We put science to work.™

Savannah River National Laboratory ™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

Feasibility and Alternatives for Receipt, Storage, and Processing of HTGR Pebble Fuel at SRS

Risk Assessment (WFO Task 3)

~~Official Use Only~~

~~Contains information which may be exempt from public release under the Freedom of Information Act (5 U.S.C.552), exemption number(s) 4 and Category "Commercial/Proprietary". Approval by the Department of Energy prior to release is required.~~
~~Reviewed by: T. F. Severynse/SRNL~~ ~~Date: 9-9-14~~
~~Guidance If Applicable: N/A~~

Alexcia Delley
October 2014
SRNL-TR-2014-00201, Revision 0

SRNL.DOE.GOV

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

Keywords: German Fuel, Graphite Destruction, High Temperature Gas-Cooled Reactor (HTGR), Risk Assessment

Retention: Permanent

Feasibility and Alternatives for Receipt, Storage, and Processing of HTGR Pebble Fuel at SRS

Risk Assessment (WFO Task 3)

Alexcia Delley

October 2014

Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

REVIEWS AND APPROVALS

AUTHOR

Alexcia O. Delley 10-16-2014

Alexcia O. Delley, SRNL
Clean Energy Directorate- Nuclear Programs Date

APPROVALS

10/16/2014

William D. Stephens, HTGR
Project Manager Date

W F Bates 10/16/14

William. F. Bates, HTGR
Program Owner Date

REVISION HISTORY

Revision	Date	Description of Revision
Revision 0	October, 2014	Initial Issue

ACKNOWLEDGEMENTS

The author expresses her sincere thanks to the team of subject matter experts listed in Table 1 for the time they dedicated to the identification and assessment of the HTGR pre-conceptual risks.

Table 1: HTGR Alternative Evaluation Team

HTGR RISK ASSESSMENT TEAM	
NAME	**FUNCTION**
Tony Creed	Vulnerability Assessment/Security
Alexcia Delley	Systems Engineering (Risk Assessment Process Lead)
Glynn Dyer	Engineering (Design Authority)
Ken Fuller	Program Lead
John Harley	Solid Waste
Robert Jones	HTGR Process (Waste Disposition Lead)
Maxine Maxted	Department of Energy- Savannah River (Used Nuclear Fuel Program Manager)
Mike Mobley	Engineering (H-Area)
Edward Moore	HTGR Process (Alternatives Development Lead)
Bhogilal Patel	Design Engineering (Lead)
Robert Pierce	Technology Maturation
Edward Sadowski	Material Control & Accountability and Safeguards and Security
Tom Severynse	HTGR Process (Process Intensification)
William Stephens	Project Manager
Dave Welliver	Nuclear & Criticality Safety Engineering (H-Area)

EXECUTIVE SUMMARY

The U. S. Department of Energy Contractor, Savannah River Nuclear Solutions (SRNS), LLC and Forschungszentrum Jülich GmbH (Jülich) are partnering to develop a digestion technology to process graphite-based high temperature gas-cooled reactor (HTGR) nuclear fuel. The fuel consists of small kernels of uranium /thorium (U/Th) embedded in a graphite sphere ("pebbles").

This report satisfies the WFO Agreement WFO-13-021 (Reference 1), Statement of Work: Task Identification Number 3. This task states that the SRS team will evaluate the pre-conceptual scope of the project and program and will develop the following elements into a risk analysis for the alternatives evaluated: 1. Identification of technical and programmatic risks, 2. Identification of potential opportunities (for streamlining or other process and project improvements), 3. Identification of preliminary handling strategies to address or mitigate each risk identified 4. Establishing a preliminary grading of consequences and likelihoods for each identified risk, and 5. Preliminary judgment of cost impacts for each risk and for associated handling strategy.

The information in this report will be summarized and/or referenced in the appropriate sections of the "Report on Feasibility and Alternatives for Receipt, Storage and Processing of HTGR Pebble Fuel at SRS" (Reference 2) described above.

The information and data used in this Risk Assessment were based on subject matter experts' judgments, expertise, and insight at the time of the assessment. As the unknowns associated with the Project's objectives and requirements are better defined, additional risk assessment(s) may be performed to incorporate new or updated information. Because the project is in the pre-conceptual design phase, actual cost data and schedule dates were not developed for each risk or for the associated handling strategy. Plans are to develop this information as part of Reference 1, Step 2 deliverable (if approved).

The results of the Risk Assessment are summarized in Appendix A. A total of twenty-eight risks were identified:

- Eight High risks (29%)
- Fourteen Moderate risks (50%)
- Six Low risks (21%).

The following list of major risks include all eight of the "high" level risks and a few "moderate" level risks that were judge by subject matter experts to be significant to the success of the project. The "moderate" level risks are indicated by an asterisk (*) after the risk number.

The major Program Risks are:

- The NEPA Process determines that an EIS is required (Risk number 1).
- Project cost estimates exceed expectations (Risk number 19).
- SRS cannot receive all of the AVR Fuel by September, 2016 (Risk number 23).
- A Waste Incidental to Reprocessing (WIR) is required (Risk number 24).
- Security requirements for shipment of fuel to SRS cannot be met per the project schedule (Risk number 28)*.

The major Project Risks are:

- Processing Facilities cannot obtain new or modify existing permits (Risk numbers 2 and 3) *.
- SRS cannot dispose of the HLW without impacting the receipt facility waste acceptance criteria, mission, or closure schedule (Risk number 4).
- E-Area Performance Assessment (PA) cannot be modified to allow disposal of LLW grout or the LLW cannot be shipped off-site (Risk number 6).
- LLW cannot be trucked to a new unloading station in Tank Farm or Salt Waste Processing Facility (SWPF) (Risk number 7).
- If H-Canyon is the selected Processing Facility, SRS does not finish processing the fuel in a timely manner and the project has to pay the full cost of operating the Canyon (Risk number 12)*.
- The process cannot be designed to meet requirements (e.g., equipment size, operational scale, etc.) in support of the mission (Risk number 14).
- DOE-SR or DOE- HQ does not approve SRS Deviation Request to protect the material in compliance with Category IV requirements rather than Category II requirements (Risk number 22) *.

The major Technical Risks is:

- Technology Readiness Levels (TRL) cannot be reached per the Technology Maturation Plan and project schedule (Risk number 10)*.

During the Risk Assessment, the following opportunities were identified. Plans are to complete an Opportunity Assessment as part of Reference 1, Step 2 deliverable (if approved).

- **Improved Digestion Process** (Applicable to Options 1-6) –(b)(3)(4) [redacted]

- **Utilize existing Spent Fuel (**Applicable to Option 6) –The charge step requires the addition of depleted uranium metal or LEU fuel to dilute the U-233 and U-235 content to less than 10% by weight (TBD). It requires the addition of aluminum or aluminum fuel to provide at least 4 mass units of aluminum per mass unit of uranium plus thorium. A higher ratio would be required for uranium-only or thorium-only fuels. It is anticipated that at least half the blend-down uranium and half the aluminum could be obtained through use of existing LEU or high-aluminum HEU fuel. Preliminary calculations indicate that use of existing fuels for this purpose would add 40 more canisters, but would eliminate a net 100 canisters from the final L-Area dry storage needs. The DU needs could also be met through use of existing NU or DU scrap from around the DOE complex. It is assumed that any fuel used would be in a slug form and would not require any size reduction to fit into the crucible. These feeds are introduced into the cell via the same entry method as the pebble cans are introduced. The size of the ingot is designed to match the nominal batch size of elements from 500 average pebbles. To match this, the slugs would have to be approximately 4.2” in diameter and 47” or so inches tall. These dimensions are approximate. The material balance and projected canisters for this operation listed in the material balance assume fresh aluminum and DU, since this calculation is an important reference to consider as the actual list of feeds is established.

- **Optimized Scrubber Design** (Applicable to Options 1-6) – If the scrubber design is optimized, cost associated with the Off-gas System could be reduced. The preliminary material balance requires substantial quantities of water for cooling and (b)(3)(4), resulting in a large liquid waste effluent for recycle or disposal.

- **Optimize Salt Recycle (Re-use)** (Applicable to Options 1-6) – If the salt recycle process is optimized, waste volume could be reduced. The preliminary material balance requires a carbon-to-salt ratio of ≥10; disposition of the spent salt, either by dissolution and disposal as liquid waste, or packaging and disposal as solid waste will be more cost effective if the salt can be regenerated and reused.

- **Kurion Technologies – Modular Vitrification Systems** (Applicable to Option 5) **-** Kurion has developed a Modular Vitrification System (MVS®), which turns Kurion Ion Specific Media and other media into glass. The MVS® is a proprietary in-container, hot-walled induction process that the company is maturing into a scalable and low-cost application of vitrification (a volume reduction and stabilization process that immobilizes waste in a leach-resistant glass matrix so that the resulting waste form provides the ultimate assurance of long-term environmental isolation). Kurion is working with Pacific Northwest National Laboratory to demonstrate this technology on radioactive waste and radioactive simulants.

Table of Contents

List of Tables

List of Figures

List of Acronyms

AVR	*Arbeitsgemeinschaft Versuchreaktor*
CY	Calendar Year
DOE	Department of Energy
DU	Depleted Uranium
EA	Environmental Assessment
EIS	Environmental Impact Statement
HEU	Highly Enrichment Uranium
HLW	High Level Waste
HTGR	High Temperature Gas-Cooled Reactor
HQ	Head Quarters
Jülich	Forschungszentrum Jülich GmbH
LEU	Low Enrichment Uranium
LLW	Low Level Waste
M&O	Management and Operations
MC&A	Material Control and Accountability
MVS	Modular Vitrification System
NEPA	National Environmental Policy Act
NU	Natural Uranium
S&S	Safeguards and Security
SSCs	Systems, Structures, and Components
SNM	Spent Nuclear Material [**TBV]**
SOW	Statement of Work
SRNL	Savannah River National Laboratory
SRNS,LLC	Savannah River Nuclear Solutions, LLC and its duly authorized representatives
SRS	Savanah River Site
T&PRA	Technical and Programmatic Risk Assessment
TBD	To Be Determined
TBV	To Be Verified
TH	Thorium
THTR	*Thorium Hochtemperaturreacktor*
TRL	Technology Readiness Level
U. S.	United States
U	Uranium

WFO	Work for Others
WIR	Waste Incidental to Reprocssing

1. INTRODUCTION

The U. S. Department of Energy Contractor, Savannah River Nuclear Solutions (SRNS), LLC and Forschungszentrum Jülich GmbH (Jülich) are partnering to develop a digestion technology to process graphite-based high temperature gas-cooled reactor (HTGR) nuclear fuel. The fuel consists of small kernels of uranium /thorium (U/Th) embedded in a graphite sphere ("pebbles").

The fuel was fabricated using DOE-owned enriched uranium, and irradiated in two reactors, AVR (*Arbeitsgemeinschaft Versuchreaktor*) and THTR (*Thorium Hochtemperaturreacktor*) in Germany. The used fuel, consisting of approximately 920,000 pebbles, is stored at two locations in casks that are suitable for both storage and transportation. Fuel from the THTR reactor is stored in 303 casks at a cask Storage Facility in the city of Ahaus, and fuel from the AVR reactor is stored in 152 casks at the Jülich Research Center. The total uranium content of the used fuel is approximately one metric ton

The development of a digestion technology to process the fuel will be performed under the Work for Others Agreement WFO 13-021, "Research and Development on Graphite Destruction for the Pebble Bed Fuel Elements" (Reference 1). The single Step 1 deliverable is a "Report on Feasibility and Alternatives for Receipt, Storage and Processing of HTGR Pebble Fuel at SRS" (Reference 2). The report will contain an update on technology maturation of the graphite digestion process, a discussion of alternative technologies and facility locations, and a risk assessment of the alternatives.

This report satisfies Reference 1, Statement of Work: Task Identification Number 3. This task states that the SRS team will evaluate the pre-conceptual scope of the project and program and will develop the following elements into a risk analysis for the alternatives evaluated: 1. Identification of technical and programmatic risks, 2. Identification of potential opportunities (for streamlining or other process and project improvements), 3. Identification of preliminary handling strategies to address or mitigate each risk identified 4. Establishing a preliminary grading of consequences and likelihoods for each identified risk, 5. Preliminary judgment of cost impacts for each risk and for associated handling strategy.

The information in this report will be summarized and/or referenced in the appropriate sections of the "Report on Feasibility and Alternatives for Receipt, Storage and Processing of HTGR Pebble Fuel at SRS" (Reference 2) described above.

The information and data used in this Risk Assessment were based on subject matter experts' judgments, expertise, and insight at the time of the assessment. As the unknowns associated with the Project's objectives and requirements are better defined, additional risk assessment(s) may be performed to incorporate new or updated information. Because the project is in the pre-conceptual design phase, actual cost data and schedule dates were not developed for each risk or for the associated handling strategy. Plans are to develop this information as part of Reference 1, Step 2 deliverable (if approved).

2. RISK ASSESSMENT PROCESS OVERVIEW

Figure 1 describes the six steps of a typical Risk Assessment Process. This report satisfies the WFO Agreement WFO-13-021 (Reference 1), Statement of Work: Task Identification Number 3, the following four steps (highlighted by blue text) of the six step process was completed:

1) Risk Planning
2) Risk Identification
3) Risk Grading
4) Risk Handling

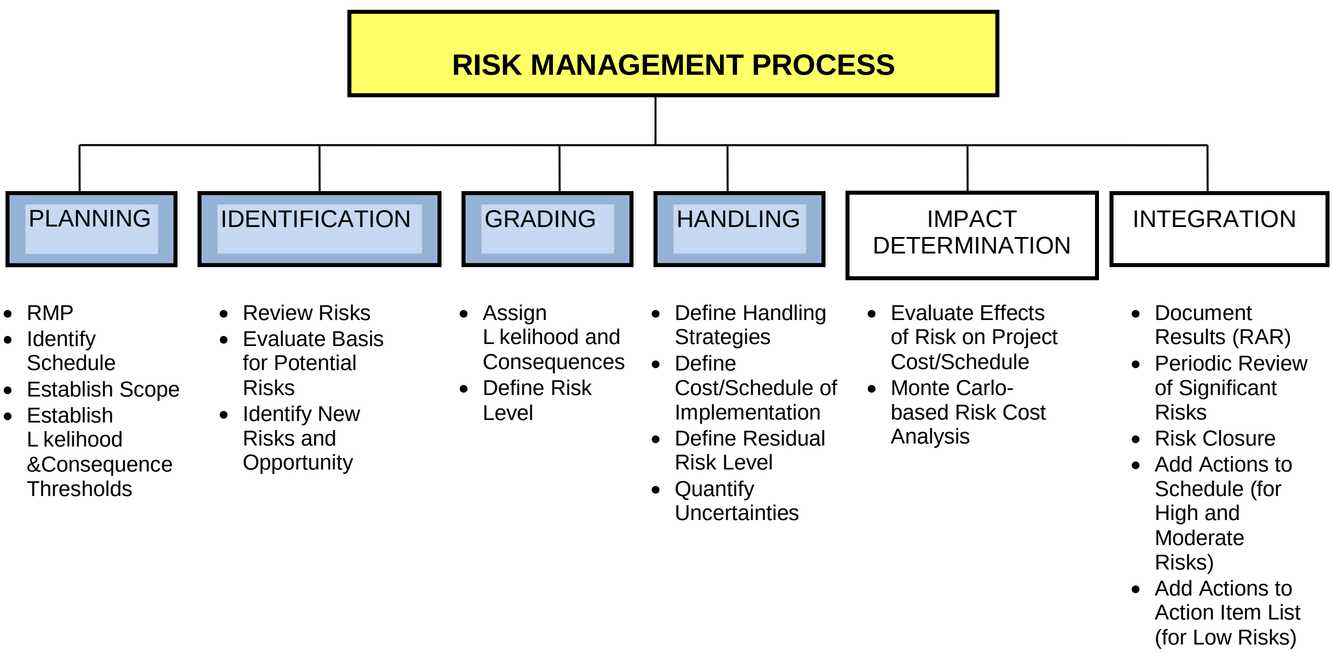

Figure 1: Risk Management Process

3. RISK PLANNING

The HTGR Project pre-conceptual Technical and Programmatic Risk Assessment (T&PRA) was conducted during facilitated team meetings held on June 25th , June 30th, July 1st, July 22nd, August 4th, and August 11th. A team of SRNS subject matter experts identified and assessed the HTGR Project's technical, program, and project risks using the Risk Assessment Process described in Section 2. The team members are listed in the Acknowledgment Section of this report.

3.1.1 Assessable Elements and Scope

3.1.1.1 Assessable Element

Assessable elements divide a project, program or activity into discrete entities against which an effective assessment for risks may be performed and the results evaluated to provide the input needed to make necessary decisions.

The HTGR risks were identified and assessed by the assessable elements (i.e., functions) identified in Figure 2. The diagram provides the hierarchical relationship between the functions to be performed by the program. The top-level function was broken down into sub-functions. The sub-functions are the actions or capabilities necessary to perform the top-level function. The functions were allocated as follows:

A. The top level function F 0.0 was allocated to the HTGR Program scope.

B. Sub-functions F 1.1 and F 1.2 were allocated to the US Government/DOE receipt scope.

C. Sub-function F 1.3 was allocated to SRS receipt scope.

D. Sub-function F 1.4 was allocated to the Storage Location scope.

E. Sub-functions F 1.5 through F 1.8 were allocated to the Process Facility scope.

F. Sub-function F 1.9 was allocated to the on-site Disposal Facilities scope.

G. Sub-function F 1.10 was allocated to the HTGR Program scope.

3.1.1.2 Scope

The scope of the Risk Assessment is illustrated in Figure 3. The scope started with sub-function F 1.1 "Receive Fuel in US" and ended with sub-function F 1.10 "Transport Waste Off-sit for Disposal". In most cases, risks associated with Functions F 1.1, F 1.2 and F 1.10 were categorized as Program Risks, and risks associated with Functions F 1.3 through F 1.9 were categorized as Project or Technical risks.

The categories and assessable elements associated with each HTGR risks are documented in Appendix A, columns 3 and 4, respectively.

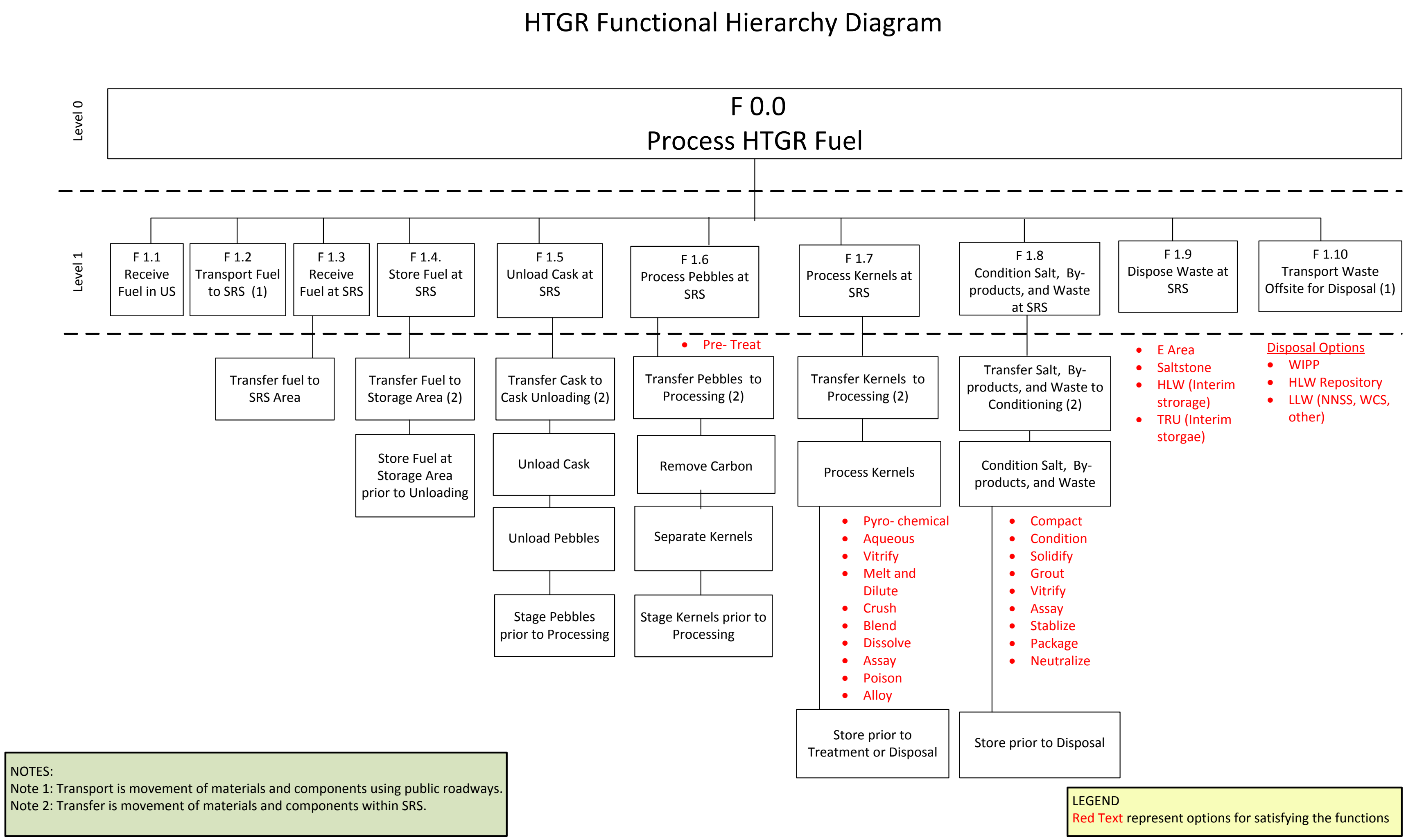

Figure 2: HTGR Functional Hierarchy Diagram

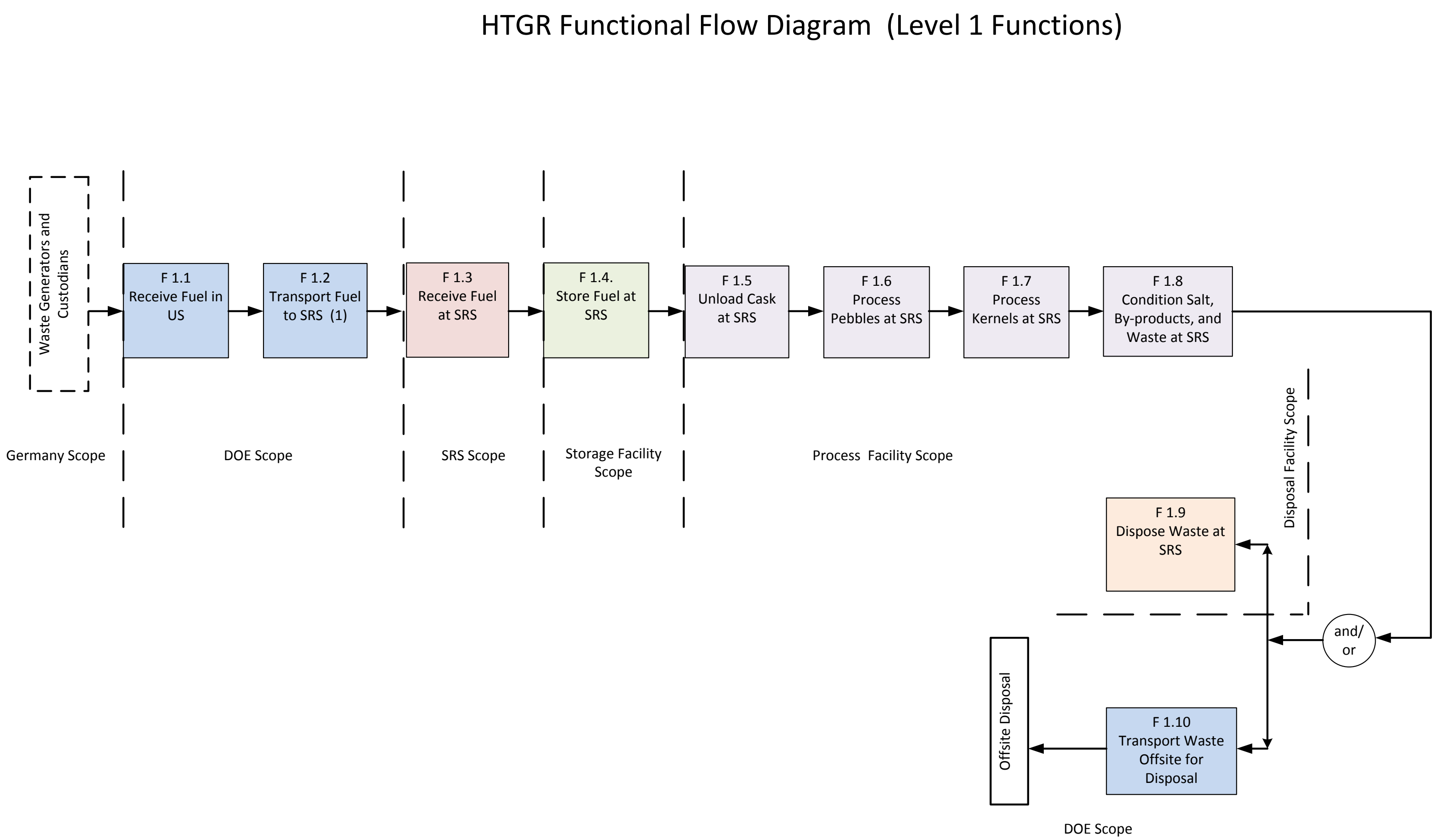

Figure 3: HTGR Functional Flow Diagram (Level 1 Functions)

3.1.2 Likelihood and Consequence Thresholds

During the risk assessment, the risks were graded using the likelihood of occurrence criteria described in Table 2, and the severity of consequence criteria described in Table 3. The estimates of probability and consequence were based on the team's subject matter experts' skills, experience, and insight.

The likelihood of occurrence and the severity of consequence associated with each HTGR risk are documented in Appendix A, columns 14 and 15, respectively.

Table 2: Likelihood of Occurrence Criteria

Likelihood of Occurrence Criteria	
Matrix	
Non-Credible[1]	Determined (through formal probability calculations) to have a probability of occurrence of $\leq 10^{-6}$ (or other non-credible probability defined for the activity)
Very Unlikely	• Will not likely occur anytime in the life cycle of the facilities
Unlikely	• Will not likely occur in the life cycle of the facility modified by this project
Likely	• May occur sometime during the life cycle of the project;
Very Likely	• Will likely occur sometime during the life cycle of the project

Table 3: Severity of Consequence Criteria

Severity of Consequence Criteria[2]	
Matrix	
Negligible	• Minimal consequences; unimportant. • Negligible impact on program; slight potential for schedule change; compensated by available schedule float.
Marginal	• Small reduction in modification/project technical performance. • Moderate threat to facility mission, environment, or people; may require minor facility redesign or repair, minor environmental remediation or first aid/minor medical intervention.

[1] This category is normally reserved for the evaluation of residual risks associated with *Crisis* consequences.

[2] Any one or more of the criteria in the five levels of consequence may apply to a single risk. The overall consequence level for the risk being evaluated must be based upon the highest level for which a criterion applies.

Severity of Consequence Criteria[2]	
Matrix	
Significant	• Significant degradation in modification/project technical performance. • Significant threat to facility mission, environment, or people; requires some facility redesign or repair, significant environmental remediation or causes injury requiring medical treatment.
Critical	• Technical goals of modification/project cannot be achieved. • Serious threat to facility mission, environment, or people; possibly completing only portions of the mission or requiring major facility redesign or rebuilding, extensive environmental remediation or intensive medical care for life- threatening injury.
Crisis	• Modification/project cannot be completed. • Catastrophic threat to facility mission, environment, or people; possibly causing loss of mission, long term environmental abandonment, and death

4. RISK IDENTIFICATION

Risk identification is an organized approach for determining which events are likely to affect the activity and for documenting the characteristics of the events that may happen with a basis as to why these events are considered risks.

During May and June of 2014, DOE-SR identified HTGR risks and documented them in Reference 3. These risks were reviewed and included in this risk assessment.

During brainstorming sessions, new risks were identified for each of the assessable elements (i.e., functions) identified in Section 3.1.1.1 Based subject matter experts' skills, experience, and insight, the brainstormed risk were clarified and some were combined.

The final list of HTGR risks are documented in Appendix A, column 5.

5. RISK GRADING

Risk grading is the process of evaluating the likelihood that the risk event will occur and assessing the range of possible outcomes (consequences). Risk grading may be performed using a numeric or matrix method, depending upon the preference of the risk assessment team. The end result is the same in both cases.

The HTGR Risk Assessment team preferred the matrix method. Therefore, The HTGR Risks were graded using the grading matrix provided in Figure 4. The intersection of the matrix likelihood and consequence values provided the risk level of *Low*, *Moderate* or *High*.

The risk levels associated with each HTGR risk are documented in Appendix A, column 16.

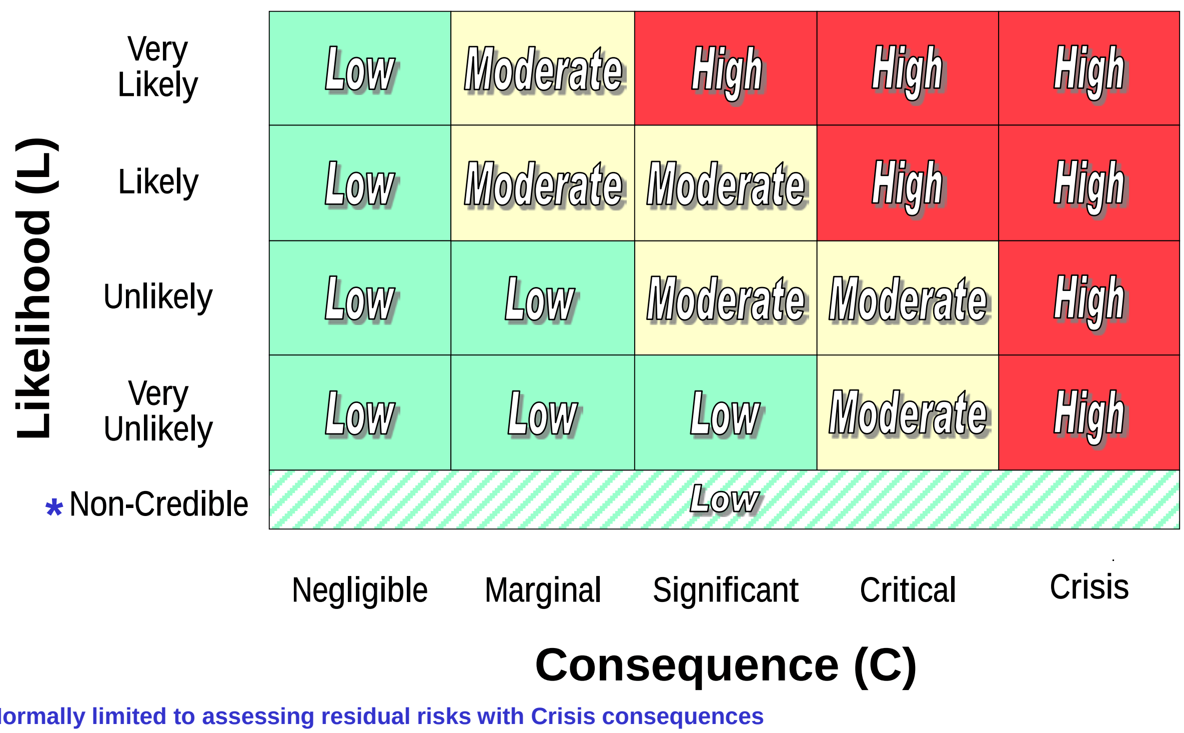

Figure 4: Risk Grading Matrix.

6. RISK HANDLING

Risk handling is the identification of executable actions to effectively manage a given risk. All of the HTGR risks were handled via one of the following methods described in Table 4.

Table 4: Risk Handling Methods

Handling Method	Description
Avoid	This strategy focuses on totally eliminating the specific threat or risk driving event usually by eliminating the potential that the risk event can occur (i.e. take action to drive the likelihood of occurrence to zero and/or eliminate the consequences).
Transfer	This strategy is used when an activity scope with identified risks can be transferred to another activity or entity, especially when this risk can be more easily handled within the receiving activity or entity.
Mitigate	This strategy identifies specific executable actions that will improve the chances that an activity will succeed by: 1. Lessening the likelihood of the occurrence of the risk, or 2. Lessening the consequence of a risk, or 3. Any combination of the two.
Accept	Accepting a risk is essentially a "no action" strategy. Selection of this strategy is based upon the decision that it is more cost effective to continue the activity as planned with no resources specifically dedicated to addressing the risk.

The handling strategies associated with each HTGR risk are documented in Appendix A, column 17.

7. RISK ASSESSMENT RESULTS

The results of the Risk Assessment are summarized in Appendix A. A total of twenty-eight risks were identified:

- Eight High risks (29%)
- Fourteen Moderate risks (50%)
- Six Low risks (21%).

A. **High Risks: Eight of the twenty-eight risk (29%) were ranked as high**.

Likelihood of Occurrence

- One (risk number 19) of the eight high risks likelihood of occurrence was judged to be very likely. It was categorized as a Program risk associated with the project cost estimate.
- Four (risk numbers 4, 6, 7, and 14) of the eight high risks likelihood of occurrence was judged to be likely. They were categorized as Project risks associated with management of the waste (risk numbers 4, 6 and 7)) and operating the Process Facility (risk number 14).
- The remaining three (risk numbers 1, 23, and 24) high risks likelihood of occurrence was judged to be unlikely.

Severity of Consequence

- Three (risk number 1, 23, and 24) of the eight high risks severity of consequence was judged to be crisis. They were categorized as Program risks associated with the NEPA process (risk number 1), receiving the AVR Fuel by September 2016 (risk number 23), and Waste Incidental for Reprocessing (WIR) requirements (risk number 24).
- Four (Risk number 4, 6, 7, and 14) of the eight high risks severity of consequence was judged to be critical. They were categorized as project risks associated with management of the waste (risk numbers 4, 6 and 7)) and operating the Process Facility (risk number 14).
- One (risk number 19) of the eight high risks severity of consequence was judged to be significant. It was categorized as a Program risk associated with the project cost estimate.

B. Moderate Risk: Fourteen of the twenty-eight risks (50%) were ranked as moderate.

Likelihood of Occurrence

- Three (risk numbers 12, 13, and 15) of the fourteen moderate risk likelihood of occurrence was judged to be likely. They were categorized as Project risks associated with operating the Process Facility.
- Eleven of the fourteen moderate risks likelihood of occurrence was judged to be unlikely.

Severity of Consequence

- One (risk number 5) of the fourteen moderate risks severity of consequence level was judged to be critical. It was categorized as a Project risk associated with managing the number of HLW glass canisters produced by the project.
- Twelve of the fourteen moderate risks severity of consequence was judged to be significant. One (risk number 10) was categorized as a Technical Risk associated with the processing technology ability to reach the appropriate Technology Readiness Levels (TRLs) per the project schedule. Seven (risk number 3, 8, 12,13,17,21, and 22) were categorized as Project Risks. Three (risk number 25, 27, and 28) were categorized as Program Risks.
- One (risk number 15) of the fourteen moderate risks severity of consequence level was judged to be marginal. It was categorized as a Project Risk associated with unplanned facility events impacting schedule and/or mission.

C. Low Risks: Six of the twenty-eight (21%) were ranked as low.

Likelihood of Occurrence

- All six of the low risks likelihood of occurrence was judged to be unlikely.

Severity of Consequence

- One (risk number 9) of the six low risks severity of consequence level was judge to be significant. It was categorized as a Program risk associated with the characterization of the fuels by the Germans.
- Five (risk numbers 2, 11, 16, 18, and 26) of the six low risks severity of consequence level was judged to be marginal. One (risk number 11) was categorized as a Technical risk and it was associated with material and equipment that may be provided by the Germans. Three (risk numbers 2, 16, and 18) were categorized as Project risks. Two (risk numbers 9 and 26) were categorized as Program risks.

8. OPPORTUNITY ASSESSMENT

Opportunity Assessment is the identification and grading of opportunities (i.e. determine likelihoods and benefits) to ensure that they are understood and can be prioritized. During the Risk Assessment, the following opportunities were identified. Plans are to complete an Opportunity Assessment as part of Reference 1, Step 2 deliverable (if approved).

- **Improved Digestion Process** (Applicable to Options 1-6) – (b)(3)(4) [redacted]

- **Utilize existing Spent Fuel (**Applicable to Option 6) – The charge step requires the addition of depleted uranium metal or LEU fuel to dilute the U-233 and U-235 content to less than 10% by weight (TBD). It requires the addition of aluminum or aluminum fuel to provide at least 4 mass units of aluminum per mass unit of uranium plus thorium. A higher ratio would be required for uranium-only or thorium-only fuels. It is anticipated that at least half the blend-down uranium and half the aluminum could be obtained through use of existing LEU or high-aluminum HEU fuel. Preliminary calculations indicate that use of existing fuels for this purpose would add 40 more canisters, but would eliminate a net 100 canisters from the final L-Area dry storage needs. The DU needs could also be met through use of existing NU or DU scrap from around the DOE complex. It is assumed that any fuel used would be in a slug form and would not require any size reduction to fit into the crucible. These feeds are introduced into the cell via the same entry method as the pebble cans are introduced. The size of the ingot is designed to match the nominal batch size of elements from 500 average pebbles. To match this, the slugs would have to be approximately 4.2” in diameter and 47” or so inches tall. These dimensions are approximate. The material balance and projected canisters for this operation listed in the material balance assume fresh aluminum and DU, since this calculation is an important reference to consider as the actual list of feeds is established.

- **Optimized Scrubber Design** (Applicable to Options 1-6) – If the scrubber design is optimized, cost associated with the Off-gas System could be reduced. The preliminary material balance requires substantial quantities of water for cooling and (b)(3)(4) [redacted], resulting in a large liquid waste effluent for recycle or disposal.

- **Optimize Salt Recycle (Re-use)** (Applicable to Options 1-6) – If the salt recycle process is optimized, waste volume could be reduced. The preliminary material balance requires a carbon-to-salt ratio of $\geq$10; disposition of the spent salt, either by dissolution and disposal as liquid waste, or packaging and disposal as solid waste will be more cost effective if the salt can be regenerated and reused.

- **Kurion Technologies – Modular Vitrification Systems** (Applicable to Option 5) **-** Kurion has developed a Modular Vitrification System (MVS®), which turns Kurion Ion Specific Media and other media into glass. The MVS® is a proprietary in-container, hot-walled induction process that the company is maturing into a scalable and low-cost application of vitrification (a volume reduction and stabilization process that immobilizes waste in a leach-resistant glass matrix so that the resulting waste form provides the ultimate assurance of long-term environmental isolation). Kurion is working with Pacific Northwest National Laboratory to demonstrate this technology on radioactive waste and radioactive simulants

9. COST

Because the project is in the pre-conceptual design phase, actual cost data and schedule dates were not developed for each risk or for the associated handling strategy. Plans are to develop this information as part of Reference 1, Step 2 deliverable (if approved).

10. CONCLUSION

The results of the Risk Assessment are summarized in Appendix A. A total of twenty-eight risks were identified:

- Eight High risks (29%)
- Fourteen Moderate risks (50%)
- Six Low risks (21%).

The following list of major risks include all eight of the "high" level risks and a few "moderate" level risks that were judge by subject matter experts to be significant to the success of the project. The "moderate" level risks are indicated by an asterisk (*) after the risk number.

The major Program Risks are:

- The NEPA Process determines that an EIS is required (Risk number 1).
- Project cost estimates exceed expectations (Risk number 19).
- SRS cannot receive all of the AVR Fuel by September, 2016 (Risk number 23).
- A Waste Incidental to Reprocessing (WIR) is required (Risk number 24).
- Security requirements for shipment of fuel to SRS cannot be met per the project schedule (Risk number 28)*.

The major Project Risks are:

- Processing Facilities cannot obtain new or modify existing permits (Risk numbers 2 and 3) *.
- SRS cannot dispose of the HLW without impacting the receipt facility waste acceptance criteria, mission, or closure schedule (Risk number 4).
- E-Area Performance Assessment (PA) cannot be modified to allow disposal of LLW grout or the LLW cannot be shipped off-site (Risk number 6).
- LLW cannot be trucked to a new unloading station in Tank Farm or Salt Waste Processing Facility (SWPF) (Risk number 7).
- If H-Canyon is the selected Processing Facility, SRS does not finish processing the fuel in a timely manner and the project has to pay the full cost of operating the Canyon (Risk number 12)*.
- The process cannot be designed to meet requirements (e.g., equipment size, operational scale, etc.) in support of the mission (Risk number 14).

- DOE-SR or DOE- HQ does not approve SRS Deviation Request to protect the material in compliance with Category IV requirements rather than Category II requirements (Risk number 22) *.

The major Technical Risks is:
- Technology Readiness Levels (TRL) cannot be reached per the Technology Maturation Plan and project schedule*.

11. REFERENCES

1. Work for Others Agreement No.-WFO-13-021, *"Research and Development on Graphite Destruction for the Pebble Bed Fuel Elements"*, April 23, 2014
2. SRNL-TR-2014-00184 "*Report on Feasibility and Alternatives for Receipt, Storage and Processing of HTGR Pebble Fuel at SRS"* , Revision 0 (Draft)
3. DOE- SR *"German HEU Fuel Program Detailed Risk Areas*", June 2014, Revision 3
4. SRNL-TR-2014-000185, "*Research and Development on Graphite Destruction for the Pebble Bed Fuel Elements – Alternative Evaluation Process and Results"*, September 2014, Revision 0 (Draft)

12. APPENDIX A: RISK ASSESSMENT SUMMARY TABLE

(b)(3)(4)

(b)(3)(4)

(b)(3)(4)

(b)(3)(4)

(b)(3)(4)

(b)(3)(4)