Integrated Waste Treatment Unit
Phase 1 Results / Phase 2 Project Plan

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Technical Issues Resolution Project

December 7, 2016

SBW Treatment (IWTU) Overview

- IWTU is a 53,000 sq. ft. facility designed to treat 900,000 gallons of Sodium Bearing Waste (SBW) using the Fluidized Bed Steam Reforming process
- The process will convert SBW into a solid, granular, carbonate product for on-site storage pending final disposition
- IWTU construction completed in 2011 and CD-4 achieved in 2012
- Process instabilities and equipment problems identified during non-radiological testing operations to date have delayed the transition to radiological operations
- Instabilities are associated with the primary reaction vessel, the Denitration Mineralization Reformer (DMR), and include particle size control, difficulties maintaining fluidization conditions and scale formation within the DMR
- Problems have also included various equipment quality and reliability issues

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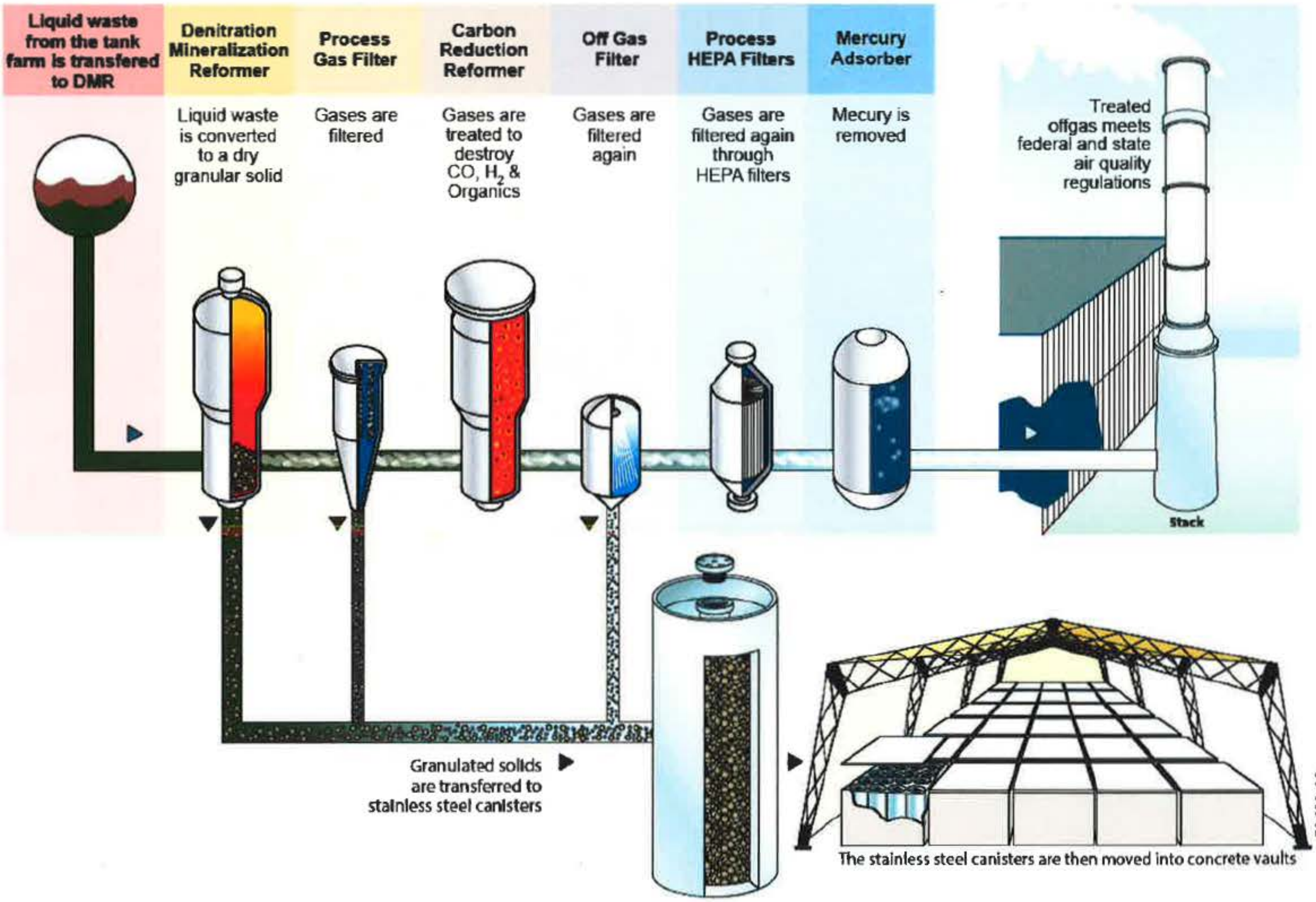
Illustration of IWTU Process



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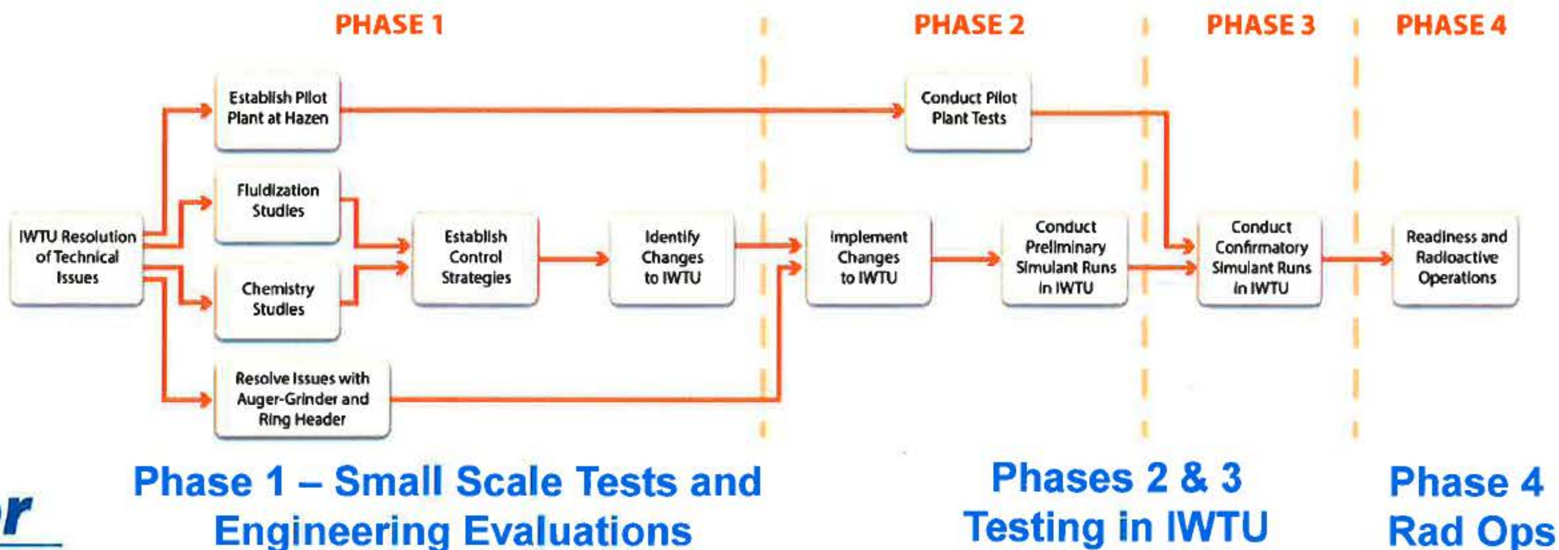
Approach to Address DMR Instabilities and Other Remaining Issues with the IWTU

- Fluor Idaho was awarded the contract to operate the Idaho Cleanup Project including the IWTU and assumed operational control in June, 2016
- Fluor established a systematic, mechanistic based approach involving 4 phases to address issues with the IWTU
- A team of specialists was assembled to work with IWTU staff, including experts in fluidized bed technology that have solved similar problems in industry
- Flour established a Technical Review Group consisting of subject matter experts from National Labs, industry and academia to provide input and advice



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Approach for Phase 1

1. **Collected Data and Information** – Evaluated the design basis, reviewed data from prior IWTU simulant runs and observed plant operations
2. **Set Priorities** – Structured the Phase 1 approach with a primary focus on the DMR instabilities (process focus) followed by assessments of the balance of plant (equipment focus)
3. **Established a Working Hypothesis** – Developed working explanation of the causes of the DMR instabilities
4. **Identified Knowledge Gaps** – Identified areas of uncertainty or gaps in knowledge for the DMR
5. **Conducted Investigative Program** – Planned and carried out specific, focused tests, engineering analyses and modeling to provide data to close knowledge gaps and confirm working hypothesis. Conducted plant review activities for the balance of plant.
6. **Reviewed Results** – Assessed results to identify and confirm process and plant modifications to solve the problems
7. **Developed the Plan for Phase 2** – Used the results to formulate the approach for Phase 2

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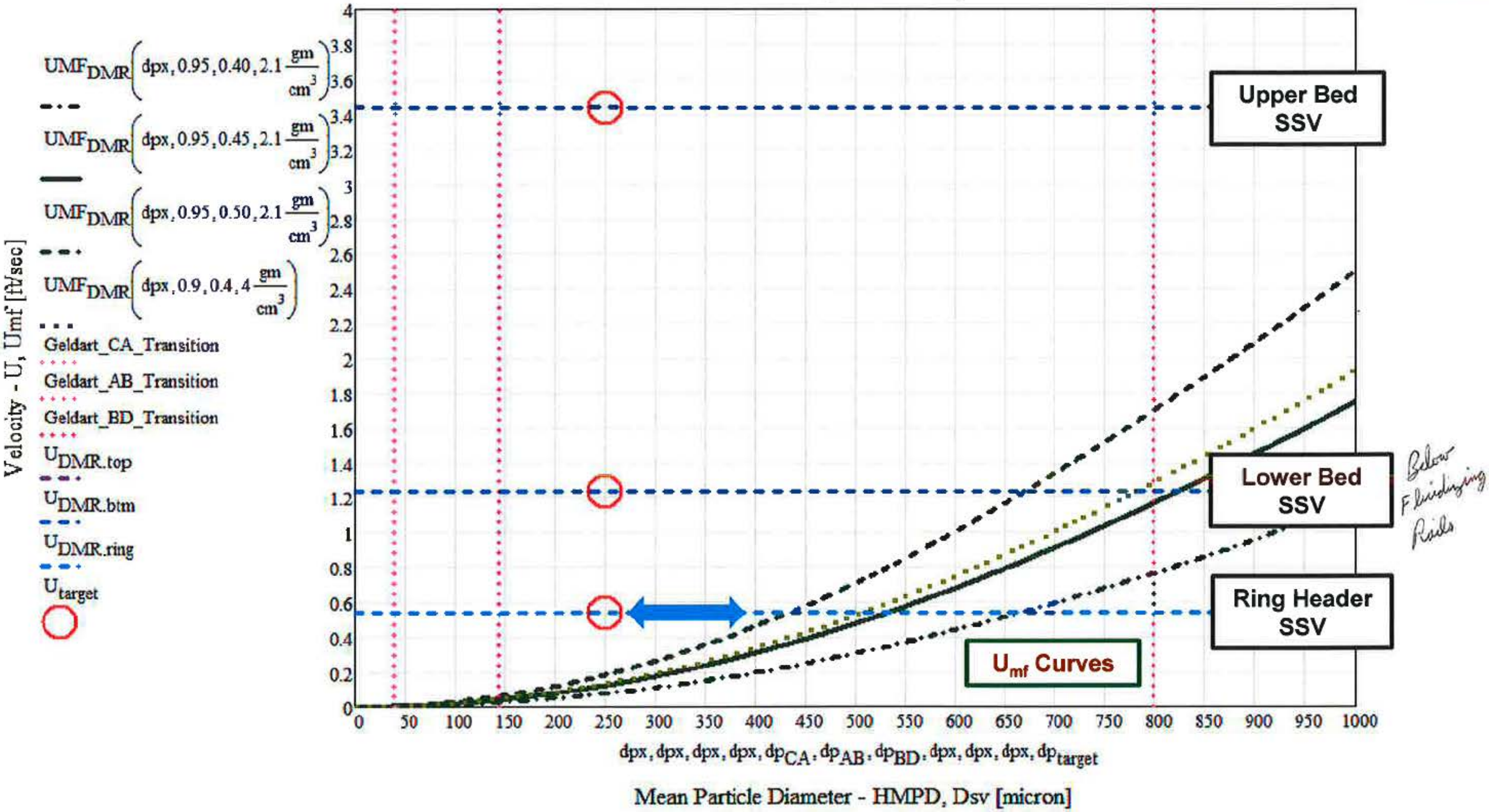
Phase 1 Project Knowledge Gaps and Approach to Address Them

Knowledge Gap	Approach	Importance to the Program
Uncertainty concerning existing waste-feed injector performance.	• Determine waste-feed droplet sizes with simulated waste as a function of injector design and nozzle atomizing ratio.	• Important aspects of particle growth and particle size control. • Used to establish range of acceptable feed rates for a given nozzle design.
Uncertainty concerning the behavior of the injected waste feed droplets.	• Determine the time constant(s) for waste-feed conversion to carbonate.	• Rapid evaporation and conversion of the feed droplet to decompose nitrates and form hydroxides likely influences factors such as particle growth and particle cohesiveness. • Influences control strategies relating to droplet size and particle size control.
Characteristics of reversible carbonation and hydration reactions as a function of different H_2O / CO_2 ratios.	• Small-scale chemistry tests with the microscope hot stage and the 2-inch split-tube furnace.	• Testing helps confirm mechanisms that could cause wall scale formation and defluidization. • Also helps to develop recovery strategies.
Specific control strategies and operating boundaries that successfully provide sustainable and predictable operation.	• Engineering analyses and modeling of fluidization. • Integrated testing with an 18-inch pilot scale DMR (occurs in Phase 2).	• Assess combined behaviors of the above factors in a small-scale and representative fluidized bed environment. • Allows control strategies and operating boundaries to be evaluated; recovery strategies to be tested; and evaluation of other mechanisms causing the instabilities such as the scale formation.

Phase 1 Results Summary – Lots of Work Completed in 4.5 Months

	Phase 1 Element	Key Results
Fluidization and Chemistry	Fluidization Studies	• Defined inadequacies in fluidization and particle size control and identified required changes. • Confirmed slow waste feed conversion – which is the most plausible explanation for wall scale and particle cohesion. • Defined approach for process and equipment modifications to the DMR.
	Waste Feed Injector Droplet Size Testing	• Established that flowrates less than 0.6 gpm may result in unacceptably large droplet size for the existing waste feed injectors..
	Droplet Conversion Testing	• Engineering analysis supportive of slow waste feed conversion..
	2-inch diameter FBR test bed	• Confirmed stable bed operations achieved with 5% CO_2. Confirmed reversibility of reactions.
	Microscope Testing w / Hot Stage	• Demonstrated that <1% CO_2 in high steam environment inhibited formation of NaOH – limits cohesive particles.
	18-inch diameter FBR test bed	• Design complete and vessel fabricated for testing during Phase 2 • Test Plan for Phase 2 developed.
	Analysis of IWTU May Simulant Run Samples	• Confirmed lack of particle size control. • Analysis of DMR products provided evidence for slow conversion of waste feed. • Cementitious material analysis provided understanding of auger-grinder failure mechanism. • Carbonate particle reactivity observed under ambient conditions.
	Computational Fluid Dynamics (CFD) Modeling	• Aligned model with observed data from May simulant run. • Demonstrated existence of cold plumes which is supportive of slow waste feed conversion.
Plant and Equipment	Auger-Grinder	• Testing replicated failure mechanism from May 2016 simulant run – steam and crushed DMR bed product (or fines) resulted in formation of cementitious material. • Requirements for redesign established with input from industry expert. • Fabrication of prototype auger-grinder test unit completed and on track for testing in Phase 2.
	Ring Header / DMR Access	• CFD analysis confirmed 2-inch ring header design acceptable, report issued. • Revised manway design 90% complete pending final stress analysis.
	Plant Review	• Extent of Condition review of 4 critical systems that experienced significant and repeated problems, identified root causes, and confirmed no similar problems elsewhere in the plant. • Plant review identified required modifications for balance of plant to enhance reliability, operability and ease of maintenance. Modifications have been prioritized and sequenced into Phase 2 project plan. • RAM model logic completed, model developed to inform production schedule and maintenance.

Fluidization Engineering Assessments Used to Establish Operating Strategies for the DMR



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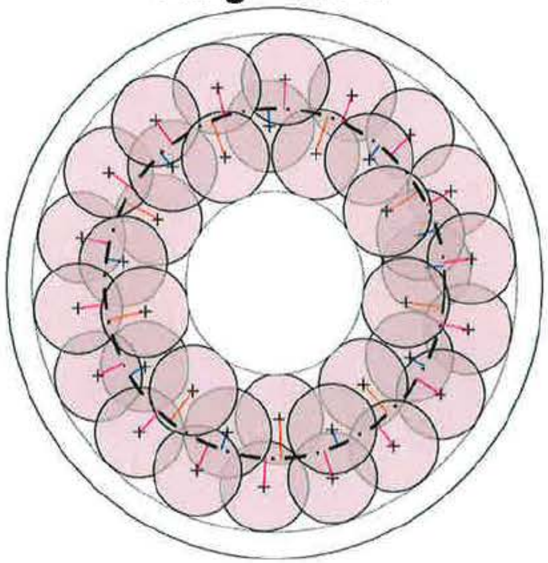
Operation map of DMR illustrating the operating margin (blue arrow) in terms of the mean particle diameter and the minimum fluidization velocity in ring header region. Strategy for Phase 2 is to target 250 micron sized particles to enhance process control.

Ring Header and Fluidizing Gas Rails

- Ring header provides relatively uniform bubble flow based on Computational Fluid Dynamics modeling
- However, with unconstrained particle size growth above 500 micron, the ring header region defluidizes
- North and South regions at Fluidizing Rails above ring are not fluidized if defluidization occurs in ring area
- Temperature transients and presence of "sandcastles," or agglomerations, are consistent with this behavior
- Modifications to the rails will distribute gas flows more evenly across the bed

Ring Header

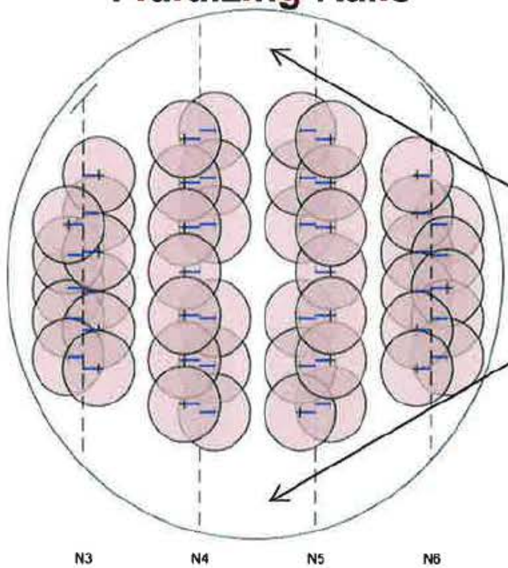


Ring Header Flow Distribution

Ring provides 140 scfm of steam and N_2

Middle area fluidized by Auger-Grinder purge

Fluidizing Rails



Fluidizing Rails Flow Coverage (68%)

Areas Not Effectively Fluidized by the Rails

Rails provide 204 scfm of steam and O_2

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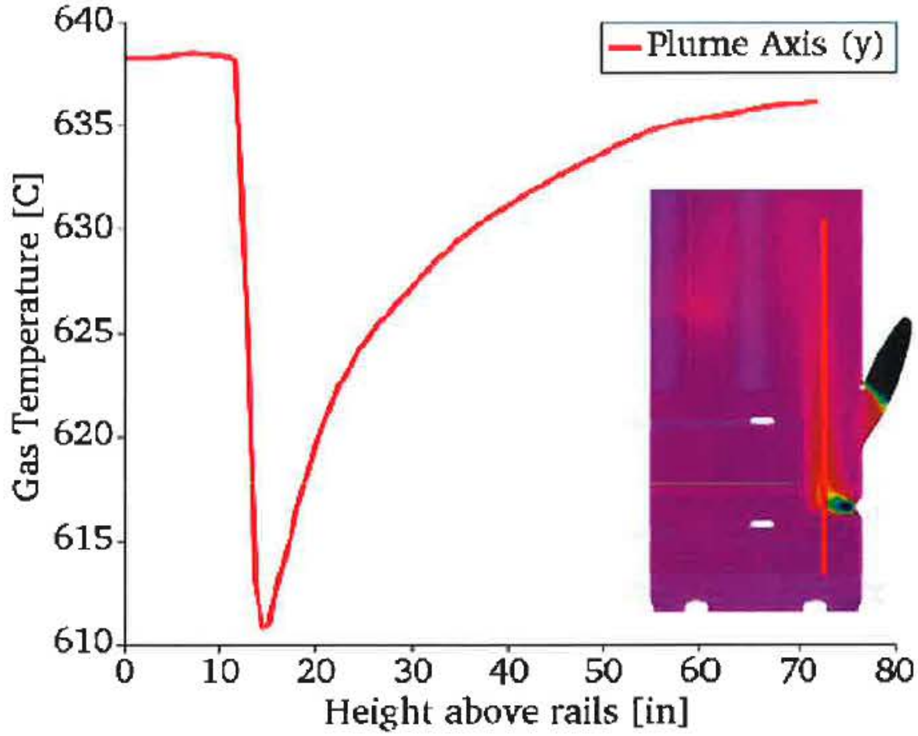
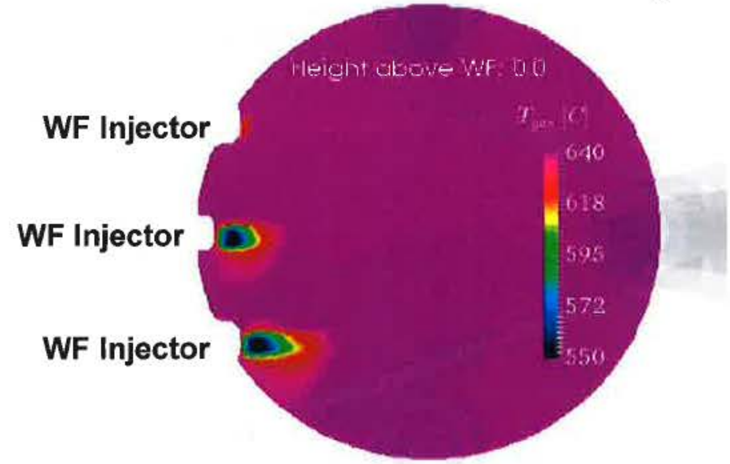
NETL Modeling – Temperature Profiles in the DMR

Model results align with May simulant run and are consistent with slow conversion of waste feed due to the presence of relatively cool waste feed plumes

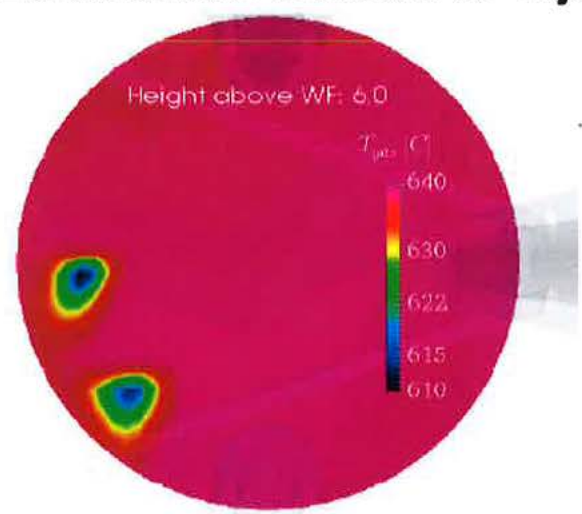


Data extracted along red line

Horizontal slice at the WF Injectors



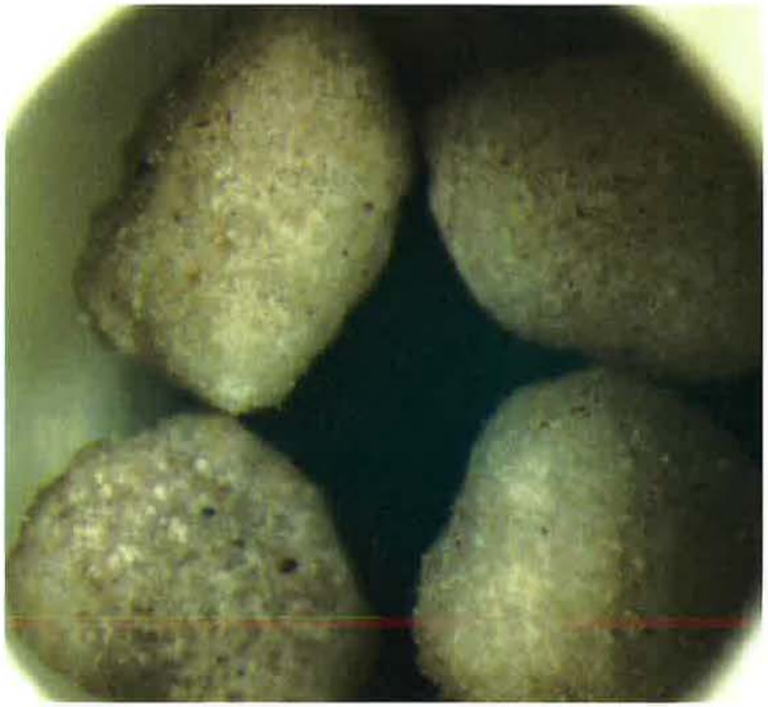
Horizontal slice 6-in above WF Injectors



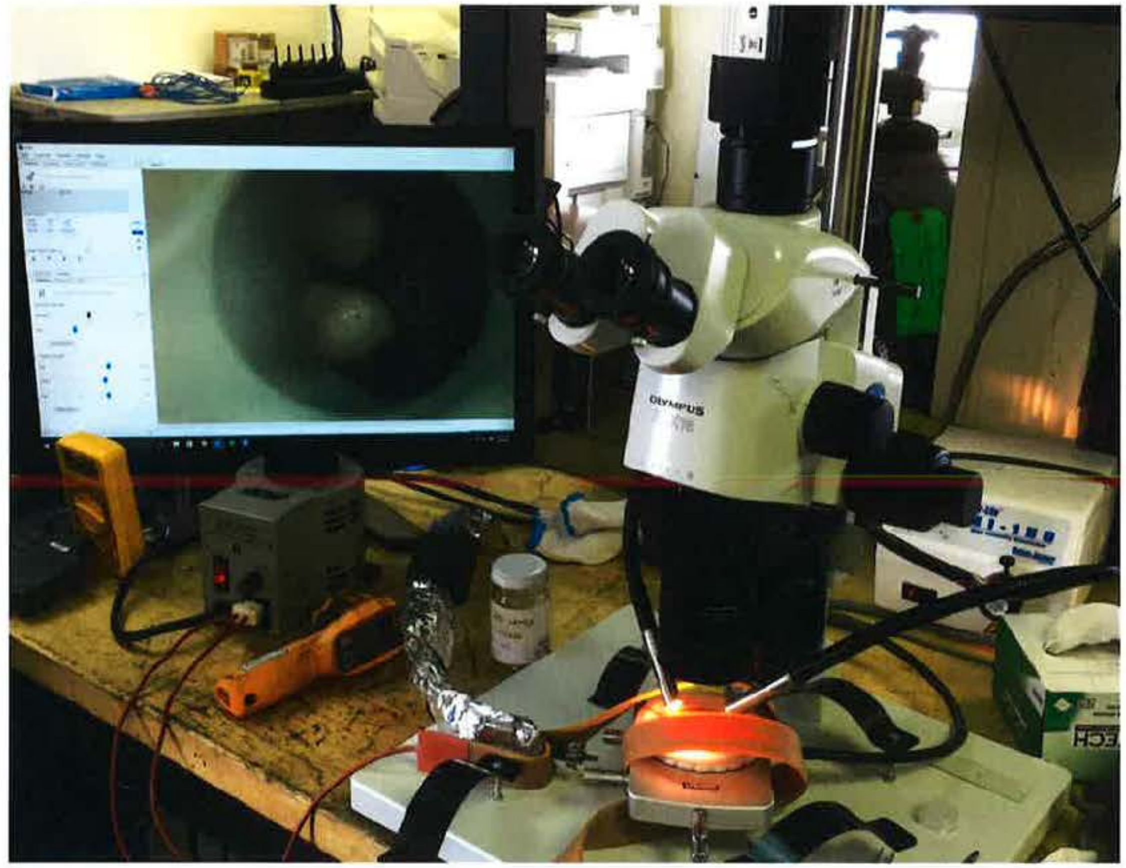
Temperature differentials within the injection plumes are sufficient to significantly slow conversion reaction rates.

Microscope Testing with the Heated Stage

Determined that having <1% CO_2 present prevents the reaction with steam to form NaOH on the particles



DMR bed particles at 640 deg. C being exposed to different combinations of N_2, CO_2 and steam during microscope tests



Microscope System with Heated Stage

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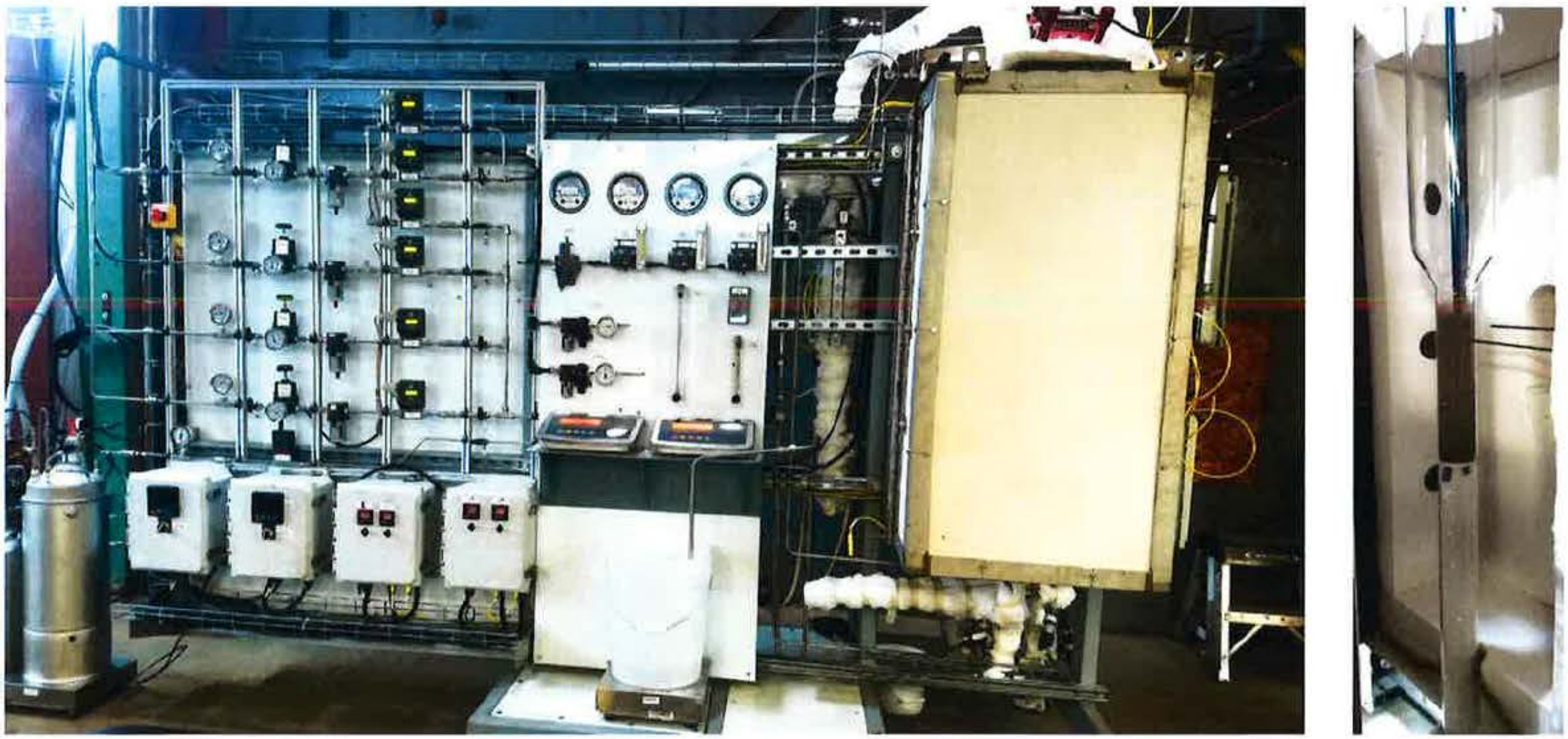
2-Inch Diameter Fluid Bed System Tests

- System designed, assembled and tested
- Determined that having 5% CO_2 level with balance of steam + nitrogen ensured stable bed / no sandcastle formation over a period of several days



Process Skid and Fluidizing Vessel

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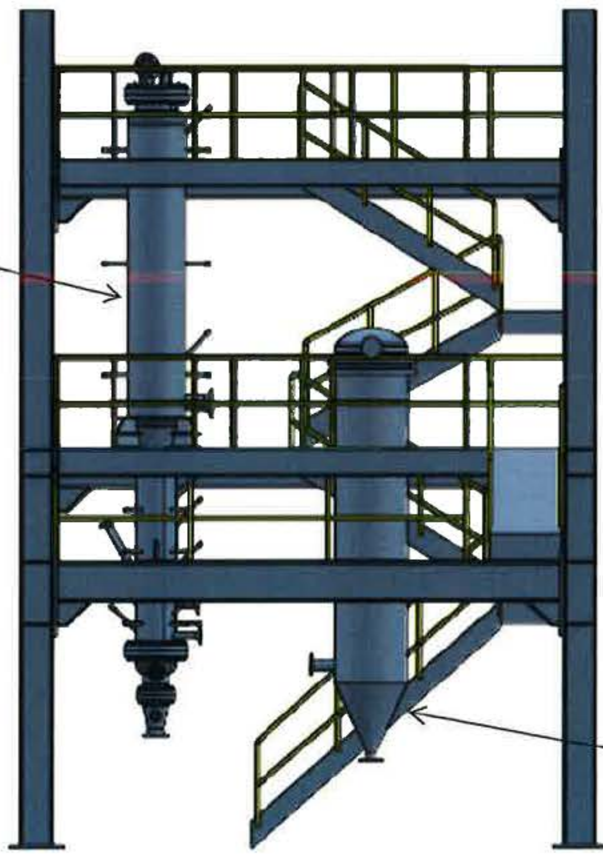
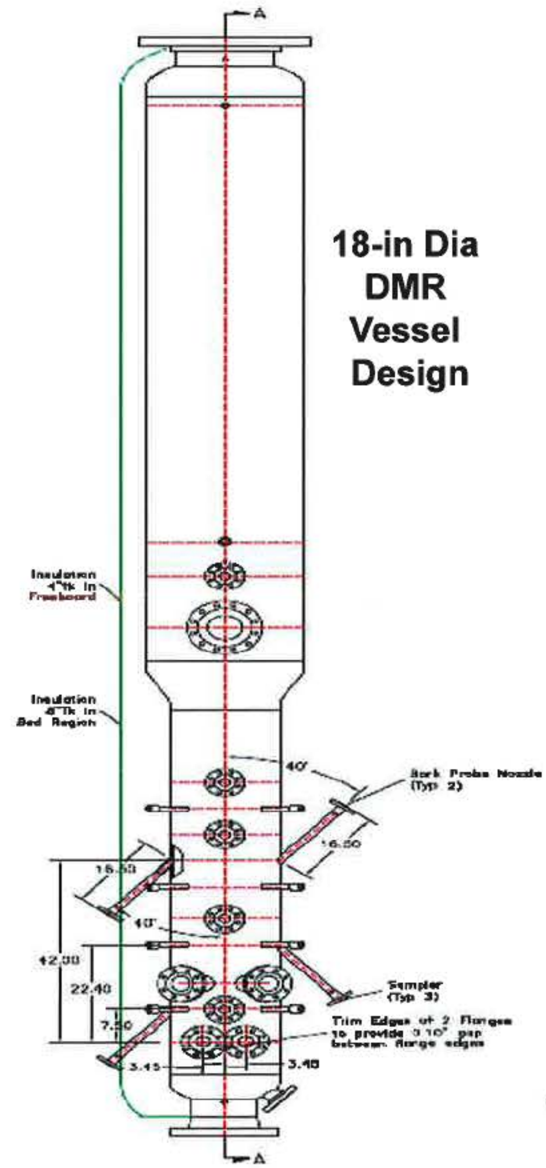
18-inch Diameter DMR Pilot Plant System at the Hazen Research Test Facility

- Vessel design completed and fabricated
- Vessel and balance of systems currently being installed and prepared for testing
- Test Plan for Phase 2 activities issued





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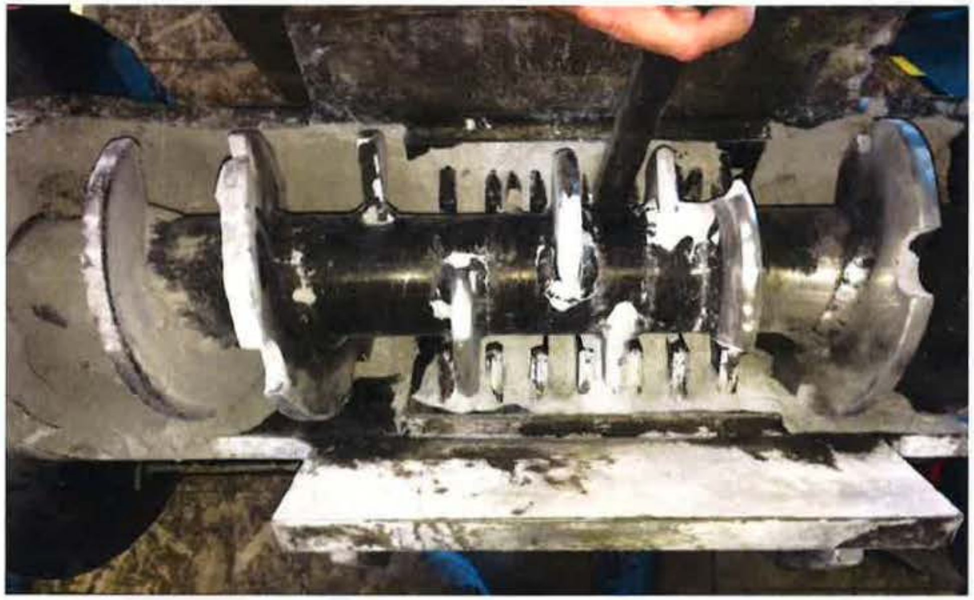
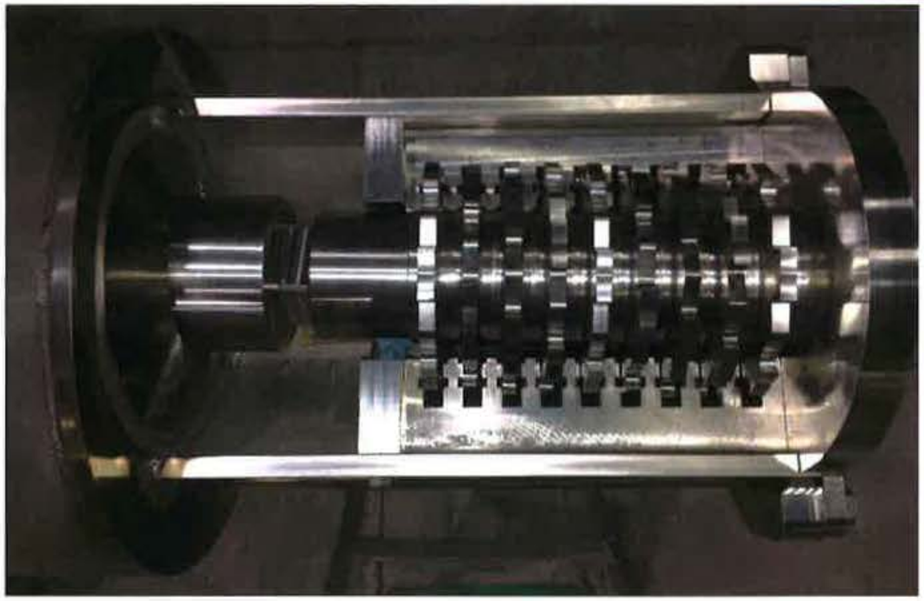
Auger-Grinder Testing Identified Failure Mechanism from May Simulant Run



Auger-Grinder used in the May 2016 simulant run.



Prototype Auger-Grinder currently being tested.

- **Auger-Grinder is located on the bottom of the DMR and conditions the product to enable pneumatic transfer to the product collection and packaging area**
- **The Auger-Grinder failed during previous simulant runs**
- **Test results indicate steam forms a cementitious material that locks up the auger-grinder**
- **The purge strategy to minimize presence of steam in the unit is very important**
- **The Project team developed and is currently testing a new prototype that includes improvements in its mechanical design**

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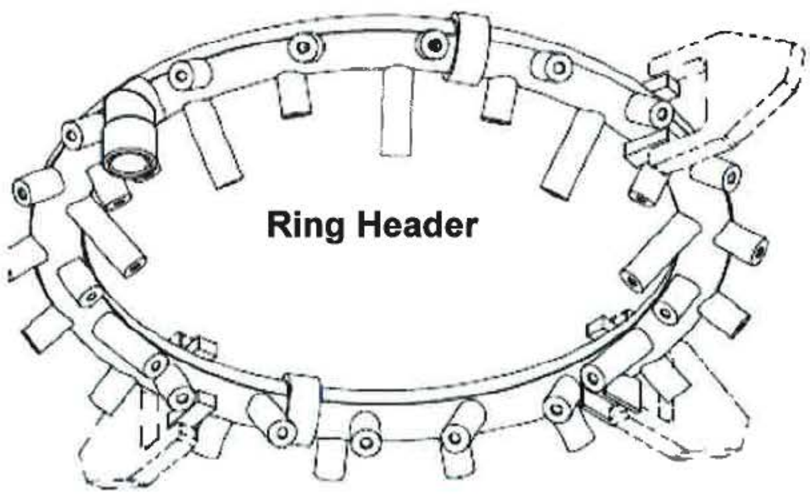
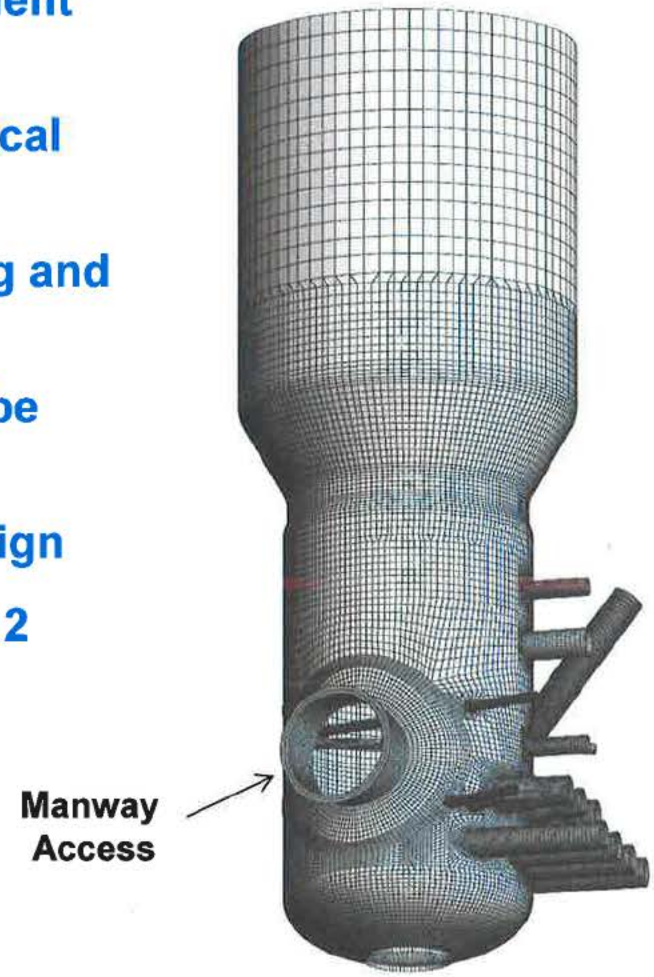
DMR Manway Design and Ring Header Repair

- Ring header damaged due to fluidizing jet impingement during December 2015 simulant run
- Damaged ring needs to be replaced before radiological operations commence
- Replacement ring design analyzed via CFD modeling and confirmed acceptable
- Repair requires safe access into DMR – manway to be installed on side of DMR
- Continuing to refine stress analysis and finalize design
- Manway installation is on the critical path for Phase 2





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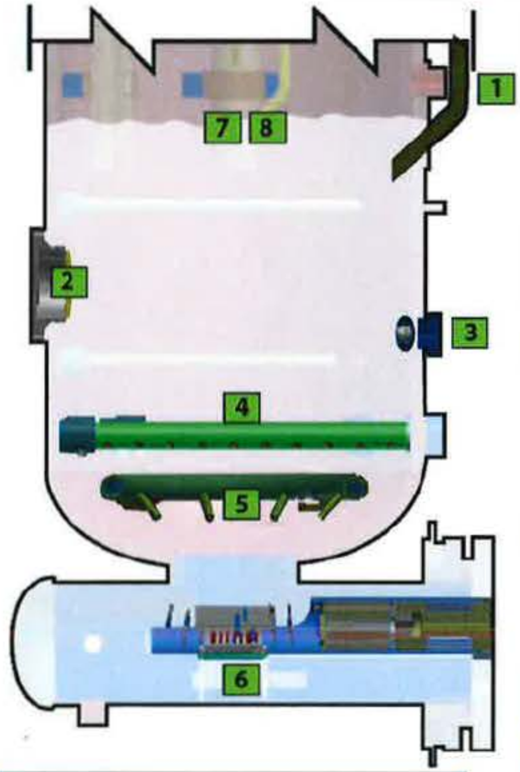
DMR Issues Identification, Causes and Solutions Resulting from Phase 1 Work

Wall Scale	
Observation	Wall Scale
Impact	Build-up of Scale Deposits
Root Cause	Slow Conversion of Feed
Solution 3 7 8	Reduce the Feed Rate Use all Three Waste Feed Injectors Increase DMR Operating Temp Increased DMR Bed Depth

Formation of Sandcastles	
Observation	Sandcastles / Agglomerations
Impact	Temperature and Fluidization Instabilities
Root Cause	Slow Conversion of Waste Feed Insufficient Fluidization Insufficient Particle Size Control
Solution 1 2 3 4 5	Refine Fluidization Strategy Modify Fluidizing Gas Rails Implement Seeding Control Requires Manway Access Insure sufficient CO_2



DMR Instabilities	
Observation	Temperature Excursions
Impact	Instabilities, Shutdowns
Root Cause	Defluidization Channeling of Gases Wall Scale
Solution 1 4 5 7 8	Refine Fluidization Strategy Modify Fluidizing Gas Rails Implement Particle Size Control

Ring Header Damage	
Observation	Erosion of Ring Header
Impact	Breach Would Defluidize DMR
Root Cause	Jet from Fluidizing Gas Rails
Solution 2 4 5	Modify Fluidizing Gas Rails Replace Ring Header Requires Manway Access

Auger Grinder Failure	
Observation	Auger-Grinder Locked Up
Impact	Inability to Transfer Product Results in Plant Shutdown
Root Cause	Build-up on Rotating Parts Insufficient Mechanical Design Lack of Adequate Purge
Solution 6	Auger Grinder Root Cause Analysis Industry Expert Consultant Extensive Prototype Testing Improved Purge Gas Strategy Improve Mechanical Design Recovery Capability

DMR Modifications	
1	Seeding Size Control
2	Manway
3	Waste Feed Injector
4	Fluidizing Rails
5	Ring Header
6	Auger-Grinder
7	Increase DMR Temperature
8	Increase Bed Height

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The graphic summarizes the 5 main issues impacting the DMR, the causes and proposed solutions.

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Phase 2

Primary Activities in Phase 2 to Address Phase 1 Outcomes

- **Modifications include manway installation and ring header repair**
- **Auger-Grinder design development tests, confirmatory simulant testing, followed by fabrication and testing of final unit**
- **3 runs with simulated waste (see table below)**
- **3 test series at Hazen using the 18-inch diameter DMR pilot plant**
- **Additional bench tests and engineering evaluations to improve understanding and mitigation strategies for cool waste feed plumes / slow waste feed conversion and wall scale formation**
- **Other engineering assessments (e.g., WF injector testing with solids, radiological operations studies)**

Simulant Run	IWTU Simulant Runs Primary Test Objective	Simulant-Feed-On Duration (days)
1	Validate operation of revised auger-grinder design under plant operating conditions	20
2	Validate fluidization improvements including particle size control and DMR modifications	30
3	Validate operating, control & recovery strategies	50

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Phase 2 Project Work Locations

Wide range of work activities at multiple locations – requires significant coordination / management

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Assessment of Phase 1 and Plans for Phase 2

Excellent technical performance with clear outcomes

- **Identified the principal issues responsible for the DMR instabilities and selected the preferred solutions to be evaluated in Phase 2 IWTU runs**
  - Fluidization and process control shortcomings (rail design, lack of particle size control) that resulted in defluidization, sandcastles or agglomerations, and the observed DMR temperature transients
  - Design and operational features that contribute to cool waste feed plumes which lead to slow waste feed conversion, likely result in wall scale and increase the potential for cohesive particles
  - Confirmed chemistry issues through analysis, engineering assessments and bench scale testing
- **Identified and replicated the failure mechanism for the auger-grinder**
- **Developed design, fabricated next generation unit and started testing**
- **Established approach for the ring header repair and developed manway design**
- **Identified required modifications to improve reliability through various Plant Review activities, root cause analyses and extent of condition reviews**

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