DEFENSE NUCLEAR FACILITIES
SAFETY BOARD

Washington, DC 20004-2901

August 3, 2015

Mr. Mark Whitney
Principal Deputy Assistant Secretary for
Environmental Management
U. S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Mr. Whitney:

Members of the Defense Nuclear Facilities Safety Board's (Board) staff conducted a review of the safety basis for the Defense Waste Processing Facility (DWPF) at the Savannah River Site. This review identified issues with flammable gas analysis and controls, specific administrative control implementation, and safety analysis assumptions; these issues are detailed in the attached staff report. The Board's staff team communicated these issues to the Department of Energy (DOE) site office, and the site office is addressing some of the concerns.

Pursuant to 42 U.S.C. § 2286b(d), the Board requests a report within 90 days that discusses 1) DOE's analysis of interactions between non-safety and safety components in the melter off-gas system, 2) the adequacy of compensatory measures for the retained hydrogen Potential Inadequacy of Safety Analysis (PISA), and 3) the path forward for resolving the melter feed rate, retained hydrogen and antifoam flammability PISAs.

Sincerely,

Jessie H. Roberson
Vice Chairman

Enclosure

c: Mr. Jack Craig
Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

May 1, 2015

MEMORANDUM FOR: S. A. Stokes, Technical Director

COPIES: Board Members

FROM: P. Meyer, D. Shrestha, S. Sircar

SUBJECT: Defense Waste Processing Facility Safety Basis Review

Members of the Defense Nuclear Facilities Safety Board's (Board) staff performed a review of the safety basis for the Defense Waste Processing Facility (DWPF) at the Savannah River Site. The staff members conducted discussions with representatives of the Department of Energy Savannah River Operations Office (DOE-SR) and Savannah River Remediation (SRR) in October 2014, December 2014, February 2015, and April 2015. This report documents the key findings from the staff team's review.

Facility Description. DWPF is a key part of the system for processing and immobilizing the high-level waste stored at the Savannah River Site tank farms. DOE-SR transfers most of the radioactive portions of the high-level waste to DWPF where the waste is chemically processed and borosilicate glass frit is added. The processed waste is transferred into the melter and heated to a molten form. The molten waste is poured into stainless steel canisters where it cools into a hard glass, immobilizing the radionuclides. Since 1996, DOE has produced about 4000 canisters and expects to produce approximately 4600 more canisters over the remaining lifetime of DWPF.

Safety Basis. The safety analysis for the facility is documented in a Final Safety Analysis Report (FSAR). Although, the FSAR does not follow the formatting guidance of DOE Standard 3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, the FSAR states that it meets the technical requirements of Standard 3009-94. The staff team's concerns about the safety basis for DWPF are summarized below.

Inadequate Technical Basis for Melter Off-Gas Flammability Control. The processed waste transferred into the melter includes some organic materials that can decompose to form gases such as hydrogen and carbon monoxide. Accumulation of hydrogen and carbon monoxide above the composite lower flammability limit (CLFL) can lead to explosions. The FSAR and Technical Safety Requirements (TSR) have a suite of controls for preventing explosions in the melter off-gas system. These controls include air flows to the melter vapor space and the off-gas, limits on the melter vapor space temperature, and limits on the melter feed composition. SRR and Savannah River National Laboratory (SRNL) personnel use a process model of the melter and its off-gas system to develop these controls. The model calculates the concentrations of hydrogen and carbon monoxide in the off-gas system after a "surge" event, in which the melter off-gassing rate temporarily increases. The review team's concerns regarding the melter off-gas flammability control are:

Melter Feed Rate—The model used by SRR and SRNL to develop off-gas flammability controls assumes a maximum melter feed rate of 1.5 gallons per minute (gpm) to limit the rate at which organic materials are introduced to the melter. There is no safety-related control for directly measuring and limiting the feed rate. Rather, the feed rate assumption is protected indirectly via the vapor space temperature measurement based on an expectation that the vapor space temperature would decrease as the feed rate is increased. If the vapor space temperature drops below a set point, an interlock signal stops the melter feed pump. The staff team questioned whether this control strategy is adequate to limit the feed rate to 1.5 gpm.

As SRR personnel were preparing their response to the staff team's questions, SRR declared a Potential Inadequacy of the Safety Analysis (PISA) because the assumed relationship between the feed rate and the temperature may be non-conservative while the melter bubblers are in use. Operational data from DWPF in May 2014 illustrates this concern; SRR fed the melter at 1.5 gpm and the vapor space temperature stayed well above the interlock temperature throughout the run. SRR and SRNL hypothesized that the relationship between the feed rate and vapor space temperature changed because of the installation and use of melter bubblers, which were installed in 2010 to increase processing rates. As a compensatory measure, SRR stopped using the bubblers and has been feeding the melter at around 0.7 gpm. This interim measure is adequate to address the staff team's concern regarding the controls for protecting the feed rate limit of 1.5 gpm.

Identification of Safety Controls—A variety of structures, systems and components (SSC) play a role in how the melter off-gas system responds to a surge event. Many of these SSCs, including controllers and valves, are not identified as safety controls. The FSAR does not include analysis of whether the concentration of flammable gases would still be kept below the desired level if the non-safety SSCs failed to operate as expected. If such SSCs are relied upon for the safety function of limiting the flammable gas concentrations, then they should be evaluated for identification as safety controls. DOE-SR and SRR personnel informed the staff team that the next revision of the model calculation will evaluate whether failures of these non-safety SSCs would have a detrimental impact on the control of flammable gases. The staff team believes it would be prudent to perform this evaluation.

Documentation—The staff team also observes that the documentation of the assumptions, methods, and results for the model calculation could be improved. DOE-SR's 2013 assessment had similar conclusions. SRNL has a Corrective Action Plan to address DOE-SR's findings.

The analysis regarding the prevention of explosions in the melter is an example where the documentation could be improved. The safety analysis assumes that if explosions are prevented in the off-gas system, then explosions should be prevented in the melter as well. The safety controls limit the flammable gas concentrations in the off-gas system at a location where the off-gas has cooled and the water has condensed out. SRR expects the flammable gas concentrations to be lower in the melter due to the presence of substantial amounts of water vapor. However, the staff team notes that the lower flammability limit (LFL) typically decreases with increasing temperature, so the LFL would be lower in the melter vapor space. There is also less dilution air in the melter vapor space because some of the dilution air is introduced downstream of the melter. DOE-SR, SRR, and SRNL informed the staff team that they intend to evaluate this topic in the next revision of the model calculation.

Path Forward—SRR is considering various long-term control strategies to resolve this PISA, including possibly upgrading the ventilation system to safety class. The staff team will continue to review the development of controls to address this hazard.

Inadequate Technical Basis for Flammable Gas Retention and Release in DWPF Vessels. The staff team also reviewed the mixing system designs, waste rheology, and flammable gas controls for DWPF process vessels. Hydrogen gas is generated in the waste due to radiolysis and the catalytic decomposition of formic acid. During normal operations, mechanical agitation in the process vessels allows the hydrogen to be released from the waste where it is diluted and safely removed from the vessel headspace by the vessel purge system. The staff team raised questions related to the potential for hydrogen to be trapped within the waste when process vessels are not agitated. SRR reports that the waste is non-Newtonian and has a yield stress; wastes with a yield stress are well-known to retain gas [1]. If sufficient hydrogen is generated and retained during this period, either a spontaneous release or an induced release due to resumption of agitation could create the potential for headspace flammability.

For the DWPF vessels, SRR did not have an adequate technical basis to conclude that the flammable gases retained in the waste during a mixing system outage would be small enough, and released slowly enough, to allow the vessel purge system to maintain the headspace safely below the CLFL. The review team concluded there was not adequate assurance that the flammable gas hazard was understood, appropriately analyzed, and adequately controlled in DWPF process vessels. Further, the staff team found that, under bounding assumptions, the CLFL in the Chemical Process Cell (CPC) vessels' headspace may be exceeded due to a spontaneous release or upon mixing system restart.

In response to the staff team's questions, SRR acknowledged the lack of adequate documentation supporting safe operations after the loss of mixing in the DWPF process vessels. On December 17, 2014, SRR declared a PISA due to the DWPF Safety Basis not specifically addressing the issue of flammable gas retention in DWPF vessels. SRR then found that this represented an Unreviewed Safety Question (USQ).

SRR is currently considering options to resolve the PISA/USQ identified for this issue. After discussions with SRR personnel, the staff team identified the following technical considerations that may be useful in evaluating and resolving this issue:

Gas Generation Rate—The staff team notes that mixing could be lost during or shortly after formic acid addition. In this case, the catalytic contribution to the hydrogen generation rate should be analyzed because loss of agitation would not result in an instantaneous termination of the reaction. Given that the catalytic hydrogen generation rate is more than an order of magnitude greater than the radiolysis contribution, even a relatively small amount of residual catalytic generation after loss of mixing could result in a significant contribution to the retained gas volume and significantly shorten the amount of time required to accumulate a hazardous volume of hydrogen.

Gas Retention—The analysis of the retained gas volume should be physically representative and adequately conservative for a loss of agitation scenario. The staff team notes the slurry may retain gas as it settles, given its non-Newtonian rheology (yield stress). Settling is a relatively slow process that can occur on the order of days based on qualification testing of DWPF sludge [2]. Further, the maximum amount of gas that the sludge can retain should be determined conservatively based on relevant data. Experiments conducted at Pacific Northwest National Laboratory (PNNL) [1] demonstrate that the maximum retained gas fraction in weak sludge depends on the yield stress. Given the maximum design basis yield stress for waste slurries processed in the CPC of 15Pa [2], the PNNL data suggests retained gas fractions in excess of 20% are possible.

Gas Release Mechanisms—Buoyant Displacement Gas Release Events (BDGRE) [3] can occur when retained gas in a solids layer causes the layer to become buoyant with respect to the supernatant layer. A BDGRE for a fully settled solids layer may not be credible due to very high gas fractions required for buoyancy. However, a BDGRE may be possible during solids settling, where the density difference between the compacting solids layer and supernatant is necessarily smaller and a lower retained gas fraction is required to achieve buoyancy. Additionally, a bubble cascade spontaneous gas release event [4] may pose a credible hazard given the anticipated conditions of the sludge in the process vessels.

Gas Release Rate—The rate at which the gas is released can affect headspace flammability. If the gas is released too quickly, then the purge flow may be insufficient to maintain the headspace safely below the CLFL. The FSAR currently does not provide a basis for the release rate. If the revised safety basis will credit a specific gas release rate, then a rigorous technical basis is required. For example, other DOE projects have accomplished this through tests employing appropriate scale laws, representative mixing system geometries, and simulants [5]. The review team believes that the gas release after the startup of mixing may occur quickly, challenging the purge system's ability to maintain the headspace within safe conditions. For example, gas release measurements in a mechanically agitated system with a 10 Pa slurry in an 18-inch test vessel were conducted at SRNL [6]. This test was conducted in turbulent flow conditions that are also anticipated in CPC vessels. The test demonstrated a gas release time on the order of tens of seconds (see Figure 5.14 of [6]).

Reliance on Operational Data—SRR indicated that they would evaluate historical gas release data from the DWPF process vessels. If observational data will contribute to the technical basis for concluding that there is no hazard, then the actual waste rheology and gas generation rate during the period of observation must be understood. Future sludge batches may have different physical properties that lead to different gas retention characteristics. If the safety basis will assume that gas retention is limited, then appropriate controls on the waste properties will be necessary.

Interim Compensatory Measure—SRR instituted a compensatory measure intended to place the facility in a safe condition while new controls are being developed. If agitation is lost in specific CPC vessels for more than one hour, SRR cannot resume agitation without an engineering evaluation showing that the resulting gas release will not cause the vessel headspace to exceed 95 percent of the CLFL. For scenarios not involving formic acid, SRR's evaluation is based on operational data from a single agitation outage during processing of the current sludge batch. For scenarios involving formic acid, SRR had not identified an approach for performing this evaluation at the time of the April 2015 discussion. Further, the staff team notes that the compensatory measure does not consider the possibility of a spontaneous gas release during an agitation outage.

Path Forward—SRR is considering various long-term control strategies to resolve this PISA. These control strategies may not rely principally on estimates of gas retention and release behavior. Additionally, SRR is pursuing an alternate reductant project that will eliminate or lower catalytic hydrogen generation; however, radiolytic hydrogen generation will remain a hazard. SRR is also developing the path forward for a separate PISA regarding the flammable degradation products of the antifoam used during waste processing. The staff team will continue to review the development of controls addressing the flammability hazards in the process vessels for all the scenarios discussed in this report.

Screening of Process Cell Explosions. The FSAR identifies events where waste spills in process cells can lead to an explosion due to the accumulation of hydrogen and organic vapors. These potential Design Basis Accidents are screened out from further analysis and the FSAR states that these events "cannot occur" because it would take more than four days after the spill to reach the LFL. SRR personnel explained that they assume that the operators would take some action within four days to interrupt the accident progression. A supporting calculation mentions that "ventilation can be restored in four days." Beyond that, the FSAR does not specify how operators would detect the condition, what specific actions they would take, or whether those actions would be adequate to prevent the explosion. The FSAR does not show the consequences of these events in comparison to the Evaluation Guideline and safety-related controls are not identified. The staff team believes the contractor's approach is inconsistent with DOE Standard 3009-94. Standard 3009-94 describes a process for analyzing Design Basis Accidents that includes unmitigated release calculations and comparison against the Evaluation Guideline. In this case, the FSAR does not enter this process.

Inconsistent Implementation of Standard 1186. SRR personnel use a remotely operated crane that travels over the process cells to install or remove equipment. The equipment being moved by the crane could be accidentally dropped onto important SSCs in the process cells. The FSAR identifies such load drops as initiating events for several Design Basis Accidents, with estimated unmitigated consequences to the collocated worker exceeding 100 rem Total Effective Dose. The FSAR identifies the Load Lift Program as a safety significant control that prevents events initiated by load drops. DOE Standard 1186 states that an administrative control shall be designated as a Specific Administrative Control (SAC) if it "is identified in the [Documented Safety Analysis] as a control needed to prevent or mitigate an accident scenario, and has a safety function that would be safety significant or safety class if the function were provided by an SSC." The FSAR does not identify any SACs from within the Load Lift Program, despite the FSAR taking credit for the program as if it were a safety significant SSC. In order to comply with DOE standards, either a SAC should be identified, or the safety control set should be revised such that an administrative program is not relied upon for preventing these events. The staff team notes that the safety significant ventilation system provides a layer of defense-in-depth for these events, as it would mitigate the consequences to the collocated worker.

Consequence Analysis. SRR and SRNL are currently revising their consequence analyses to reflect changes in plume dispersion methods. DOE headquarters personnel reviewed these methods and gave their concurrence. During the December 2014 review meeting, SRR personnel stated that they will continue to use 50th percentile meteorology conditions for the analysis of consequences to the collocated worker from natural phenomena events. The staff team questioned this approach. The use of 50th percentile conditions is not conservative and was not included in the dispersion analysis methods reviewed by DOE headquarters. In March 2015, DOE-SR directed SRR to instead use the relative atmospheric concentration (χ / Q') value specified in DOE Standard 1189, *Integration of Safety into the Design Process*. SRR was already planning to use the Standard 1189 value for collocated worker consequence analysis for other accident events.

Documentation of Assumptions and Controls. Some areas of the FSAR do not clearly describe the technical basis for the control set or the accident analysis. For example, there is a TSR control for monitoring the concentration of hydrogen in the vapor space of the Sludge Receipt and Adjustment Tank (SRAT) and the Slurry Mix Evaporator (SME) tank. The TSR states that the hydrogen concentration in the SRAT and SME shall be less than or equal to 60% of the LFL. However, the TSR and its bases do not specify how the LFL is defined for these vessels. The vapor space of these vessels could include hydrogen, Isopar^{TM} L, ammonia, antifoam degradation products, and nitrous oxide at elevated temperatures that can complicate the determination of the LFL. In another example, the mitigated consequence analysis for spills in the Low Point Pump Pit assumes that cell covers reduce the dose consequences to the collocated worker by a factor of two. The FSAR does not provide the basis for this factor of two.

Cited References

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[2] Areizs, J.M. and C.L. Crawford, *Sludge Washing and Demonstration of The DWPF Flowsheet in the SRNL Shielded Cells for Sludge Batch 8 Qualification*, SRNL-STI-2013-00116, Rev 0, Savannah River National Laboratory, Aiken, SC, April, 2013.

[3] Meyer, P.A and C.W. Stewart, *Preventing Buoyant Displacement Gas Release Events in Hanford Double-Shell Waste Tanks,* PNNL-13337, Pacific Northwest National Laboratory, Richland, WA, January, 2001.

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