Joyce L. Connery, Chair
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DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

July 26, 2022

The Honorable Jennifer M. Granholm
Secretary of Energy
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Granholm:

The Defense Nuclear Facilities Safety Board (Board) completed a safety review of the condition and structural adequacy of the 296-H stack, located within the Savannah River Tritium Enterprise (SRTE) at the Savannah River Site. This reinforced concrete stack, built in 1956, is near several facilities at SRTE, including Building 234-H (also referred to as H-Area Old Manufacturing) and the 217-H vault in which tritium is stored. If the stack collapsed onto the 217-H vault due to a natural event such as an earthquake, tornado, or high winds, a tritium release could result. The site management and operating contractor, Savannah River Nuclear Solutions, LLC (SRNS), is preparing to implement a revised safety basis that eliminates release scenarios for the vault, not by showing the vault would remain intact in a natural event, but instead by attempting to show that a stack collapse would not impact the vault.

The Board reviewed the SRNS analyses and identified multiple safety concerns, including inappropriate reliance on linear elastic analysis to predict where along its height the stack would fail, the omission of tornado-driven missiles from the analysis, the failure to adequately assess the current condition of the stack, the failure to consider air monitoring penetrations as credible failure locations, and the absence of any documented structural analysis of the stack foundation and pedestal. Of note, in response to these safety concerns, SRNS contended that inspections of the stack were not necessary and that the lack of analysis qualifying the structural adequacy of the foundation and pedestal was justifiable. The enclosed staff report provides more detail on these safety concerns.

The Board is concerned that the National Nuclear Security Administration (NNSA) has not established a defensible technical basis for its conclusion that the potential collapse of the 296-H stack would not impact the 217-H vault. Pursuant to 42 United States Code § 2286b(d), the Board requests that NNSA provide the Board—within 120 days of receipt of this letter—with a report that provides NNSA's assessment of the validity of the SRNS stack collapse analyses and addresses the specific concerns cited in this letter.

Sincerely,

Joyce L. Connery
Chair

Enclosure

c: The Honorable Jill Hruby
Mr. Jason Armstrong
Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Report

April 7, 2022

Savannah River Site 296-H Tritium Stack Structural Review

Summary. The Defense Nuclear Facilities Safety Board's (Board) staff completed a safety review of the 296-H stack, located at the Savannah River Site (SRS), to evaluate the stack's condition and structural adequacy. This reinforced concrete stack, built in 1956, is near several facilities at the Savannah River Tritium Enterprise (SRTE) including Building 234-H—also referred to as H-Area Old Manufacturing—and the 217-H vault, in which a significant amount of tritium is stored. SRTE is operated by Savannah River Nuclear Solutions, LLC (SRNS) for the National Nuclear Security Administration (NNSA) Savannah River Field Office (SRFO).

The objectives of the staff's safety review were to: (1) assess the adequacy of structural evaluations of the 296-H stack; (2) understand the current condition of the stack based on inspection history; and (3) understand how the current documented safety analysis (DSA) and recently approved and soon to be implemented combined Tritium Facilities DSA address a stack collapse accident. The Board's staff conducted this review in 2021 through early 2022, including an on-site interaction and walkdown of SRTE facilities in November 2021. The review team consisted of staff members D. Andersen, D. Brown, Z. McCabe, Y. Li, and L. Lin.

The staff's safety review focused on an assumption and supporting analysis in the combined Tritium Facilities DSA that a 296-H impact into the 217-H vault is not credible. SRFO has approved this DSA, but SRNS has not yet implemented it. A significant amount of tritium is stored in the 217-H vault, and the combined Tritium Facilities DSA credits the vault structure as a safety class fire barrier. Since SRNS concludes stack impact into the 217-H vault after natural phenomena hazard (NPH) events is not possible, the vault structure has never been analyzed for such an impact. Based on this safety review, the Board's staff concludes NNSA and SRNS have inadequately demonstrated that should the 296-H stack collapse, it cannot impact the 217-H vault at SRTE. The Board's staff reached this conclusion after identifying the following five concerns, discussed in detail later in the report:

- **Prediction of Stack Failure Location**: SRNS inappropriately relies on linear elastic analysis to predict where along its height the stack will fail, and thus excludes the 296-H stack as a credible threat to the 217-H vault. Since the stack does not pass code-based structural evaluations for approximately the bottom two-thirds of its height, only nonlinear analysis and a more detailed examination of all possible failure mechanisms can predict where the 296-H stack will fail. In addition, the SRNS analysis does not consider the impacts of tornado-driven missiles.

- **Unknown Stack Interior Condition**: The interior of the 296-H stack has never been inspected, and exterior inspections have only been conducted via ground-based visual

examinations. The last formal external visual inspection of the stack occurred in 2007, after which the stack was removed from the SRS Structural Integrity Program.

- **Single Reinforcement Design**: The 296-H stack was constructed with only a single layer of vertical and horizontal ("confining") reinforcement. The American Concrete Institute Code 307-08, *Code Requirements for Reinforced Concrete Chimneys*, no longer permits this design and now requires new stacks to be designed and constructed with two layers of reinforcement, one for the outer face and one for the inner face of the stack. This change in requirements arose from observations that reinforced concrete stacks with a single layer of reinforcement were developing vertical cracking from wind and thermal cycling.

- **Air Monitoring Penetrations**: SRNS has not considered air monitoring penetrations, added in the 1990s, as a credible location for stack failure. These penetrations do not have reinforcement detailing around them and are located sufficiently low in the stack that failure at this location makes stack impact into the 217-H vault a credible scenario.

- **Lack of Foundation/Pedestal Analysis**: SRNS cannot locate the analysis qualifying the foundation and pedestal for structural adequacy. SRNS concludes the stack cannot fail at these locations based on undocumented engineering judgment. This technical justification is inadequate for eliminating the foundation and pedestal as credible failure locations.

Without further addressing these safety concerns raised by the Board's staff, the assumption that the 296-H stack cannot impact the 217-H vault lacks an adequate technical basis.

Background. This section describes the 296-H stack configuration and how the current and upcoming safety bases address potential stack accidents.

296-H Stack—The 296-H stack at SRTE was constructed in 1956 and is the primary ventilation exhaust stack for Building 234-H. The stack is located close to the east side of Building 234-H and is approximately 147 feet from the 217-H vault. The stack is 183'8" tall above its pedestal, and its outer diameter tapers from almost 13 feet at its base to 9 feet at the top. The stack and its pedestal are constructed of reinforced concrete and are founded on a 36-foot octagonal reinforced concrete mat. Regarding steel reinforcement for the stack, there is a single vertical layer along with a single layer of horizontal confining steel; the latter is configured as spiral rings with a six-inch pitch. Lastly, due to the non-caustic nature of effluent gases, the stack does not have an interior liner. An aerial photo of the 296-H stack next to Building 234-H is shown in Figure 1.

Safety Bases and the Stack Collapse Accident—The current safety basis [1] and recently approved and soon to be implemented combined Tritium Facilities DSA [2] take different approaches to handling a 296-H stack collapse induced by NPHs. Presently, SRTE operates under two DSAs, one for the Tritium Extraction Facility and another for all other tritium facilities. As part of the combined Tritium Facilities DSA, they will operate under one common

Figure 1. *Aerial View of 296-H Stack, next to Building 234-H, at SRTE*

DSA. NNSA approved the combined Tritium Facilities DSA in December 2019 but has not yet implemented it. NNSA plans to partially implement this DSA by the end of calendar year 2023.

The current safety basis for SRTE does not rely on the 296-H stack to remain standing after design basis wind/tornado and seismic events, and does not identify it as a credited structure, system, or component (SSC). The safety basis accident scenarios that involve a stack collapse assume a complete release of material from Building 234-H, while the inventory in the 217-H vault is protected from a falling stack by the safety-significant Highly Invulnerable Encased Safes (HIVES) [3]. The HIVES only provide protection during impact scenarios and are not credited in fire scenarios due to ventilation openings on their sides, front, and back.

The upcoming combined Tritium Facilities DSA credits the 217-H vault structure, doors, a ventilation damper, and penetration seals as part of the safety-class fire barrier that protects the material in the vault from fire scenarios initiated elsewhere, including NPH-initiated events. This combined DSA relies on a statement in the consolidated hazard analysis [4] that "[i]t is not physically possible for the 296-H stack to impact Building 217-H due to seismic or tornado events based on analysis." Concluding that the stack will not impact the 217-H vault allows SRNS to remove the vault material at risk (MAR) and potential consequences from consideration in NPH-initiated fire scenarios. In another fire scenario involving the 217-H vault, the MAR equates to an unmitigated dose consequence of more than 6,000 rem total effective dose (TED) to the co-located worker and more than 15 rem TED to the maximally exposed offsite individual. The 217-H vault has not been analyzed for adequacy from stack impact and HIVES are unable to act as a fire barrier due to ventilation openings in their sides, front, and back. Thus, a stack collapse that impacts the 217-H vault followed by a fire that then travels into the 217-H vault could result in a significant increase to the calculated dose consequences of NPH-initiated fire scenarios.

The objective of the staff's safety review was to assess the adequacy of the SRNS structural evaluations, the current condition of the stack, and the defensibility of the SRNS assumption that the stack will not impact the 217-H vault after an NPH-induced failure. As for stack impact into Building 234-H, there are no credited controls to mitigate the consequences of this accident, and NNSA accepted this risk as part of its approval of the safety basis.

Staff Review. The Board's staff conducted a safety review of the structural adequacy of the 296-H stack at SRS from 2021 through early 2022. On November 17, 2021, the Board's staff conducted an on-site interaction with personnel from NNSA and SRNS to discuss staff lines of inquiry. In addition, the staff observed the exterior condition of the 296-H stack from the ground, performed a walkdown of Building 234-H, and observed the HIVES storage configuration in the 217-H vault. During this review, the staff identified five concerns, discussed below.

Prediction of Stack Failure Location—As discussed earlier, the combined Tritium Facilities DSA relies on analyses demonstrating an NPH-initiated failure of the stack impacting the 217-H vault is not credible. The two key analyses are the tornado/wind analysis [5] and the seismic analysis [6]; of these two, the tornado/wind analysis governs. For the tornado/wind analysis, the stack does not pass code-based checks for adequate strength for approximately the bottom two-thirds of the stack (i.e., from the pedestal to approximately 120 feet above the pedestal). The maximum demand-to-capacity ratio is 1.23 and occurs at 90 feet above the pedestal, the location where the stack first transitions to its thinnest wall thickness. SRNS asserts that the 296-H stack will fail at this exact location since this is where the highest demand/capacity ratio is calculated from the linear elastic, code-base evaluation. The remaining length of stack above this location (93'8") is less than the distance from the center of the stack to the 217-H vault (147').

The SRNS position that stack failure will occur at the location of the highest demand/capacity ratio is flawed. The highest demand/capacity can help predict where a plastic hinge might first form; however, the 296-H stack is not anticipated to hinge through its entire cross-section at one instance. Predicting how plastic hinges develop requires more sophisticated nonlinear analysis and consideration of local, and not just global, structural details. The failure of reinforced concrete can be caused by complex local phenomena such as lap splice failure, concrete crushing, failure around penetrations, and local buckling. Also, as reinforcing steel begins to yield, structural loads will be redistributed in a manner that cannot be predicted using linear elastic analysis.

There is also considerable variability in materials and dynamic loads that must be considered as part of predicting how a structure will fail. Properties of aged structural materials are not precisely known, and that variability should be considered in conjunction with observations and data from inspections. NPH loads typically used in an analysis, such as wind loading profiles and seismic response spectra, are probabilistically derived and not developed to represent a singular event. Also, they were developed to evaluate global, not local, structural adequacy. The likelihood of different failure mechanisms cannot be predicted without considering different realizations of wind and seismic events as part of a fragility analysis.

An example of an NNSA facility where a nonlinear, probabilistic approach is being applied is the Plutonium Facility (PF-4) at the Los Alamos National Laboratory (LANL). Although the structural configuration of that facility is much different than the 296-H stack at SRS, the same general principles regarding the prediction of failure mechanisms apply. LANL could not show PF-4 met linear elastic code-based checks, therefore it identified the need for column testing and nonlinear, probabilistic analysis to predict facility failure modes. This then allows for identifying opportunities for possible retrofit and demonstrating compliance with NPH performance goals.

Lastly, the Board's staff notes that SRNS has not included the consideration of tornado-driven missiles in its analysis. DOE-STD-1020, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*, requires consideration of these missiles for facilities designated as Wind Design Category-3/Performance Category-3 (WDC-3/PC-3) or higher. Since the 296-H stack is a two-over-one hazard to the safety-class 217-H vault structure, PC-3 requirements apply. DOE-STD-1020-2016 [7], Section 2.3.2, states "the methods to address common-cause failure and system interaction as presented in ANSI/ANS-2.26-2004 (R2010) should be followed for design basis NPH events." Since it is not feasible to retrofit the 296-H stack to enhance its strength, and the stack or vault cannot be moved to prevent adverse interaction, ANS-2.26-2004 [8] allows for either analyzing the stack to PC-3 requirements (the requirements of the two-over-one target, the 217-H vault) or showing the 217-H vault can still perform its function as a safety-class fire barrier after stack impact. Since SRNS has never analyzed the adequacy of the 217-H vault for stack impact, both for structural integrity and as a fire barrier, all PC-3 requirements, including the consideration of tornado-driven missiles, apply to the 296-H stack.

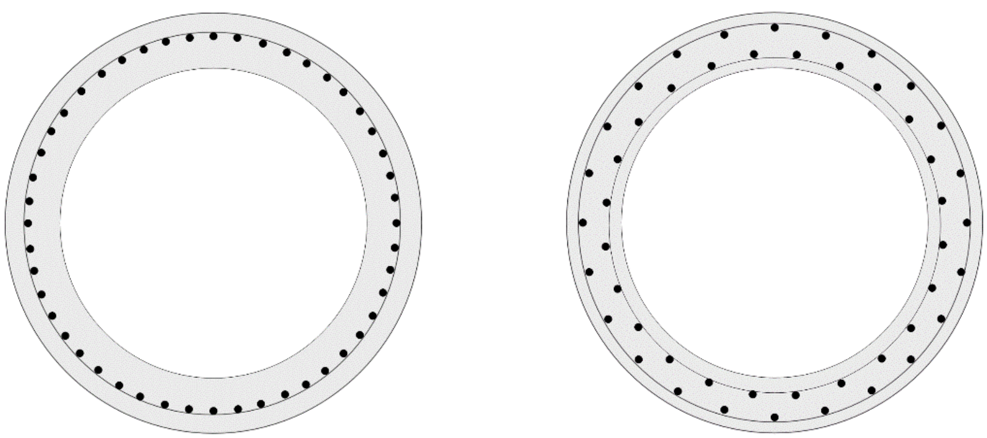
Unknown Stack Interior Condition—SRNS and previous site contractors have never inspected the interior of the 296-H stack and have only performed ground-based visual inspections from the exterior in the past. The last visual inspection of the exterior was conducted in 2007. These inspections ceased in 2008 when the stack was removed from the SRS Structural Integrity Program and no longer credited as a safety-related SSC. The practice of not inspecting both the exterior and interior of the stack is contrary to the guidance provided in the American Society of Civil Engineers, *Chimney and Stack Inspection Guidelines* [9]. This document recommends conducting visual inspections between every six and twenty-four months, and full height interior and exterior examinations every two to five years. These guidelines acknowledge that the interiors of some stacks are difficult to access and recommends considering non-destructive evaluations. Inspection of the 296-H stack has two challenges: the stack has no access hatches to its interior and no external ladder to facilitate exterior examination and access to the top.

SRNS contends that inspections are not needed for the 296-H stack. SRNS personnel stated that the interior of the stack is expected to be in good condition due to the non-caustic nature of the effluent gases. However, this does not consider degradation that can be caused by environmental conditions (e.g., precipitation, thermal loading, humidity) and cyclic pressure loads on and within the stack. In addition, based on past ground-based exterior observations of the stack, SRNS does not believe formal exterior inspections of the stack are needed. However, without a thorough exterior examination along the stack height, degradation features can be overlooked. In the next section, the susceptibility of single-reinforced concrete stacks to vertical cracking from wind and thermal cycling is discussed. These types of cracks could lead to additional degradation of the stack and, if located on the interior, be undetected.

Single Reinforcement Design—Due to the vintage of the 296-H stack, it was designed with dated practices. In particular, the stack only contains one layer of vertical reinforcing steel along its length and only one layer of circumferential (confining) reinforcing steel in the horizontal direction. Figure 2 compares a single reinforcement configuration with a two-layer ("two-face") reinforcement configuration. American Concrete Institute Standard 307-08, *Code Requirements for Reinforced Concrete Chimneys* [10], states the following in its commentary Section R4.1 (emphasis added):

> *For the 1995 edition, the Committee re-evaluated the previous exemptions regarding two-face reinforcement and minimum wall thickness for chimneys 300 ft or less in height and less than 20 ft in diameter. Recent information has indicated that two-face circumferential reinforcement is necessary to* ***minimize vertical cracking*** *due to radial wind pressures and reverse thermal gradients due to the effects of solar heating…. [T]he current committee believes that two-face reinforcement should be required in all chimney columns, regardless of size, considering the* ***aggressive environment surrounding chimneys****.*

Since SRNS does not inspect the interior of the 296-H stack, the presence of vertical cracks within the stack has not been determined. It is SRNS's position that there are likely no



(a) (b)

Figure 2. *Example Cross-sections for Vertical and Horizontal ("confining") Reinforcement (a) Single Layer of Reinforcement (b) Two Layers of Reinforcement ("two face") [Note: These are not cross-sections of the 296-H stack]*

interior vertical cracks since they would propagate through the thickness of the stack and be seen on the exterior of the stack. However, the Board's staff notes that interior vertical cracks may not manifest themselves on the exterior of the stack due to the presence of confining steel surrounding the vertical reinforcement.

Air Monitoring Penetrations—Four penetrations were added approximately 31 feet above the stack pedestal in the 1990s for installation of air monitoring equipment [11, 12]. Reinforcement detailing around penetrations in reinforced concrete is typically included in design; however, since these penetrations were added decades after construction of the stack, this detailing does not exist. Penetrations, particularly larger penetrations where ductwork enters a stack, have been identified as the cause of stack failure when exposed to extreme NPH loads. Although the penetrations for the air monitoring equipment are small (approximately four inches by eleven inches, created by overlapping four four-inch diameter concrete cores), they are located at the same elevation and collectively could be considered as a plausible location for stack failure (assuming good condition of the stack, including the uninspected interior). In addition, since the demand/capacity from the code-based evaluations at this location already exceed one, the stress concentration effects from the holes would likely lead to the most demanding structural loads. If the stack fails at the location of the air monitoring penetrations, as opposed to where the code evaluation predicts, impact into the 217-H vault could be credible. The staff believes confirmatory analysis should be performed.

Lack of Foundation/Pedestal Analysis—The Board's staff requested the structural analysis of the foundation and pedestal for the 296-H stack. SRNS informed the staff that the analysis is assumed to exist but could not be found. SRNS personnel stated that the foundation and pedestal are adequate based on undocumented engineering judgment. The Board's staff believes that SRNS should document its evaluations that the reinforced concrete pedestal and foundation mat have adequate strength, the soil bearing capacities are adequate, and that overturning of the stack is not possible for design basis NPH events. Failure of the stack at the foundation or pedestal would make stack impact into the 217-H vault a credible accident.

Conclusion. The 296-H stack has not been sufficiently analyzed or inspected to conclude impact into the 217-H vault is not credible. SRNS's assumptions regarding stack failure location and stack condition lack a defensible basis. In particular, the Board's staff notes SRNS's use of linear elastic analysis is inappropriate for predicting stack failure location; this approach does not consider complex failure mechanisms, local effects, and structural details that might result in other plausible failure mechanisms. Also, the interior condition of the stack is unknown, and ground-based visual inspections ceased in 2007, counter to industry-recommended concrete stack inspection practices. The current condition of the interior of the stack should not be assumed since this could impact the conclusions of how the stack is predicted to fail. Lastly, without a structural analysis of the 296-H stack foundation and pedestal, this location cannot be excluded as a possible stack failure location. If an NPH event causes a 296-H stack collapse that impacts the 217-H vault with a follow-on fire, the calculated dose consequence to the public and co-located worker could drive the need for additional safety controls.

References

[1] Savannah River Nuclear Solutions, *Tritium Facilities Safety Analysis Report*, WSRC-SA-1-2-VOL-1&2, Rev. 26, October 2020.

[2] Savannah River Nuclear Solutions, *Tritium Facility Documented Safety Analysis,* U-DSA-H-00002, Revision 0, August 2019.

[3] Savannah River Site, *Hardened Safe Design (U),* T-CLC-H-00170, Revision 1, September 7, 1995.

[4] Savannah River Nuclear Solutions, *Consolidated Hazard Analysis for the Savannah River Site Tritium Facilities (U),* S-CHA-H-00030, Revision 2, August 2019.

[5] Savannah River Site, *Tornado Analysis of Three H-Area Stacks 295-H, 296-H and 297-H (U),* T-CLC-H-00203, Revision 1, July 20, 2016.

[6] Savannah River Site, *Seismic Evaluation of 295-H, 296-H and 297-H Stacks (U),* T-CLC-H-00208, Revision 1, July 20, 2016.

[7] Department of Energy, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities,* DOE-STD-1020, 2016.

[8] American Nuclear Society, *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design,* ANS-2.26, 2004.

[9] American Society of Civil Engineers, *Chimney and Stack Inspection Guidelines*, 2003.

[10] American Concrete Institute, *Code Requirements for Reinforced Concrete Chimneys,* ACI 307-08, 2008.

[11] Savannah River Site, *Tritium Exhaust Stack Sampling, Piping Details Sheet 3,* Drawing S5-2-19883, Revision 1, August 1, 1990.

[12] Savannah River Site, *Tritium Exhaust Stack Sampling, Piping Details Sheet 4,* Drawing S5-2-19884, Revision 1, May 6, 1993.

[13] Savannah River Site, *Technical Safety Requirements (U), Tritium Facilities,* WSRC-TS-96-17, October 2020.