Safety in Design Tailoring Strategy

for

HTGR Fuel Receipt and Disposition Feasibility Study

N-ESR-H-00027

Revision 0

September 2014

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REVISION HISTORY

Revision	Date	Description of Revision
0	September 2014	Initial Issue

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ACRONYMS AND ABBREVIATIONS

AVR	Arbeitsgemeinshaft VersuchsReaktor
CAIR	Compliance Assessment Implementation Report
CAN	Contract Administrator Notice
CHAP	Consolidated Hazard Analysis Process
CSDR	Conceptual Safety Design Report
CD	Critical Design
DBA	Design Basis Accident
DOE	U.S. Department of Energy
DSA	Documented Safety Analysis
HC	Hazard Category
HEU	Highly Enriched Uranium
HTGR	High Temperature Gas-Cooled Reactor
IPT	Integrated Project Team
N&CSE	Nuclear and Criticality Safety Engineering
NEPA	National Environmental Policy Act
NIM	Nuclear Incident Monitor
PSDR	Preliminary Safety Design Report
PDSA	Preliminary Documented Safety Analysis
SC	Safety Class
SDIT	Safety Design Integration Team
SDS	Safety Design Strategy
SiC	Silicon Carbide

ACRONYMS AND ABBREVIATIONS (continued)

SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
SSC	Structure, System and Component
THTR	Thorium High Temperature Reactor
U.S.	United States of America

1.0 PURPOSE

This document describes the overall safety approach to be taken for the high temperature gas-cooled reactor (HTGR) fuel receipt and disposition. The proposed action is to receive and store U.S. origin highly enriched uranium (HEU) from Germany and process it with an ultimate disposition of down blending to low enriched uranium for reuse or disposal.

The U.S. Department of Energy (DOE) is currently in the National Environmental Policy Act (NEPA) process to consider potential impacts and alternatives prior to DOE making the final decision to receive at the Savannah River Site (SRS) (Ref. 1). This is not an accepted project at this time; the project team is only authorized to analyze what would be needed if a DOE decision was made to accept the material. This project is being analyzed in two distinct parts:

- HTGR Fuel Receipt and Storage
  - Receipt of 455 Casks containing the HTGR Fuel at SRS in L-Area
- HTGR Disposition
  - Development of the technology for the HTGR fuel chemical digestion of the graphite
  - Alternative analysis for ultimate processing and disposition of the HTGR fuel

The HTGR Fuel Receipt and Disposition project is being funded by Germany and is considered "Work for Others" and, therefore, is not required to be executed in accordance with DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets* (Ref. 2). For the first part of the project, HTGR Fuel Receipt and Storage, the critical decision process from DOE Order 413.3B is not anticipated to be used. However, it is anticipated that the critical decision process from DOE Order 413.3B will be generally applied to the second part, HTGR Disposition.

The HTGR Fuel Receipt and Storage part of this project is not anticipated to be a major modification as the receipt and storage of casks containing special nuclear material is a similar operation for either L- or H-Area at SRS. As this part is not a major modification it will not be governed by DOE-STD-1189-2008, *Integration of Safety into the Design Process* (Ref. 3). A major modification is defined by 10 CFR 830, Subpart B, Nuclear Safety Management (Ref. 4) and DOE-STD-1189-2008 as a project that "substantially changes the existing safety basis for the facility." A Major Modification Evaluation will be performed per 11Q, Procedure 1.12, "Major Modification Determination" (Ref. 5). A separate safety basis strategy will be developed for the L-Area documented safety analysis (DSA) revision. The remainder of this document will be solely dedicated to the HTGR disposition. The consolidated hazard analysis performed for the receipt and storage of the casks at SRS was performed for receipt in either L- or H-Area. The current direction is to proceed with receipt in L-Area.

For the HTGR Disposition part of the project, the safety basis development will be governed by DOE-STD-1189-2008, *Integration of Safety into the Design Process* (Ref. 3) at least until the final alternative is chosen and a major modification determination can be performed. This safety design tailoring strategy largely mimics the format and content of a safety design strategy (SDS) (Ref. 6) and will be used as an enhanced planning document for the integration of safety into the design process. The intent is to document the preliminary safety work performed during this feasibility study, to communicate DOE expectations for execution of safety activities during design, and to provide a plan for the major safety deliverables for estimating purposes.

2.0 DESCRIPTION OF PROJECT/MODIFICATION

U.S. original HEU material was provided to other countries for peaceful uses and the development of nuclear energy. Germany used the U.S. original HEU material to explore the use of coated fuel particles embedded in graphite spheres, used in pebble-bed reactors, cooled by helium (HTGR).

The HEU material was used in two reactors in Germany:

- AVR (Arbeitsgemeinshaft Versuchsreaktor) Research Reactor (1967-1988) was the first high temperature reactor in Germany to test the technology of graphite spheres.

- THTR (Thorium High Temperature Reactor)-300 Prototype Research Reactor (1983-1989) was a demonstration research reactor to prove the AVR concept design to produce electricity.

The HTGR HEU fuel consists of approximately 1 million, 60-mm diameter graphite spheres (about the size of a billiard ball), which collectively contain about 900 kg of HEU. Each graphite sphere (called pebbles) contains thousands of small kernels containing uranium and thorium oxides. Totaling the kernels, each sphere contained (pre-irradiation) approximately

- 200 g of A3-3 graphite

- 1 g of uranium, 93% enriched in U-235

- 10 g thorium

The HTGR HEU Fuel is currently stored in 455 CASTOR® THTR/AVR casks with 152 casks located at the AVR Research Reactor and 303 casks at the THTR Prototype Research Reactor. The CASTOR® cask is certified in Germany by the equivalent to the U.S. Nuclear Regulatory Commission. The cask documentation is in the process of being reviewed and approved for DOE/U.S. Department of Transportation-certified Type B Casks.

The Savannah River National Laboratory (SRNL) is performing research on the technical considerations related to the processing of HTGR fuel. The focus is specifically on the removal of graphite and Silicon Carbide (SiC) from the fuel pebbles and kernels (Ref. 7).

An alternative analysis was performed during this initial feasibility study. Initially nine different alternatives were brainstormed. The team evaluated the alternatives and reduced the number to four.

3.0 SAFETY APPROACH

The overall goal of the HTGR Disposition safety design is to provide robust protection to members of the public, co-located workers, and the facility workers by identifying all hazardous scenarios with the potential for significant consequences and selecting controls to either prevent accident events from occurring or mitigate the resulting consequences of the event. In general, passive controls are preferred over active controls, preventers are preferred over mitigators, and engineered controls are preferred over administrative controls or operator actions, although all of these may be used where deemed appropriate either independently or in combination with one another.

Selection of safety controls will be performed in accordance with the consolidated hazard analysis process (CHAP) methodology described in SCD-11, *Consolidated Hazard Analysis Process (CHAP) Program and Methods Manual* (Ref. 8). Functional classification of structures, systems and components (SSCs) and controls shall be performed in accordance with Manual E7, Procedure 2.25, *Functional Classifications* (Ref. 9). For events challenging 25 rem for the offsite receptor, safety class (SC) controls shall be selected. As required by DOE-STD-1189 (Ref. 3), if the unmitigated dose associated with an event exceeds 5 rem to the offsite receptor, the need for SC controls will be considered and the rationale for the decision to classify an SSC as SC will be explained and justified in the conceptual safety design report (CSDR), preliminary safety design report (PSDR), and preliminary documented safety analysis (PDSA) prepared for conceptual, preliminary and final design phases, respectively.

3.1 SAFETY GUIDANCE AND REQUIREMENTS

For the HTGR Disposition part of the project, the safety basis development will be governed by DOE-STD-1189, *Integration of Safety into the Design Process* (Ref. 3), at least until the final alternative is chosen and a major modification determination can be performed.

This is not an accepted project at this time; the project team is only authorized to analyze what would be needed if a DOE decision was made to accept the material. Therefore, the project team is at a stage preceding the pre-conceptual phase. DOE-STD-1189 gives the requirements for integrating safety in design for each stage of a project starting at the pre-conceptual phase. Although not at the formal pre-conceptual phase of the project, the safety design guiding principles are being utilized. Described below are the requirements from DOE-STD-1189 for the pre-conceptual phase, Critical Design (CD)-0 Establish Mission Need, and the current progress during this feasibility study to meet these requirements. All requirements will need to be completed prior to submittal of a CD-0 package if the project is accepted by DOE.

- Designation of a safety lead responsible for providing safety input to guide early project planning consistent with the guiding principles and key concepts of DOE-STD-1189.
  - Safety lead is designated and assigned to the Integrated Project Team.
- Organization of a Safety Design Integration Team (SDIT)
  - The formal organization of the SDIT will occur at the CD-0 stage, but nuclear safety and criticality personnel have been identified as part of the Integrated Project Team (IPT) and did participate in the alternative analysis.
- Review of the design requirements
  - DOE Order 420.1C and associated Guide 420.1-1A will be required for this project as they are the latest revision. However, they have not yet formally been accepted through the CAN/CAIR process for the Savannah River Nuclear Solutions (SRNS) contract. Further review and listing of the design requirements will be performed in the CD-0 phase.
- DOE Expectations for safety-in-design efforts should be formally documented.
  - This safety basis tailoring strategy provides a documented approach to communicating the safety-in-design efforts required by DOE-STD-1189 for this feasibility study. DOE-STD-1189 requires a full SDS written for the CD-1 phase of the project.
- An initial alternative analysis of a new facility versus existing facility.
  - The initial brainstorming for alternatives has been completed with nine alternatives selected for evaluation. The evaluation of a new facility was not one of the alternatives brainstormed as multiple existing facilities at SRS are capable of performing the mission for qualitatively less cost.
- Further understanding of the process technology to be utilized.
  - As the digestion process is a new technology under development by SRNL, both criticality and Nuclear and Criticality Safety Engineering (N&CSE) accident analysis experts performed a review.
    - A criticality review of the digestion process was completed.
    - N&CSE accident analysis experts have reviewed the material characterization information to perform a scoping calculation showing bounding unmitigated release consequences to the public from the digestion process. Due to other priorities, this could not be finished for this feasibility study and will be scheduled for the next phase.

- Initial assessment of hazards from each alternative.
  - The initial down select from nine alternatives to four involved availability of safety systems in one area verses another area as input to the cost parameter. (i.e., H-Canyon has SC ventilation and nuclear incident monitors (NIMs) whereas L-Area does not)
  - Engineering personnel reviewed the existing H-Canyon accident analysis calculations for used nuclear fuel for other missions to get a relative idea of consequences for dissolution and solvent extraction processes.
  - Engineering personnel spoke with personnel in the Defense Waste Processing Facility to get an understanding of what types of accidents required a SC off-gas system.
- Performance of a high level hazard analysis is defined in Section 4.1 of DOE-STD-1189 as: "Scoping hazard analysis during pre-conceptual planning involves a qualitative assessment of the facility/process risks in conjunction with any facility and initial technology selection alternative reviews performed."
  - As the four alternatives most preferred are further matured through the CD-0 process, additional scoping hazard analysis will be performed to determine the major hazard controls that will have a significant influence on the facility design and cost.

3.2 HAZARD IDENTIFICATION

The facilities being evaluated for the disposition of the HTGR fuel include the L-Area Complex and H-Canyon. Both facilities are Hazard Category (HC)-2 facilities in accordance with DOE-STD-1027, Change Notice 1, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports* (Ref. 10). This HC is not expected to change as a result of the new HTGR Disposition mission changes. The HTGR radiological inventory will be comprised primarily of the same material type that contributed to the existing HC-2 designation for the facility.

3.3 KEY SAFETY DECISIONS

Key safety decisions are those that may result in significant cost or pose the potential for costly re-work. The key decisions will be evaluated after the four alternatives most preferred are further matured.

4.0 RISKS TO PROJECT SAFETY DECISIONS

The HTGR Preliminary Risk Matrix is located in Appendix B of SRNL-RP-2014-00464 (Ref. 7). Given the potentially significant cost and schedule impacts for the project associated with safety decisions, DOE-STD-1189 requires that risks and opportunities associated with safety-in-design issues should be specifically annotated in the risk assessment process to enable an understanding of all risks associated with the SDS for the facility (verses programmatic and operational non-safety risks that may be in the risk assessment). In the risk matrix in Appendix B, the risks and opportunities associated with safety-in-design are annotated with the words "Safety-in-Design" in the risk title.

After a review of the entire HTGR risk matrix against the types of risks in Table F-1 of Appendix F of DOE-STD-1189 (Ref. 3), four risks were identified and annotated with the "Safety-in-Design" designation.

Risk No.	Risk Title and Handling Strategy	Risk Level	Risk Handling Strategy
[redacted] (b)(5)			

5.0 SAFETY ANALYSIS APPROACH AND PLAN

For future planning and estimating efforts, the following is a list of major safety basis activities and/or documents for each phase of the project. A detailed list for CD-0 is shown in Section 3.1.

Pre-CD-1 Conceptual Design

- Prepare SDS

- Develop preliminary hazards analysis
- Prepare facility-level design basis accident (DBA) unmitigated analysis calculations
- Specify safety functions and classifications
- Develop CSDR
- DOE reviews CSDR and prepares a conceptual safety validation report

Pre-CD-2 Preliminary Design

- Conduct CHAP meetings and prepare report
- Prepare system-level DBA unmitigated analysis calculations
- Update safety SSC functions and classifications
- Develop PSDR
- Update SDS, if needed.
- DOE reviews PSDR and prepares preliminary safety validation report

Pre-CD-3 Final Design

- Update hazards analysis
- Prepare mitigated accident analysis calculations
- Update SSC functions and classification
- Develop PDSA
- Update SDS, if needed.
- DOE reviews PSDA and prepares safety evaluation report

Pre-CD-4 Construction, Transition, and Closeout

- Develop DSA
- Develop technical safety requirements
- DOE reviews DSA and prepares safety evaluation report

6.0 SAFETY DESIGN INTEGRATION TEAM (SDIT) – INTERFACES AND INTEGRATION

The formal organization of the SDIT will occur at the CD-0 stage, but nuclear safety and criticality personnel have been identified as part of the IPT and did participate in the alternative analysis.

7.0 REFERENCES

1. Public Meeting, Potential Acceptance of German Pebble Bed Research Reactor Highly Enriched Uranium (HEU) Fuel Environmental Assessment Presentation by U.S. Department of Energy, Office of Environmental Management, June 24, 2014.

2. *Program and Project Management for the Acquisition of Capital Assets.* DOE Order 413.3B, U.S. Department of Energy, Washington, DC, November 2010.

3. *Integration of Safety into the Design Process.* DOE-STD-1189-2008, U.S. Department of Energy, Washington, DC, March 2008.

4. *Nuclear Safety Management.* Title 10 Code of Federal Regulations, Part 830, Subpart B, "Safety Basis Requirements," U.S. Department of Energy, Washington, DC, January 2001.

5. *Facility Safety Document Manual.* Manual 11Q, Procedure 1.12, "Major Modification Determination" (Rev. 2, January 2010), Savannah River Site, Aiken, SC.

6. *Facility Safety Document Manual.* Manual 11Q, Procedure 1.13, "Safety Design Strategy" (Rev. 1, December 2009), Savannah River Site, Aiken, SC.

7. *Scale-Up Maturation Plan for Digestion of Graphite Fuel Pebbles.* SRNL-RP-2014-00464, Rev. 0, Savannah River National Laboratory, Aiken, SC, June 2014.

8. *Consolidated Hazard Analysis Process (CHAP) Program and Methods Manual.* SCD-11, Rev. 10, Savannah River Site, Aiken, SC, September 2012.

9. *Conduct of Engineering and Technical Support Procedure Manual.* Manual E7, Procedure 2.25, "Functional Classifications" (Rev. 20, November 2012), Savannah River Site, Aiken, SC.

10. *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23 Nuclear Safety Analysis Reports.* Change Notice 1, DOE-STD-1027-92, U.S. Department of Energy, Washington, DC.