DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

September 16, 2016

Dr. Monica C. Regalbuto
Assistant Secretary for Environmental Management
U. S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Dr. Regalbuto:

The Defense Nuclear Facilities Safety Board began a review in 2015 of the nuclear criticality safety program at the Savannah River Site (SRS). Over the course of this review, there were four significant operational issues related to credited criticality controls. We acknowledge that corrective actions were taken to address each of the four incidents.

The review revealed that fissionable material operations at SRS rely heavily on administrative and often non-independent controls. As evidenced by the recent events, administrative and non-independent controls are more susceptible to implementation errors and common-mode failures, respectively. The review concluded that identifying and protecting safety margin during fissionable material operations could minimize the impact of these weaknesses by producing a system more tolerant of control failures. The enclosed report provides additional details for your consideration.

Sincerely,

Joyce L. Connery
Chairman

Enclosure

c: Mr. Jack Craig
Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

April 21, 2016

MEMORANDUM FOR: S. A. Stokes, Technical Director

COPIES: Board Members

FROM: J. Meszaros, T. Battaglia, Z. Beauvais, M. Bradisse, T. Davis

SUBJECT: Savannah River Site Nuclear Criticality Safety Program

A Defense Nuclear Facilities Safety Board (Board) staff team reviewed the Savannah River Site (SRS) nuclear criticality safety program in 2015 and the beginning of 2016. The staff team met with personnel from the Department of Energy's Savannah River Operations Office (DOE-SR) and Savannah River Nuclear Solutions (SRNS) during the weeks of March 9, May 11, and November 9, 2015, and on March 10, 2016.

The staff review of the SRS nuclear criticality safety program sought to determine whether the content and implementation of the SRNS criticality safety program complies with applicable DOE requirements and standards. The review focused on program implementation at H-Canyon and HB-Line due to the operational complexity of facility processes and the presence of fissionable material quantities that pose a credible inadvertent criticality risk.

Background. The staff team reviewed nuclear criticality safety-related programmatic documents in order to evaluate whether the SRNS program complies with applicable requirements. The staff team assessed many elements of the SRNS program, including implementation and maintenance of criticality accident alarm systems, emergency response planning, contractor and federal program oversight, evaluation of criticality safety-related controls for inclusion in the facility safety basis, and use of criticality safety-related postings and labels.

The staff team reviewed Nuclear Criticality Safety Evaluations (NCSEs) and supporting calculations in order to determine whether SRNS personnel properly analyze credible upset conditions in evaluations and identify the criticality safety controls needed to ensure that processes will remain subcritical during all normal and credible abnormal conditions. The staff team also reviewed operational procedures to evaluate whether criticality safety-related controls are sufficiently implemented. As a result of the staff team's review of programmatic documents, NCSEs, and operational procedures, they believe that SRNS management should consider implementing program improvements. Of note, the staff team believes that SRNS personnel should modify the process by which criticality safety limits are identified in NCSEs. The basis for this position is discussed herein.

Criticality Safety Approach. The SRNS approach for analyzing criticality hazards and developing controls involves a review of operations by cognizant site personnel to identify credible initiating events that could result in critical configurations. Criticality scenarios that are considered incredible or beyond extremely unlikely (i.e., less frequent than 10^{-6}/year [1, 2]) may be identified, but are not necessarily considered further. The SRNS approach focuses on preventing credible criticality scenarios (i.e., more frequent than 10^{-6}/year) by developing two or more controls for each initiating event. These controls provide protection by either controlling two independent process parameters (preferred), or providing two controls on a single process parameter.

The Board's Technical Report entitled TECH-29, *Criticality Safety at Department of Energy Defense Nuclear Facilities* [3], summarizes an earlier staff effort to evaluate criticality safety programs across the DOE defense nuclear complex. It notes that the SRS approach to nuclear criticality safety is different from the approach used at other defense nuclear facilities. It further evaluates the strengths and weaknesses of the SRS process, as described in the excerpt below.

> "The advantage of [the SRS approach] is that each criticality scenario is carefully described and documented such that all plant personnel can clearly understand the criticality risk....Under this approach, when a process error or control failure occurs, there is little ambiguity with regard to remaining safety margin. The disadvantages are that additional care must be taken to ensure that all credible criticality scenarios have in fact been identified. Further, because there is a large number of criticality scenarios, the identification of at least two controls for every scenario can be difficult. The result is that criticality safety engineers often use non-independent controls or rely excessively on administrative controls."

The 2015 Board's staff team review found similar strengths and weaknesses in the SRNS approach to nuclear criticality safety and believes actions are warranted to improve some of these weaknesses.

Process Analysis Requirement. Title 10, Code of Federal Regulations, Part 830, *Nuclear Safety Management* (10 CFR Part 830), requires that DOE nonreactor nuclear facilities with fissionable material in a form and amount sufficient to pose a potential for criticality, define a criticality safety program in the associated documented safety analysis that:

(i.) "Ensures that operations with fissionable material remain subcritical under all normal and credible abnormal conditions,
(ii.) Identifies applicable nuclear criticality safety standards, and
(iii.) Describes how the program meets applicable nuclear criticality safety standards."

In addition, Appendix A to Subpart B of 10 CFR Part 830 states that DOE Order 420.1, *Facility Safety* [4], provides DOE's expectations with respect to criticality safety. DOE Order 420.1 states that criticality safety programs must satisfy the requirements of the criticality safety standards of American National Standards Institute (ANSI)/American Nuclear Society (ANS)-8, and specifically highlights ANSI/ANS-8.1, *Nuclear Criticality Safety in Operations with Fissionable Material Outside Reactors* [5].

ANSI/ANS-8.1 states that "before a new operation with fissionable material is begun, or before an existing operation is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions." Many DOE sites meet this "process analysis" requirement by demonstrating through calculations that a process remains subcritical during normal conditions and following postulated upsets from these normal conditions. Credible postulated upset conditions are chosen based on an evaluation of the fissionable material system by key cognizant professionals (e.g., operations supervisors and criticality safety staff) and will vary based on the process or operation of interest. Criticality safety limits on key parameters (e.g., mass, spacing, and concentration) are typically set at or near normal conditions so that any credible control failure does not result in an inadvertent criticality. This methodology thus results in a system that can tolerate control failures.

The SRNS approach to process analysis involves the application of two or more controls to prevent operation outside of identified criticality safety limits. Hypothetical operation at the criticality safety limits is considered to be credibly abnormal and is verified to be subcritical via calculation. Operation outside of these limits is considered incredible based on the control set identified. The staff team observed in several H-Canyon and HB-Line NCSEs [6-11] that criticality safety limits often provide minimal margin to a critical configuration. The SRNS methodology is illustrated in Figure 1.

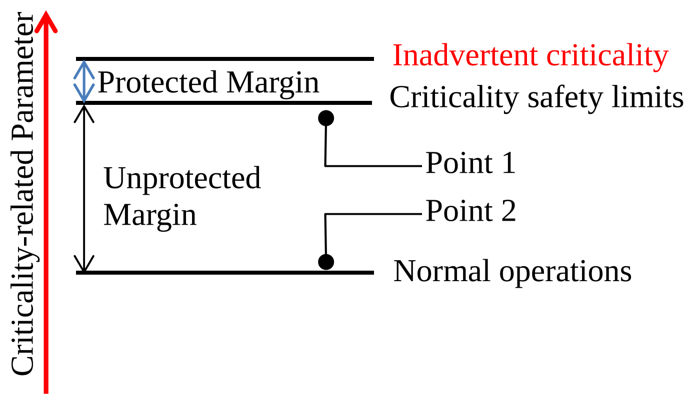

Figure 1: The SRNS Approach to ANSI/ANS-8.1 Process Analysis Compliance

The SRNS process does not prohibit operation near criticality safety limits (Point 1 in Figure 1), though in practice, HB-Line and H-Canyon operations are conducted well below criticality safety limits (Point 2 in Figure 1). The staff team is concerned that the SRNS criticality safety program does not establish appropriate margin in criticality safety limits. The staff team reviewed a subset of SRNS operations that apply margin to criticality safety limits in order to account for measurement, equipment, and process uncertainty. The SRNS criticality safety program and implementing procedures do not require this practice, however, and the staff team notes that it is not uniformly applied by SRNS.

The staff team believes that the SRNS methodology would be better aligned with the ANSI/ANS-8.1 process analysis requirement if appropriate, defensible safety margins were included in criticality safety limits. Safety margin should be identified based on an evaluation of the process so that credible control failures do not result in an inadvertent criticality. As a result, criticality safety limits would be set closer to normal operating conditions. This proposed methodology is described in Figure 2.

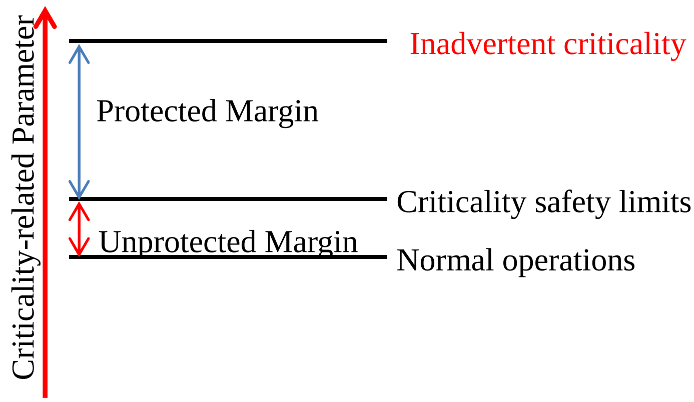

Figure 2: The Board's Staff Team's Proposed Approach

The staff team believes that the identification and protection of appropriate safety margin is especially important at SRS, given that the control set includes many administrative and often non-independent controls. The need for this action is further supported by recent events involving credited criticality safety controls at H-Canyon and HB-Line. These events serve to illustrate that control failure is credible. Several of the events also illustrate that the common mode failure (CMF) of non-independent controls can impact all criticality safety controls credited to prevent a given process upset. Additional detail is included in the following paragraphs.

Administrative Controls. The staff team found that SRNS relies heavily upon administrative controls. For instance, the H-Canyon Double Contingency Analysis [6] identifies 5 passive engineered controls, 19 active engineered controls, and 163 administrative controls. Yet the SRNS nuclear criticality safety manual [1] specifically notes that administrative controls rely "on the judgment, training, and responsibility of people for implementation. Administrative means of control may be action, caution, or verification steps in a procedure, or steps in a surveillance program. Because these means of control are human based, and therefore subject to error in application, they are generally regarded as the least desirable means of criticality control."

The staff team also identified many non-independent, administrative controls in reviewed NCSEs. For instance, verification of a criticality safety limit and second person verification of the same limit are considered two controls on a single parameter, but may involve two workers verifying the same indications at essentially the same time. The staff team notes that the SRNS criticality safety manual [1] requires that areas of CMF associated with controls be identified and mitigated to the extent that is practical; however, recent events involving criticality safety controls challenge whether CMF of non-independent, administrative controls can be fully mitigated.

H-Canyon and HB-Line Criticality Safety-Related Events. The staff team discussed with SRNS personnel four events that occurred between February 2015 and February 2016. These events were the subject of detailed causal analyses by SRNS personnel. These analyses identified several causes related to control implementation, conduct of operations, procedure quality, and process weaknesses. Table 1 highlights some of the identified causes that are relevant to the scope of this review.

Date of Event	Facility	Brief Description of Event	Cause(s)
February 2015	HB-Line	Loss of credited criticality safety controls that protect a large plutonium nitrate solution storage tank due to undetected loss of tank agitation in an upstream tank.	Inadequate CMF analysis of tank agitation control.
September 2015	HB-Line	Loss of credited criticality safety control on spacing after workers transporting fissionable material failed to follow steps in a procedure that required use of a specially designed cart.	Less-than-adequate compliance with conduct of operations requirements.
January 2016	HB-Line/ Analytical Lab	Laboratory transcription error in the analysis of samples taken to ensure compliance with criticality safety limits for a large plutonium nitrate solution storage tank.	Erroneous data entry caused by human error. Spreadsheet used at the lab propagated the error.
February 2016	H-Canyon Second Uranium Solvent Extraction Cycle	Operators were unable to establish steady feed flow and thus could not initiate a steady-state procedure. This procedure included controls to verify three process limits that protected a mass criticality safety limit in the mixer-settler tanks.	Inadequate implementation of process limits in procedures.

Table 1: Recent H-Canyon and HB-Line Criticality Safety-Related Events

Although the staff team reviewed corrective actions associated with each of the events and generally believes that site management has proposed appropriate actions, these events collectively illustrate the staff's concerns relating to administrative and non-independent controls. All of the events listed in Table 1 involved failure and/or improper implementation of administrative controls, and thus illustrate why these controls are the least desirable method for preventing criticality accidents.

Further, the events that occurred in February 2015 and January 2016 illustrate the staff team's concern that CMF associated with non-independent controls is difficult to fully evaluate and mitigate. The February 2015 event involved the failure of agitation in an HB-Line tank prior to transfer. SRNS personnel tied the agitation failure to an inadequate CMF analysis in the appropriate NCSE. As a result of agitation failure, criticality safety controls requiring representative sampling and independent representative sampling of the tank's contents prior to transfer were rendered unreliable. These controls protect criticality safety limits for the contents of a downstream tank; fortunately, the contents of the tank at the time of control failure were well within identified criticality safety limits. Thus, inadvertent operation of the tank outside of analyzed conditions was prevented through margin provided by process controls, not credited safety controls.

The January 2016 event impacted the same sampling and independent sampling controls associated with the same HB-Line tank. In this case, the samples were not analyzed independently because a spreadsheet used at the lab propagated a data entry error from the analysis of one sample to the analysis of the other sample. The relevant HB-Line NCSE [9] evaluates CMF associated with these controls and notes that the potential for CMF exists but is mitigated in part because the "analyses require a high level of procedural and measurement-system scrutiny to ensure the independence and accuracy of the analyses." Fortunately, the error in implementing the sampling controls was in a conservative direction that required SRNS personnel to dilute the contents of the HB-Line tank prior to transfer, so inadvertent operation outside of analyzed conditions was avoided.

The staff team is concerned with the recent frequency of events related to the credited control set at HB-Line and H-Canyon. Non-independent controls have been impacted or lost on multiple occasions. Because it may be impractical to replace current control sets, these events collectively illustrate the need for a system that is tolerant of control failure. The application of appropriate, defensible safety margins to current criticality safety limits as is described in the preceding paragraphs would help produce such a system.

Conclusions. In 2015, a staff team reviewed the SRNS nuclear criticality safety program and its compliance with applicable DOE requirements and industry best practices. The staff noted the criticality safety-related control set extensively relies upon administrative controls, which in many cases are not independent. In light of these identified weaknesses and control failures that occurred between February 2015 and February 2016 at H-Canyon and HB-Line, the staff team believes appropriate, defensible safety margin should be captured as part of the SRNS nuclear criticality safety program and included in NCSEs moving forward. Such a practice will better align SRNS methodology with the ANSI/ANS-8.1 process analysis requirement that is required by both 10 CFR Part 830 and DOE Order 420.1.

References

1. SDC-3, Rev. 28, *Nuclear Criticality Safety Manual*, Savannah River Nuclear Solutions, October 9, 2014.

2. SRNS-IM-2009-00035, Rev. 3, *Criticality Safety Methods Manual*, Savanah River Nuclear Solutions, January 2014.

3. DNFSB TECH-29, *Criticality Safety at Department of Energy Defense Nuclear Facilities*, Defense Nuclear Facilities Safety Board, February 2001.

4. DOE Order 420.1B, *Facility Safety*, U. S. Department of Energy, December 2005.

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6. N-NCS-H-00243, Rev. 9, *H-Canyon Double Contingency Analysis*, Savannah River Nuclear Solutions, September 2014.

7. N-NCS-H-00249, Rev. 4, *Nuclear Criticality Safety Evaluation: Safety of Spent Nuclear Fuel Dissolution*, Savannah River Nuclear Solutions, November 20, 2013.

8. N-NCS-H-00276, Rev. 1, *Nuclear Criticality Safety Evaluation: Dissolution of Plutonium Metal*, Savannah River Nuclear Solutions, December 19, 2013.

9. N-NCS-H-00277, Rev. 3, *Nuclear Criticality Safety Evaluation: HB-Line Phase II Pu Oxide Operations*, Savannah River Nuclear Solutions, August 29, 2013.

10. N-NCS-H-00278, Rev. 2, *Nuclear Criticality Safety Evaluation: Plutonium Metal Handling in HB-Line Phase 3*, Savannah River Nuclear Solutions, August 16, 2012.

11. N-NCS-H-00286, Rev. 0, *Nuclear Criticality Safety Evaluation: Dissolution of Plutonium Metal in 6.1D without Soluble Neutron Poison*, Savannah River Nuclear Solutions, December 18, 2013.