DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

December 16, 2015

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 is concerned that due to structural degradation, the H-Canyon Exhaust Tunnel at the Savannah River Site may not be able to perform its important safety class function during and following a design basis earthquake. The tunnel seismic analysis uses a methodology that has not been validated and relies on assumptions that require technical justification. The Department of Energy directed Savannah River Nuclear Solutions to gather additional information through sampling and analysis to address the concerns with the structural integrity of the H-Canyon Exhaust Tunnel. The enclosed report is provided for your information and use as you investigate and resolve these concerns.

Sincerely,

Joyce L. Connery
Chairman

Enclosure

c: Mr. Jack Craig
Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

September 25, 2015

MEMORANDUM FOR: S. A. Stokes, Technical Director

COPIES: Board Members

FROM: B. Caleca, E. Gibson, and Z. McCabe

SUBJECT: H-Canyon Seismic Performance and Condition

Members of the Defense Nuclear Facilities Safety Board's (Board) staff performed a review of the seismic analysis for the H-Canyon Exhaust (HCAEX) Tunnel at the Savannah River Site (SRS). This review focused on a new suite of structural and geotechnical calculations to determine the HCAEX Tunnel's ability to perform its safety function. The staff review team's effort noted several issues with the HCAEX Tunnel analysis.

Background. The HCAEX Tunnel is a critical part of the H-Canyon Facility safety class ventilation system. The ventilation system is credited in the Documented Safety Analysis to mitigate the dose consequence during and after a design basis earthquake (DBE) to the maximally-exposed off-site individual and collocated worker. To perform its safety function, the HCAEX ventilation system mitigates the release of radioactive contamination by pulling exhaust air from the processing canyons through the sand filter, where radioactive material is removed. The HCAEX Tunnel provides a pathway connecting H-Canyon to the sand filter. Failure of the HCAEX Tunnel would reduce or eliminate the negative differential pressure in the ventilation system, which could allow contamination to migrate into uncontaminated areas. Furthermore, if this happened concurrently with a release of radiological material due to a seismic event, it could result in an unfiltered ground-level release of radioactively contaminated air, especially if the low tunnel vacuum/supply fan interlock failed to shut down the supply fans [1]. In addition to the safety class ventilation exhaust and sand filter, safety significant controls (tank seismic design and purge ventilation) are implemented at H-Canyon for collocated and facility workers.

The HCAEX Tunnel is constructed of reinforced concrete, located 12–16 feet underground. It connects the hot and warm canyons to a sand filter and the exhaust stack. The Department of Energy (DOE) constructed the original HCAEX Tunnel in 1953 and built a second sand filter and tunnel extension in the 1970s. Beyond the H-Canyon Facility, the HCAEX Tunnel consists of five sections. The four sections of the HCAEX Tunnel located upstream of the sand filter have degraded. The degradation has been documented and monitored since 1990. Recent inspections revealed that the HCAEX Tunnel degradation is severe and may impact its ability to perform its safety function during and following a DBE. Savannah River

Nuclear Solutions (SRNS) developed a new set of calculations intended to demonstrate that the HCAEX Tunnel is able to perform its safety function, despite the extensive degradation.

Safety Issues. The Board's staff team reviewed the set of calculations and identified the following safety issues:

- The analytical methodology used to determine the tunnel demand is not validated.

- The depth and extent of degradation is unknown.

- The strength of the concrete used for analysis is not technically justified.

The Board's staff review team believes these issues require resolution to determine if the HCAEX Tunnel can adequately perform its safety class safety function during and following a DBE. These issues do not impact the tunnel safety function during other, non-seismic accident scenarios.

Analytical Methodology—SRNS determined the seismic demand on the HCAEX Tunnel by applying a "racking" methodology. Racking analyses typically use an equivalent static load to approximate a dynamic earthquake demand on an embedded structure and include soil-structure interaction (SSI) effects. SRNS developed an original racking methodology to determine the equivalent static loading by altering the approach documented in J. Wang's *Seismic Design of Tunnels: A Simple State-of-the-Art Design Approach*. The Wang methodology empirically determines a racking coefficient based on the ratio of the flexibility between the soil and tunnel, which is used to account for SSI effects. The racking coefficient is then multiplied by the maximum relative displacement between the top and bottom of a tunnel, which is determined from a free-field dynamic analysis of the soil. The resulting deformation is then applied to a model of the tunnel to determine the resultant force. In Wang's report, this methodology is validated with other accepted methodologies for tunnel SSI analyses [2].

When determining the equivalent static force for the HCAEX Tunnel, SRNS modified the Wang approach to calculate the static equivalent of the SSI effects. Rather than calculating the flexibility ratio to determine the racking coefficient, SRNS adopted a racking coefficient of unity, which does not account for SSI effects. To account for SSI effects, SRNS represented the surrounding soil as springs on the underside of the HCAEX Tunnel model. The springs allowed for some rigid body rotation, which would reduce the seismic demand on the tunnel [3]. Because the SRNS methodology has not been verified through comparison with other accepted methodologies, the Board's staff review team believes the SRNS analysis methodology requires verification to ensure it provides accurate results.

Depth of Degradation—Since 2003, five robotic crawlers have entered and inspected the HCAEX Tunnel system. Due to unforeseen issues, the first four crawlers were only able to inspect certain portions of the HCAEX Tunnel. The most recent crawler inspection (June 2015), however, was able to inspect the entirety of the previously uninspected portions of the HCAEX Tunnel. These inspections revealed water ingress at low points in the tunnel and signs of significant concrete degradation. Coarse and fine aggregate have eroded and fallen to the tunnel bottom. At multiple locations, the degradation of the concrete is so severe that reinforcing bar (rebar) is visible. In the worst locations, two layers of the interior rebar (vertical and horizontal) are visible, indicating that more than two inches of the concrete walls have eroded.

SRNS engineers assume that if rebar was not visible during periodic inspections, there is sufficient concrete cover to protect and allow for an adequate bond to develop the full strength of the embedded rebar [4]. Considering there are sections of the tunnel with and without exposed rebar, it is evident that the degradation of the tunnel is not uniform. It is possible to have enough concrete to cover the rebar during an inspection, but not enough to allow for the reinforced concrete to develop tensile strength. Additionally, if the degradation reduced concrete strength significantly in regions where rebar is not exposed, there may not be a bond between rebar and concrete, and the rebar may not be providing the required support to the tunnel structure. Therefore, the current practice of periodic visual inspections of the HCAEX Tunnel is insufficient to determine what rebar can be credited in a structural analysis. Without direct sampling or measurement, the thickness or strength of the concrete cover cannot be determined with certainty. Currently, there are no physical samples or measurements to confirm that the cover concrete is sufficient and that it has retained its strength where rebar is not visible.

SRNS suggested that the degradation was caused by nitric acid vapors in the canyon exhaust air and that acid degradation is limited to the visible surface of the HCAEX Tunnel. This conclusion is based on concrete data from the F-Canyon Sand Filter (294-1F) and studies by V. Pavlík on nitric acid degradation of concrete. The condition of the concrete in 294-1F cannot be considered equivalent to that in the HCAEX Tunnel. The 294-1F data was from concrete downstream of the sand filter, and there were no observations of concrete falling from the walls in 294-1F [5]. The Pavlík studies provide the best available information on nitric acid degradation, but Pavlík only observed degradation up to 3 years, and he cautioned against using the relationships for long term assessments of structural elements exposed to nitric acid degradation [6, 7]. The concrete data from 294-1F and the Pavlík studies do not alter the observable evidence that concrete in the HCAEX Tunnel is weakening to the point where it falls off the roof and walls.

Therefore, regardless of the degradation mechanism of the HCAEX Tunnel, the staff team believes SRNS should develop an adequate technical basis to determine the amount of rebar that can be credited. This should include determining the depth of the degradation and the concrete competency.

Concrete Strength—The current HCAEX Tunnel structural mechanics acceptance criteria document allows analysts to assume that aging effects have resulted in a 20 percent increase in concrete strength over the design concrete compressive strength in the structural analysis. However, the Nuclear Regulatory Commission’s Information Notice 2012-17 cautions against the use of concrete compressive strength greater than the design minimum, as it can result in reduction of safety margin inherent in codes and standards [8]. The structural mechanics acceptance criteria document states that the increased strength of the HCAEX Tunnel concrete is further justified from concrete testing results from other facilities that used the same mix design as the HCAEX Tunnel [3]. However, concrete compressive strength can be highly variable, even within the same structure, which is the reason design and evaluation codes recommend testing the areas of interest in an existing structure for concrete strength [9].

Testing specific areas of concern is also supported by ASTM International's C 823M-12, *Standard Practice for Examination and Sampling of Hardened Concrete in Constructions*, in that different categories of concrete should be considered when determining concrete properties. A category of concrete is defined as "a specified level of quality in concrete that is observed to be in a definable range of condition as a result of service or test exposure, as distinguished from concrete in the same or related constructions that is either of differing specified quality or of the same specified quality but in observably different condition at the time of examination." [10] The cores in which SRNS observed the 20 percent increase in strength were taken from the walls and slabs inside H-Canyon, F-Canyon, and the K-Area complex. All of these locations are in observably different conditions from the HCAEX Tunnel, and from a different structural component or a completely separate structure.

Further, SRS engineering standards manual 01060, *Structural Design Criteria*, references American Concrete Institute (ACI) 349-06, *Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary,* which states that "[i]f required, concrete strength shall be based on results of cylinder tests or tests of cores removed from the part of the structure where the strength is in doubt." [11, 12] No cores have been taken from the degraded HCAEX Tunnel and there are no known industry guides or standards that allow for the use of an increase from the design compressive strength without cores taken from the area that is actually being evaluated. Based on this information, the Board's staff review team does not believe that SRNS has adequately justified the use of a 20 percent increase in design concrete compressive strength.

Additional Staff Team Concern. In addition to the three safety issues described above, the Board's staff team identified that the reduction of soil load factors used in the static analysis may require additional justification. This concern is not as significant as those concerns previously described, but may affect the safety margins in the respective SRNS calculations. While the reduction of these factors does not suggest the tunnel will fail under normal conditions, the staff team believes the concern described below should be addressed when determining if the HCAEX Tunnel can meet its safety function.

Soil Load Factor Reduction—The static analysis of sections 1, 3, and 4 of the tunnel resulted in demand to capacity (D/C) ratios greater than unity for two load combinations. D/C ratios greater than unity imply that the capacity of the structure is unable to withstand the expected demand. Typically, if a D/C ratio is close to unity, it is reasonable to reduce known conservatisms in the input demand. When calculating the input demand, estimated loads are multiplied by load factors to capture the associated uncertainty. For two load combinations, SRNS reduced one of the load factors prescribed by ACI 349-06 for the lateral earth pressure from the surrounding soil.

The SRNS staff's reasoning is that soil testing was performed near the HCAEX Tunnel, so there is less associated uncertainty in the characterization of the lateral earth pressures. However, the testing showed that there is high variability in the compaction of fill along the tunnel walls. Additionally, one borehole was used to determine the lateral earth pressure coefficients for the entire length of the tunnel (greater than 400 ft). There is no guidance in ACI 349-06 on the level of characterization required to reduce the load factors or the level to which the load factors can be reduced [12]. Based on the data available, the fill surrounding the HCAEX Tunnel is not well characterized. Therefore, the staff team concludes that the basis for reducing the uncertainty associated with the load factors specified by ACI 349-06 is not adequately justified.

Conclusion. The current analysis of the HCAEX Tunnel has unjustified assumptions and an unproven methodology. The staff review team concludes that these safety issues and concerns indicate that the HCAEX Tunnel may not be capable of performing its safety function during and following a DBE. The DOE Savannah River Operations Office and SRNS have provided a conceptual path forward outlining the actions to potentially address the staff's issues and concerns. The Board's staff team believes SRNS and the DOE Savannah River Operations Office should consider validating the assumptions and analytical methodology or develop an alternative method for providing the safety function of the HCAEX Tunnel.

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[5] Westinghouse Savannah River Co., *Evaluation of 294-1F Sand Filter for the Degraded Condition of Concrete*, T-CLC-F-00162, Rev. 0, January 2000.

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[11] Savannah River Site, *Structural Design Criteria*, SRS Engineering Manual WSRC-TM-95-1, Engineering Standard 01060, Rev. 10, August 12, 2010.

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Savannah River Nuclear Solutions, *CAEX Tunnel Evaluation: Section 3 – 292-H Fan House to Sand Filter*, T-CLC-H-1110, Rev. 0, December 2014.

Savannah River Nuclear Solutions, Rev. 0, *CAEX Tunnel Evaluation: Section 4 – Fan House to Sand Filter*, T-CLC-1111, December 2014.