Bruce Hamilton, Chairman
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DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

June 11, 2019

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 Defense Nuclear Facilities Safety Board received the NNSA Administrator's response to Draft Recommendation 2019-1, *Safety of the Savannah River Tritium Facilities*, on April 10, 2019. The Board considered the NNSA Administrator's response and appreciates the actions DOE/NNSA is taking. The information contained in the NNSA Administrator's response, however, does not obviate the need for the Recommendation. The Board concludes that there remains an issue of adequate protection of public health and safety in the event of an energetic accident at the Tritium Facilities, comprising several defense nuclear facilities, at the Savannah River Site. On June 5, 2019, the Board, in accordance with 42 U.S.C. § 2286d(a)(3), approved Recommendation 2019-2, which is enclosed for your consideration along with all related findings, supporting data, and analysis.

After you have received this Recommendation, the Board will promptly make the Recommendation and any related Secretarial correspondence available to the public as required by 42 U.S.C. § 2286d(b). The Board believes that this Recommendation contains no information that is classified or otherwise restricted. To the extent that this Recommendation does not include information restricted by DOE under the Atomic Energy Act of 1954, as amended, please arrange to have this recommendation and any related Secretarial correspondence placed promptly on file in your regional public reading rooms. The Board will also publish this Recommendation in the Federal Register.

The Board will evaluate DOE's response to this Recommendation in accordance with the Board's Policy Statement 1, *Criteria for Judging the Adequacy of DOE Responses and Implementation Plans for Board Recommendations.*

Yours truly,

Bruce Hamilton
Chairman

Enclosures

c: Mr. Joe Olencz

RECOMMENDATION 2019-2 TO THE SECRETARY OF ENERGY

Safety of the Savannah River Site Tritium Facilities
Pursuant to 42 U.S.C. § 2286a(b)(5)
Atomic Energy Act of 1954, as Amended

Introduction. The Tritium Facilities at the Savannah River Site (SRS) consist of several defense nuclear facilities, including the 217-H Vault, Buildings 233-H and 234-H, and the Tritium Extraction Facility, used for processing and storing tritium. The Defense Nuclear Facilities Safety Board (Board) is concerned about adequate protection of the public health and safety in the event of an energetic accident at the Tritium Facilities.

The facilities' approved Documented Safety Analysis (DSA) and the November 2018 revision to the DSA awaiting approval by the National Nuclear Security Administration (NNSA) of the Department of Energy (DOE) both have analyzed several credible accidents that could result in very high doses, creating the potential for acute radiation sickness or fatality[1] in a significant number of individuals. These energetic accidents include building-wide fires due to a variety of initiating events, crane drops, and explosions with the potential to release large quantities of tritium.

The probability of such an event within the lifetime of the facility is not negligible. Assuming a 50-year lifetime for the facilities, the probability that an unlikely event could occur within that time period ranges from 0.5 percent to about 40 percent. Such an event could lead to a significant number of potentially exposed individuals, posing a significant challenge to both SRS's emergency management system and to local emergency and medical facilities.

The current situation at the Tritium Facilities does not adequately address either DOE's standards of care or standards of practice as defined by its own requirements. Consequently, adequate protection is not assured. The Board has concluded that DOE needs to take actions to improve the safety of the Tritium Facilities, upgrades to safety management programs and the implementation of robust controls to ensure adequate protection of public health and safety.[2]

[1] Acute radiation-induced sickness and acute radiation fatality, as used in this report, refers to possible outcomes of the acute radiation syndrome. This syndrome is the result of an acute, or short duration, exposure to a very high level of ionizing radiation. In this context, the word acute does not imply immediate incapacitation or death, as the syndrome and its impact on a human body may take hours to months to progress to recovery or death.

[2] The Board has raised concerns regarding the safety posture at the Tritium facilities since 1992. The Board's concerns over the potential for energetic accidents with very high calculated dose consequences have been frequently communicated to DOE. DOE has routinely responded to the Board's concerns with improvements in the safety controls, only to allow those controls to be downgraded after a number of years. *(See the Attachment for a list of previous Board correspondence.)*

Recommendations. The Board recommends that DOE:

1. Identify and implement near-term compensatory measures at SRS to mitigate the potential for high radiological consequences to individuals who would be impacted by a release from the Tritium Facilities. (For example, potential near-term compensatory measures could include, but are not limited to reducing the material at risk (MAR) and/or limiting the number of potentially exposed individuals or other physical or administrative controls.)

2. Identify and implement long-term actions and controls to prevent or mitigate the hazards that pose significant radiological consequences to acceptably low values consistent with the requirements of DOE directives.

3. In parallel with the above recommendations, evaluate the adequacy of the following safety management programs and upgrade them as necessary to ensure that SRS can effectively respond to energetic accidents at the Tritium Facilities, and that it can quickly identify and properly treat potential victims:

    a. The staffing and training requirements for individuals expected to take specific actions in response to alarms, abnormal operations, and emergencies;

    b. The adequacy of the Emergency Preparedness programs in H-Area to account for all individuals in the vicinity and ensure that all potentially affected individuals understand their responsibilities and required actions in the event of a large tritium release from the Tritium Facilities and are prepared to implement them;

    c. The ability of the site's Fire Department to respond to fires, explosions, and other accidents at the Tritium Facilities that could lead to a large tritium release;

    d. The capability of the site-wide radiological protection and occupational medicine programs to respond to an accident and monitor a large number of people with potentially serious uptakes of tritiated water vapor; and

    e. The ability and preparedness of community emergency and medical resources to support the site in such situations.

Background.

Effects of Tritium Release: Much of the in-process tritium at the Tritium Facilities may be in the form of gas, and material in storage is either in pressure vessels or deposited on hydride beds. Exposure to tritium gas does not result in significant doses to individuals, as the gas is not retained by the human body after inhalation. However, any significant release of tritium gas during an energetic accident or upset condition has a high potential of resulting in a fire, even if a fire did not initiate the release. In the energetic accidents of concern to the Board, tritium, an isotope of hydrogen, may be ignited, converted into water by oxidation, and then dispersed as a vapor.

Tritiated water vapor represents a significant risk to those exposed to it, as its dose consequence to an exposed individual is 15,000 to 20,000 times higher than that for an equivalent amount of tritium gas.[3] As with normal water vapor, tritiated water vapor is quickly absorbed into the lungs and through the skin, and rapidly mixes with the water in the body. The target organ for the exposure is the whole body, with a biological half-life[4] of 10 days [1]. The combination of a rapid intake and a short biological half-life means a large fraction of the radiological dose is acutely delivered within hours to days rather than chronically delivered over many months to years. Tritium's chemical and radiological characteristics also create difficult challenges that complicate the approaches to responding to such accidents and providing medical assistance to exposed individuals. A tritium release becomes even more challenging when considering that hundreds of workers in the SRS H-Area occupy the defense nuclear facilities and other administrative and training buildings surrounding the Tritium Facilities.[5]

Emergency Preparedness: Since 2011 the Tritium Facilities have conducted several seismic and/or multi-facility drills and exercises. The Board's staff have observed these drills and exercises and found that they have improved communications and coordination among the tritium facilities, as well as coordination of protective actions with other nuclear facilities within the H-Area. However, neither DOE nor the site contractor, Savannah River Nuclear Solutions (SRNS), has conducted exercises involving the evacuation of large numbers of individuals from an area due to a large tritium release, nor have they planned for the related logistical issues or for monitoring large numbers of individuals to identify those who might be at risk of a significant tritium intake and would require immediate medical intervention. While reliance on the Emergency Preparedness programs is not a long-term solution, this program will be essential in mitigating the consequences of a significant tritium release until an adequate control set can be implemented.

Past Communication: During a June 16, 2011, public hearing in Augusta, Georgia, the Board raised concerns regarding high consequences due to a potential fire in the Tritium Facilities. The Board further communicated this concern to NNSA in an August 19, 2011, Board correspondence in which it identified a shift in the safety philosophy applied to the Tritium Facilities at SRS. The Board noted that downgrading of safety related controls at the Tritium Facilities has "weakened the safety posture, reduced the safety margin, and increased the potential for both the workers and the public to be exposed to higher consequences."

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[3] The ratio of the dose conversion factors for inhalation between tritiated water and tritium gas is a factor of 10,000; additionally, a factor of 1.5 is applied for the workers, and a factor of 2.0 is applied for the public, to account for tritiated water absorption through the skin [1].

[4] The biological half-life is defined as "the time required in a given radionuclide for its activity to decrease, by biological clearance and radiological decay, to half its original activity" [8]. This half-life is a function of the radiological half-life of the radioactive material and how rapidly it is removed from the body by metabolic processes.

[5] A training building with a cafeteria is about 300 meters from the Tritium Facilities; the building hosts a significant transient population.

The Deputy Administrator for Defense Programs replied to the Board's concerns on November 14, 2011, stating that NNSA would develop new analytical models to better understand the risk posed by the Tritium Facilities' operations, and at the same time NNSA would pursue "additional interim safety controls for Tritium Facilities, such as MAR segregation" to reduce the consequences of a potential accident. The attachment to the NNSA letter identified a series of analytical and administrative activities that SRNS would conduct and stated that, "A review of the control selection for the design basis events considering the new analysis will be performed. Emphasis will be placed on utilizing existing passive and active engineered controls vice administrative controls. Any changes to controls will be reflected in a future update to the Documented Safety Analysis."

A letter from SRNS to NNSA dated July 12, 2018 [2], indicates that SRNS is considering a number of engineering controls, but the Board is not aware of any formal actions or implementation of any near-term compensatory measures based on this strategy. SRNS's proposed strategy mainly consists of performing analyses. These analyses may result in SRNS proposing revisions to the Tritium Facilities DSA to credit existing engineered controls or may lead SRNS to pursue installation of new engineered controls. Any physical modifications or additions would likely take years to implement under SRNS's proposed strategy. Furthermore, the Board is not aware of any commitments made by NNSA to implement engineered controls based on the contractor's strategy.

Conclusion. The Board has concluded that adequate protection of public health and safety currently is not assured, should an accident, such as an earthquake or large fire, occur at these facilities and there continues to be a risk of exposure to significant radiological consequences in case of an energetic event at these facilities.

Bruce Hamilton
Chairman

Recommendation References

1. Canadian Nuclear Safety Commission, *Health Effects, Dosimetry and Radiological Protection of Tritium*, Minster of Public Works and Government Services Canada, INFO-0799, April 2010.

2. Spangler, R. W., Senior Vice President NNSA Operations and Programs, SRNS, letter to N. N. Nelson-Jean, NNSA Savannah River Field Office, Transmittal of the Schedule for Implementing the Strategy for Risk Reduction to the Co-Located Worker in Tritium Facilities (U), SRNS-T0000-2018-00227, July 12, 2018.

Risk Assessment for Recommendation 2019-2
Safety of the Savannah River Site Tritium Facilities

In making its recommendations to the Secretary of Energy and in accordance with 42 U.S.C. § 2286a.(b)(5), the Board shall consider, and specifically assess risk (whenever sufficient data exists). Risk is generally defined as the quantitative or qualitative expression of possible loss that considers both the likelihood that an event will occur and the consequences of that event. For Recommendation 2019-2, *Safety of the Savannah River Site Tritium Facilities*, sufficient data does not exist to precisely determine the likelihood that an event will occur and the consequences of that event. However, the Board can use information from the Tritium Facilities' DSAs to develop a qualitative risk assessment.

The Tritium Facilities' DSAs use risk binning to estimate the frequencies of several of the energetic accidents discussed in the Recommendation to be *Unlikely*, which DOE Standard 3009, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, assigns a frequency range of 10^{-2} to 10^{-4} per year. Assuming a 50-year lifetime for the facility, and given the broad frequency range, the probability that an event could occur within that time period ranges from 0.5 percent to about 40 percent.

The large-scale release of tritium postulated for these accidents has a significant potential to result in acute injuries or fatalities. Such an event could lead to a significant number of potentially exposed individuals, resulting in a mass casualty situation that would pose a significant challenge both to the Savannah River Site's emergency management system and to local emergency and medical facilities.

Therefore, the Board has determined the qualitative risk at the Savannah River Site's Tritium Facilities is significant enough to require the Department of Energy to take action.

Findings, Supporting Data, and Analysis

Degradation of Safety Posture.

Introduction—In December 1991, Congress amended the Defense Nuclear Facilities Safety Board's (Board) enabling legislation, expanding its jurisdiction into defense nuclear facilities and activities involved in the assembly, disassembly, and testing of nuclear weapons. According to the Board's 1992 *Annual Report to Congress* [1]:

> As a consequence, additional technical activities were conducted at the following plants, sites and laboratories:
>
> - Pantex Plant,
> - Oak Ridge Y-12 Plant,
> - Los Alamos National Laboratory,
> - Tritium Facilities at the Savannah River Site,
> - Building 991 at Rocky Flats,
> - Nevada Test Site,
> - Sandia National Laboratories (Albuquerque and Livermore),
> - Lawrence Livermore National Laboratory, and
> - Pinellas Plant

As part of these additional technical activities, in 1992 the Board and its staff began to review safety basis documents for Building 233-H (known at the time as the Replacement Tritium Facility, RTF) [2-9]. At that time the facility had been built but had not commenced operations. Later, the Board reviewed the design and safety basis of the Tritium Extraction Facility from the conceptual design stage to its final startup. In both cases, the Board identified safety issues that were remediated by design modifications or administration of operational limits to ensure that the public and the workers were adequately protected.

Since the Board's initial interactions with the Tritium Facilities in 1992, the Board's concerns over the potential for energetic accidents with very high dose consequences have been frequently communicated to the Department of Energy (DOE). A listing of those communications is provided in the Attachment. These communications and the DOE responses to them illustrate a pattern that, in itself, is a concern to the Board. The Board's early involvement in the safety of the Tritium Facilities prompted DOE to implement a range of safety improvements; however, those improvements either were downgraded or were found to be ineffective by 1999. After the Board's interactions with DOE in 1999, improvements were again identified and implemented. By 2011, those improvements had been downgraded and the Board found it necessary to raise the subject again. Today, the Board has determined that its concerns are such that a formal Recommendation is needed to ensure prompt action is taken and sustained.

As noted, in 2011 the Board identified a degradation in the facilities' safety posture that appears to have begun in the period between 1999 and 2011. The Board initially communicated those concerns in 2011, and the National Nuclear Security Administration (NNSA) responded on November 14, 2011, with a series of commitments that included updating the methodology and assumptions to meet current DOE requirements and expectations for conservative analyses, as reflected in Subpart B to 10 CFR 830 and its safe harbor methodology in DOE Standard 3009-

94. NNSA also stated that "A review of the control selection for the design basis events considering the new analysis will be performed. Emphasis will be placed on utilizing existing passive and active engineered controls vice administrative controls. Any changes to controls will be reflected in a future update to the Documented Safety Analysis (DSA)." The current Savannah River Site (SRS) contractor, Savannah River Nuclear Solutions LLC (SRNS), submitted that DSA update to NNSA's Savannah River Field Office (SRFO) in July 2017. SRFO requested and the contractor submitted a revised version of that DSA on November 2018, and it is currently undergoing DOE's review and approval process. Consequently, the currently approved safety bases still contain many of the weaknesses that concerned the Board in 2011.

The following discussions briefly describe some of the original activities and the controls applied to for Building 233-H. This building contains the majority of the process tritium inventory and poses the most unmitigated risk in case of an energetic accident.

Building 233-H's Past Safety Basis—The Board and DOE worked through several issues with the hazards analysis and control set in the original *Final Safety Analysis Report* (FSAR)[1] [2-9] during the early 1990s, prior to startup of Building 233-H. The fire event analyzed in the FSAR was based on 0.1 percent oxidation of the tritium released during the accident. The site contractor at the time, Westinghouse Savannah River Company[2] (WSRC) performed a conservatively bounding analysis assuming that 100 percent of the tritium would be oxidized in a facility fire and documented this analysis in an addendum to the FSAR. Furthermore, WSRC performed a seismic analysis that indicated that a stack would collapse on top of the tritium reservoir storage vault. DOE and WSRC designed and constructed more than a dozen safes known as HIVES (Highly Invulnerable Encased Safes) to protect the storage reservoirs from the impact load of a stack and vault roof collapse. The bounding scenario conservatively calculated the consequences of a seismic event that triggers a fire involving the entire inventory from the reservoirs and the process systems [9]. The maximum individual dose at the site boundary for a two hour exposure was estimated to be about 5.1 rem total effective dose equivalent (TEDE[3], an ionizing radiation dose unit in use at the time). The corresponding value for onsite dose was 328 rem TEDE. [This value was calculated prior to the issuance of DOE Standard 3009; the 1993 calculation used an older methodology and different assumptions than those currently accepted for safety analyses. Consequently the results cannot be compared to the values in the current safety bases.]

The FSAR control set ultimately established by WSRC was a mixture of administrative operational limits and engineered controls. An administrative control limited the total amount of tritium in the facility, including the reservoirs in the seismically qualified areas. Four limiting

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[1] Final Safety Analysis Reports were a predecessor to the current Documented Safety Analysis documents.

[2] The current SRS contractor, Savannah River Nuclear Solutions assumed responsibility for the site in August 2008. The prior contractor at the site, Westinghouse Savannah River Company, assumed responsibility for the site in 1989. In 2005, Westinghouse Savannah River Company changed its name to Washington Savannah River Company.

[3] There are two basic components to an individual's radiation dose, the dose from internal emitters and the dose from external emitters. Prior to 2007, the dose from internal emitters such as tritiated water was measured in rem Committed Effective Dose Equivalent (rem CEDE); the dose from external radiation sources such as an X-ray machine was measured in rem Effective Dose (rem ED); and the sum of the two components was the Total Effective Dose Equivalent (rem TEDE). In 2007 the units were changed to committed effective dose (rem CED) and total effective dose (rem TED), but they are numerically equivalent to doses in rem CEDE and rem TEDE.

conditions for operations (LCO) limited the system pressure for the relief tanks, contaminated nitrogen tanks, and the Z-bed recovery tanks to sub-atmospheric conditions to protect their inventory from a system rupture. An additional three LCOs limited the inventory of the mix tanks, deuterium storage beds, and the tritium reservoirs, which were stored in non-seismically qualified areas [7]. WSRC classified the HIVES as safety related[4] to protect the reservoirs in the vault from impacts. Finally, WSRC used a tritium storage seismic detection and isolation system to further reduce the amount of tritium released during a seismic event. Over the years though, many of the above controls were eliminated or downgraded for various reasons. It is useful to review previously implemented controls for ideas on how the Board's current concerns might be addressed.

During a June 16, 2011, public hearing in Augusta, Georgia, the Board raised concerns regarding high consequences to co-located workers due to a potential fire in the Tritium Facilities. The Board further communicated this concern to NNSA in a Board correspondence dated August 19, 2011, in which the Board identified a shift in the safety philosophy applied to the Tritium Facilities at SRS. The Board noted that the downgrading of safety related controls at the Tritium Facilities has "weakened the safety posture, reduced the safety margin, and increased the potential for both the workers and the public to be exposed to higher consequences."

NNSA's Deputy Administrator for Defense Program sent a letter to the Board on November 14, 2011, that relayed the Tritium Facilities commitments to the Board for improving safety posture of those facilities. In the attachment to that letter, the field office manager stated that, "A review of the control selection for the design basis events considering the new analysis will be performed. Emphasis will be placed on utilizing existing passive and active engineered controls vice administrative controls. Any changes to controls will be reflected in a future update to the Documented Safety Analysis (DSA)." SRNS submitted that DSA update to SRFO in July 2017. As previously noted, correspondence between SRFO and the SRNS led to a revised DSA submitted in November 2018, which is currently in DOE's review and approval process.

Tritium Facilities' Current Safety Basis—The current safety basis of the Tritium Facilities is comprised of a DSA [10] and technical safety requirements (TSR) [11] that are derived from the DSA.[5] The DSA and TSR documents contain a set of controls that SRNS commits to maintain to assure adequate protection. The DSA is supported by a comprehensive hazard analysis documented in the Consolidated Hazards Analysis Process (CHAP) [12], which is not subject to NNSA's review and approval. The CHAP concluded that "[f]or some events, the mitigated consequences remained in the B1 or B region [consequence categories that require safety class controls for the public or safety significant controls for workers] because available controls either did not exist and/or were insufficient" to reduce the unmitigated dose consequences to the co-located workers for several high consequence accidents.

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[4] The RTF startup activities preceded DOE's creation and issuance of Standard 3009-94. The terminology of "safety related" was meant for protection of the public and/or the workers.

[5] At the time of this writing the Tritium Extraction Facility (TEF) was operating under a separate safety basis, but SRNS combined the two safety bases in the DSA submitted in November 2018. However, TEF has a much smaller inventory than the main processing building so it is not discussed extensively in this section.

The calculated dose consequences supporting the current DSA were based on calculations performed in 2008. Those calculated dose consequences for the energetic accidents of concern in this Recommendation ranged up to 6,300 rem total effective dose (TED) to the co-located workers and about 2 to 13 rem TED to the offsite public [13-17]. While those calculations were based on methods and assumptions accepted at the time, they do not meet current DOE expectations for safety basis calculations. More recent analysis, completed by SRNS in 2013, concluded that, using current methodology and assumptions, the calculated dose consequences would increase by a bounding factor of 7.42 for the co-located worker and a bounding factor of 3.45 for the offsite public [18]. It should be noted that NNSA reduced the limit on the total amount of tritium that can be present within the Tritium Facilities by about half in 2011, as discussed in the November 14, 2011, letter to the Board, but that reduction has not been included in the bounding factors given above. These factors are bounding values because there will be some variation in the parameters specific to each accident scenario.

Feasible solutions to address concerns could consist of several controls, each providing layers of protection. Furthermore, solutions may require pursuing controls that dramatically reduce the probability of an initiator, but may not fully prevent an accident. For example, a seismic power cut off system may eliminate many, but not all, ignition sources present in a facility following a seismic event because some systems may be required to continue to function or may have stored energy. Similarly, the reliability of systems like fire suppression systems may be improved through upgrades and modifications or performance of additional surveillances and maintenance, but they may not be able to be fully qualified to protect individuals after all seismic events.

Mitigative controls, such as minimizing the number of non-essential personnel in close proximity to the Tritium Facilities; using readily available technologies to minimize humidity in the air of buildings used for sheltering in place; and having pre-approved plans for decreasing the biological half-life of tritium, could potentially reduce both the number of individuals with intakes and the severity of those intakes. The development of near- and long-term solutions may involve an integrated approach using multiple forms of controls.

Analysis of Emergency Preparedness at the Savannah River Site.

The attachment to the NNSA letter dated November 14, 2011, described improvements that would be made to the site Emergency Preparedness program to respond to a significant event at the Tritium Facilities. The Tritium Facilities conducted several seismic and/or multi-facility drills and exercises in subsequent years. The Board’s staff observed these drills and exercises and the planned improvements. The drills and exercises improved communications and coordination among the Tritium Facilities and helped improve coordination of protective actions with other nuclear facilities within H-Area. The Tritium Facilities also have made emergency preparedness drill and exercise scenarios more challenging by including deflagrations and stack collapses, and have tested their ability to respond to accidents during night shifts, when staffing is lower.

However, the Tritium Facilities Emergency Preparedness program has not prepared responses to the full range of credible accidents in the DSA and the Emergency Planning

Hazards Assessments (EPHA). The DSA includes credible scenarios with co-located worker doses reaching calculated dose consequences in the thousands of rem. The radiological consequences in the EPHAs [19, 20] are usually lower because of differences in the analytical methodologies and assumptions, but still range up to 700 rem TED for co-located workers and 62 rem TED for workers at the nearby central training facility (which also includes a cafeteria). However, the dose consequences to workers in the most challenging drills and exercises [21, 22] were less than 5 rem TED.

The default protective actions for the Tritium Facilities' Emergency Action Levels are to evacuate the immediate area, and for all others to remain indoors (as well as close all doors and windows, and turn off ventilation to the building) [23, 24]. During tritium drills and exercises, this usually involves having workers evacuate the affected process area and/or evacuate from the affected building to another nearby building within the Tritium Facilities. However, the EPHA has scenarios where the maximum distance for the Threshold for Early Lethality may extend up to 320 meters, beyond the Tritium Facilities fence line.

Part of the reason for the lower radiological consequences in the drills and exercises is that the assumed releases are much smaller because the Seismic Tritium Confinement System is assumed to function and confine the inventory during a seismic event. However, the DSA does not qualify this system to be credited during a seismic event. Additionally, the drills and exercises often limit explosions and fires to one room, rather than involving the entire building, as the DSA and EPHA assume. Because the radiological consequences in the drill and exercise scenarios are much lower than those in the DSA and EPHA, the drill and exercise scenarios assume that Tritium Facilities personnel can remain safely indoors indefinitely, that operators can perform their assumed response actions with little impact from the release, that those workers evacuating to another building within the Tritium Facilities do so without any adverse effects, and that the medical response is usually limited to injured workers with relatively minor contamination or intakes.

Using radiological consequences from the severe accidents in the DSA or EPHA, however, might drive the need to evacuate personnel at the Tritium Facilities, and possibly other nearby areas, to a safer location to avoid a significant intake. SRS does not have any procedural guidance or criteria for when workers should evacuate the Tritium Facilities area, and possibly other nearby areas, rather than remain indoors, due to the potential for acute radiological consequences [23-26]. Furthermore, SRS has not conducted exercises involving evacuation of a large number of workers from an area due to a radiological release, nor has the site planned for the related logistical issues such as evacuating or monitoring a large number of workers to determine which ones may be at risk of a significant tritium uptake and may require medical intervention.

Findings, Supporting Data, and Analysis References

[NOTE: The current SRS contractor, Savannah River Nuclear Solutions assumed responsibility for the site in August 2008. The prior contractor at the site, Westinghouse Savannah River Company, assumed responsibility for the site in 1989. In 2005, Westinghouse Savannah River Company changed its name to Washington Savannah River Company.]

1. Defense Nuclear Facilities Safety Board, *Annual Report to Congress*, April 1993.

2. Westinghouse Savannah River Company, *RTF Safety Analysis Report*, DOE Approval Copy, Rev.1, WSRC-SA-1-1, August 28, 1992.

3. K.R. O'Kula, *RTF Compliance with Department of Energy Safety Goal*, WSRC-TR-93-183, April, 1993.

4. Westinghouse Savannah River Company, *RTF Safety Analysis Report, Attachment 5.B Integrated DBE Analysis*, Vol 20, Revision 0, WSRC-SA-1-1, August 23, 1993.

5. N.K. Savani, *Request for Information on the DBE Analysis*, SRT-TML-93-0052, May 5, 1993.

6. J. Robertson, *Determining Inventory LCOs for RTF*, S NMP-SDG-93-0076, Revision 4, September 20, 1993.

7. Westinghouse Savannah River Company, *RTF Final Safety Analysis Report, Inventory Control*, Revision 0, WSRC-SA-1-1-VOL-19, August 26, 1993.

8. Westinghouse Savannah River Company, *RTF Final Safety Analysis Report*, *Integrated DBE Analysis*, Revision 0, WSRC-SA-1-1-VOL-20, August 26, 1993.

9. S.J. Robertson, *White Paper; Basis for MID Calculations for RTF DBA and BDBA Scenarios*, September 20, 1993.

10. Savannah River Nuclear Solutions, LLC, *Tritium Facilities Documented Safety Analysis*, Rev. 23, WSRC-SA-1-2, Vol. 1 and 2, May 2017.

11. Savannah River Nuclear Solutions, LLC, *Tritium Facilities Technical Safety Requirements*, Rev. 28, WSRC-TS-96-17, May 2017.

12. Savannah River Nuclear Solutions, LLC, *Tritium Facilities Consolidated Hazards Analysis*, Rev. 11, WSRC-TR-2004-00163, May 2017.

13. Washington Savannah River Company, *Tritium Facilities Loss of Confinement Accident Analysis (U)*, Rev. 0, S-CLC-H-01127, February 2008.

14. Washington Savannah River Company, *Tritium Facilities Fire Accident Analysis (U)*, Rev. 0, S-CLC-H-01131, February 2008.

15. Washington Savannah River Company, *Tritium Facilities Explosion Accident Analysis (U)*, Rev. 0, S-CLC-H-01137, February 2008.

16. Washington Savannah River Company, *Tritium Facilities Natural Phenomena Plus Fire Accident Analysis (U)*, Rev. 0, S-CLC-H-01139, February 2008.

17. Washington Savannah River Company, *Tritium Facilities Natural Phenomena Plus Loss of Confinement Accident Analysis (U)*, Rev. 0, S-CLC-H-01144, February 2008.

18. Savannah River Nuclear Solutions, *Dispersion Modeling Project Implementation*, S-ESR-G-0033, Rev. 0, October 2013.

19. Savannah River Nuclear Solutions, LLC, *Emergency Planning Hazards Assessment for the Tritium Facilities (TF),* Rev. 10, S-EHA-H-00006, March 2016.

20. Savannah River Nuclear Solutions, LLC, *Emergency Planning Hazards Assessment for the Tritium Extraction Facility (TEF)*, Rev. 2, S-EHA-H-00009, January 2016.

21. Savannah River Nuclear Solutions, LLC, *Savannah River Site 2012 Site Emergency Response Organization Emergency Preparedness Evaluated Exercise Multiple-Facility/Multiple-Contractor Seismic Event*, Rev. 03, F9640052.DRSC000103, April 2012.

22. Savannah River Nuclear Solutions, LLC, *Savannah River Tritium Enterprise 2017 Facility Emergency Preparedness Evaluated Exercise*, Rev. 00, F3040087.DRSC000100, July 2017.

23. Savannah River Nuclear Solutions, LLC, *Emergency Classification (EALs)*, Rev. 29 EPIP TRIT-001, IPC 1, May 1, 2017.

24. Savannah River Nuclear Solutions, LLC, *FEC Response Actions*, Rev. 35, EPIP TRIT-111, April 24, 2018.

25. Savannah River Nuclear Solutions, LLC, *Fire and Fire Alarm Response, Process Buildings*, Rev. 31, EOP TRIT-1468, May, 31, 2018.

26. Savannah River Nuclear Solutions, LLC, *Response to Severe Weather and Natural Disasters*, Rev. 21, AOP TRIT-6122, IPC-1, August 16, 2018.

Attachment

Summary of Board Correspondence concerning Safety at the Tritium Facilities

- **December 18, 1995**
- To: Assistant Secretary for Environmental Management
- Subject: Central Training Facility capability to respond to releases

- **March 18, 1999**
- To: Under Secretary of Energy
- Subject: Review of Draft Consolidated Tritium Safety Analysis Report

- **December 7, 1999**
- To: Assistant Secretary for Defense Programs
- Subject: Design review for Tritium Extraction Facility

- **July 19, 2002**
- To: National Nuclear Security Administration Deputy Administrator for Defense Programs
- Subject: Seismic safety at the Tritium Extraction Facility

- **July 16, 2010**
- To: NNSA Administrator and Assistant Secretary for Environmental Management
- Subject: Inclusion of controls concern at the Savannah River Site

- **August 19, 2011**
- To: NNSA Administrator
- Subject: Review of Safety Basis, Savannah River Site Tritium Facilities

- **August 7, 2014**
- To: NNSA Administrator
- Subject: Summary of Board views on current challenges faced by NNSA

- **January 7, 2016**
- To: NNSA Administrator
- Subject: Review of the Tritium Extraction Facility Documented Safety Analysis

- **June 4, 2018**
- To: Secretary of Energy
- Subject: Review of the Revised Documented Safety Analysis at Tritium Facilities

Supplemental Staff Analysis of Dose Consequences

The calculated dose consequences supporting the current DSA were based on calculations performed in 2008. Those calculated dose consequences for the energetic accidents of concern in this Recommendation ranged up to 6,300 rem total effective dose (TED)[1] to the co-located workers and about 2 to 13 rem TED to the offsite public [1-5]. Those calculations were based on methods and assumptions accepted at the time. More recent analysis, completed by the SRS contractor in 2013, concluded that using current methodology and assumptions would increase the calculated dose consequences by a bounding factor of 7.42 for the co-located worker and a bounding factor of 3.45 for the offsite public [6].[2] It should be noted that SRS lowered the limit on the total amount of tritium that can be present within the Tritium Facilities by about a factor of two in 2011, but that reduction has not been included in the bounding factors given above. These factors are bounding values because there will be some variation in the parameters specific to each accident scenario. The calculations supporting the revised DSA indicate that calculated dose consequences for the co-located worker could exceed 18,000 rem TED for some scenarios. [7]

According to the International Commission on Radiation Protection (ICRP), the threshold dose for a 1 percent incidence rate of fatality in an exposed population is 100 rad[3], and the threshold for a 50 percent incidence of fatality in an exposed population is 300 to 500 rad, assuming no medical intervention [8]. The onset of radiation-induced sickness generally coincides with the 1 percent fatality threshold. These thresholds are for acute exposures that are the result of external radiation sources at very high dose rates, such as those that occur during a criticality accident.

However, high protracted exposures that occur over periods of days to weeks can also result in injury or fatality, but with somewhat higher thresholds. ICRP reports that for exposures where the dose rate is about 20 rad/hour the thresholds may increase by about 50 percent, and if the dose is delivered over the period of a month the thresholds may double [8]. This increase in thresholds is due to the fact that for lower dose rates, the body has more opportunity to repair the damage, thus reducing the likelihood of injury or fatality. Therefore, protracted doses are evaluated by looking at both the accumulated dose and the rate at which the dose accumulates.

For internal exposures such as the situations addressed in this Recommendation, the dose to an exposed individual is cited as the committed effective dose, which is the total dose that has accumulated in the body until the radioactive material has either decayed away or been eliminated through biological processes. The accumulation time is dependent on the specific

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[1] There are two basic components to an individual's radiation dose, the dose from internal emitters and the dose from external emitters. Prior to 2007, the dose from internal emitters such as tritiated water was measured in rem Committed Effective Dose Equivalent (rem CEDE); the dose from external radiation sources such as an X-ray machine was measured in rem Effective Dose (rem ED); and the sum of the two components was the Total Effective Dose Equivalent (rem TEDE). In 2007 the units were changed to committed effective dose (rem CED) and total effective dose (rem TED), but they are numerically equivalent to doses in rem CEDE and rem TEDE.

[2] These multiplication factors only apply to the calculated radiological dose consequences for certain accident scenarios (depending on the input parameters). Other accident scenarios may have a smaller multiplication factor.

[3] The rad is a unit of absorbed dose, which is the quantity used for evaluating the potential for deterministic ionizing radiation effects such as acute injury or fatality. In the case of tritiated water vapor, the absorbed dose in rad is numerically equal to the committed effective dose.

radioactive material and its chemical form. Some materials such as tritium gas are not retained in the body for any significant amount of time; other materials, such as plutonium oxide, will be retained in the body for many years.

***Dose Consequences to Workers and Co-Located Workers*:** The behavior of tritiated water in the body can be modelled in a straightforward manner. For the doses evaluated here, it is assumed that the exposures occur within a 3-minute or 20-minute time period in accordance with the specific DSA scenarios, and that the biological half-life of tritiated water in the body is 10 days [9]. Although the intake is of a short duration, the rate at which the radiation from the decay of the tritium deposited in the body is determined by the biological half-life. Therefore, the doses from tritiated water in the body tend to be protracted doses, and must be compared against the ICRP's protracted dose thresholds. Given these conditions, the total dose and dose rates associated with an intake of tritiated water are inherently related to each other such that one can predict either parameter if the other parameter is known. This relationship allows one to directly determine the specific total dose and dose rate associated with each of the ICRP mortality thresholds discussed above.

Table 1 shows that a postulated total dose of about 18,000 rem TED will exceed the dose threshold for radiation-induced sickness within the first two hours, and a postulated dose of about 3,500 rem TED will exceed the onset of radiation-induced sickness within the first fifteen hours (the onset of radiation-induced sickness generally coincides with the 1 percent fatality threshold). Once the absorbed doses exceed the injury threshold, the onset of symptoms of radiation-induced sickness likely will occur within hours to a day. When these symptoms are observed, medical personnel would begin more aggressive life-saving interventions on those individuals.

Table 1. *Threshold Dose and Dose Rate Criteria with no medical intervention*

Threshold Criteria [8]				**Corresponding Tritium Total Dose***	
Criteria	**Threshold Dose Rate**	**Threshold Dose**		**Total Dose**	**Time to Threshold Dose**
Acute Threshold for 1% Mortality**	~50 rad/hr and up	100 rad		18,000 rem TED	2 hours
Upper Protracted Threshold for 1% Mortality	~10 - 30 rad/hr	150 rad		3,500 rem TED	15 hours
Lower Protracted Threshold for 1% Mortality	~0.3 rad/hr	200 rad		250 rem TED	28 days
Acute Threshold for 50% Mortality	~50 rad/hr and up	300-500 rad		18,000 rem TED	6 hours
Upper Protracted Threshold for 50% Mortality	~10 - 30 rad/hr	450-750 rad		3,500 rem TED	45 hours
Lower Protracted Threshold for 50% Mortality	~0.8 rad/hr	600-1000 rad		750 rem TED	31 days

* When a range of doses or dose rates is used in the threshold criteria, the corresponding tritium dose and time to threshold dose were determined using the lower values in order to identify the lowest total dose that would exceed the specified threshold dose.

** A 1 percent or 50 percent mortality threshold means that at the specified dose and dose rate values, fatalities could be expected in 1 percent or 50 percent of the exposed population, with no medical intervention.

Prior to the onset of radiation-induced sickness, early medical intervention for tritiated water intakes could be taken by aggressively increasing fluid exchange in the patient. This could reduce the biological half-life to as little as three days [10]. Such intervention would reduce the total dose by up to about 60 percent, but would have no impact on the dose already accumulated in the individual prior to the onset of treatment. However, tritium's chemical and radiological characteristics create difficult challenges that complicate the approaches to responding to such accidents and providing medical assistance to exposed individuals. For example, detection of tritium contamination in the field and assessment of potential intakes require specialized equipment, expertise, and most importantly, timely response.[4]

It must also be recognized that the dose to co-located workers is calculated at 100 meters from the release point or at the point of plume touchdown, whichever results in a higher dose. Doses within that first 100 meters could be much higher, depending on the release mechanism and plume travel path. However, current models cannot accurately estimate doses to individuals nearer than 100 meters, as the doses are very sensitive to the specifics of each release mechanism, the effects of building wakes, the location of the individual, and a variety of other parameters. Consequently, radiation-induced sickness or fatalities within the facility workers should be anticipated for all accidents where the 100-meter dose is above 100 rem TED.

Dose Consequences to the Offsite Public: While the facilities' DSAs estimate that the calculated dose consequences to individuals beyond the site boundary from these accidents are low enough to avoid immediate acute health effects, they do represent the potential for an increased likelihood of latent cancer fatalities in the exposed population [8]. In addition, the calculated dose consequences challenge DOE's evaluation guideline of 25 rem TED for safety-class controls. (The evaluation guideline is not to be viewed as an acceptable dose; it is a tool for determining the need for safety class controls.) However, the currently approved DSAs do not provide an adequate set of controls to prevent or mitigate some of these accidents.

It is no coincidence that the calculated dose consequences to the offsite public approach the evaluation guideline for the same accident scenarios that result in very high calculated dose consequences to facility workers and co-located workers. As discussed in the Board's Technical Report, *Protection of Collocated Workers at the Department of Energy's Defense Nuclear Facilities and Sites* [DNFSB/Tech-20, 1999], protection of the offsite public rests heavily on measures taken to protect co-located workers, and protection of co-located workers rests heavily on measures taken to protect the immediate facility workers. In other words, protection of the public begins with the protection of the workers.

[4] The Board's staff does not have confidence that current field equipment can provide the ability to rapidly screen a large group of individuals for potential intakes. Given these circumstances, the onset of symptoms from acute radiation sickness may be the first signs of a significant tritium intake, which would preclude early medical intervention. Dealing with the large number of people who could be adversely affected by a significant release at the Tritium Facilities could severely strain or overwhelm local emergency response and medical resources.

REFERENCES

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3. Washington Savannah River Company, *Tritium Facilities Explosion Accident Analysis (U)*, Rev. 0, S-CLC-H-01137, February 2008.

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