DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

December 7, 2018

The Honorable James Richard Perry
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Perry:

The Department of Energy directed the Savannah River Site management and operating contractor, Savannah River Nuclear Solutions (SRNS), to perform additional testing and analysis of concrete representative of the H-Canyon Exhaust (HCAEX) Tunnel. The additional examination led DOE to conclude that the ability of the HCAEX Tunnel to perform its intended safety class safety function during and following a design basis earthquake is indeterminate. Subsequently, SRNS has implemented necessary compensatory measures via a Justification for Continued Operations that ensures safe operation of H-Canyon until the issue is resolved.
In addition, SRNS has commenced a non-linear fragility analysis of the HCAEX Tunnel to determine if the performance goal is met or exceeded in its degraded state.

The Board conducted a review of the input, assumptions, methodology, and acceptance criteria for the non-linear fragility analysis. The Board has identified a safety item-safety observation regarding non-linear fragility analysis and concludes that some assumptions and input parameters are inappropriate and could lead to a conclusion that is not technically defensible. The Board advises you that this should be resolved prior to completing the analysis and relaxing compensatory measures. The enclosure is provided for your information and use.

In addition, the Board understands you are already working on an evaluation of whether or not the HCAEX Tunnel is necessary as a post-seismic safety class control. Pursuant to 42 U.S.C. § 2286b(d), the Board requests a briefing and a copy of the evaluation as soon as it is completed. If the evaluation is not completed within 180 days of receipt of this letter, please provide a briefing to the Board on the status of the evaluation and the schedule for completion, with quarterly update briefings until such time as the evaluation is completed, briefed, and delivered to the Board.

Yours truly,

Bruce Hamilton
Chairman

Enclosure

c: Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Report

October 2, 2018

H-Canyon Exhaust Tunnel Fragility Analysis Input and Assumptions

The Defense Nuclear Facilities Safety Board (Board) documented safety items in a December 16, 2015, letter to the Department of Energy's (DOE) Assistant Secretary for Environmental Management (EM-1) regarding the ability of the H-Canyon Exhaust (HCAEX) Tunnel to perform its safety class confinement function during and after a design basis earthquake (DBE) [1]. The DOE Savannah River Field Office (DOE-SR) directed the management and operating contractor, Savannah River Nuclear Solutions (SRNS), to obtain additional information on the strength and condition of the HCAEX Tunnel concrete.

The examination of the HCAEX Tunnel concrete led DOE-SR and SRNS to determine in June 2017 that the ability of the HCAEX Tunnel to perform its safety function during and after a DBE is indeterminate. As a result, they have implemented compensatory measures [2] [3]. DOE-SR since has directed SRNS to perform a non-linear fragility analysis of the HCAEX Tunnel to determine if it can meet its performance goal and perform its safety function. Members of the Board's staff (staff team) conducted an on-site review of the input, assumptions, methodology, and acceptance criteria for the non-linear fragility analysis of the degraded HCAEX Tunnel in August 2018.

The focus of this staff team review was to understand the interpretation and application of new concrete data regarding the non-linear fragility analysis. The staff team reviewed the Savannah River National Laboratory (SRNL) concrete evaluation report, testing data, and the non-linear fragility analysis acceptance criteria [4–6]. This staff report documents potential safety items the staff team identified with the interpretation and application of the data gathered from the recent concrete examination regarding the condition of the HCAEX Tunnel and the ongoing non-linear structural analysis.

The team concluded that some input parameters for the non-linear fragility analysis are not appropriate and could lead to a conclusion that is not technically defensible. Given that SRNS has implemented necessary compensatory measures via a Justification for Continued Operations, the staff team recognizes that these input parameters do not affect the ability of the HCAEX Tunnel to perform its safety function and thus are not an immediate safety concern. However, if DOE does not properly address these potential safety items, the conclusion of the non-linear fragility analysis could result in premature relaxation of necessary compensatory measures while the ability of the HCAEX Tunnel to perform its safety function during and after a DBE remains indeterminate.

Background. The HCAEX Tunnel is a critical part of both the H-Canyon facility safety class and the HB-Line safety significant ventilation systems. The ventilation systems are credited in the documented safety analyses (DSA) to mitigate dose consequences to the maximally exposed off-site individual (for H-Canyon) and co-located worker (for H-Canyon and HB-Line) during and after a DBE. To perform its safety function, the HCAEX ventilation system mitigates the release of radioactive contamination by pulling exhaust air from the processing canyons and HB-Line through the sand filter, where radioactive material is removed (Figure 1). The HCAEX Tunnel provides a pathway connecting H-Canyon and HB-Line to the sand filter [7] [8].

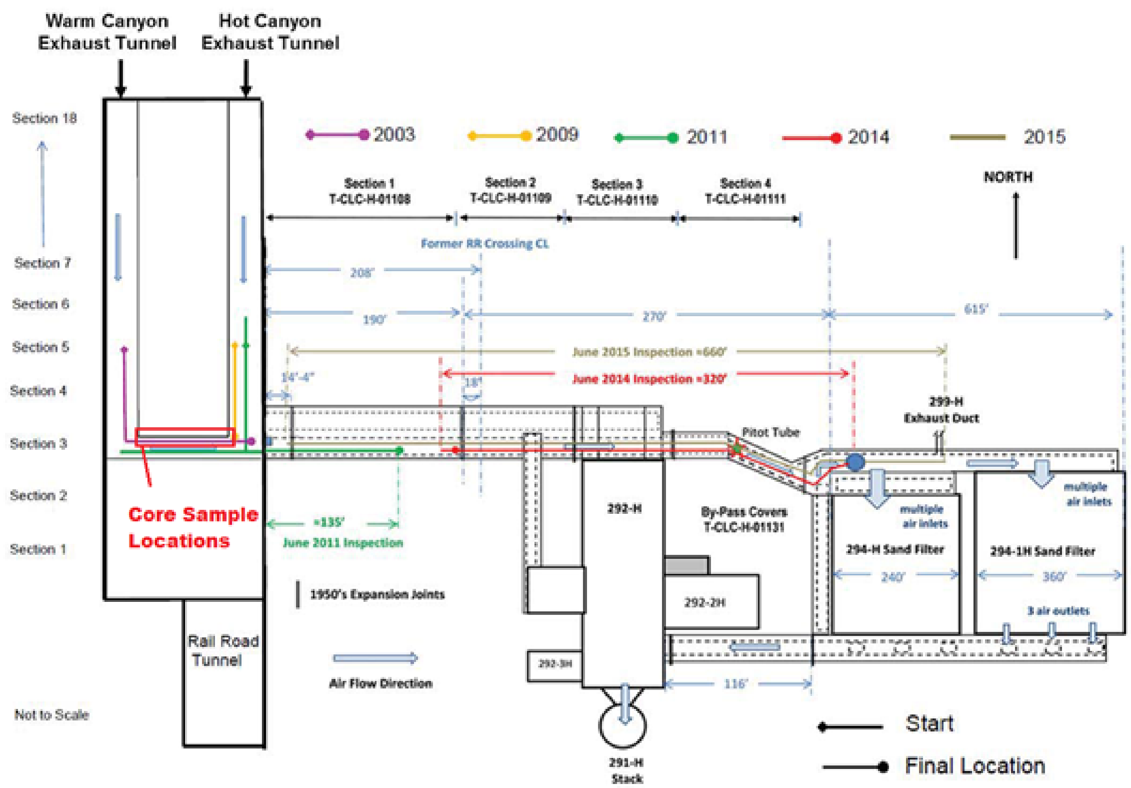

Figure 1. *HCAEX ventilation system layout, concrete sampling locations, and several past inspection routes.*

Failure of the HCAEX Tunnel could reduce or eliminate the negative differential pressure in the ventilation system, which could allow contamination to migrate into uncontaminated areas. Furthermore, if the failure 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 [7] [8]. The H-Canyon Justification for Continued Operations (JCO) implemented several compensatory measures to reduce the calculated dose consequences below the evaluation guideline for the maximally exposed offsite individual and the 100 rem total effective dose threshold for the collocated worker [2]. The staff team performed an independent analysis of the JCO and determined that it provides adequate protection to the maximally exposed offsite individual and collocated worker, if implemented properly [9].

The approximately 500-foot long HCAEX Tunnel is constructed of reinforced concrete and is located 12–16 feet underground. DuPont constructed the original HCAEX Tunnel in 1953 and built a second sand filter and tunnel extension in the 1970s. Original design specifications included a painted-on protective liner on the interior of the HCAEX Tunnel [10]. However, the nitric acid vapors in the HCAEX ventilation stream (accelerated by mechanical erosion as a result of the 30–40 mph HCAEX air stream) have since removed the protective coating and degraded the underlying concrete.

DOE has recorded and visually monitored the degradation since 1990 through the use of pole cameras and robotic crawlers. Past inspections have revealed that the ongoing HCAEX Tunnel degradation is severe and may impact its ability to perform its safety function during and following a DBE (Figure 2).

In 2014, SRNS developed a set of calculations intended to demonstrate that the HCAEX Tunnel is able to perform its safety function, which the staff team reviewed [11–14]. On December 16, 2015, the Board sent a letter describing safety items associated with the structural analysis to EM-1 [1]. The staff issue report attached to the December 16, 2015, letter describes several safety items—safety observations, including that the value for concrete compressive strength used in the structural analysis was not technically justified and that the depth and extent of degradation was unknown despite SRNS engineers' judgment.

Figure 2. *Stills from 2014 crawler inspection video showing two layers of exposed rebar. Degraded concrete debris can be seen accumulated at the bottom of the wall (right).*

Potential Safety Item—Safety Observation, Inappropriate Fragility Analysis Input. Non-linear fragility analysis is a probabilistic analysis rather than the typical deterministic analysis; thus, conservative input and assumptions are not appropriate. Instead, it is necessary to consider the probable range for each input parameter involved. The non-linear fragility analysis will consider several input parameters, including concrete compressive strength, concrete loss, soil properties, and seismic hazard. Each of these inputs will be weighted by an associated probability or uncertainty. Both the inputs and their respective uncertainty will factor into the overall fragility (probability of failure) of the HCAEX Tunnel.

For instance, the SRNS analysis will consider two levels of ground motion, the DBE and the seismic margin earthquake (SME). The DBE has a horizontal peak ground acceleration (PGA) of 0.153 g associated with an annual frequency of exceedance (AFE) of $4x10^{-4}$, whereas the SME has a horizontal PGA of 0.2884 g associated with an AFE of $1x10^{-4}$. As such, the SME has significantly higher ground accelerations, but is four times less likely to occur in a given year than the DBE. SRNS will consider ground motions from both earthquakes in the analysis (along with all other variables) and use them to determine if the HCAEX Tunnel can meet or exceed its performance goal of an annual probability of failure of $2x10^{-4}$ and a less than 10 percent probability of failure given a ground motion 50 percent higher than the DBE ground motion [6].

The staff team notes that it is important to appropriately consider the range of possible HCAEX Tunnel conditions for a non-linear fragility analysis, as opposed to simply using conservative inputs and assumptions. However, if data are not available or are indeterminate, a probable range of input parameters should be included in the analysis and weighted in a technically defensible manner. Otherwise, the non-linear fragility analysis will not result in a defensible conclusion unless SRNS engineers gather additional confirmatory data that agrees with the assumed input parameters. In the case of the HCAEX Tunnel, improper input could result in the analysis concluding that the performance goal is met or exceeded and the JCO compensatory measures are unnecessary, when the opposite could be true. For this reason, the staff team believes the two items discussed herein should be resolved prior to the finalization of the non-linear fragility analysis and possible subsequent relaxation of compensatory measures prescribed by the H-Canyon JCO.

As mentioned previously, the non-linear fragility analysis is influenced by both concrete compressive strength and concrete loss (i.e., wall, roof, and floor thickness). Although SRNS engineers will perform several analyses varying concrete compressive strength, the concrete compressive strength for each individual analysis only will consider a single value for all concrete modeled, due to the analytical method being used. Rather than consider a loss of concrete strength for the HCAEX-affected region, SRNS engineers are taking into account the loss of concrete strength in the affected portion by neglecting zero, one, and two inches of concrete past the interior rebar of the HCAEX Tunnel (Figure 3). The staff team notes that SRNS engineers have not developed and documented an approach for including the uncertainty associated with concrete degradation because they do not have data available to support a probabilistic approach.

The following sections of this report describe why the staff team concludes that specific assumptions and input parameters regarding concrete compressive strength and concrete loss are inappropriate.

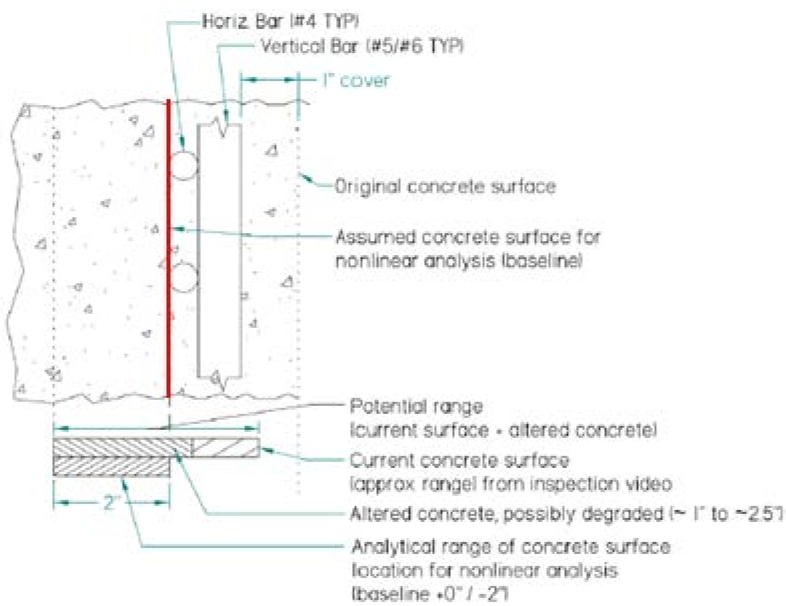

Figure 3. *Diagram of HCAEX Tunnel wall concrete considered and discounted in the fragility analysis.*

Concrete Compressive Strength—SNRS's non-linear fragility analysis will vary concrete strength by developing models that each have one of two concrete compressive strengths as a single uniform value for both the affected and unaffected concrete. Based on engineering judgment and the in-situ material strength statistical analysis of all of historical SRS concrete placed using the same mix as the HCAEX Tunnel, SRNS will use 2500 psi for the 95th percentile and 4000 psi for the median concrete compressive strength [6]. While 2500 psi is the design strength[1] of this concrete (placed in the 1950's), SRNS engineers determined that 3000 psi is appropriate to use as the 95th percentile concrete strength based on the inclusion of the new testing data with the existing concrete data from several other facilities and structural components [4]. As such, SRNS engineers believe 2500 psi is a conservative value that accounts for potential concrete degradation due to acid attack in the affected portion of the concrete. Further, SRNS engineers believe that all SRS concrete samples included in the statistical analysis are representative of the HCAEX Tunnel concrete, including concrete taken from other facilities where environmental conditions differ significantly from those at the HCAEX Tunnel.

The basis for determining the 3000 psi (95th percentile) and 4000 psi (median) values is a dataset of core strengths from different locations over the course of 36 years. When considering all the available core strength data, the staff team noted that SRNS had determined that a non-traditional statistical analysis, the lognormal method, was required because the high level of variability in strength data would not allow the use of normal distribution-based approaches. The need to select the lognormal approach was attributed to potential poor quality control and high levels of variability during construction. Further, when applying the lognormal approach, the overall dataset of available core strength data was modified to remove all H-Canyon column data, due to excessively low strengths attributed to improper placement techniques. More than half of the cores taken from columns exhibited strengths below 2500 psi (American Concrete Institute minimum strength for "structural" concrete), the average strength was approximately 2600 psi, and the 95th percentile strength was only 1500 psi [4].

In addition to eliminating the column data from the statistical analysis, the approach of using the strength data from the north and south wall of the Personnel Tunnel also is questionable. The strengths for cores taken from the north wall were unusually low, with 85 percent of cores from that location showing strengths below 2500 psi, with an overall average of approximately 2300 psi, and the 95th percentile strength was only approximately 2100 psi [4]. The north wall data set was not ignored in the structural analysis but "grouped" into two data points when combined with the remainder of the dataset, thereby lessening the impact of the measured low strengths on the statistical analysis. (The south wall was included in the same manner). The staff team concluded that by ignoring the strength data from the columns and grouping the low strength north wall cores into only two data points, the overall data set is skewed toward higher strengths.

For the reasons described above (high variability, lognormal analysis, exclusion of column data, grouping of north wall data, etc.), the strengths SRNS determined in the in-situ material strength calculation—3000 psi (95th percentile) and 4000 psi (median)—are not technically justified. The staff team concludes that 2500 psi (95th percentile) and 4000 psi (median) are reasonable values for the concrete *unaffected* (emphasis added) by the HCAEX environment in the non-linear fragility analysis. However, the staff team notes that the high variability and various H-Canyon locations of low strength (north wall of the Personnel Tunnel and columns) leads to the conclusion that a conservative value for the 95th percentile compressive strength would be less than 2500 psi. Nevertheless, a conservative value would not be appropriate for the non-linear fragility analysis as it could skew the results inappropriately.

[1] Concrete design strength is not the expected compressive strength of concrete, but rather a high confidence value for the compressive strength of a given batch of concrete. This value is confirmed to be met or exceeded through laboratory evaluations (compression testing) of concrete cylinders cast at the time of concrete placement. Concrete has met the design strength if the following conditions are satisfied: (1) "Every arithmetic average of any three consecutive strength tests equals or exceeds [the design strength], and (2) "No strength test falls below [the design strength] by more than 500 psi." [16]

As was previously detailed, the cores used for compressive strength testing were not exposed to the HCAEX environment. Past work has shown that acid attack can significantly increase porosity, increase shrinkage, and reduce strength [15]. The staff team concluded that applying a dataset of undamaged concrete strength, 2500 psi for the 95th percentile and 4000 psi for the median, to concrete undergoing active acid attack is not technically justified.

SRNS engineers have stated there is no evidence to support the staff team's position that the strength of the concrete directly exposed to the HCAEX environment has been degraded. However, SRNS has not presented any data or direct evidence to justify the assumption that the concrete has not degraded. SRNS engineers presented indirect data (e.g., non-destructive testing, such as pulse velocity and indentation hardness) and anecdotal evidence, such as observations of difficulties in chipping away concrete from this zone, as justification that the affected region of the concrete (directly exposed to nitric acid vapor, moisture, and high velocity exhaust) are not undergoing strength loss.

On the other hand, all relevant publications have found that nitric acid attack has significantly reduced the compressive strength in concrete. Given the fact that more than two inches of concrete already has been lost from the interior of the HCAEX tunnel, it is difficult to believe that the concrete that has degraded and now takes the form of debris on the tunnel floor maintained full strength (i.e., 2500 psi/4000 psi) prior to falling. Further, petrographic and chemical evaluations of the HCAEX-affected concrete confirmed that active nitric acid attack and carbonation are taking place, with calcium being leached out from the concrete to the exposed surface, portlandite being replaced by calcium carbonate, and nitrate ions diffusing into the exposed, darkened region at very high concentrations (up to 3000 ppm nitrate concentration for concrete more than 1.5 inches from the HCAEX-exposed surface).

The peer reviewer for the SRNL report (see Appendix A for further discussion), CTLGroup, in its report reviewing the available SRNL testing documents [17], recommended that additional cores should be extracted to attempt to quantify the actual strength of the concrete exposed directly to the HCAEX environment. However, SRNL has not performed such testing, which represents a lost opportunity to have a stronger technical basis for the non-linear fragility analysis. Absent such direct strength data, there is no technical justification to assume that strengths are unaffected by the aggressive combination of nitric acid attack, carbonation, and wind-driven erosion/abrasion.

While concrete compressive strength may not significantly impact the structural capacity in bending of the HCAEX Tunnel, any appreciable change in structural capacity might appreciably influence the probabilistic performance of the HCAEX Tunnel. However, it is noteworthy that the innermost concrete (i.e., the affected concrete) will be under the highest compressive and tensile stresses. If the material degrades rapidly under cyclical load either due to degraded compressive or tensile strength, additional wall thickness may be lost during a seismic event. In addition, concrete strength more directly influences shear capacity, which past analyses by SRNS engineers have identified as a potential failure mode for the HCAEX Tunnel. Without a stronger basis for the compressive strengths of the HCAEX Tunnel, it is necessary to consider lower median and 95th percentile compressive strengths if SRNS continues to apply uniform strength values when modeling affected and unaffected concrete.

Concrete Loss—SRNS engineers have proposed three depths of concrete loss in their non-linear modeling of the HCAEX Tunnel structure: 0, 1, and 2 inches of concrete loss. These depths are measured from the inside face of the inner reinforcement layer (red line in Figure 3). Thus, the 0 inch case represents over 2 inches of absolute wall thickness lost from the as-constructed concrete walls, floor, and roof. None of the three cases credit the tensile capacity of the inner reinforcement. As previously stated, these different levels of concrete loss are how SRNS is taking into account degradation of the concrete affected by the HCAEX environment. SNRS's non-linear fragility analysis uses analytically robust, but simple rotational springs, which assume uniform concrete compressive strength through the thickness of the HCAEX Tunnel walls [6] [18].

SRNS engineers stated during the staff review that the 0 inch (baseline) case was a conservative starting point because only some of the crawler inspection photos taken showed both layers of inner reinforcement exposed. Based on the most recent crawler inspections showing large areas of the tunnel with both layers of interior reinforcement exposed, the staff team concludes that the baseline condition is more accurately described as being representative of the current HCAEX Tunnel condition rather than as a conservative starting assumption [19]. While the distinction between conservative and appropriate described above may seem of little consequence to the non-linear fragility analysis, SRNS engineers explained to the staff team that this "conservatism" is a further reason why a 95th percentile concrete compressive strength of 2500 psi is acceptable for the affected and unaffected concrete.

Additionally, at the time of the staff team's on site interaction with SRNS and DOE-SR, SRNS personnel had not yet formally determined how they would take into account the uncertainty associated with concrete loss in the non-linear fragility analysis. SRNS engineers lack sufficient data to determine a reliable statistical distribution. Thus, SRNS engineers informally told the staff team that they intend to use a weighted average of the three cases of concrete loss, the weights of which likely will be determined by engineering judgment. The staff team recognizes that sufficient data to determine a probability associated with various amounts of concrete loss does not exist without further analysis from additional samples, therefore, a weighted average is an acceptable approach. However, the weights assigned to each level of concrete loss must be technically defensible considering their potential impact on the non-linear fragility analysis.

Future considerations. There is no evidence that the concrete degradation of the HCAEX Tunnel is slowing. If the non-linear fragility analysis allows SRNS engineers to conclude that the HCAEX Tunnel meets or exceeds its performance goal, determination of when the critical threshold of concrete degradation will occur will be paramount. However, the staff team notes that the ongoing efforts by SRNS engineers will provide information only on the present condition of the HCAEX Tunnel.

Degradation Rate—In order to determine the critical point in time when the HCAEX Tunnel will no longer be able to meet or exceed its performance goal, SRNS engineers will require additional information. For instance, accurate nitrate profiles derived from powder samples prepared in 1–2 mm increments are required to estimate the effective diffusion rate of nitrates into the concrete. SRNL has generated some information, but the data points are too far apart to allow for accurate quantification of the rate of diffusion. Without such data, it is very difficult, if not impossible, to reliably estimate the future rate of concrete degradation. However the concrete cores exposed to the HCAEX environment were consumed in the SRNL examinations. Therefore, this effort would require additional cores exposed to the HCAEX environment.

Critical Point of Degradation—Given the ongoing concrete degradation and section loss, the staff team concludes that it would be appropriate to analytically consider section losses beyond two inches relative to the baseline in Figure 3 in order to inform on the future configuration of the HCEAX Tunnel. The remaining material on the inside face of the tunnel walls, roof, and floor is undergoing or will eventually begin to undergo chemical alteration and a concomitant decrease in strength. SRNS engineers stated that they intend to do additional analysis to determine the depth at which the tunnel cannot meet its performance goal, but will not include these results in the non-linear fragility analysis. If the depth of degradation determined is close to the depth at which nitrate-bearing concrete is in the HCAEX Tunnel walls, it may be prudent to consider this information in the non-linear fragility analysis. Additionally, knowing this value in combination with inspection of the tunnel informs the future viability of the HCAEX Tunnel structure.

DOE-SR Response. During the onsite portion of the review, the staff team described the aforementioned concerns to representatives of DOE-SR and SRNS. At that time DOE-SR indicated to the staff team that it will be discussing these issues further internally and with SRNS. On September 24, 2018, DOE-SR hosted a teleconference with the staff team and SRNS representatives to discuss potential analytical approaches that could resolve the staff team concerns. However, DOE-SR has not yet determined the specifics of the path forward, or formally documented them.

Conclusion. In lieu of conclusive data regarding the actual conditions in the HCAEX Tunnel, engineering judgment is required to determine the input parameters for the non-linear fragility analysis. However, if the engineering judgment used to determine the input parameters for the non-linear fragility analysis is not sound, the usefulness of the non-linear fragility analysis results will be limited. At worst, this could lead to skewing the results of the analysis to an incorrect conclusion.

An inaccurate determination of whether the HCAEX Tunnel can meet or exceed its performance goal could result in the relaxation of necessary compensatory measures included in the H-Canyon JCO that provide a safety class safety function during and after a DBE. Therefore, the staff team concludes that the potential safety items described in this report regarding the input and assumptions related to concrete affected and unaffected by the HCAEX environment should be resolved prior to completion of the non-linear fragility analysis. Otherwise, the results of the non-linear fragility analysis and any decisions that it informs will be questionable.

Appendix A

Update Since December 16, 2015, Board Letter

As a result of the safety items described in the Defense Nuclear Facilities Safety Board's (Board) letter to the Department of Energy's (DOE) Assistant Secretary for Environmental Management (EM-1), DOE's Savannah River Field Office (DOE-SR) directed Savannah River Nuclear Solutions, LLC (SRNS) to obtain concrete samples representative of the H-Canyon Exhaust (HCAEX) Tunnel concrete. The intent of this sampling was for DOE to be able to develop a technically defensible value for compressive strength to be used in the structural analysis and to determine the depth of concrete degradation. SRNS sampled several locations from the H-Canyon Section 3 Personnel Tunnel, which is south of the HCAEX Crossover Tunnel (Figure A-1) [4]. The HCAEX Crossover Tunnel spans east-west underneath H-Canyon before tying into the exterior HCAEX Tunnel to the east of the facility (see Figure A-1). The warm canyon and hot canyon tie into the crossover tunnel at the far west and east sides of H-Canyon respectively, thus it is exposed to air with characteristics similar to that in the HCAEX Tunnel.

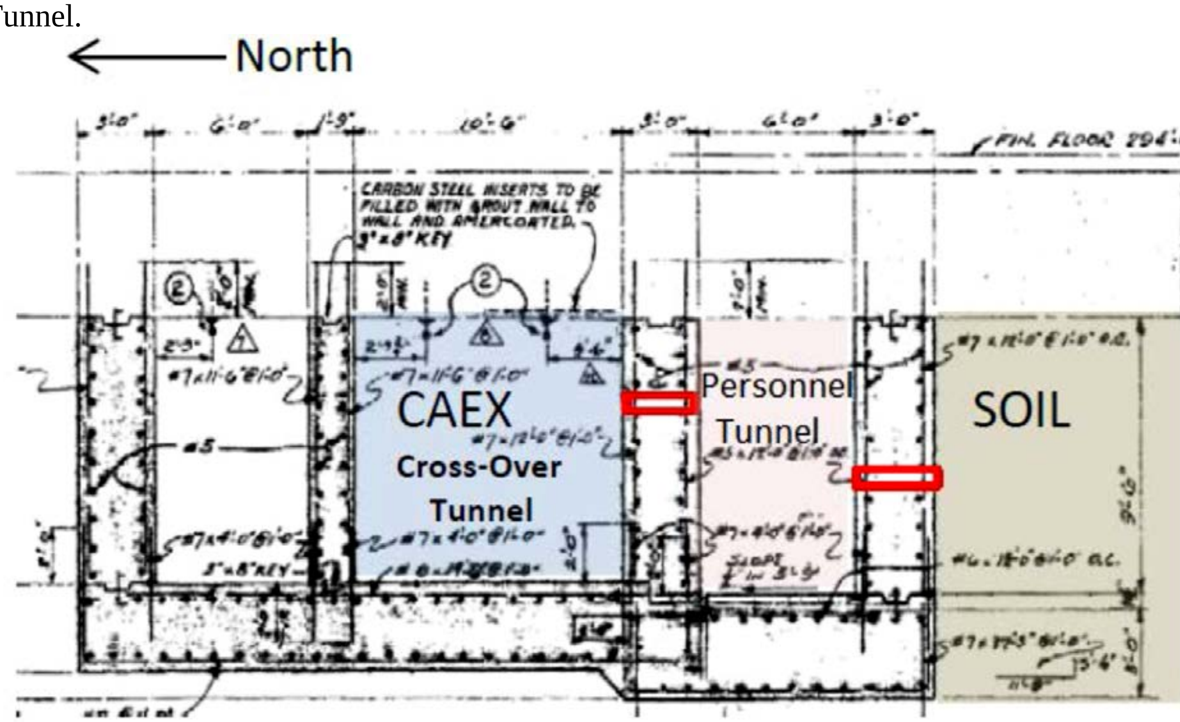

Figure A-1. *Section view of HCAEX Crossover and Personnel Tunnel with typical sampling locations marked.*

Concrete Compressive Strength. The Board's December 16, 2015, letter to EM-1 on the HCAEX Tunnel described safety items regarding SRNS's assumption that the HCAEX Tunnel had a 3000 psi concrete compressive strength, 20 percent higher than the originally specified design strength of the concrete used in the HCAEX Tunnel. SRNS had based this value on a set of concrete data from structures built with the same concrete mix specifications in various locations at the Savannah River Site (SRS), including F-Canyon, L-Area, K-Area, and the H-Canyon facility structure.

The Board's letter noted that these samples are not representative of the HCAEX Tunnel because they are not from environments similar to the HCAEX Tunnel (see comparison in Figure A-2). The existing data was mostly from above-ground concrete structures with no exposure to chemical attack. The SRNS sampling plan created in response to the Board's letter included several sample locations on the north (adjacent to the HCAEX exposed Crossover Tunnel) and south walls (adjacent to sheet piles) of the Personnel Tunnel. SRNS intended to use these concrete compressive strength test results to determine a representative value for use in the HCAEX Tunnel structural analysis [20].

Figure A-2. *Comparison of a still from the 2017 crawler inspection video of inside HCAEX Tunnel (left), and a set of two coring locations on the exterior wall of the H-Canyon Facility (right).*

Testing of the north wall concrete revealed much lower compressive strength[2] (average of approximately 2300 psi) than the larger sample set used previously (average of approximately 4200 psi). The staff concludes that even without exposure to nitric acid, the Crossover Tunnel did not meet the material properties previously assumed. To characterize the cause of the concrete's low strength, DOE-SR sent several concrete samples to the United States Army Corps of Engineers (USACE), which concluded that the low concrete strength of the north wall "is attributable to the increased abundance of clay coatings on aggregates, higher observed capillary porosity, and increased air content" compared to the south wall[3]. Regarding the clay-coated aggregates, USACE states that the origin is likely due to poor aggregate washing [21].

SRNS engineers postulated that bad weather and poor quality control led to the dirty aggregate that reduced compressive strength in these samples, as described in the USACE report. SRNS engineers stated that because they are unaware of similar issues anywhere else at SRS, and since the HCAEX Tunnel concrete was placed at a different time than the Crossover Tunnel, it is unlikely that HCAEX would have quality problems similar to those seen in the Crossover Tunnel. Therefore, SRNS engineers determined that it was inappropriate to use only the data from the north and south walls of the Personnel Tunnel in the structural analysis as originally

[2] The sample locations from the north wall of the Personnel Tunnel were not originally cored all the way through to the side of the wall exposed to the HCAEX environment, leaving approximately eight inches of concrete yet to be cored. The compressive testing results do not include results from concrete exposed to the HCAEX environment.
[3] The concrete cores removed from the south wall (adjacent to sheet piles) of the Personnel Tunnel are included in a data set consisting of 20 values, 12 of which were below the originally reported median of 4000 psi. The average compressive strength of all the south wall concrete cores is approximately 3800 psi [4].

intended. Instead SRNS engineers included the new data with the existing data set that the Board previously determined was not representative of the HCAEX Tunnel concrete [1]. As a result of this testing, SRNS included four new data points in its existing analysis, increasing the data set to 48 total data points, and determined that the original conclusion of 3000 psi for the 95th percentile remained appropriate [4].

Concrete Loss. The Board's letter to EM-1 raised a safety item regarding SRNS engineers' assumption that the severe degradation of the concrete was a surface phenomenon and did not affect the concrete beneath the surface. Originally, SRNS engineers assumed that if rebar was not visible during bi-annual crawler inspections, there was sufficient concrete cover to protect and allow for an adequate bond to maintain the full strength of the embedded rebar [4]. The Board questioned the technical basis for this assumption and determined that the practice of periodic visual inspections was insufficient to determine which rebar can be credited in a structural analysis. Further, the studies cited by SRNS engineers as justification for why the degradation was a surface phenomenon had limited applicability to the HCAEX Tunnel in the manner cited [22] [15]. Therefore, the Board concluded that without physical samples or measurements to confirm SRNS engineers' assumptions, they were not appropriate and lacked conservatism [1].

In addition to gathering data regarding concrete compressive strength, DOE-SR directed SRNS to examine samples of concrete exposed to the HCAEX environment. Of the locations on the north wall of the Personnel Tunnel examined, six locations were cored through the portion of the wall exposed to the HCAEX environment. Savannah River National Laboratory (SRNL) examined five of the six cores (one was damaged during the coring process). Visual examination of the cores led SRNS to conclude that its original assumption that the acid attack was only a surface phenomenon was inaccurate. In fact, the visual examination revealed a distinct transition between the affected and unaffected portion of the concrete several inches from the exposed surface (Figure A-3). Contrary to the SRNS engineers' assumption, these cores show that an additional two to three inches of concrete closest to the surface exposed to the HCAEX environment is affected by that environment, which could impact the concrete strength.

Figure A-3. *Concrete core exposed to the HCAEX environment (left side of core) removed from north wall of the Personnel Tunnel.*

Due to the preliminary results of the SRNL examination, SRNS personnel determined that the ability of the HCAEX tunnel to perform its safety class safety function is indeterminate. This resulted in SRNS declaring a potential inadequacy in the safety analysis and a positive Un-reviewed Safety Question [3]. SRNL personnel performed further evaluation of the concrete exposed to the HCAEX environment and documented it in the "Characterization of Concrete Exposed to the H-Canyon Exhaust" [5]. SRNL personnel did not perform compressive strength testing of the concrete affected by the HCAEX environment (i.e., the darkened region in Figure A-3). They did, however, perform micro-hardness and ultrasonic-pulse velocity testing on these samples, which yielded inconclusive results. At this time, SRNS does not plan further physical evaluation or sampling of HCAEX exposed concrete.

References

[1] Letter, Joyce L. Connery, Chairman, Defense Nuclear Facilities Safety Board, to Monica C. Regalbuto, Assistant Secretary of Energy for Environmental Management, *H-Canyon Seismic Performance and Condition*, December 16, 2015.

[2] Savannah River Nuclear Solutions, LLC, *H-Canyon Justification for Continued Operations*, U-JCO-H-00003, Revision 0, Aiken, SC, November 2017.

[3] Savannah River Nuclear Solutions, *Unreviewed Safety Question Evaluation: PISA PI-2017-0012, H-Canyon Exhaust Tunnel 2017 Concrete Core Testing Identified Increased Degraded Concrete Depth not analyzed in T-CLC-H-1108, T-CLC-H-1109, T-CLC-H-1110, and T-CLC-H-1111*, TRP-HCA-2017-00315, June 29, 2017.

[4] Savannah River Nuclear Solutions, *221F and 221H-Canyon In-Situ Material Strengths*, T-CLC-H-00274, Revision 1, November 15, 2017.

[5] Savannah River National Laboratory, Serrato, Langton, Duncan, Corley, and Ward, *Characterization of Concrete Exposed to the H-Canyon Exhaust*, SRNL-TR-2017-00356, Revision 0, January 2018.

[6] Savannah River Nuclear Solutions, *H-Canyon Exhaust Tunnel Nonlinear Fragility Analysis Methodology and Acceptance Criteria*, T-TRT-H-00018, Revision 1, May 22, 2018.

[7] Savannah River Nuclear Solutions, LLC, *Savannah River Site H-Canyon & Outside Facilities, H-Area Documented Safety Analysis*, S-DSA-H-00001, Revision 12, Aiken, SC, August 2017.

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