed	O.K	Fifth Conclusion May detonate is not unsupported and the unknowns associated with FGT's make it a prudent conclusion until more data can be obtained. Final Conclusion Supported by last paragraph of 3.2 The relation between drill string detonation is established in Appendix I, first bullet under 2.1. The last sentence will be revised and "partial dome collapse" will be eliminated. Section 3.2 presents arguments (Ref. 9, 10) why detonation is likely. The geometry (diameter and length) is suitable for the wave speed to reach detonation wave speed (Ref. 9). Ref. 10 presents studies detonation issue in H2-N20 mixtures to determine necessary concentration etc. The words "and cause partial dome failure" have been deleted from the text.

Comment Coding
S - Significant   O - Optional   E - Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 31

BEI 24 J-11 3.3 S (continued)		OK	The main conclusion is that if there is enough concentration in the drill string and spark detonation "may" occur. This accident was used to estimate the bounding releases. The necessary controls were also determined to prevent hydrogen accumulation in the drill string. There was also a concern about a detonation wave propagating into the waste as a detonation or deflagration wave. Nonetheless, it is agreed that a dome structural damage is a step taken without further structural analysis. However, a detonation in the drill string must be mitigated regardless of the extent of the structural damage.	

Comment Coding
S Significant O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 32

NM 21 L-1 1.0 (Item 3.) S OK	This section claims to derive "realistic accident frequencies". It should include a description/methodology on how they could be derived without full identification of the required mitigative controls, procedures, and of SSCs. CHANGE "DERIVE" TO "OBTAIN"	OK	The actual statement in 1.0 of Appendix L is "The probabilistic model is merely intended for use in comparing the bounding consequences against the WHC Risk Guidelines that require a realistic estimate of frequencies and allow for qualitative estimates for phenomena for which there are a lack of data". Derive is not the operative word here. Appendix L defines the probability of a GRE and of exceeding the LFL in the dome. The frequency of accidents are determined in Section 4.0.	
NM 22 L-4 2.1 O OK	The fifth paragraph of this section postulates that "... the retained gas volume is proportional to the waste volume" and concludes " no GRE during intrusion into the tanks would be interpreted as encouraging." The retained gas volume is actually proportional to 1) the concentration of beta and alpha emitters in the waste layer adjacent to water and radiolytically decomposing waste, 2) the water volume, and 3) the layering characteristics of sediments both above and below the water-Sr-90 and Cs-17 interface. The Sr-90/Water interface produces hydrogen gas. The Sr-90, Cs-137 interface with the balance of the waste produces the other gases.	OK	While the rate of gas generation is a function of the radiolytic load, the gas retention is more of a function of the physical properties. For a given set of properties, larger waste volumes would retain larger amounts of gas. (not necessarily True Conclusion This is not essential to the argument at hand.	

Comment Coding
S Significant O Optional, E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 33

din 18 L-8 3.0 gen S OK Define ranges of freq & use ranges	A quantitative likelihood for a gas release volume and gas release rates are discussed in this section. There are two comments regarding this discussion. 1) the terms used to describe the likelihood have established frequency of occurrences assigned to them for radiological risk guidelines (See Section 5.5.1). and the frequency of occurrence used in the gas release likelihood does not use the same frequency of occurrence ranges. Wherever these terms are used, they should have the same definition. Either make the frequency of occurrences consistent or reclassify the events using "other" descriptive terms. 2) the largest gas release that has been observed in one of the tanks is 10,000 cubic feet and this release has been assigned a frequency of occurrence of less than 1E-6. If an event has occurred, then it is difficult to classify the event as having such a low frequency of occurrence without providing a better justification for the event.	1. A consistent nomenclature should be used for specifying hazard classification. This nomenclature should also be used for such items as ... categorization.	Table L-1 gives the preliminary bins. The words are used in a qualitative sense rather than numerical implications. Next page gives the probability curves and indicates that probability of 10,000 ft^3 release is 1E-3. In this appendix, the bins are quantified based on the probabilities and not frequencies (as done in Section 5.0). NOTE: Tank 101-SY is not on the list of tanks for which the SA is currently applicable (that is the tank where 10,000 ft^3 was observed). Such a release in an SST is an incredible event.	2. Provide the basis & justification for this conclusion in SA.
NM 23 L-12 3.2 O	The second paragraph of this section states "Adding ammonia (that is also known to exist) reduces the LFL but reduces the amount of hydrogen volume in the release." This statement would be true if the production rates of the two gases were inter-dependent, and the "gas bubble" is at atmospheric pressure. However, the pressure in the "gas bubble" continues to increase until buoyancy is achieved, and the total production of each gas is cumulative (total pressure is equal to the sum of their partial pressures). The conclusions in this section should be consistent with this principle.		Accept - The text will be clarified for a given release volume, saying that a larger ammonia fraction in the release gas would imply smaller hydrogen fraction. Thus, a larger release volume is needed to reach the LFL.	

Comment Coding
S Significant O Optional E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 34

din 19 N-1 2.1 E O.K.	This section specifies that the 50 ton live load limit is not exceeded by the RMCS equipment. However, on the next page, Table N-1, a weight break-down is provided that indicates that the total potential weight exceeds the limit by about 9 ton. On page 2-25, a similar table indicates that the loads would exceed the limit by about 10 ton. Some rationale should be provided to indicate the acceptability of the loads and the discrepancy between the tables should be eliminated. THERE ARE TWO TABLES IN REVISE SA		Accept - Not all of the equipment listed in Table N-1 is on the tank. See 4.6.1. The discrepancy between the tables will be eliminated. Only one table is now used and additional explanation is provided under static dome loading. P 2-27 & P N-2 PLEASE CORRECT	
din 20 N-11 Tbl N-2 S	This table provides the rotational speed and downward force limits as determined by the drill string analysis. The limits are a function of the drill string length. These limits should be reflected in Table 2-7 that provides the operational parameters for the drilling operation. Only the maximum limits are provided and not the limits as a function of drill string length. For example, the limits for drill string greater than 45 ft. would be less than 650 lbs force and less than 40 rpm. The limits on the force and rpm should be included in Section 2 consistent with that provided in the table at the end of Section 6, pages 6-34,-35 for operation of the drill string greater than 45 ft.	OK	Accept - line will be added to Table 2-~~7~~ 6.	
BEI 32 R-4 4.0 E	line 7, the 7 is dropped off in ^{137m}Ba	OK	Accept - text will be modified.	
BEI 33 R-5 4.1 E	Last sentence in ¶1, the power of the number 8.71 has been dropped. (8.71 E-4 Ci/g).	ok	Accept - text will be modified.	

Comment Coding
S Significant O Optional E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 35

BEI 34 R-5 4.1 0 O.K.	This reviewer has performed an independent calculation for the radiation at the surface of the filter housing and agrees with the magnitude of the number. However the field at the surface is given to 3 significant figures (317 Mr/hr). This implied accuracy greatly exceeds the uniformity of the filter geometry. Fields can be expected to vary by as much as a factor of 10 (greater or less than the 317 mR/hr), depending on the uniformity of deposition and the exact region of the filter one is 1 cm from. Only Single Digit Accuracy is		Both results are above allowable limits (100 mr/h). Therefore. accuracy considering uncertainty does not change the conclusion. The necessary controls to mitigate the event have been established and are specified in Section 6.0. warranted !!	
din 21 U-gen gen 0 See Text change OK	In this section the functional requirements for the flammable and toxic gas sensors is described. The sensors described include the Wittaker Cell and the SMC combustible gas sensor. These sensors would only detect the presence of combustible gas and would be minimally effective in detecting the presence of toxic gases. The SMC detector appears to marginally satisfy the functional requirements for the combustible gas sensor. The rationale for the selection of this detector should be provided in this Appendix. It would seem prudent to reassess the use of the SMC detector to satisfy the flammable gas detection functional requirements.		The sensors were not intended to detect toxic gases. The sensors meet the requirements of Appendix U.	

THE TITLE OF APPENDIX U IS "FUNCTIONAL REQUIREMENTS FOR FLAMMABLE AND TOXIC GAS SENSORS" THIS SECTION SHOULD PROVIDE THE "REQUIREMENTS" FOR THE TOXIC GAS SENSORS AND A DESCRIPTION OF HOW THOSE REQUIREMENTS ARE IMPLEMENTED. IT STATES THAT THE MAJOR TOXIC GAS IS AMMONIA.

Comment Coding
S Significant O Optional E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 1

INTERIM OPERATIONAL SAFETY REQUIREMENTS FOR ROTARY MODE CORE SAMPLING IN FLAMMABLE GAS SINGLE SHELL TANKS

HANFORD SITE, RICHLAND WASHINGTON

12. Item	13. Comment(s)/Discrepancy(s) (Provide technical justification for the comment and detailed recommendation of the action required to correct/ resolve the discrepancy /problem indicated.)	14. Hold Point	15. Disposition (Provide justification if NOT required.)	16. Status
din-1 SR 3.7.1.2 S	A calibration of the hydrogen detector should be performed at initial setup at each location and every month thereafter. The calibration should test the shutoff electronics as well as the sensor reading. This includes both the total concentration limit as well as the rate of concentration increase limit.		Per Section 6.0 of the SA Wittaker Sensor - initial and monthly SMC Sensor - initial and daily RMCS Instrumentation- every six months (including rate of rise in hydrogen concentration) ~~[illegible]~~	ok
din-2 SR 3.7.1.3 S	The system response time for the Flammability Detector should be tested the same as is required for the Hydrogen Detector. OK	See Change	Only one system response time is required for both sensors. Both detectors will be tested and calibrated to the same standard. VERIFY IN REVISED TEST NOT CALIBRATED TEST	
din-3 SR 3.7.4.1 S	The nitrogen purge flow is supplied to the drill string purge gas, the riser sleeve annulus, the hydrostatic head of the drill string, the shielded receiver, and the sample receiver weather cover. Bypass to the purge flow is influenced by each individual tank setup for the riser sleeve and the drill string purge flow. A surveillance test for bypass to the purge flow should be performed after each setup and not wait for 6 months for determining the bypass flow to these features. This will ensure that the purge flow is installed correctly for each tank setup.		A 6 month test was specified after examining data on purge gas system components and function. The physical design of the system prohibits an incorrect hookup. O.K. The hookup involves different size Hansen quick disconnect fittings. Only one arrangement is physically possible. This is a design safety feature. SHOULD BE DESCRIBED IN S.A.	

RESPONSE TIME FOR FLAMMABILITY DETECTOR NEEDS TO BE IDENTIFIED

Comment Coding

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 2

din-4 LCO 3.7.5 S	The Rotary Drilling Parameters were selected to prevent an over temperature condition from occurring during the waste drilling operation. Other limitations are defined in Appendix N which need to be factored into establishing limits on these parameters. Buckling of the drill string when the drilling greater than 45 ft. puts a limit on the drill force of less than 650 lbf rather than 750 lbf. Drill string resonance when drilling greater than 45 ft. imposes a rotational frequency limit of 40 rpm rather than the 55 rpm specified. The conditional limits for drilling greater than 45 ft should be factored into the LCO. The LCO on the penetration rate should be clarified to indicate that the penetration rate commences when the drill string is at the surface of the waste in the tank.		Temperature is not the primary concern for the drill string over 45 ft. The requirements for a drill string over 45 ft. are Level 3 (item 6.9.12.2 and 6.9.12.14) and only Level 1 controls are in this LCO. Applicability statement is RMCS Waste Intrusive Operations which occurs at the surface of the waste. (See also previous DIN-4 comment in the SA comments)	ok
BEI-1 3.7.5 S	Action A. Required Action. It appears that the required action does not prevent the restart into a potentially dangerous situation. The 10 minutes is OK, but it seems as if an additional check, verification, or other evaluation should be made prior to resumption of operations.		Automatic trips due to the varied nature of the waste are expected, the 10-min. wait is to assure bit and associated waste have properly cooled. On a restart operators will be expected to exercise all required monitoring and precautions. No other evaluations are necessary to operate within the safety envelope established by the credited design features and administrative controls.	ok

Comment Coding
O Optional E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 3

din-5 SR 3.7.5.1 S	The surveillance section should specify how many measurements are required to be operable for each of the drill string parameter measurements. This includes the RPM, the force, and the penetration rate measurements. Is only one required for each?		RPM - SR 3.7.5.1 states: "There shall be dual RPM measurement sensors both of which shall be operable when rotating the drill bit below the waste surface." Down force and penetration rate: Only one sensor is required. During the calibration process for RPM, downforce, and penetration rate sensors are set at zero and full scale and then one or more intermediate points are measured. Therefore, a minimum of 3 points are measured for each sensor.	OK
din-6 LCO B3.7.1 E	The first sentence should be revised as follows "...tank in question ~~is~~ does not exceed 25%..."		Accept.	OK
din-7 B3.7.3 A.1 E O.K.	The negative pressure in the tank can only be restored by the cessation of the exhauster. The other portions of the RMCS operation will tend to reduce the negative pressure, such as the purge flow. This should be clarified in the writeup. Is only one vacuum breaker required to be operational on the tanks during drilling operations?		Accept - words will be added to B 3.7.3. Only 1 vacuum breaker required. THE SECTION B3.7.3 HAS NOT BEEN REVISED TO INDICATE THAT THE EXCESSIVE NEGATIVE PRESSURE WOULD BE MITIGATED BY SHUTTING OFF THE EXHAUSTER.	

Comment Coding

C. Optional E. Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 4

din-8 B3.7.4 LCO O O.K	Because the tank purge flow bypass is dependent on the setup with each tank, the leak rate should be tied to each tank setup rather than just every 6 months. A faulty setup could significantly increase the purge flow bypass. B.3 (E) Change this sentence to read: "A temperature outside the bounds of the safety assessment must be corrected prior to resuming operations."		The unique hookup feature discussed in din-3 prevents faulty hookups. Unique hookup should be described in SA. Accept addition of words to B.3..	
din-9 B3.7.5 APPL O	This section should describe the "other" restrictions that must be imposed on the Rotary Drilling Parameters". This includes the restrictions imposed by the drill string buckling and resonance when drilling greater than 45 ft. These parameter restrictions are just as important as the ones specified.		Those are Level 3 requirements. The current IOSR changes implement the Level 1 changes. Level 3 controls are of lesser importance that Level 1 controls. Level 3 requirements provide defense in depth and will be implemented into operating procedures.	OK
din-10 5.31.10 S	It is not clear why the restrictions are imposed on the vertical height of the exhauster inlet and not the exhauster outlet. The height of both of the stacks are important for the proper dispersal of the potentially radioactive and combustible gases and the potential for igniting of the combustible gases.		The exhauster outlet height is fixed by design/configuration control. The restriction proposed by Section 6.0 of the SA is only on the breather filter inlet that could become the outlet during various accident scenarios.	OK

Comment Coding

O Optional E Editorial

REVIEW COMMENT RECORD (RCR)	1. Date 5/10/96	3. Review No.
	2. Project No.	4. Page 5

din-11 5.31. gen S	The administrative controls for the Rotary Mode Core Sampling should include the additional requirements that must be met prior to satisfy the assumptions cited in the SA; 1) a changeout of the HEPA filter on the exhauster outlet following each tank drilling operations (page 4-51) and 2) the checking on the thunderstorms or lightning within the 50 miles of the planned drilling site for the potential of drilling operation shutdown (page 4-57).		1. 6.9.6.5 requires daily monitoring of HEPA filter housing and changeout at a contact reading of 100 mr/hr. 2. 6.6.10.3 covers lighting and thunderstorms. These are Level 3 controls. The current IOSR modifications only reflect Level 1 controls. However, per the SA, all controls will be implemented via procedures prior to RMCS operations.	os

Comment Coding
S Significant O Optional E Editorial

B87-36.

If $T_o = 300°K$

$T_f = \underline{400°C} = 400+300 = 700°K$

$\Delta P \doteq \frac{700}{300} \times 14.7\,psi = 35\,psi$

This assumes 14.7 psi

∴ SAR used 400°C as ignition Temp, not 580°C

Principles of Combustion

Kenneth Kuan-yun Kuo
Distinguished Alumni Professor
Department of Mechanical Engineering
The Pennsylvania State University
University Park, Pennsylvania

A WILEY-INTERSCIENCE PUBLICATION
JOHN WILEY & SONS
New York · Chichester · Brisbane · Toronto · Singapore

or

$$t = 64 \times 10^{-8} \text{ sec} \approx 10^{-6} \text{ sec} = 1\ \mu\text{sec}$$

This is certainly a very rapid combustion process. In an actual combustion process, not all reactions are chain-branching. However, the reaction rate is still very fast even for a very small portion of chain-branching reactions. For a combustion process in which 1% ($\alpha' = 1.01$) of the reactions are chain-branching, the time required for all the molecules in the volume to react would be only

$$\frac{\alpha'^{N+1} - 1}{\alpha' - 1} = \frac{1.01^{N+1} - 1}{0.01} = 10^{19} \text{ molecules/cm}^3$$

$$N = 3934$$

$$t = 3934 \times 10^{-8} \text{ sec} \approx 40\ \mu\text{sec}$$

This is still a very fast reaction.

In general, branched-chain reactions and explosions can be studied by considering the following chemical kinetics:

$$M \xrightarrow{k_1} R \qquad \text{chain-initiating}$$

$$R + M \xrightarrow{k_2} \alpha' R + M^* \qquad \text{chain-branching}$$

$$\left.\begin{aligned} R + M &\xrightarrow{k_3} P \\ R &\underset{\text{(on wall)}}{\xrightarrow{k_4}} M \\ R &\xrightarrow{k_5} \text{nonreactive species} \end{aligned}\right\} \text{chain-terminating} \qquad (2\text{-}58)$$

The rate equation (applying the steady-state assumption) is

$$\frac{dC_R}{dt} = 0 = k_1 C_M + (\alpha' - 1) k_2 C_R C_M - k_3 C_R C_M - k_4 C_R - k_5 C_R \quad (2\text{-}59)$$

Solving for C_R gives

$$k_1 C_M \quad (2\text{-}60)$$

The rate of change of the product concentration is given as

$$\frac{dC_P}{dt} = k_3 C_R C_M = \frac{k_1 k_3 C_M^2}{k_3 C_M + k_4 + k_5 - k_2(\alpha' - 1) C_M} \qquad (2\text{-}61)$$

The quantity $k_2(\alpha' - 1)C_M$ is positive; as its value increases it tends to decrease the denominator in Eq. (2-61). The critical value of α' is given as

$$\alpha'_{\text{critical}} = 1 + \frac{k_3 C_M + k_4 + k_5}{k_2 C_M} \qquad (2\text{-}62)$$

and we have

$$\alpha' \geq \alpha'_{\text{critical}} \Rightarrow \text{chain-branching explosion}$$

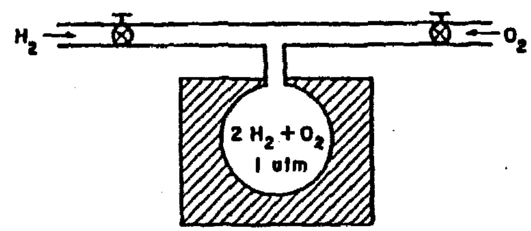
$$\alpha' < \alpha'_{\text{critical}} \Rightarrow \text{no explosion}$$

However, it is important to note that for some actual explosion processes, because the concentration of R does not remain small, the steady-state approximation may not be valid. Other reaction steps may also become important. The postulated reaction kinetics in Eq. (2-58) may not always be applicable during an explosion.

8 EXPLOSION LIMITS

8.1 H_2-O_2 System

It is experimentally observed that a pressure vessel containing hydrogen and oxygen under the conditions shown in Fig. 2.11 will explode as the pressure is raised. Intuitively, one would assume that as the pressure is raised, the concentration of free radicals would be increased, which would lead to an explosion. However, an explosion is also experimentally observed as the pressure is lowered.



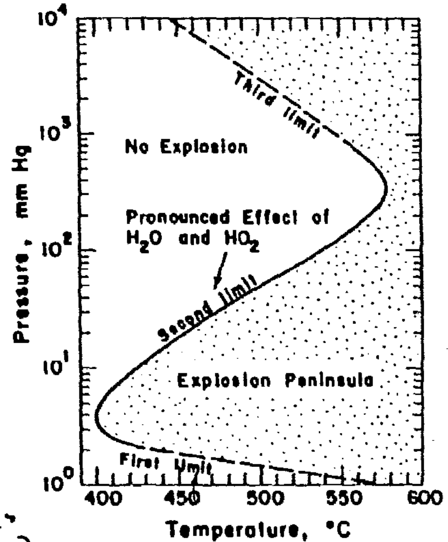


Figure 2.12 Explosion limits of a stoichiometric hydrogen–oxygen mixture in a spherical vessel. First and third limits are partly extrapolated. First limit is subject to erratic changes. (From Ref. 6.)

The existence of explosion limits in a closed vessel can be understood very simply from qualitative considerations of competition between chain-breaking and chain-branching reactions on surfaces and in the gas phase. Typical experimental results for hydrogen–oxygen mixtures are plotted schematically in Fig. 2.12. The first, or lower, explosion limit occurs at roughly the same pressure over a relatively large temperature range. The lower explosion limit is determined by a balance between the removal of chain carriers on the surface (wall effect) and production of chain carriers by gas-phase reactions. In this low pressure range, the number of collisions and the rate of production of chain carriers are both low. From Eq. (2-62) we know that

$$\alpha'_{\text{critical}} = (1 + C_1) + \frac{C_2}{C_M} \quad \text{and} \quad C_M \propto p$$

The lower the pressure, the larger the value of $\alpha'_{\text{critical}}$, and hence the smaller the chance for explosion. However, none of these analyses can predict the exact location of the explosion limits; they can only explain the mechanism of reaction in each region.

As the pressure is raised, the rate of production of chain carriers by gas-phase reactions increases to the point at which surface destruction is no longer sufficient to prevent a branching explosion. The lower explosion limit defines the condition at which chain branching in the gas phase is balanced by chain breaking at the surface.

kinetics:

Recommended by a number of investigators in the 1920s:

$$H_2 \rightarrow 2H + 106 \text{ kcal/mole} \quad \text{(dissociation)} \tag{A}$$

Suggested by Lewis and von Elbe:[6]

$$H_2 + O_2 + M \rightarrow H_2O_2 + M^*$$
$$\hookrightarrow 2OH + 51 \text{ kcal/mole} \tag{B}$$

and after the OH radical is generated,

$$OH + H_2 \rightarrow H_2O + H - 15 \text{ kcal/mole}$$
$$H + O_2 \rightarrow OH + O + 16 \text{ kcal/mole}$$
$$O + H_2 \rightarrow OH + H + 2 \text{ kcal/mole}$$

The reaction proposed in (A) is more endothermic than the reaction in (B). However, reaction (B) requires a third-body reaction which is not as likely as the dissociation reaction. At low temperatures, therefore, reaction (B) is more likely, and at high temperatures reaction (A) is more likely.

At high pressures the second explosion limit is approached. The existence of the second explosion limit is readily explained if the three-body reaction

$$H + O_2 + M \rightarrow HO_2 + M \tag{2-63}$$

is added to the scheme. In this reaction the symbol M denotes any third molecule that stabilizes the combination of H and O_2. Because the metastable intermediate hydroperoxide radical (HO_2) is thought to be relatively unreactive, it is able to diffuse to the wall. HO_2 becomes a vehicle for the destruction of free valences, and therefore the above reaction is considered a chain-breaking reaction. With increasing pressure, the frequency of ternary collisions $H + O_2 + M$ increases relative to the frequency of binary collisions $H + O_2$. There is therefore a pressure above which the rate of removal of free valences exceeds the rate of formation of free valences by chain-branching reactions, and the second explosion limit is established. The destruction of the HO_2 molecule on the wall can be expressed by the reaction

$$HO_2 \xrightarrow{\text{wall}} \tfrac{1}{2}H_2 + O_2$$

$$HO_2 \xrightarrow{\text{wall}} \tfrac{1}{2}H_2O + \tfrac{3}{4}O_2$$

At some pressure above the second explosion limit, however, HO_2 is assumed to participate in the chain propagation process according to the reaction

$$HO_2 + H_2 \rightarrow H_2O_2 + H$$
$$\qquad\qquad \llcorner\!\!\rightarrow 2\,OH$$

Therefore, above a critical pressure, there is a rapid increase in the number of radicals. This critical pressure defines the third explosion limit. Now H_2O has a bond frequency very close to that of HO_2, the structures being

H—O—H

O—O—H

so H_2O is an excellent third body for the reaction given in Eq. (2-63). The region for pronounced effect of H_2O and HO_2 is indicated in the explosion-limit diagram. It is useful to note that for $T > 600°C$, HO_2 cannot be stabilized and therefore explosion is observed at all pressures.

The treatment of explosion limits in flow systems can be worked out through an extension of the methods developed for closed reaction vessels.

8.2 $CO-O_2$ System

As shown in Fig. 2.13, mixtures of carbon monoxide and oxygen also exhibit the phenomenon of explosion limits. The chain-initiating reaction is

$$CO + O_2 \rightarrow CO_2 + O, \qquad \Delta H_r = -9 \text{ kcal/mole} \quad \text{(exothermic)}$$

This initiating reaction is hard to achieve without H_2. Lewis and von Elbe[6]

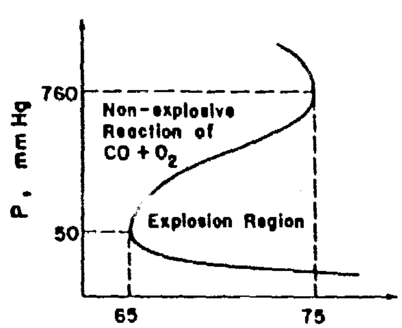


Figure 2.13 Explosion limits of a stoichiometric carbon monoxide–oxygen mixture.

have suggested that the explosion limit is essentially controlled by the reactions

$$M + CO + O \rightarrow CO_2 + M$$

$$M + O + O_2 \rightarrow O_3 + M^* \qquad \text{(exothermic)}$$

$$O_3 + CO \rightarrow CO_2 + 2O \qquad \text{(very rapid)}$$

$$O_3 + CO + M \rightarrow CO_2 + O_2 + M^*$$

It should be noted that the behavior of the $CO-O_2$ system is changed radically by the admixture of small amounts of H_2 or H_2O, and that the rate-controlling reaction mechanism now involves H, OH, H_2, HO_2, and H_2O as well as O, O_2, CO, CO_2, and O_3.

The water-gas reaction is most probably surface-catalyzed:

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad \text{(surface)}$$

and should be followed by the surface reaction in the hydrogen–oxygen reaction

$$H_2 + O_2 \rightleftharpoons H_2O_2 \qquad \text{(surface)}$$

Chain carriers are then provided by the dissociation at H_2O_2 in the gas phase:

$$H_2O_2 \rightarrow 2OH$$

$$OH + CO \rightarrow CO_2 + H$$

$$H + O_2 \rightarrow OH + O$$

9 RATE LAWS FOR ISOTHERMAL REACTIONS UTILIZING DIMENSIONLESS PARAMETERS[3]

For the sake of brevity, the following discussion will be restricted to a pair o opposing chemical reactions. Generalization to chain reactions can be mad without difficulty.

For the most general opposing chemical reactions,

$$\sum_{i=1}^{N} \nu_i' M_i \underset{k_b}{\overset{k_f}{\rightleftharpoons}} \sum_{i=1}^{N} \nu_i'' M_i$$

As seen in Section 2.5, the net rate of production of species M_i is given by th

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Ignition Temperature, Handbook of Physics and chemistry = 580 - 590 C							
Air + 2H2 + O2 --> Air + 2H2O + HEAT							
2% H2							
							air
Reactants	Cp	Hf g	Hv	m	mol wt	vol %	mol %
	cal/mol/K	kcal/mol	kcal/mol	mol			
N2	7.28	0		78	28		78
O2		0		21	32		21
H2		0		2	2	0.019802	
			sum	101			
PRODUCTS							
H2O g	8.82	-57.8	9.72	2	18		
N2	6.9	0		78	28		
O2	7.07	0		20	32		
	delta H = -e16*c16			115.6			
	delta T = delta H/sum(Cp*m)			165.7966			
		e21/(b16:18 *e16:18)					
Air + 2H2 + O2 --> Air + 2H2O + HEAT							
4% H2							
							air
Reactants	Cp	Hf g	Hv	m	mol wt	vol %	mol %
	cal/mol/K	kcal/mol	kcal/mol	mol			
N2	7.28	0		37	28		78
O2		0		9.961538	32		21
H2		0		2	2	0.040848	
			sum	48.96154			
PRODUCTS							
H2O g	9	-57.8	9.72	2	18		
N2	6.916	0		37	28		
O2	7.072	0		8.96	32		
	delta H = -e16*c16			115.6			
					Ignition Temp = 580 C		
	delta T = delta H/sum(Cp*m)			342.7652			
		e21/(b16:18 *e16:18)					

Air + 2H2 + O2 --> Air + 2H2O + HEAT							
30 % H2							
							air
Reactants	Cp	Hf g	Hv	m	mol wt	vol %	mol %
	cal/mol/K	kcal/mol	kcal/mol	mol			
N2	7.28	0		3.714286	28		78
O2		0		1	32		21
H2		0		2	2	0.297872	
			sum	6.714286			
PRODUCTS							
H2O g	8.2	-57.8	9.72	2	18		
N2	7	0		3.71	28		
O2	7.36	0		0	32		
				5.71			
	delta H = -e16*c16			115.6			
	delta T = delta H/sum(Cp*m)			2728.346			
		e21/(b16:18 *e16:18)					
	Vol Change = (mol2/mol1) (delta T/300)				7.734182		
Air + 2H2 + O2 --> Air + 2H2O + HEAT							
6% H2							
							air
Reactants	Cp	Hf g	Hv	m	mol wt	vol %	mol %
	cal/mol/K	kcal/mol	kcal/mol	mol			
N2	7.28	0		25	28		78
O2		0		6.730769	32		21
H2		0		2	2	0.059293	
			sum	33.73077			
PRODUCTS							
H2O g	9	-57.8	9.72	2	18		
N2	6.916	0		25	28		
O2	7.072	0		5.7	32		
	delta H = -e16*c16			115.6			
					Ignition Temp = 580 C		
	delta T = delta H/sum(Cp*m)			499.9775			

		e21/(b16:18 *e16:18)					
Air + 2H2 + O2 --> Air + 2H2O + HEAT							
8% H2							
							air
Reactants	Cp	Hf g	Hv	m	mol wt	vol %	mol %
	cal/mol/K	kcal/mol	kcal/mol	mol			
N2	7.28	0		22	28		78
O2		0		5.923077	32		21
H2		0		2	2	0.066838	
			sum	29.92308			
PRODUCTS							
H2O g	9	-57.8	9.72	2	18		
N2	6.916	0		22	28		
O2	7.072	0		4.92	32		
	delta H = -e16*c16			115.6			
					Ignition Temp = 580 C		
	delta T = delta H/sum(Cp*m)			564.0504			
		e21/(b16:18 *e16:18)					
At 4% H2, the molar change is 49 moles goes to 48 moles							
Delta T = 343							
Pf/Pi = Mf/Mi * Tf/Ti		=	2.01984				
			29.69164	psi ..			
If I use ingintion temperature of delta T = 564 K, = 580 C							
then I must use 6.6% H2							
Pf/Pi = Mf/Mi * Tf/Ti			2.552544				
			37.52239	psi			

APPENDIX 5

QUALITY ASSURANCE PLANS

Quality Assurance Plan for Safety Documents Independent Review

1.0 INTRODUCTION

This document outlines the quality assurance plan and methods of review for the independent review team (IRT). This team is formed to independently review safety related documents and procedures to assure compliance with safety standards and requirements. Consequently, the IRT is independent of influence from authorship or prior review of documents or parts of documents presented for its review, analysis, or commentary.

The (IRT) shall be formed in accordance with the charter of the requesting organization. The charter may specify the scope of the document to be reviewed, the review criteria, and the review team qualifications. The documents presented to the IRT will be reviewed in the breadth and depth necessary to provide an opinion on whether significant hazards have been identified, appropriate mitigating features have been provided, risks were properly evaluated, and compliance with the applicable requirements as outlined in the appropriate DOE Orders and Standards has been achieved. The review will also be performed in accordance with a set of review standards and criteria described below.

2. REVIEW STANDARDS

The review process is intended to verify that the safety document reviewed ensures compliance with applicable safety-related statutes, rules, and DOE Orders and Standards, and verify safe operations where applicable. Consequently, documents shall be reviewed on the basis of six broad standards of performance: accuracy, completeness, traceability, consistency, readability, and functionality. However, design basis accidents are omitted from the independent review of some safety documents because their associated facility design basis pre-existed the requirements of the DOE Order.

Accuracy means that the document is technically and grammatically accurate. Completeness means that all requirements are addressed, promised statements are provided, and the document is complete from an independent view. Traceability means that the references used in the document exist and contain the promised information, and that the assumptions and bases made re supported by the references as required. Consistency means that the statements made and parameters used in the document agree throughout the document. Readability means that statements made must be understandable by an educated but novice reader and that the document is grammatically adequate. Functionality means that the document satisfies the functional objective of a Safety Analysis Review by establishing a safety envelope, and justifies the conclusions made therein. These six standards are to be applied by the reviewers in preparing their comments.

3. CRITERIA FOR REVIEWER INDEPENDENCE

IRT reviewers shall be independent of the document preparation. Reviewers shall not have specified a singular approach, ruled out a specific approach, participated in writing the document, performed analyses included in the document or established any input into the document presented for review. However, a reviewer with input into part of the document may evaluate another part of the document where the reviewer's technical qualifications allow such activity.

4. RESPONSIBILITIES

The responsibility of the IRT members include:

4.1 Review safety analyses and changes in safety analysis documents to ensure that, where applicable:

- a. Appropriate TSRs have been developed, based upon the described basis and analysis results documented in the SAR, that will ensure safe operations of the facility.
- b. Compliance with applicable guides, codes, and standards is demonstrated.
- c. Deviations from current DOE design criteria are evaluated and documented.
- d. Potential hazards and energy sources are identified and that the facility classification as Category 1, 2, or 3 is appropriate.
- e. Potential consequences are adequately analyzed.
- f. The proposed operation will limit risks to the health and safety of the public and the employees, and will adequately protect the environment.

4.2 Assess changes involving criticality and verify the system remains within the operational safety envelope and satisfies all applicable DOE requirements.

4.3 Determine if the hazard classification category remains correct in document revisions and addenda.

4.4 Determine if restart plans are consistent with the applicable ASA, SA, SAR, FSAR, TSRs, and USQDs.

4.5 Assess if deficiencies in design or operation of structures, systems, or components affect risk.

5. REVIEW COMMENT FORMAT AND COMMENT REQUIREMENTS

Comments made by the reviewer(s) shall be technically and grammatically accurate, complete, traceable, consistent with other comments made by the reviewer(s), readable by the document's author(s), and shall assist the author(s) in making the document comply with the requirements imposed on the document. The document's author(s) should be able to understand from the comment the requirement or technical content that has not been met by the document, and should include guidance and suggestions to the authors for correcting the document accordingly.

Comments shall be prepared using word processing software, and provided in the format shown in Figure 1. Reviewers shall use WordPerfect macros provided by the IRT chairman. This will ensure that comments will be in the required format.

For each comment, the reviewer shall enter their initials, the Chapter, page, and paragraph numbers to which the specific comment applies, comment code, and the comment. The initials will be used to identify individual reviewers after all review comments have been combined into a single document and sorted. The chapter, page, and paragraph numbers serve to locate the place in the document text where the comment applies, and provide a means of sorting and organizing the combined comments of all reviewers. The comment code and comments are discussed in the following paragraphs.

The comment code indicates the level of concern that the comment should generate. Comments shall be classified as significant (S), optional (O), or editorial (E). No other codes or notations may be used to classify comments.

Significant comments have safety significance related to the technical content of the document and require additional explanation or description to ensure an adequate safety basis. Significant comments will be resolved before the IRT will issue a final safety evaluation report (SER) without comment. The author(s) response to significant comments will be returned to the original reviewer for evaluation of the response. If there is no agreement reached on a specific comment and resolution thereto, then the IRT may issue the SER noting an exception to the comment's resolution.

Optional comments by their nature do not raise a significant issue to the safety basis or the communication of the safety basis. They are related to the technical content of the document and require additional explanation or description based on the reviewer's background and experience. Author's responses to optional comments may be accepted by the IRT Chair without further consultation with the original IRT reviewer.

Editorial comments identify grammatical or writing structures that are either incorrect or awkward. Comments shall not be classified as editorial if the grammatical or structural errors generate a significant misunderstanding or ambiguity to the safety basis.

6. PERSONNEL ASSIGNMENTS

Table 1 provides a matrix of review personnel and the chapters assigned for review to the individual reviewers. The assignments are made to obtain both technical depth and breath in the review.

7. REVIEW SCHEDULE AND ACTIVITIES

7.1 Author Briefing

Review of the document will commence with an authors and IRT representative briefing. At this briefing, the authors are expected to brief the IRT representative on their graded approach, and any commitments or agreements made with DOE for the document format and content.

7.2 Initial Reviewers' Meeting - Training

Review of the document will begin after a formal meeting with the IRT. The chairman will ensure documentation of the attending IRT members. He will brief the assembled IRT on the document to be reviewed and request members who may have a conflict of interest in reviewing the document to identify themselves.

The chairman will then present the document to the IRT. He will proceed chapter by chapter through the document asking for and providing comments as areas in question arise. Refer to the printed list of reviewer chesklist to raise issues for discussion (Appendix A).

7.3 First Review Meeting

A meeting of the IRT will convene at mid-review schedule to discuss preliminary review comments. The comments, at this meeting, are expected to be limited to those considered to be significant or fatal to the safety basis. These consequences will be transmitted to the author(s) after an appropriate IRT peer review. This will provide the IRT members and author(s) with an early trend of the comments, allow the author(s) to give early feedback to the IRT, and allow the author(s) time to prepare for further discussion at the final review meeting, and allow the reviewers to exchange information. **Reviewers will provide the IRT administrator with electronic copies of their preliminary comments three working days prior to this first meeting.**

7.4 Final Review Meeting

The final review meeting will be held at the end of the review. The reviewers will provide the IRT administrator with electronic copies of their final comments three working days prior to the final meeting. In this final meeting, the reviewers will review all comments, evaluate all the comments for technical validity and evaluate the proposed corrections included in each comment. Rejected comments or proposed corrections will be noted as such and eliminated from the comments compilation which will be forwarded to the author(s) for evaluation and disposition. Reasons for rejecting comments will be documented and recorded in meeting minutes. The author(s) will be briefed on the compiled comments, and after receiving their evaluation, the SER will be drafted incorporating their evaluation and disposition of the compiled comments.

7.5 Adherence to Schedule

The IRT staff is expected to adhere to the review schedule as published. If unforeseen circumstances dictate a change in schedule, IRT members will be notified of the change.

7.6 IRT Review Document Schedule

Meeting minutes will be published for review by the IRT members within 3 working days following the first and final meetings. IRT members shall return their comments on the draft meeting minutes to the IRT chairman within five working days of the draft issuance. The final meeting minutes will be published with the SER. The SER will be published within five working days of final comment resolution or agreement that resolution cannot be achieved on all comments.

8.0 REVIEW CRITERIA

The review criteria for the document are provided in an outline format as a series of questions the document should answer with amplifying information. The review criteria have been extracted from the requirements of DOE Order 5480.23 as annotated by the charter and as pertaining to hazards analysis and classification of the facility, and accident analysis. Some clarifications have been added in some instances.

8.1 Hazards Analysis

Does the document identify the inventory of hazardous materials such as radioactive materials, chemicals, explosives, radiation sources etc. as necessary to support the safety analysis?

Hazard classification for each major hazard.

Overall facility hazard classification.

Analyses of Normal, Abnormal, and Accident Conditions Should be Based on Cited Hazards.

Hazards Table

Hazards for each facility covered by the document should be listed in a separate table. A complete list of all hazards must be given in the document.

Each facility-specific table should contain the following columns, but not necessarily in the order given below:

1. **Hazard Category** such as Radiological, electrical, chemical, etc.

2. **Hazard Description.** Identify some specific feature about the hazard. For example, specific quantities of radionuclides, specific quantities of hazardous chemicals, specific electrical hazards, etc.

3. **Hazards Assessment.** Assessment is a judgement about how the hazard could contribute to an accident. For example, information about methods to avoid an incident such as spills, corrosion, leaks, explosions, etc.

4. **Effects or Consequences.** Consequences estimate the potential loss. For example, injury or death, equipment loss, environmental damage, etc.

5. **Preventive Measures.** Preventive measures make specific commitments which, when enforced, will help forestall the postulated incidents.

Each facility-specific table of hazards should list the hazards categories by level of risk (Hazard Classification). The classification criteria are derived from DOE-STD-1027-92, and 29 CFR-1910.

- Hazards that are standard industrial hazards (SIH) or that are routinely accepted by the public (RABP) need only be identified in the document, and OSHA controls are acceptable.

- Hazards that lie between RABP/SIH and category 3 hazards need to be identified in the document, and the safety commitments shall be discussed and analyzed in the document.

- Category 3 and above hazards need to be identified in the document and are expected to have technical specification requirements TSRs associated with them to provide controls.

- Any administrative controls relied on for the categorization shall be identified and summarized for the derivation of the TSRs.

- Tables 1 and 2 provide examples of hazard identification and classification for a hypothetical above ground storage tank containing radionuclides in an aqueous solution and in a sludge at the bottom of the tank.

Table 1. Example for Hazard Identification and Classification for Tank Sludge.

Hazard Category	Hazard Description	Hazard Assessment	Effects or Consequences	Preventative Measures
At least Category 3				
Radiological	1000 Ci ^{90}Sr	spills, leaks, corrosion	area and worker contamination	Tank and spill containment design, Inservice tank inspection.
Electrical	None			
Chemical	100 ± 1 lbs mercury	spills, leaks, corrosion	area and worker contamination	Tank and spill containment design, Inservice tank inspection.
Less than category 3				
Radiological	5 ± 1 g Pu as PuO_2	spills, leaks, corrosion	area and worker contamination	Tank and spill containment design, Inservice tank inspection.
Electrical	None			
Chemical	1 ± 0.1 lb As	spills, leaks, corrosion	area and worker contamination	Tank and spill containment design, Inservice tank inspection.
Routinely Accepted by the Public (RABP)				
Radiological	< 2 nCi/g ^{137}Cs			
Electrical	480 V electrical supply to tank heater	Electrical shock	Worker injury and death	OSHA compliance programs.
Chemical	None			

Table 2. Example for Hazard Identification and Classification for Tank Liquid.

Hazard Category	Hazard Description	Hazard Assessment	Effects or Consequences	Preventative Measures
At least Category 3				
Radiological	500 ± 50 Ci ^{137}Cs	spills, leaks, corrosion	area and worker contamination	Tank and spill containment design, Inservice tank inspection.
Electrical	None			
Chemical	2000 ± 100 lb Cl	spills, leaks, corrosion	area and worker contamination	Tank and spill containment design, Inservice tank inspection.
Low Temperature	Freezing	Liquid freezes	Tank Failure	Tank design, Class 1E power supply for tank heater.
Less than category 3				
Radiological	None			
Electrical	None			
Chemical	None			
Routinely Accepted by the Public (RABP)				
Radiological	None			
Electrical	None			
Chemical	None			
Drowning	Tank liquid	Worker falls in tank	Worker injury and death	OSHA compliance programs.

8.2 Accident Analysis

The document shall describe a thorough analyses of the postulated events that could lead to a breach of the principal health and safety criteria. The document shall also identify the frequency at which these events may occur. It shall establish the design basis accidents where these have been identified, and identify the safety systems that must be operable to prevent or mitigate each identified design basis accident. It shall demonstrate that the principal health and safety criteria can be met by the facilities evaluated for all identified design basis accidents, and to establish the safe operating envelope for the facilities evaluated. The accident analysis should be based on the facility description and operation, the identified hazards analysis and classification of the facility, and the identified principal health and safety criteria. The accident analysis should form the basis of the TSR (or ISORs), and may also provide the basis for personnel training materials and facility management and organization. Questions that must be addressed are:

Does the document provide a listing of possible event scenarios that could lead to releases of radioactive or hazardous materials?

- Are scenarios provided for each identified hazard?

  Are the identified scenarios appropriate for the facilities evaluated?

  Are all possible scenarios identified?

- Do the scenarios challenge the release barriers identified for the facilities evaluated such as waste containers and buildings?

- Does the document provide event frequencies for each of the hypothetical events?

  Are the event frequencies supported by appropriate analyses or other evidence?

  Does the document identify the structures, systems, and components that are relied upon to reduce the frequency of occurrence (preventive measures)?

- **Although design basis accidents are not relevant to this document, they are included here for completeness.**

  DABs are accidents postulated for the purpose of establishing functional requirements for safety-significant structures, systems, components, and equipment. They are usually used to demonstrate that the design, when challenged by a postulated bounding accident, will not violate the principal health and safety criteria.

- Are design basis accidents (DBA) identified?

  Does the document identify phenomenologically similar events bounded by a specific DBA? For example, explosions may be bounded by an explosion initiated by a leaking propane heater.

- Are phenomenologically dissimilar events covered by different Dabs? For example, while a propane leak might bound explosions, fires might be bounded by a diesel transport fuel tank leaking.

- Is each DA supported as a bounding event by appropriate evidence or reasoning?

Does the document provide a deterministic analysis for each hypothetical event classified as an operational or design basis accident?

- Are the following issues identified for each analysis in the document?

  - Initial conditions
  - Boundary conditions
  - Key assumptions
  - Identification of structures, systems, and components that are assumed to be operational such as fire suppression.
  - Facility design data and information available.

- Reviewers shall review referenced documents such as engineering design files.

- Do the analyses results demonstrate that the principal health and safety criteria will be met?

  - Are the structures, systems and components required to be operational so as to meet the principal health and safety criteria consistent with the identification of engineered safety features in the facility description and operation?

  - Do the analyses results indicate any limits (e.g. a maximum operating temperature) must be satisfied to meet the principal health and safety criteria? Are the failure conditions for engineered safety features identified?

9. MECHANICS OF THE REVIEW PROCESS

9.1 IRT Chairman Role

The IRT Chairman shall base the review and concurrence on an integrated systems concept. The chairman shall also provide for group discussion among reviewers on significant issues regarding the document undergoing review.

9.2 IRT Members Role

a. Perform their review in accordance with relevant DOE Orders and standards which include references 1-7.

b. Follow the review guidance provided in the Reviewer Checklist (Appendix A) and the review plan provided with the document at the time it is distributed. Additionally, feel free to make any pertinent comment on any item in the document being reviewed.

c. Review the parent document (ASA, SA, SAR, FSAR, or TSR) where available, for compatibility during the review.

d. Visit the site where the proposed involvement will occur, if necessary and when possible, to better understand the activity under review and to obtain a proper frame of reference for comments.

e. Provide written comments (disk copy or electronic file transfer) to the IRT Chairman, normally three days prior to the scheduled review meeting. Where possible, comments shall be written using WordPerfect software in a format specified by the IRT Chairman.

f. Notify the IRT Chairman if absence from the scheduled review meeting is anticipated so that provision for absentia comments or alternate reviewer arrangements can be made.

g. Review for factual accuracy and make any necessary corrections to the draft meeting minutes.

h. Provide written comments on draft meeting minutes to the IRT chairman.

i. Review the author responses to comments, as requested by the IRT chairman.

j. Serve, if assigned, as safety process observer during Title 1 design or readiness reviews.

9.3 Document Review Process

When a document is received by the IRT for review, the Chairman screens and checks if the appropriate signatures are attached to the document, the attached graphics are readable, maps are in appropriate scale, the document is accurate, legible, its format is correct format, and if there are obvious technical errors or shortcomings.

If deficiencies are found in the document, it is returned to the author to correct the deficiencies. After all deficiencies are corrected and the document is returned to the IRT, the Chairman shall:

a. Determine if the document involves fissionable materials, if so, arrange for review by a member of the Criticality Subcommittee.

b. Determine if the review request is complex. If so, arrange for the IRT to be briefed on the document by the authors, normally before scheduling for review.

c. Schedule a review meeting normally two weeks from the date the document is received. Factors that could modify this two week schedule include: the document's size or complexity, special scheduling arrangements agreed upon between the IRT Chairman and the document's manager, or the IRT document review load.

d. Prepare a review plan, the scope of which may range from simply establishing the schedule and appointing the reviewers to determining specific review requirements for each reviewer.

e. Prepare a cover letter appointing the reviewers, setting the review meeting time and location, and specifying the document review plan. Distribute copies of the cover letter, review plan, and documents to be reviewed to the assigned committee members. Send a copy of the cover letter to the document author(s).

The IRT Chairman orchestrates the document review by using the following steps to the extent applicable for the subject document:

a. Personally review the document and prepare written comments.

b. Normally, collect all reviewer comments three days before review meeting. All comments are to be in electronic format, when possible.

c. Compile by chapter and page all reviewer comments and make 12 printed copies and one electronic disc copy.

d. Provide a printed and an electronic disc copy of compiled comments to the document author, normally two days before to the review meeting.

e. Convene and preside over the document review meeting. If unavailable, appoint the alternate chairman or, if alternate chairman is unavailable, another qualified person to preside. Conduct the review meeting and ensure traceability and control of the meeting.

f. Moderate the discussion and record all significant comments raised during the meeting not already on the compiled comment list. At the end of the review meeting, collect any reviewer comments not previously submitted.

The following actions provide closure to the review process:

a. Compile review comments and publish draft meeting minutes documenting the total IRT review comments.

b. Distribute draft copy of IRT document review meeting minutes to committee members and document author(s) for their review. (Author(s) will write a response to each comment and provide these written comments plus a copy of the revised document indicating by side-bar where changes have been incorporated, or a complete rewrite if needed, to the IRT chairman when the IRT comments have been addressed.)

c. Submit the author's responses to the reviewers for comment if the author's responses to the reviewer's comments significantly change the document.

d. Prepare the evaluation report recommending approval or disapproval of the document.

e. Distribute copies of final meeting minutes, the evaluation report, and transmittal letter to all affected persons.

f. File a copy of meeting minutes, the evaluation report, and transmittal letter to the in-process file and close the review file. A copy of all document review correspondence will be maintained on file.

Addenda, or documents which have been updated, and re-submitted for review, shall be handled as original documents.

10. REFERENCES

1 DOE Order 5480.5, "Safety of Nuclear Facilities."

2 DOE-ID Order 5480.5A, "Safety of Nuclear Facilities."

3 DOE Order 5480.21, "Unreviewed Safety Questions."

4 DOE Order 5480.22, "Technical Safety Requirements."

5 DOE Order 5480.23, "Nuclear Safety Analysis Reports."

6 DOE Order 5481.1B, "Safety Analysis and Review System."

7 DOE-ID Order 5481.1B, "Safety Analysis and Review System."

REVIEWER CHECKLIST BY DISCIPLINE

Note Reviewers shall consider but not be limited to the following items.

1. **Industrial Safety**

1.1 Understand and apply the concept of passive barriers versus active barriers for protection and mitigation against accidents and energy sources.

1.2 Ensure that all energy sources (electrical, pneumatic, chemical, mechanical, etc.) have been analyzed for accident potential and that all credible potential accidents have been completely analyzed.

1.3 Determine if the TSR relates directly to an accident analysis and that recovery actions and time limits are included.

2. **Industrial Hygiene**

2.1 Evaluate control techniques or mitigative actions specified in the document to assess their viability and feasibility in reducing or eliminating the potential health hazards.

2.2 Identify chemical, physical, biological, and ergonomic stress agents; inadequate operating conditions and procedures; and faulty facilities and equipment which may pose a potential health hazard to on-site and off-site personnel.

2.3 Recommend controls (engineering, administrative, and personal protective equipment) that will reduce or eliminate the potential health hazards identified by this review.

2.5 Assess risk to on-site and off-site personnel by:

a. Verifying exposure level calculations contained in the document.

b. Evaluating exposure levels based upon known toxicological data and anticipated exposure potential.

April 19, 1995

IRT DOCUMENT REVIEW PROCESS

Document Cycle

Procedures:

A new document arrives, copies are sent to reviewers, review comments are received electronically or on magnetic diskettes. They are compiled and sent to reviewers the day before the meeting. The first meeting is attended and draft meeting minutes are issued. Comments and resolutions are received back. Resolutions are sent to those reviewers with "S" comments for review. Final meeting minutes are sent out with the evaluation letter, PC file and hardcopy file are closed.

A New Document Arrives

A new document for review arrives with 11 copies from the author.

1. Stamp in date
2. Set up files (hardcopy file, PC, and diskette)
3. Place one copy of the report in file
4. Enter in document file schedule for review and first meeting date.
5. Notify IRT members of initial meeting date and time.
6. Prepare sufficient copies of the document - one for each IRT member.
7. Place on tracking schedule

To set up a file folder with 4 folders labeled as follows:

1 REVIEW DOCUMENT
2 MEETING MINUTES
3 RESOLUTIONS
4 FINAL EVALUATION REPORT

Receiving and Processing Review Comments

TO PREPARE COMMENTS FOR DISTRIBUTION AT REVIEW MEETING

Reviewers will provide their comments on magnetic diskettes approximately 1-2 days prior to the meeting. Comments shall be written using WordPerfect and the provided macros.

1. File a copy of each reviewers comments in the PC directory which you set up for the document.

2. When all comments are received, compile the comments into one document. Review comments should be sorted by page and paragraph and have the reviewers ID added as well as page numbering.

   Use the following procedure to sort the comments:

   1. Sort using the keys:

      N121 A131 N141 A151

      This will sort the type of comment within the numeric order of the comment.

   2. Make sufficient copies of the compiled comments (IRT members + 2) and give to the Chairman before the committee meeting. Make copies for the authors as needed (usually 2 to 5 copies).

   3. File one copy of the compiled comments in the file folder.

   4. Provide the author of the document with their copies of the compiled comments two days prior to the review meeting.

Draft Meeting Minutes

Issued after the first meeting of the committee for document review

1. Make changes to the Review Comments as indicated by the Chairman/Members. (These Review Comments will be labeled attachment 2)

   a. Count the comments per reviewer.
   b. Count comments by "S" "E" and "O."

2.

a. Fill in the subject
b. Fill in the introduction paragraph
c. List all attendees from the sign up sheet
d. List those committee members not present but who have forwarded comments
e. List those committee members not present
f. Fill in the comments sections

Dist: See master distribution list

3. Give disk and one hardcopy to the chairman for review.

4. When the revised draft meeting minutes are received back from the chairman:

5. Finalize the draft meeting minutes (put DRAFT heading on top of each page) (IRT - FILE NAME - DATE - DRAFT)

6. Obtain necessary signatures

7. Distribute copies

8. File copy of Draft Meeting Minutes in letterlog.

<u>Resolutions to Meeting Minutes</u>

Resolutions are received back from the authors.

1. Stamp in.

2. Follow chairman's direction as to action.

3. If resolutions are approved by chairman and approval letter sent out or placed in file - Note on resolution document this information.

<u>Closed Document Back for Minor Revisions</u>

1. Stamp in document

2. One copy to IRT Chairman

3. Follow Chairman's direction

USQDs

1. Document (Unreviewed Safety Question Determination) will be received by Chairman and reviewed.

2. Chairman will write Evaluation Letter.

3. Set up file, Prepare Evaluation Letter. The Distribution will be determined by Chairman.

To Close Out A Report - Evaluation Report:

1. Type the Evaluation Report

2. Type draft meeting minutes to final, remove DRAFT header and change the date but not the letter number. Incorporate any changes from comments

   Dist: See master distribution list

3. Label attachments according to:

   Meeting Minutes - Attachment 1
   Comments/Resolutions - Attachment 2
   Signature sign-off sheet - Attachment 3
   The IRT Chairman may have several attachments to the final evaluation report. These will be provided by the Chairman as he desires.

4. File the attendance rosters with the evaluation report

5. IRT Chairman signs final meeting minutes AND evaluation report

6. Make copies and distribute

7. File Evaluation letter and all attachments under the Evaluation Letter Number

8. File a copy of the Meeting Minutes under the Meeting Minutes Letter Number (do not remove previous DRAFT copy of the Meeting Minute from the letterlog.

Letters

receive draft w/disk
get letter # from letterlog file
make corrections and finalize
spell check
save on hard disk
obtain signature
make copies
distribute
file IRT copy in letterlog book

NAME	SECTION/CHAPTER OF DOCUMENT								
H. Worle									
B. Meale									
E. Hochhalter									
W. Lussie									
G. Dinneen									
G.Beitel									
R. Smith									
N. Morcos									
Seismic/Structural									
Toxicology									

Name	Charge Account Numbers	Phone #
H. Worle		6-8963
B. Meale		6-9978
E. Hochhalter		6-1038
W. Lussie		6-1659
G. Dinneen		6-6318
G. Beitel		6-0042
R. Smith		6-9345
N. Morcos		6-4926

EXECUTIVE CORRESPONDENCE

96/3861

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

RECEIVED
1996 SEP 30 AM 11: 19
DNF SAFETY BOARD

AUG 30 1996

96-QSH-042

Dr. A. L. Trego, President
Westinghouse Hanford Company
Richland, Washington

Dear Dr. Trego:

AUTHORIZATION OF THE SAFETY ASSESSMENT (SA) OF ROTARY MODE CORE SAMPLING (RMCS) IN FLAMMABLE GAS SINGLE-SHELL TANKS, WHC-SD-WM-SAD-035, REV 0a AND INTERIM OPERATIONAL SAFETY REQUIREMENTS (IOSR)

The Safety Evaluation Report (SER) provided to your staff documents the results of the RL review of the SA of RMCS in Flammable Gas Single-Shell Tanks. This document is recognized to have been prepared as a graded approach to compliance with DOE Order 5480.23, and has been determined to be acceptable for operation of the facility.

By this letter, RL is authorizing the SER and these documents as the nuclear safety authorization basis for RMCS in Flammable Gas Single-Shell Tanks at the Hanford Site.

WHC is expected to implement the requirements of the authorized SA and IOSRs as soon as is reasonably achievable from the date of this letter. Full compliance with the SA and IOSRs is expected and required. The documents are also expected to be updated and revised to meet changing facility conditions and operational requirements. You should coordinate your implementation schedule and plans with the TWRS management.

Please direct any inquiries to me, or your staff may contact, Jackson E. Kinzer, Assistant Manager, TWRS, on 376-7591.

Sincerely,

John D. Wagoner
Manager

cc: H. J. Hatch, FDH

DO NOT WRITE ON THIS COVER AS IT IS INTENDED FOR RE-USE
RETURN IT WITH THE FILE COPIES TO ORIGINATING OFFICE