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

Appendix F: Alternative Evaluation Process and Results

Alexcia Delley

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Table A: HTGR Alternative Evaluation Team

HTGR ALTERNATIVE EVALUATION TEAM	
NAME	**FUNCTION**
Thad Adams	Advisory Board
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Bond Calloway	Advisory Board
Alexcia Delley	Systems Engineering (Alternative Evaluation Process Lead)
Glynn Dyer	Engineering (Design Authority)
Kevin Fox	Technology Maturation (Lead)
Ken Fuller	Program Lead
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Mike Mobley	Engineering (H-Area)
Edwin Moore	HTGR Process (Alternatives Development Lead)
Bhogilal Patel	Design Engineering (Lead)
Robert Pierce	Technology Maturation
Brian Pool	Design Engineering
David Rose	Nuclear & Criticality Safety Engineering (L-Area)
Edward Sadowski	Material Control & Accountability and Safeguards and Security
Thomas Severynse	HTGR Process (Process Intensification)
William Stephens	Project Manager
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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").

The development of a digestion technology to process the fuel is being 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 discusses the proposed alternatives for processing the fuel including facility locations, the Systems Engineering Process used to evaluate the alternatives, and the results of the evaluation. 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. Reference 2 also discusses the proposed alternatives for storing the fuel.

The information and data used in this Alternative Evaluation were based on subject matter experts' judgments, expertise, and insight at the time of the evaluation. As the unknowns associated with the Project's objectives and requirements are better defined, the alternatives, screening criteria, and/or evaluation criteria may be modified to incorporate new or updated information.

The nine proposed alternatives evaluated during this Alternative Evaluation Process are listed in Table ES-1. These alternatives were derived from a "brainstormed" list of potential alternatives documented in Reference 5. Detailed descriptions of the nine alternatives are provided in Appendix A (Section A-1). The advantages and disadvantages associated with each alternative are discussed in Appendix A (Section A-2).

Table ES-1: Alternatives (Options)

Alternative Number	Alternative Name	Alternative Description
1	Distribution of All Constituents to HLW	Digest pebbles and dissolve kernels and salt for direct disposal to the HLW system.
2	Dissolve and Separate U for Disposition to LLW	Digest pebbles, dissolve kernels and salt, separate and blend-down uranium as LLW grout, and dispose of salt, Thorium, and fission products to the HLW system.

Alternative Number	Alternative Name	Alternative Description
2-T	Dissolve and Separate U/Th for Disposition as LLW	Digest pebbles, dissolve kernels and salt, separate and blend-down U and Th as LLW grout, and dispose of salt and fission products to the HLW system.
3	Dissolve and Separate U for Storage and Future Use	Digest pebbles, dissolve kernels and salt, separate and blend-down U to oxide for reuse, and dispose of salt, Th, and fission products to the HLW system.
4	Dissolve and Separate U for Disposition as LLW with Salt Disposal as Solid Waste	Same as option 2 but do pretreatment in L-Area.
5	Recover Kernels for Disposal via Can in Canister	Digest pebbles, blend-down and vitrify kernels for can-in-canisters disposal as HLW glass, and process salt for direct disposal to Saltstone.
6	Recover Kernels for Disposal via Melt and Dilute	Digest pebbles, and melt-dilute kernels for dry storage pending disposal with SNF , and process salt for direct disposal to Saltstone.
7	Pretreat Pebbles and Dissolve/Separate U for Disposal as LLW	Grind pebbles and burn carbon, dissolve kernels, separate and blend-down uranium as LLW grout, and dispose of offgas salt, Thorium, and fission products to the HLW system.
8	Carbon Digestion with Electrochemical Processing of Kernels	Pyro-chemically digest pebbles, separate U, Pu, Th as TRU waste, and dispose of Cs/Sr and salt as ceramic HLW.

The criteria and associated weights used to evaluate the alternatives are provided in Figure ES-1.

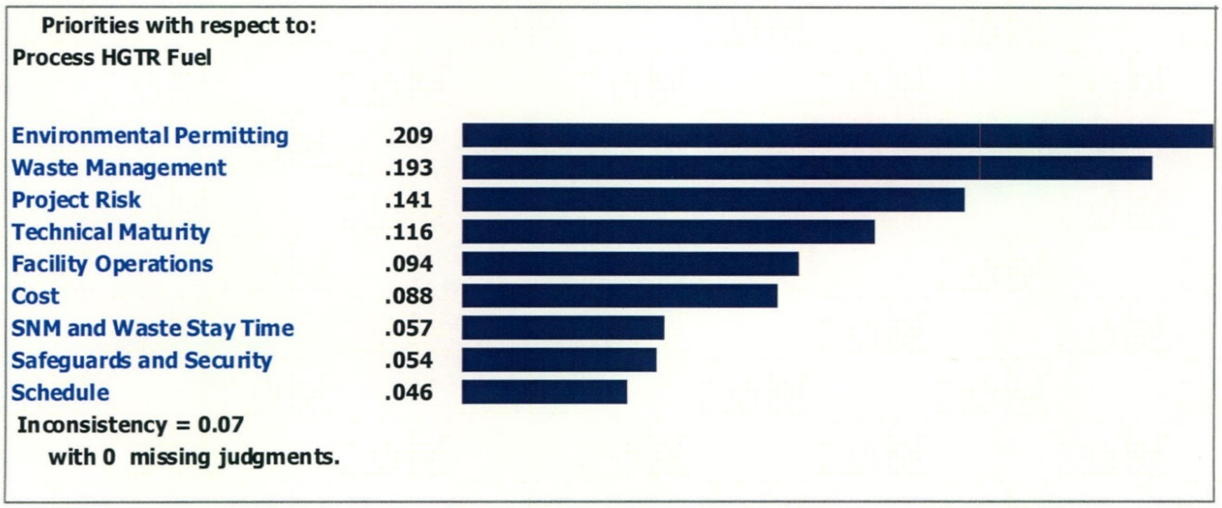

Figure ES-1: Criteria Weights

- Environmental Permitting was weighted the highest at 20.9%. This was considered to be the most important criterion because if permits cannot be obtained in a timely manner, the ability to start receiving the AVR fuel by June, 2015 (impacts storage location permit), and the ability to start and finish processing the fuel per the process schedule would be negatively impacted.
- Waste Management was weighted the second highest criteria at 19.3%. This was considered to be more important than all of the criteria except Environmental Permitting because the success of the project also depends on the ability to minimize the waste volume (LLW and HLW), minimize the number of waste containers produced, and establish waste forms with a path for disposal.
- Project Risk was weighted the third highest criteria at 14.1%. Project Risk was considered to be among the top three criteria because if the cost and schedule (process schedule) baselines cannot be met, the impact on the project success would be significant. SRNS needs to finish processing the fuel per the process schedule in order to have minimum or no impact on the H-Canyon mission, and to avoid paying the full operating cost.
- Technical Maturity was weighted at 11.6%, Facility Operations was weighted at 9.4%, and Cost was weighted at 8.8%. These criteria were considered to be moderately important when compared to the top 3 most important criteria and the 3 least important criteria.
- Special Nuclear Material (SNM) and Waste Stay Time were weighted at 5.7% because their relative importance to the selection of the processing alternative is low. This criterion was considered an Evaluation Criteria because of the impact external stakeholders opinions will have on the success of the project.

- Safeguards and Security was weighted at 5.4% because its relative importance to the selection of the processing alternative is low. This criterion was considered an Evaluation Criteria because of the impact it will have on selecting a facility for processing the fuel.
- Schedule was weighted the lowest at 4.6%. This criterion was considered to be the least important criterion with respect to selecting a processing alternative because the project schedule milestone (i.e., start receiving the AVR fuel by June 2015) is associated with the receipt and storage scope. This criterion was considered an Evaluation Criteria because minimizing the time to process the fuel impacts the H-Canyon operating and end of mission schedules.

Figure ES-2 provides the result of the Alternative Evaluations. The data shows a minor break between the top three most preferred options (1, 2-T, and 2) and the 4th most preferred option (6). Option 6 was included with option 1, 2-T and 2 as the most preferred options for completion. Option 6 is the only one of the top four options with the proposed process located in an L-Area (105-L Facility) versus the H-Area (H-Canyon).

The results of the sensitivity analyses indicated that this evaluation was robust because none of the top 3 options preference changed when the criteria weights were increased or decreased by up to 10%.

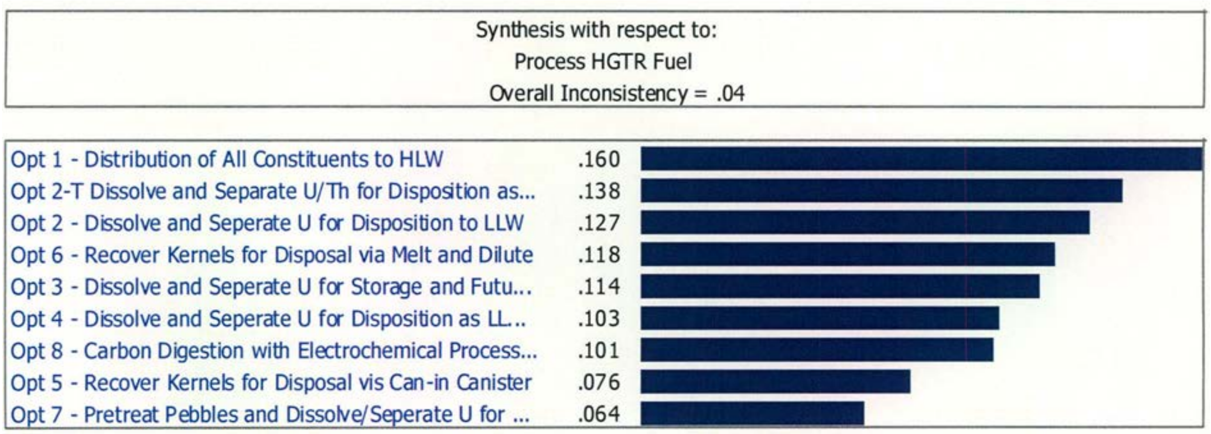

Figure ES-2: Alternative Evaluation Results

- Options 1, 2T, and 2 were the most preferred options because they all involve implementation in an existing, operating facility (H Canyon) with supporting infrastructure (utilities, ventilation, environmental monitoring).

  For Option 1, an assumption was made that the high level waste stream could be managed in the Tank Farm to allow blending with existing waste and to minimize the incremental number of HLW canisters produced. The production and disposal of HLW canisters resulting from direct conversion of the HTGR liquid waste (containing substantial quantities of thorium and down blended uranium) without blending was considered during the evaluation.

  Options 2T and 2 eliminate the major actinides from the high level waste, reducing the impact on the HLW disposal systems. Implementation of these options assumes that the E-Area Performance Assessment can be modified to allow disposal of the LLW streams that could be generated by these processes.

- Options 6 is the 4th most preferred option because of the potential synergy with the use of a previous program referred to as the "melt and dilute process". Implementation in L- Area eliminates co-occupancy issues with construction and operations in an existing facility.
- Option 3 has advantages similar to Options 1, 2-T, and 2, but was less preferred because it requires: (1) a new LEU conversion process, (2) uranium packaging, and (3) storage. The lack of an identified end-use for the material also contributed to this option being less preferred.
- Option 4 provides the uranium separation for waste disposal benefits as described in option 2, but it utilizes L Area for processing the kernels. By using L-Area for the front-end of the process, the processing schedule would be accelerated and some co-occupancy issues would be eliminated. However, this option was moderately preferred with respect to the other options because it requires inter-area shipments of kernels, salt, and liquid waste. This option would also require operations and support staffing for two facilities.
- Option 5 "can in canister" vitrification and can handling operations were deemed to be more compatible with the proposed 105-L facility layout than with the H-Canyon facility layout. Therefore, during the evaluation, it was assumed that all of the unit operations would be performed in 105-L.. This option was included with the three least preferred options because it would difficult to construct and operate the large number of unit operations, and provide the lag storage space for the kernels, glass cans, and loaded DWPF canisters.

The seven options discussed above all share the graphite digestion and kernel recovery process currently under development. Options 8 and 7 are based on alternate technologies, and were considered to balance the technology risk inherent in a new process.

- Option 8 uses electrochemical technology to sequentially separate carbon and then actinides from fission products in a salt matrix; the process is completely dry. However, this option was included with the least preferred options because of the metallic TRU waste form that would be produced by actinide recovery, and the glass waste that would be produced from spent salt processing.
- Option 7 was the least preferred option because it thermally decomposing the carbon using a fluidized bed. Although the technology is mature, disposition of ash residues and volatilization of fission products present significant engineering and regulatory challenges not present in other options.

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LIST OF ABBREVIATIONS

AVR	*Arbeitsgemeinschaft Versuchreaktor*
CY	Calendar Year
DOE	Department of Energy
DU	Depleted Uranium
EA	Environmental Assessment
EIS	Environmental Impact Statement
HEU	Highly Enriched Uranium
HLW	High Level Waste
HTGR	High Temperature Gas-Cooled Reactor
Jülich	Forschungszentrum Jülich GmbH
LEU	Low Enrichment Uranium
LLW	Low Level Waste
M&O	Management and Operations
MC&A	Material Control and Accountability
NEPA	National Environmental Policy Act
S&S	Safeguards and Security
SSCs	Systems, Structures, and Components
SNM	Special Nuclear Material
SOW	Statement of Work
SRNL	Savannah River National Laboratory
SRNS,LLC	Savannah River Nuclear Solutions, LLC and its duly authorized representatives
SRS	Savannah River Site
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

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 is being 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.

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The information and data used during the Alternative Evaluation were based on subject matter experts' judgments, expertise, and insight at the time of the evaluation. As the unknowns associated with the Project's objectives and requirements are better defined, the alternatives, screening criteria, and/or evaluation criteria may be modified to incorporate new or updated information.

2. ALTERNATIVE EVALUATION PROCESS OVERVIEW

In order to prepare the "discussion of alternative technologies and facility locations" section of the Step 1 deliverable (Reference 2), a team of SRNS subject matter experts identified and evaluated alternatives. The team members are listed in the Acknowledgment Section of this report.

The alternatives were evaluated using a structured process known as the "Systems Engineering (SE) Approach" for evaluating alternatives. This structured approach required the team to systematically complete and document the steps described below.

1. Develop Screening Criteria - Screening criteria are requirements that are non-negotiable (go/no go). They are used to determine if any of the alternatives should be eliminate from further evaluation because they do not meet the screening criteria.

2. Develop Evaluation Criteria - Usually no one alternative will be the best for all requirements and objectives. Therefore, it is necessary to define criteria to measure how well each alternative achieves the objectives and requirements.

3. Identify Alternatives - Alternatives offer different approaches for changing the initial condition into the desired condition. The team evaluates the objects and requirements, and suggests alternatives that will meet as many objectives as possible and satisfy the requirements.

4. Evaluate the Alternative - Alternatives are evaluated with respect to the criteria using an evaluation method (tool). Sensitivity analyses provide insights into the robustness of the evaluation results.

5. Validate and Verify the Evaluation - The evaluation process results can be validated and verified via several different mechanisms.

As a result of systematically completing and document the steps described above, external reviewers can recreate the thought process used to define and weight evaluation criteria, define and evaluate alternatives, down-select preferred alternatives, and make recommendation.

3. ALTERNATIVE EVALUATION RESULTS

The Alternative Evaluation Process has been described in Section 2. This section provides the results of the evaluation.

3.1 Screening Criteria

Screening criteria are non-negotiable (go/no-go) requirements that are used to determine if any of the alternatives should be eliminate from further evaluation. The three screening criteria provided in Table 1 were developed based on the objectives and performance requirements provided in Reference 4. All of the nine alternatives listed in Section 3.4 satisfied these screening criteria.

Table 1: Screening Criteria

	Screening Criteria	Definition
1.0	If the alternative doesn't allow for the uranium stream generated by its process to be discarded or down blended from HEU to LEU (appropriate standards), it will be eliminated from further evaluation.	Much of the HTGR fuel was originally fabricated using HEU. Down blending of the uranium to LEU (or lower enrichment) to increase the potential for reuse, and reduce the proliferation potential are important objectives of the program.
2.0	If the HLW stream generated by the alternative can't meet the receipt facility Waste Acceptance Criteria (WAC), it will be eliminated from further evaluation.	SRS assumes it will have the capability to dispose of HLW without impacting the receipt facility WAC, mission, or closure schedule. Examples of ways the WAC could be impacted 1) If required, funding is not provided for the expanding the HLW mission or extending the Tank Farm life; 2) Thorium in HLW poses a processing problem due to thixotropic tendency (peanut butter consistency) of thorium; 3) If fission products cannot be separated from the salt, the salt would be considered HLW with no path for disposal; 4) DWPF can only process waste that has been classified as defense waste. The classification of the waste stream generated by the process is unknown at this time. 4) The amount of salt that can be sent to the HLW is defined in the WAC. The amount of salt that will be generated by the process is unknown at this time.
3.0	If the alternative requires the AVR fuel to be shipped in a manner that doesn't allow all of the fuel to be received at SRS by	Due to regulatory commitments, receipt of AVR fuel from the Jülich facility shall be completed by September, 2016. Based on the number of casks and the projected

	Screening Criteria	Definition
	rail beginning in June, 2015, it will be eliminated from further evaluation.	shipping schedule, shipments must begin by June 2015 to complete the de-inventory of the Jülich facility by the regulatory deadline.

3.2 Evaluation Criteria and Metrics

Evaluation (also referred to as selection) criteria are defined to measure how well each alternative achieves the objectives and performance requirement. Evaluation Criteria should be selected to meet the following attributes:

- able to discriminate among the alternatives,
- complete –include all goals,
- meaningful to the decision team's understanding of the implications of the alternatives,
- independent, and
- as few in number as possible

Based on these attributes as well as the objectives and performance requirements (Reference 4), the nine evaluation criteria provided in Table 2 were generated. As the unknowns associated with the Project's objectives and requirements are better defined, these criteria and weights may be modified to incorporate new or updated information.

Table 2: Evaluation Criteria

	Evaluation Criteria
1.0	Technical Maturity
2.0	Project Risk
3.0	Cost
4.0	Schedule
5.0	Environmental Permitting
6.0	Waste Management
7.0	Facility Operations
8.0	Safeguards and Security
9.0	SNM and Waste Stay Time

3.2.1 Evaluation Metrics

To define the criteria, the metrics provided in Table 3 were developed. The last column describes how the criteria were used to evaluate the alternatives during the assessment.

Table 3: Criteria and Metrics Description

	Criteria	Metrics (Criteria Definitions)	Description (Criteria Description)
1.0	Technical Maturity	Most Technically Mature	The most technically mature alternatives scored the highest with respect to this criterion. ***Note:*** *Technical maturity was defined as "Readiness for insertion into the design process and execution schedule for the project or operations activities."*
2.0	Project Risk	Least Project Risk	The alternatives that have the least risk of not meeting the project's cost and schedule baselines scored the highest with respect to this criterion. ***Note:*** *During the assessment of this criterion, the complexity and difficulty in meeting ES&H requirements were considered.*
3.0	Cost		The alternatives that have the least" relative" capital/project and operating cost scored the highest with respect to this criterion.
		Least capital/project cost (relative)	
		Least operating cost (relative)	
4.0	Schedule		The alternatives that minimize the 1) project schedule and 2) the process schedule baselines the best scored the highest with respect to this criterion. ***Note****: During the assessment of this criterion, the re-use demand of U or the cask was considered*
		Minimize Project Schedule	
		Minimize Process Schedule	***Note:*** *During the assessment of this metric, the facility ability to have its infrastructure available for this project (modifications and operations) was considered.*
5.0	Environmental Permitting	Least impact on the ability to obtain permits (new or modified)	The alternatives that have the least impact on the facility's ability to obtain permits (new or modified) scored the highest with respect to this criterion.
6.0	Waste Management		The alternatives 1) that have the most established waste form with the least additional certification and the most clearly defined disposal path; 2) will generate the least amount of HLW and LLW waste (volume); and 3) will generate the least amount of final waste form containers scored the highest with respect to this criterion. ***Note:*** *During the assessment of this criterion,*

	Criteria	Metrics (Criteria Definitions)	Description (Criteria Description)
			the team considered if the cost associated with managing the waste had been evaluated with the cost criteria.
		Least established form/path	
		Least liquid HLW (volume)	
		Least LLW (volume)	
		Least HLW final form container	
7.0	Facility Operations	Least Facility Mission Impact	The alternatives that have the least impact on the facility's ability to compete its mission scored the highest with respect to this criterion.
8.0	Safeguards & Security	Minimize the need to change the categorization of the facility.	The alternatives that require the least physical security modifications to protect the fuel scored the highest with respect to this criterion.
9.0	SNM and Waste Stay Time		The alternatives that 1) have the most potential for the waste to be disposed off-site and 2) is least objectionable to our external stakeholders Germany, SC, GA, CAB, Concern Citizens, etc.) scored the highest with respect to this criterion.
		Most potential to store the waste offsite	
		Least objectionable to external stakeholders	

3.2.2 Evaluation Criteria Weighting

After defining the evaluation criteria, the relative weight or importance of each criterion in selecting the alternative was assessed. Criteria can be weighted using several different methods. Method selection is based on the complexity of the evaluation and the experience of the team. This evaluation used the Analytic Hierarchy Process (AHP) method for weighting criteria. Each criterion was compared with every other criterion in pair-wise comparison.

The numerical scale that was used for defining the relative importance was from 1 to 9, with 1 being equally important and 9 being extremely more important (see Table 4). The value generated by team consensus was used to determine the relative weight or importance of each criterion.

Table 4: Evaluation Scale

Scale 1 – 9	
1	Equal Important
2	Equal to Moderately More Important
3	Moderately More Important
4	Moderately to Strongly More Important
5	Strongly More Important
6	Strongly to Very Strongly More Important
7	Very Strongly More Important
8	Very Strongly to Extremely More Important
9	Extremely More Important

3.3 Criteria and Metrics – Weighting Results

This section provides the results of weighting the criterion and metric using pair-wise comparison. The criteria results are provided in Section 3.3.1. The metrics results are provided in Section 3.3.2.

3.3.1 Criteria Evaluation Results

Figure 1 shows the results of weighting the criteria.

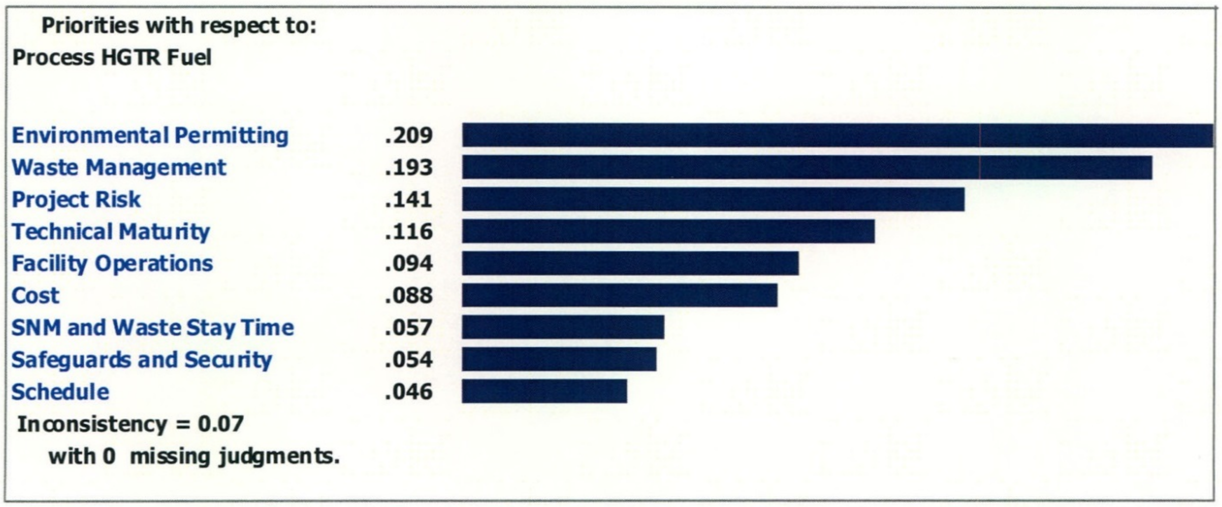

Figure 1: Criteria Weight

- Environmental Permitting was weighted the highest at 20.9%. This was considered to be the most important criterion because if permits cannot be obtained in a timely manner, the ability to start receiving the AVR fuel by June, 2015 (impacts storage location permit), and the ability to start and finish processing the fuel per the process schedule would be negatively impacted.
- Waste Management was weighted the second highest criteria at 19.3%. This was considered to be more important than all of the criteria except Environmental Permitting because the success of the project also depends on the ability to minimize the waste volume (LLW and HLW), minimize the number of waste containers produced, and establish waste forms with a path for disposal.
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- Special Nuclear Material (SNM) and Waste Stay Time were weighted at 5.7% because their relative importance to the selection of the processing alternative is low. This criterion was considered an Evaluation Criteria because of the impact external stakeholders opinions will have on the success of the project.
- Safeguards and Security was weighted at 5.4% because its relative importance to the selection of the processing alternative is low. This criterion was considered an Evaluation Criteria because of the impact it will have on selecting a facility for processing the fuel.
- Schedule was weighted the lowest at 4.6%. This criterion was considered to be the least important criterion with respect to selecting a processing alternative because the project schedule milestone (i.e., start receiving the AVR fuel by June 2015) is associated with the receipt and storage scope. This criterion was considered an Evaluation Criteria because minimizing the time to process the fuel impacts the H-Canyon operating and end of mission schedules.

3.3.2 Metrics Results

Prior to evaluating the criteria, if a criterion had two or more metrics allocated to it, the metrics (sub-criteria) were weighted using the same process and scale described in section 3.2.2. The results of weighting the metrics (sub-criteria) are provided below.

Cost

Figure 2 shows that the capital/project cost was considered to be moderately (3 times) more important than the operating cost with respect to the cost criterion.

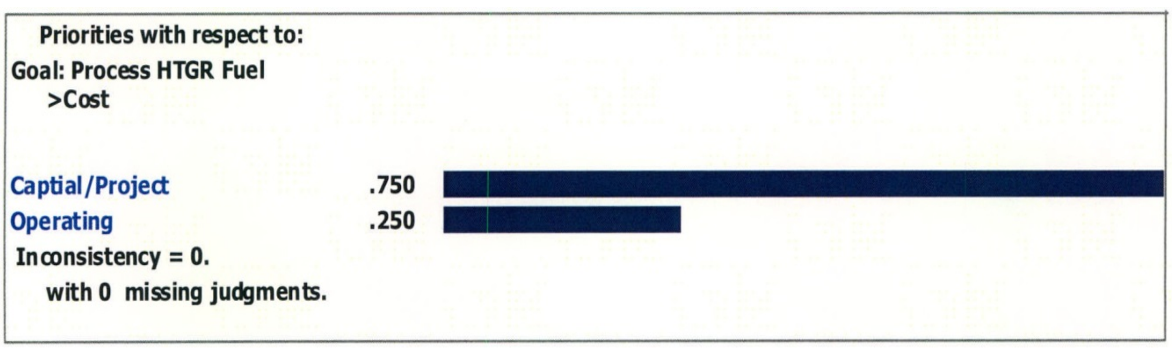

Figure 2: Cost Metric Weight

Schedule

Figure 3 shows that the process schedule was considered to be moderately to equal (2 times) more important than the project schedule with respect to the schedule criterion.

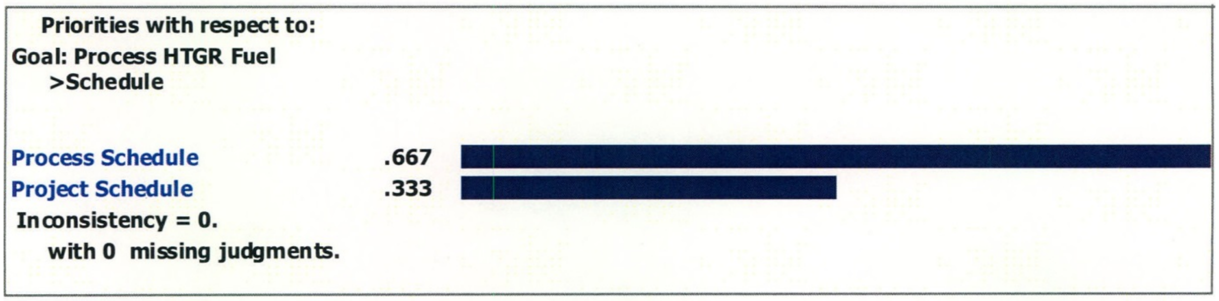

Figure 3: Schedule Metric Weights

Waste Management

Figure 4 shows that being able to establish the waste form/path was considered to be the most important metric and generating the least volume of LLW was considered to be the least important with respect to the waste management criterion. Managing the HLW volume and number of final containers (e.g. DWPF canisters) were considered to be moderately important when compared to the other metrics.

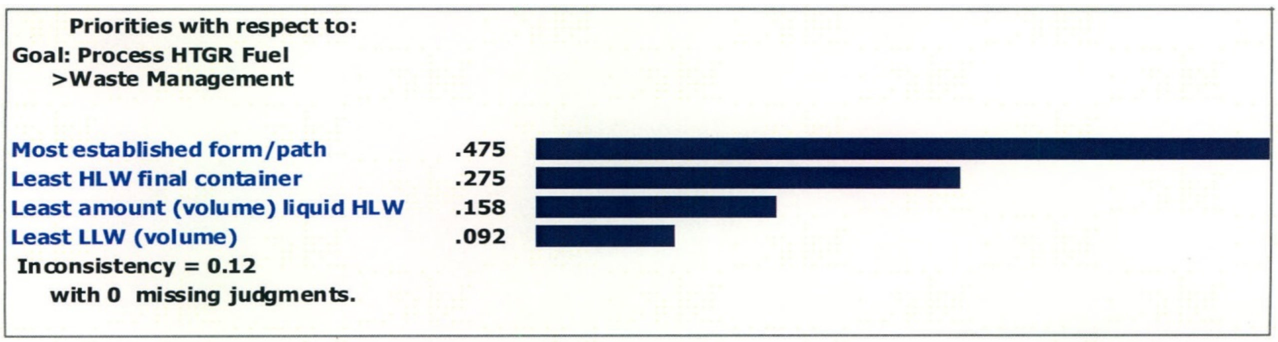

Figure 4: Waste Management Metric Weights

SNM and Waste Stay Time

Figure 5 shows that being least objectionable to external stakeholders was considered to be moderately to equal (2 times) more important than the potential to store the waste offsite with respect to the SNM and waste stay time criterion.

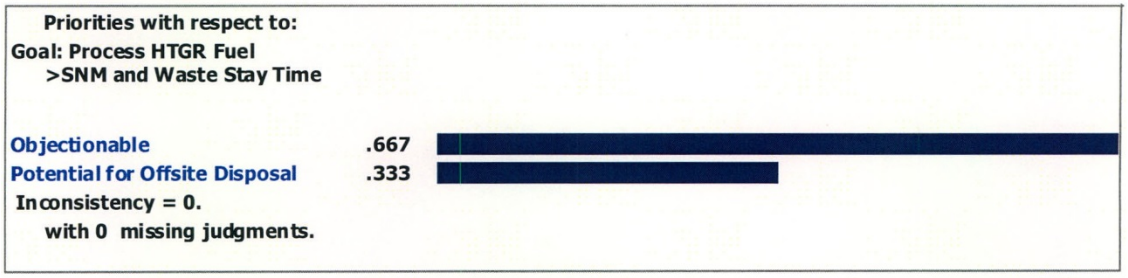

Figure 5: SNM and Waste Stay Time Metrics Weights

3.4 Alternatives

Alternatives (also referred to as options) offer different approaches for meeting the project's objectives and requirements. The nine proposed alternatives evaluated during this Alternative Evaluation Process are listed in Table 5. Detailed descriptions of the nine alternatives are provided in Appendix (Section A-1). The advantages and disadvantages associated with each alternative are discussed in Appendix A (Section A-2).

These alternatives were derived from a "brainstormed" list of potential alternatives documented in Reference 5. The "brainstormed" list was condensed into the nine credible options for development and evaluation. The bases for their selection included historical experience, assumptions on salt regeneration or reuse, off gas treatment requirements, chemical compatibility, treatment requirements for waste streams, and volume of waste produced. As these options were developed, minor modifications were identified and incorporated to improve material recovery, reduce cycle time, or minimize waste.

Table 5: Alternatives (Options)

Alternative Number	Alternative Name	Alternative Description
1	Distribution of All Constituents to HLW	Digest pebbles and dissolve kernels and salt for direct disposal to the HLW system.
2	Dissolve and Separate U for Disposition to LLW	Digest pebbles, dissolve kernels and salt, separate and blend-down uranium as LLW grout, and dispose of salt, Thorium, and fission products to the HLW system.
2-T	Dissolve and Separate U/Th for Disposition as LLW	Digest pebbles, dissolve kernels and salt, separate and blend-down U and Th as LLW grout, and dispose of salt and fission products to the HLW system.

Alternative Number	Alternative Name	Alternative Description
3	Dissolve and Separate U for Storage and Future Use	Digest pebbles, dissolve kernels and salt, separate and blend-down U to oxide for reuse, and dispose of salt, Th, and fission products to the HLW system.
4	Dissolve and Separate U for Disposition as LLW with Salt Disposal as Solid Waste	Same as option 2 but do pretreatment in L-Area.
5	Recover Kernels for Disposal via Can in Canister	Digest pebbles, blend-down and vitrify kernels for can-in-canisters disposal as HLW glass, and process salt for direct disposal to Saltstone.
6	Recover Kernels for Disposal via Melt and Dilute	Digest pebbles, and melt-dilute kernels for dry storage pending disposal with SNF, and process salt for direct disposal to Saltstone.
7	Pretreat Pebbles and Dissolve/Separate U for Disposal as LLW	Grind pebbles and burn carbon, dissolve kernels, separate and blend-down uranium as LLW grout, and dispose of off-gas salt, Thorium, and fission products to the HLW system.
8	Carbon Digestion with Electrochemical Processing of Kernels	Pyro-chemically digest pebbles, separate U, Pu, Th as TRU waste, and dispose of Cs/Sr and salt as ceramic HLW.

3.5 Alternatives Weighting

The relative weight or importance of each alternative in meeting the projects mission and objectives was assessed. Like the criteria, the importance of the alternatives can be weighted using several different methods. Method selection is based on the complexity of the evaluation and the experience of the team. This evaluation used the Analytic Hierarchy Process (AHP) method for weighting alternatives. Each alternative was compared with every other alternative in pair-wise comparison.

The numerical scale that was used for defining the relative importance was from 1 to 9, with 1 being equally important and 9 being extremely more important (see Table 6). The value generated by team consensus was used to determine the relative weight or importance of each criterion.

Table 6: Evaluation Scale

Scale 1 – 9	
1	Equal Important
2	Equal to Moderately More Important
3	Moderately More Important
4	Moderately to Strongly More Important
5	Strongly More Important
6	Strongly to Very Strongly More Important
7	Very Strongly More Important
8	Very Strongly to Extremely More Important
9	Extremely more Important

3.6 Alternative Evaluation Results

This section provides the results of the Alternative Evaluation. The results are provided in Section 3.6.1. The result with respect to each criteria and its associated metrics are provided in the remaining subsections.

3.6.1 Overall Results

Figure 6 provides the overall result of the Alternative Evaluations.

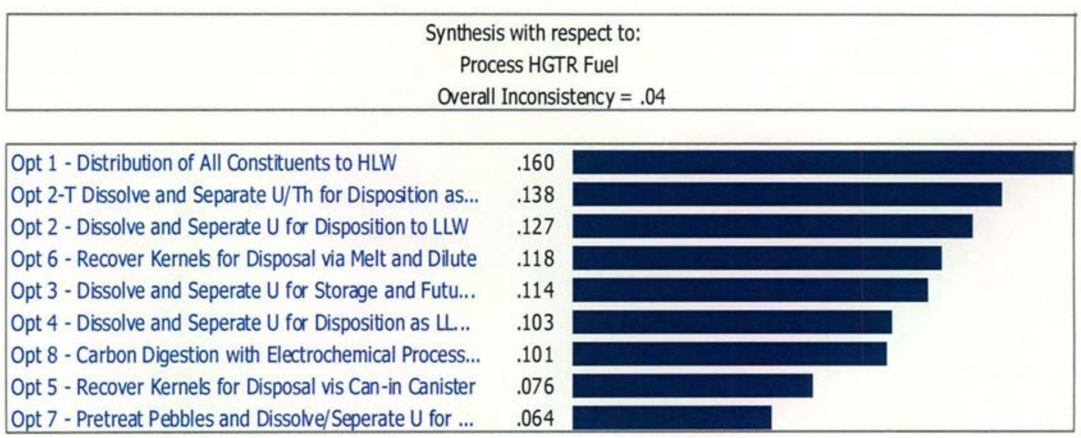

Figure 6: Alternative Evaluation Results

- Options 1, 2T, and 2 were the most preferred options because they all involve implementation in an existing, operating facility (H Canyon) with supporting infrastructure (utilities, ventilation, environmental monitoring).

For Option 1, an assumption was made that the high level waste stream could be managed in the Tank Farm to allow blending with existing waste and to minimize the incremental number of HLW canisters produced. The production and disposal of HLW canisters resulting from direct conversion of the HTGR liquid waste (containing substantial quantities of thorium and down blended uranium) without blending was considered during the evaluation.

Options 2T and 2 eliminate the major actinides from the high level waste, reducing the impact on the HLW disposal systems. Implementation of these options assumes that the E-Area Performance Assessment can be modified to allow disposal of the LLW streams that could be generated by these processes.

- Options 6 is the 4th most preferred option because of the potential synergy with the use of a previous program referred to as the "melt and dilute process". Implementation in L- Area eliminates co-occupancy issues with construction and operations in an existing facility.
- Option 3 has advantages similar to Options 1, 2-T, and 2, but was less preferred because it requires: (1) a new LEU conversion process, (2) uranium packaging, and (3) storage. The lack of an identified end-use for the material also contributed to this option being less preferred.
- Option 4 provides the uranium separation for waste disposal benefits as described in option 2, but it utilizes L Area for processing the kernels. By using L-Area for the front-end of the process, the processing schedule would be accelerated and some co-occupancy issues would be eliminated. However, this option was moderately preferred with respect to the other options because it requires inter-area shipments of kernels, salt, and liquid waste. This option would also require operations and support staffing for two facilities.
- Option 5 "can in canister" vitrification and can handling operations were deemed to be more compatible with the proposed 105-L facility layout than with the H-Canyon facility layout. Therefore, during the evaluation, it was assumed that all of the unit operations would be performed in 105-L.. This option was include with the three least preferred options because it would difficult to construct and operate the large number of unit operations, and provide the lag storage space for the kernels, glass cans, and loaded DWPF canisters.

The seven options discussed above all share the graphite digestion and kernel recovery process currently under development. Options 8 and 7 are based on alternate technologies, and were considered to balance the technology risk inherent in a new process.

- Option 8 uses electrochemical technology to sequentially separate carbon and then actinides from fission products in a salt matrix; the process is completely dry. However, this option was included with the least preferred options because of the metallic TRU waste form that would be produced by actinide recovery, and the glass waste that would be produced from spent salt processing.
- Option 7 was the least preferred option because it thermally decomposing the carbon using a fluidized bed. Although the technology is mature, disposition of ash residues and volatilization of fission products present significant engineering and regulatory challenges not present in other options.

3.6.2 Environmental Permitting

Figure 7 shows the rank of the options with respect to the Environmental Permitting criterion.

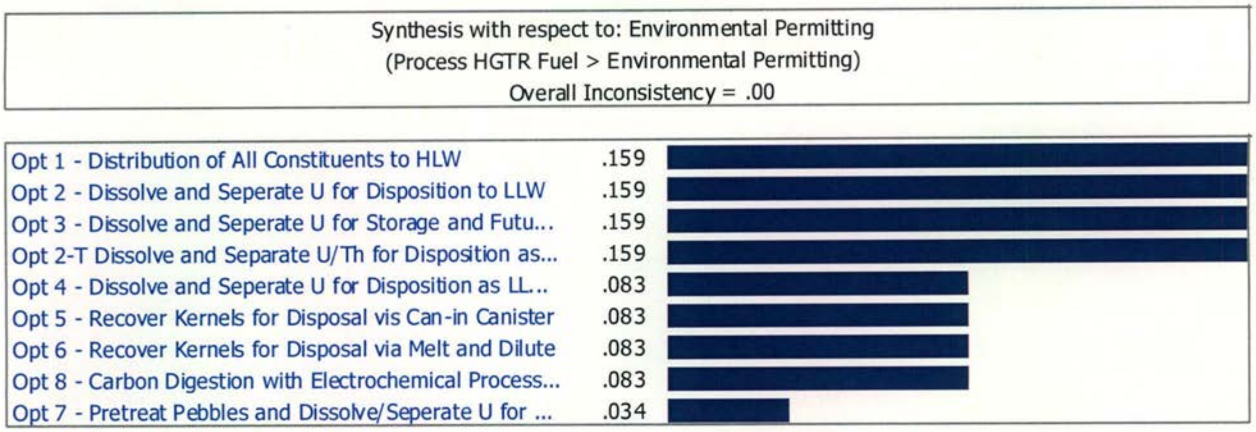

Figure 7: Environmental Permitting Criterion

- Options 1, 2, 3, and 2-T were equally the most preferred options because it was assumed that their associated processes would be performed in H-Canyon. H-Canyon has an existing environmental permit, appropriate safety classification(s), and some of the equipment that would be required to protect and/or monitor the environment (e.g., isokinetic sampler).
- Options 4, 5, 6, and 8 were equally less preferred because it was assumed that all or part their associated process would be performed in L-Area (Building 105-L). Building 105-L needs new or modified permits and major environmental monitoring equipment upgrades (e.g., stack and associated sampling equipment).
- Option 7 was the least preferred option because it involves thermally decomposing the carbon using a fluidized bed. Although the technology is mature, disposition of ash residues and volatilization of fission products present significant engineering and regulatory challenges not present in other options (e.g., carbon being released from the stack). This option also requires an incinerator. Permitting the incineration would negatively impact the project cost and schedule.

3.6.3 Waste Management

Figure 8 shows the rank of the options with respect to the Waste Management criterion. This criterion was defined by the following four metrics: 1) Least liquid HLW (volume), 2) Least LLW (volume), 3) Least HLW final form container, and 4) Most established Form/Path The rank of the alternatives with respect to each of the metrics is provided in Figures 9, 10, 11, and 12, respectively.

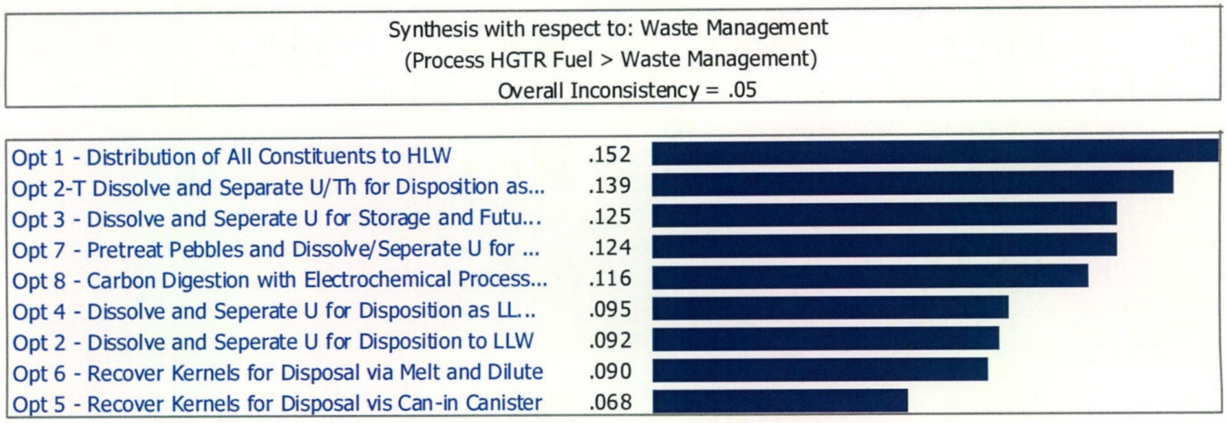

Figure 8: Waste Management Criterion

3.6.3.1 Waste Management Metrics

During the evaluation:

- The Waste Management Criterion was bounded by the following requirement: "*The total amount of waste transferred to the Tank Farm shall not exceed 300,000 gallons per year.*"

- Table 7 was developed to provide the total waste volume (gallons) produced over 3 ½ years by each option (i.e., Option 1, Option 2, and Option 3) for three cases: (1) no salt reuse, (2) 10:1 salt re-use and (3) 40:1 salt reuse.
  - Options 1, 2, and 3 were chosen because they corresponded to the latest three Environmental Assessment (EA) cases.
  - The life cycle of the HTGR program was assumed to be 3 ½ years.

- The data showed that the total volumes associated with:
  - **Case (1) No Salt Re-use** would significantly exceed the 300,000 gallons per year requirement. Therefore, Case 1 was not considered is viable. If salt is not re-used, the cost to manage the waste would not be feasible.
  - **Case (2) 10:1 Salt Re-use** would meet the 300,000 gallons per year requirement.
  - **Case (3) 40:1 Salt Re-use** would meet the 300,000 gallons per year requirement.

- Based on data available at that time, the10-:1 salt re-use ratio was selected as the base case. Preliminary data indicated it could be feasible.

Table 7: Salt Re-use

	Cases		Kernel stream to waste (Gal)	Salt stream to waste (Gal)	Conceptual canisters (#)	
No salt reuse						
1	Disposition all to HLW		157,608	2,333,760	99	
2	Disp U (Grout) to LLW @1000 fge/can		196,152	2,333,760	37	
3	Disp U (Oxide) to Reuse		196,152	2,333,760	37	
10:1 Salt reuse	**Baseline**					
1	Disposition all to HLW		157,608	351,120	99	
2	Disp U (Grout) to LLW @1000 fge/can		196,152	454,633	32	Salt stream adjusted for process waste
3	Disp U (Oxide) to Reuse		196,152	454,633	32	Salt stream adjusted for process waste
40:1 Salt reuse						
1	Disposition all to HLW		157,608	185,592	99	
2	Disp U (Grout) to LLW @1000 fge/can		196,152	240,306	32	Salt stream adjusted for process waste
3	Disp U (Oxide) to Reuse		196,152	240,306	32	Salt stream adjusted for process waste

Table 8 provides the waste volumes of each of the 9 options under consideration assuming a 10:1 salt reuse. The data is based on the best available information at the time of the assessment. During the evaluation, the various types of wastes were combined, reduced into the evaluation categories, and assigned a relative importance.

Table 8: Waste Management Metrics Baseline (2)

		Canisters	Saltstone Grout (gallons)	U Oxide Ltrs	U Grout (liters)	Drums LLW Grout	RH.TRU Drums	SNF Can (MCO canisters)	Resue Castor	Other LLW (equivalent 55 gal drums)	Gallons HLW @10:1	Relative HLW Factor	Relative LLW Factor (1=lowest)	Relative Cost Factor (1=highest)
10/1 Reuse														
1	Disposition all to HLW	99	1.23E+06							9.45E+03	5.12E+05	2.0	1.00	0.42
2	Disp U (Grout) to LLW	32	1.31E+06		1.03E+05	455			Yes	1.28E+03	5.25E+05	2.0	0.98	0.49
2T	Disp U/Th (Grout) to LLW	15	1.17E+06		1.90E+05	455			Yes	1.28E+03	4.99E+05	1.9	0.98	0.57
3	Disp U (Oxide) to Reuse	32	1.31E+06	2270					Yes	1.28E+03	5.25E+05	2.0	0.98	0.64
4	Disp U (Grout) to LLW (sep. headend)	32	1.31E+06		1.03E+05	455				9.45E+03	5.25E+05	2.0	1.00	0.57
5	Can-in-Can	49	8.40E+05							9.45E+03	3.48E+05	1.4	0.71	0.84
6	Melt & Dilute		8.40E+05					78		9.45E+03	3.48E+05	1.4	0.71	0.73
7	Crush/Grind & Burn	32	6.00E+05		1.03E+05	455				1.28E+03	2.58E+05	1.0	0.46	0.64
8	Pyrochemical (Assumes Reuse)						2000	16		9.45E+03	NA	NA	0.09	1.00

Note: TRU waste considered as 1/4 volume impact of HLW in scoring HLW canister impact

Note: LLW volume of saltstone, grout, and empty equipment were totaled and cost weighted fot relative score

Note: Relative cost factor was derived by comparing number of modules and estimating other costs (e.g., infrastructure upgrades) as equivalent modules

Waste Management: Least Liquid HLW (volume)

Figure 9 provides the rank of the options with respect to the Least Liquid HLW (volume) metric. The data provided in Table 8 was used to rank these options. In general, the options that produced the least amount of liquid HLW (volume) ranked the highest.

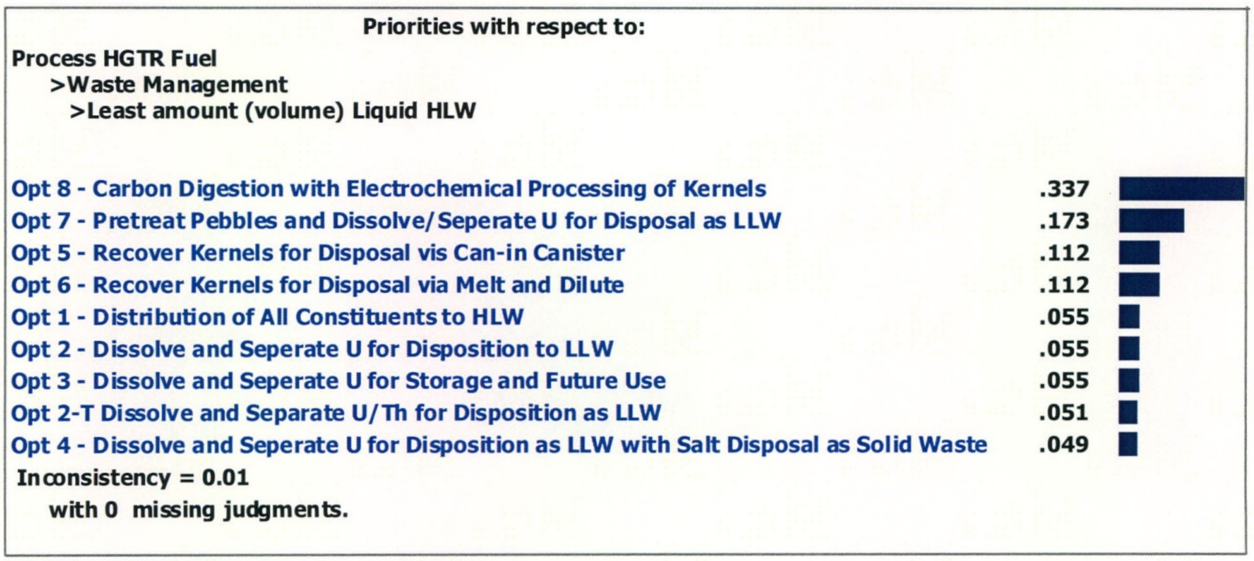

Figure 9: Waste Management (Least Liquid HLW Waste Volume) Metric

Waste Management: Least LLW (volume)

Figure 10 provides the rank of the options with respect to the Least LLW (volume) metric. The data provided in Table 8 was used to rank these options. In general, the options that produced the least amount of LLW (volume) ranked the highest.

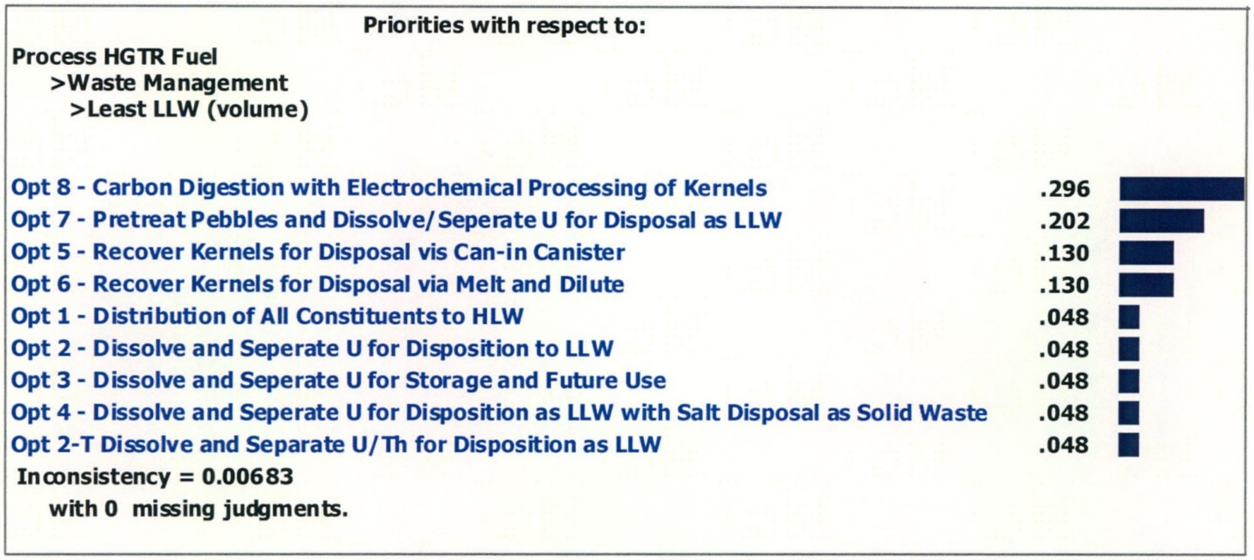

Figure 10: Waste Management (Least LLW (volume) Metric

<u>Waste Management: Least HLW Final Form Container</u>

Figure 11 provides the rank of the options with respect to the Least HLW Final Form Container metric. The data provided in Tables 8 was used to rank these options. In general, the options that produced the least HLW containers ranked the highest.

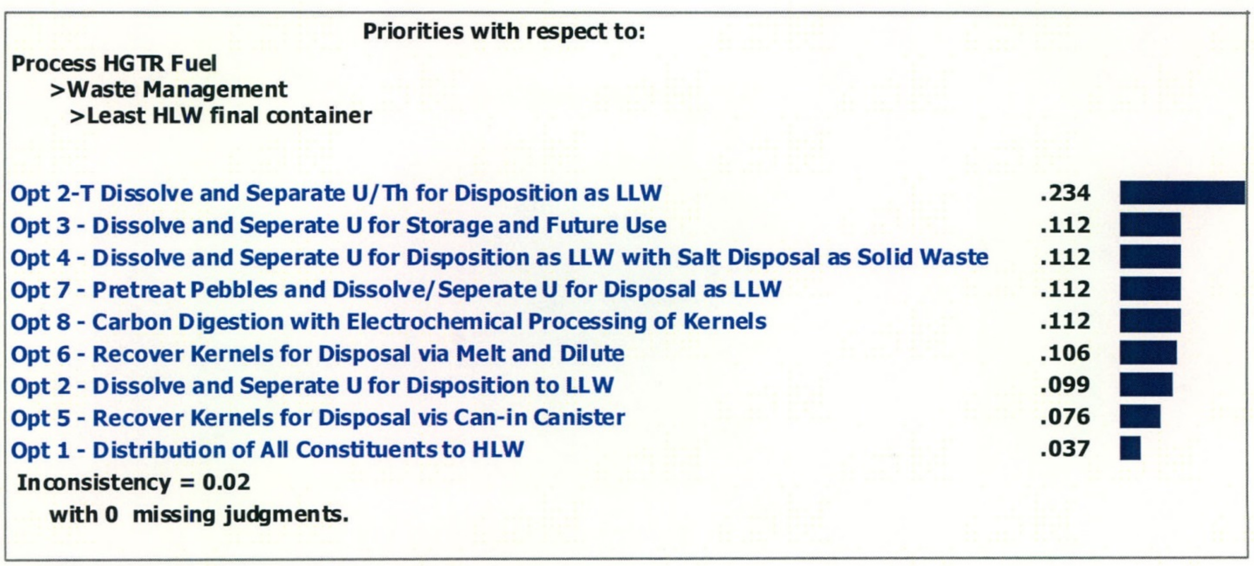

Figure 11: Waste Management (Least HLW Final Form Container) Metric

Waste Management (Most Established Form/Path)

Figure 12 provides the rank of the options with respect to the Most Established Form/Path metric.

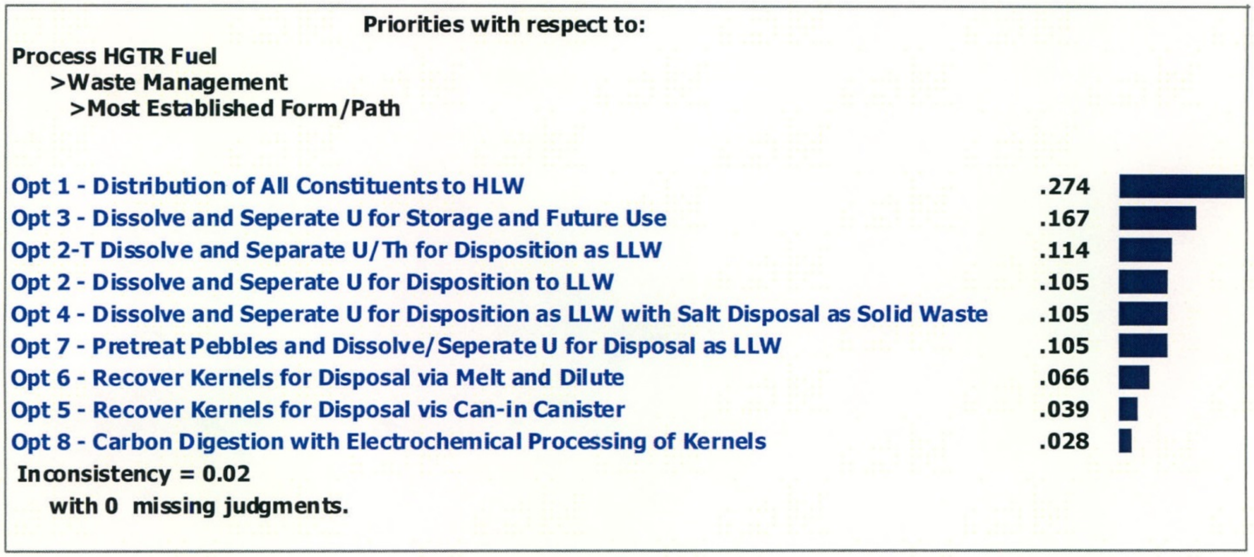

Figure 12: Waste Management (Most Established Form/Path) Metric

- Option 1 was the most preferred option because it has the most established waste form. The primary waste form generated by this process is HLW its path for disposal is the HLW Waste System. In this option, the U will be disposed of as waste.
- Option 3 was the next most preferred because the U is not going to the HLW waste system. Future use may involve generation and disposal of an unknown waste form.
- Option 2-T, 2, 4, and 7 have similar waste forms and only differ in the quantity. The quantity data provided in Table 8 was used to rank these options. In general, the options that had the most established waste forms ranked the highest.
- Option 6, 5, and 8 were the three least preferred options because the waste produced by these processes has undefined waste forms. Option 6 is a new waste form with an undefined path for disposal. Option 6 is better than Option 5 because the waste form has been analyzed and it has a favorable NEPA determination. Option 5 has been studied but not as much as Option 6.
- Option 8 was the least preferred because it has a larger number of undefined waste forms

3.6.4 Technical Maturity

Figure 13 shows the rank of the options with respect to the Technical Maturity criterion. The low technical maturity (TRL < 3) of the new digestion process was common to all of the options. Therefore, the preference of one option over another option was based on other unit operation and balance of plant processes.

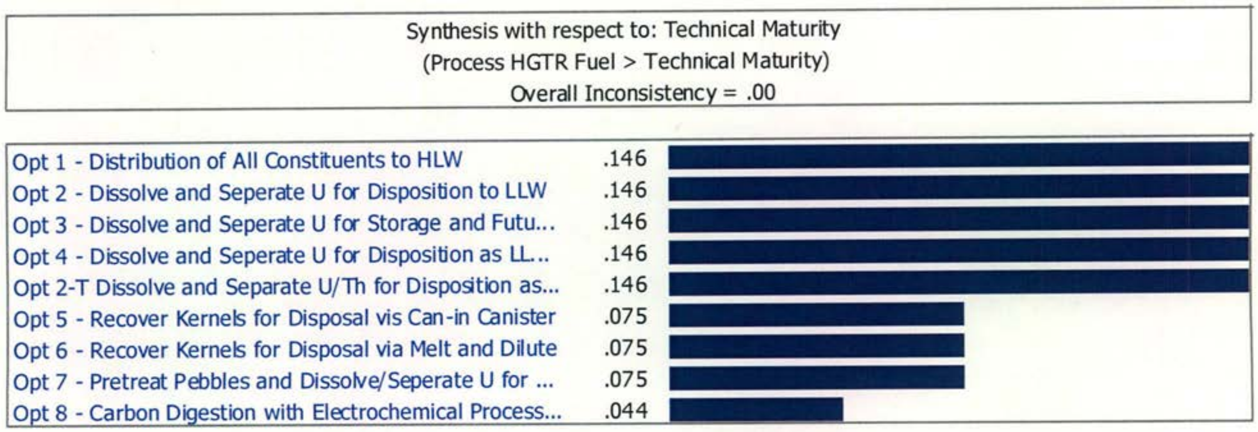

Figure 13: Technical Maturity Criterion

- Option 1, 2, 3, 4, and 2-T were equally the most preferred options because they involved utilizing H –Area proven dissolution process with supporting equipment and established balance of plant processes.
- Options 5, 6, and 7 were equally the least preferred options because they involve utilizing other unproven technologies. In an effort to reduce the risk associated with these unknown technologies, substantial work has been completed.
- Option 8 is the least preferred option because it involves a pyro-chemical process that has never been demonstrated with Thorium remotely, and because it involves a less developed salt digestion process.

3.6.4.1 Technical Maturity Criterion Baseline:

During the evaluation:

- Figure 14 was developed. The top half of the figure provides the name and number of process steps applicable to each option. The bottom half of the figure provides the TRL score for each process step along with the overall average TRL/step or function.
- Figure 15 was developed. Since the pebble digestion operations were common to all options, except Option 7 which does not have a digestion step and Option 8 which uses a different digestion process, Figure15 provides the TRL scores without the digestion operations common process steps.
- The options were ranked with respect to the Technical Maturity criterion based on data provided in Figure15.
- Figures 14 and 15 do not have data for Option 2-T because they were developed before this option was added to the list of options to be evaluated.

Options	Digest Carbon	Digest SiC	Dissolve Salt	Filter	Precipitate	2nd Filter	Dry Calcine	Crush/Grind	Carbon Burn	Package/Assay	Store	Dissolve Krnls	Solvent Ext	Blndn/Poison	Neutralize	Stabilize	Oxide Conversion	Package/Assay	Vitrify	Melt & Dilute	Can	Assay	Can-in Can	Electroreduce	U Cathode	Electrorefine	U/Th/TRU Cathode	Blend Down	Package/Assay	U/TRU Salt Clean	Cs/Sr Stabilize	Total Steps	
1	1	1	1	1								1		1	1																	7	
2	1	1	1	1								1	1	1	1	1		1														10	
3	1	1	1	1								1	1	1	1		1	1														10	
4	1	1	1	1	1	1	1			1	1	1	1	1	1	1		1														15	
5	1	1	1	1	1	1	1			1	1			1					1			1	1									13	
6	1	1	1	1	1	1	1			1	1			1						1	1	1										13	
7								1	1	1	1	1	1	1	1	1		1														10	
8	1	1	1	1	1	1	1			1	1													1	1	1	1	1	1	1	1	17	
Technical Readiness Level																																	
TRL	4	3	2	2	6	7	8	4	4	9	8	8	9	9	9	9	9	9	4	4	9	9	5	3	3	3	3	9	9	9	9		
																																Total TRL	TRL/Step
1	4	3	2	2	0	0	0	0	0	0	0	7	0	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	5.1
2	4	3	2	2	0	0	0	0	0	0	0	7	9	9	9	9	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	61	6.1
3	4	3	2	2	0	0	0	0	0	0	0	7	9	9	9	0	9	7	0	0	0	0	0	0	0	0	0	0	0	0	0	61	6.1
4	4	3	2	2	6	7	8	0	0	9	8	7	9	9	9	9	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	99	6.6
5	4	3	2	2	6	7	8	0	0	9	8	0	0	9	0	0	0	0	5	0	0	7	5	0	0	0	0	0	0	0	0	75	5.8
6	4	3	2	2	6	7	8	0	0	9	8	0	0	9	0	0	0	0	0	4	9	7	0	0	0	0	0	0	0	0	0	78	6.0
7	0	0	0	0	0	0	0	4	4	9	8	7	9	9	9	9	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	75	7.5
8	4	3	2	2	6	7	8	0	0	9	8	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	9	9	9	8	104	6.1

Figure 14: Technical Maturity with Digester Process Steps

Options	Digest Carbon	Digest SiC	Dissolve Salt	Filter	Precipitate	2nd Filter	Dry Calcine	Crush/Grind	Carbon Burn	Package/Assay	Store	Dissolve Krnls	Solvent Ext	Blndn/Poison	Neutralize	Stabilize	Oxide Conversion	Package/Assay	Vitrify	Melt & Dilute	Can	Assay	Can-in Can	Electroreduce	U Cathode	Electrorefine	U/Th/TRU Cathode	Blend Down	Package/Assay	U/TRU Salt Clean	Cs/Sr Stabilize	Total Steps	
1												1		1	1																	3	
2												1	1	1	1	1		1														6	
3												1	1	1	1		1	1														6	
4					1	1	1			1	1	1	1	1	1	1		1														11	
5					1	1	1			1	1			1					1			1	1									9	
6					1	1	1			1	1			1						1	1	1										9	
7								1	1	1	1	1	1	1	1	1		1														10	
8					1	1	1			1	1													1	1	1	1	1	1	1	1	13	
Technical Readiness Level - without first 4 common steps																																	
																																Total TRL	TRL/Step
1	0	0	0	0	0	0	0	0	0	0	0	5	0	9	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	8.6
2	0	0	0	0	0	0	0	0	0	0	0	5	6	9	9	9	3	8	0	3	0	0	0	0	0	0	0	0	0	0	0	52	8.7
3	0	0	0	0	0	0	0	0	0	0	0	5	6	9	9	3	9	5	3	3	0	0	0	0	0	0	0	0	0	0	0	52	8.7
4	0	0	0	0	4	5	7	2	3	6	5	8	9	9	9	9	3	8	0	3	0	0	0	0	0	0	0	0	0	0	0	90	8.2
5	0	0	0	0	4	5	7	2	3	6	5	3	3	6	0	3	0	0	3	0	0	7	5	0	0	3	2	0	0	0	0	66	7.4
6	0	0	0	0	4	5	7	2	3	6	5	3	3	6	0	3	0	0	0	3	9	5	0	1	3	3	0	0	0	0	0	71	7.9
7	0	0	0	0	0	0	0	3	3	7	7	8	9	9	9	9	3	8	0	3	0	0	0	0	0	0	0	0	0	0	0	77	7.7
8	0	0	0	0	4	5	7	2	3	6	5	3	3	0	0	0	0	0	0	0	0	0	0	3	3	3	3	7	7	7	7	76	5.9

Figure 15: Technical Maturity without Digester Process Steps

3.6.5 Project Risk

Figure 16 shows the rank of the alternatives with respect to the Project Risk criterion.

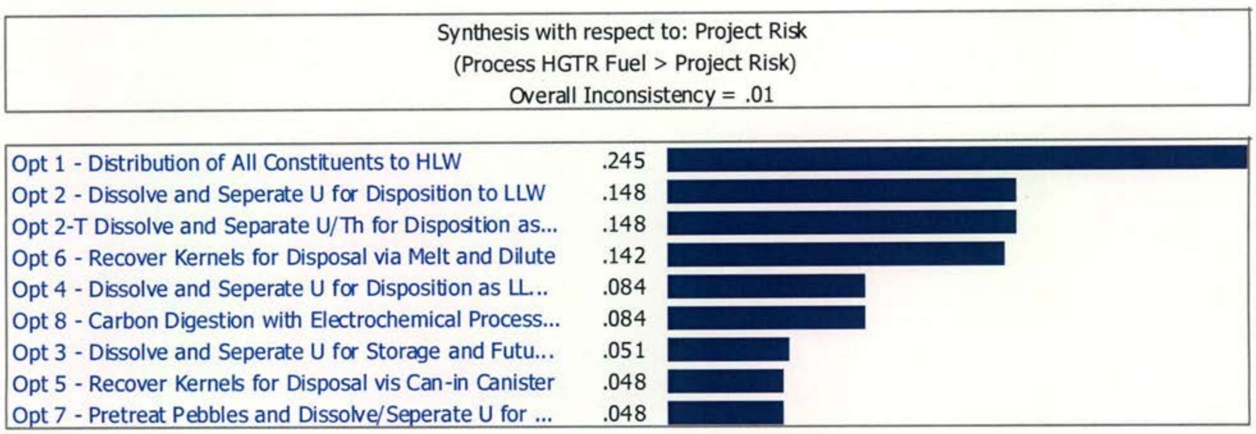

Figure 16: Project Risk Criterion

- Option 1 was the most preferred option because it minimizes the complexity associated with the design and modification of the facilities the best. It also optimizes the use of existing facilities the best.
- Options 2 and 2-T were included with the top three most preferred options because they utilize the same proven H-Canyon processes (e.g., dissolution process). The proposed cementation process has been developed and demonstrated in the Waste Solidification Building as part of another project. Although the proposed grouting process is an additional process, it is not as complex as the less preferred options.
- Option 6 was included with the top 4 most preferred option because of the potential synergy with the use of a previous development program referred to as the “melt and dilute process”. The proposed waste disposition paths uses relatively simply dry storage technology. SRS has extension experience with managing U aluminum alloys.
- Option 4 was moderately preferred because the design and modification scope involves two facilities. This option proposes that the kernel separations process be performed in L-Area (105-L) and the U disposition process be performed in H-Area (H-Canyon). The complexity associated with transferring materials from one area to another also contributed to this option being ranked lower than Options 1, 2, 2-T, and 6.
- Option 8 was included with the least preferred option because it involves a pyro-chemical process that has never been demonstrated with Thorium remotely, and because it involves a less developed salt digestion process. This option was not ranked lower because of the flexibility of the pyro-chemical process to produce waste forms with known disposition paths.
- Option 3 was one of the least preferred options because it produces U for future use versus disposal. At this time, there are no known future uses for this type of U. The U conversion

and packaging processes are more complex than grouting process associated with Options 2 and 2-T.

- Option 5 was one of the least preferred options because it involves a lot more workstations than the other options. It is closely coupled to DWPF operations and would require a lot more lag storage space than the other Options. This Option may impact DWPF operations and would require modifications to the facility. The final waste form may not be accepted by DWPF because the U loading exceeds the 897 g/cm3 disposal limit for HLW glass.
- Option 7 was the least preferred option because it involves thermally decomposing the carbon using a fluidized bed. Although the technology is mature, disposition of ash residues and volatilization of fission products present significant engineering and regulatory challenges not present in other options (e.g., carbon being released from the stack). This option also requires an incinerator. Permitting the incineration would negatively impact the project cost and schedule.

3.6.6 Facility Operations

Figure 17 shows the rank of the options with respect to the Facility Operations criterion.

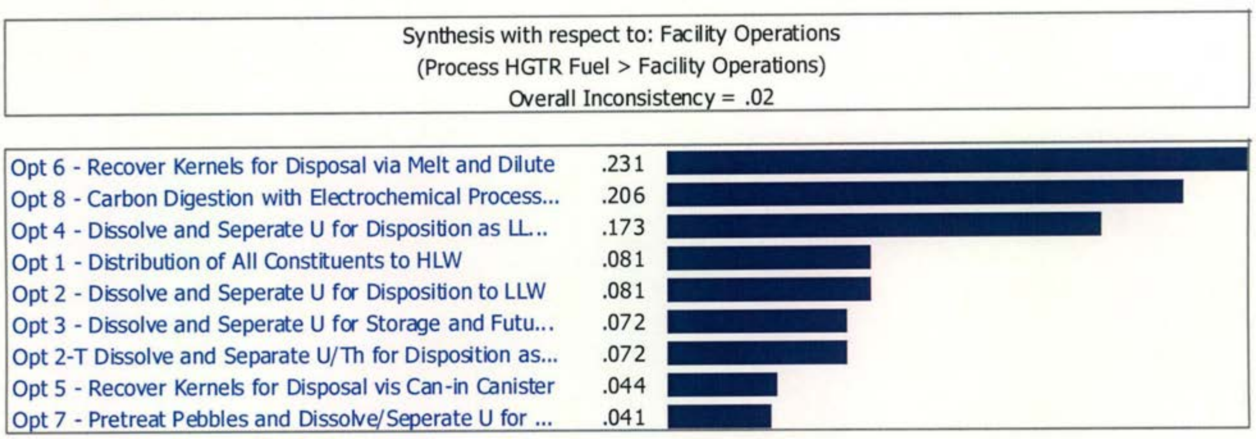

Figure 17: Facility Operations Criterion

- Option 6 was the most preferred because it was assumed that its associated processes would be performed in H-Canyon without impacting the current H-Canyon processes, operating schedule, and/or mission.
- Option 8 was the second most preferred option because it can be performed independent of current H- Canyon processes and mission and it minimizes co-occupancy during installation. Option 6 is more preferred than Option 8 because Option 8 requires unit operations that are different than ones currently used at SRS.
- Option 4 was one of the top three preferred options because it eliminates the co-occupancy and operational issues associated with installing and operating complex new equipment in H-Canyon.

- Options 1, 2, 3, and 2-T were moderately preferred because they significantly impact H-Canyon operations.
- Option 5 was included with the least preferred options because it impacts DWPF and L-Area operations.
- Option 7 was the least preferred options because the process will not completely dissolve Uranium Oxide. This option also has a complex off-gas system that may prove difficult to maintain.

3.6.7 Cost

Figure 18 shows the rank of the options with respect to the Cost criterion. This criterion was defined by the following two metrics: 1) Least capital/project cost and 2) Least operating cost. The rank of the options with respect to each of the metrics is provided in Figures 13 and 14.

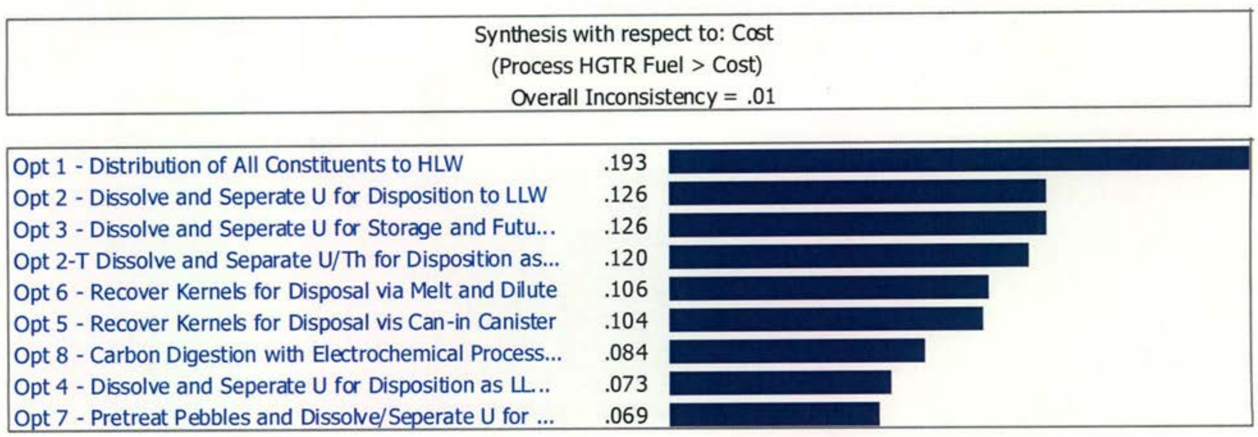

Figure 18: Cost Criterion

3.6.7.1 Cost Metrics Baseline:

During the evaluation:

- The relative cost was estimated by adding the number of required modules, and converting needed infrastructure into equivalent modules (assuming ½ module of equivalent cost for needed infrastructure where not already available, i.e., L-Area). Although the pyro-chemical facility is relatively small, the needed infrastructure would be substantial when compared to a H-Canyon option where the cell and supporting services are already in place.
- The waste volumes provided in Table 8 (Section 3.6.3.1) were used to determine relative waste cost.

3.6.7.2 Cost: Capital/Project Cost

Figure 19 provides the rank of the options with respect to the Capital/Project Cost metric.

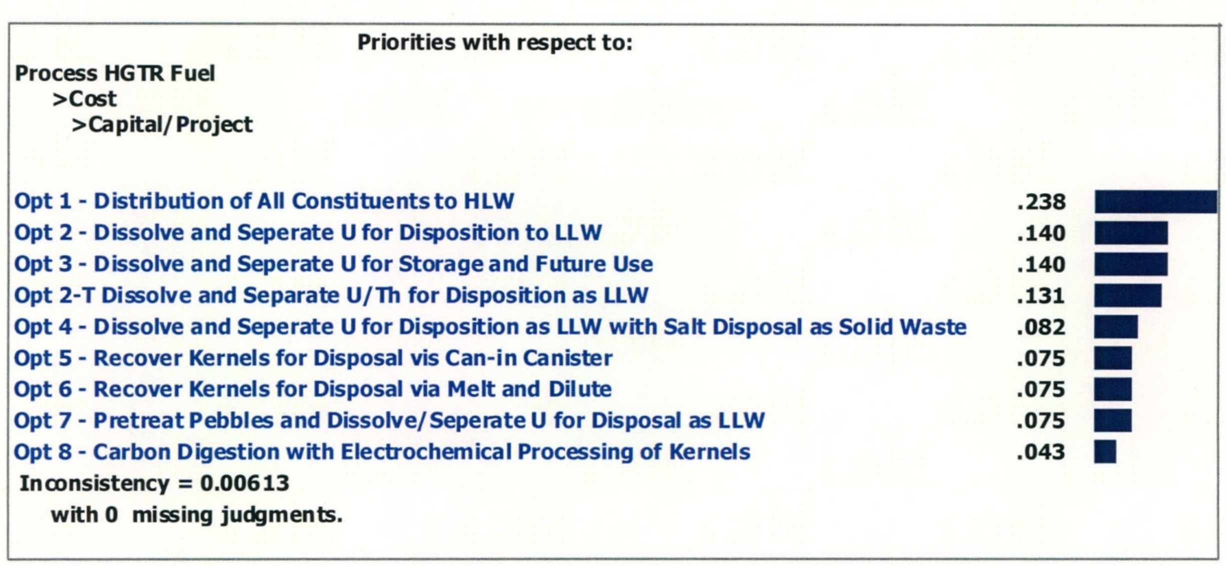

Figure 19: Cost Criterion (Capital/Project Cost metric)

- Option 1 was the most preferred option because it has the least amount of equipment to be installed.
- Options 2, 3, and 2-T were equally preferred and included with the most preferred options because they were similar to Option 1. They were a little less preferred than Option 1because of the additional equipment needed for U conversion.
- Options 4, 5, 6, and 7 were moderately preferred. They were ranked based on the data provided in Table 8 (Section 3.6.3). Option 4 and 7 both require costly capital modifications to L-Area (more work stations/unit operation) than the higher ranking options.
- Option 8 was the least preferred because it is the most expenses option. It requires a new inert Pyro-chemical Facility.

3.6.7.3 Cost: Operating Cost:

Figure 20 provides the rank of the options with respect to the Operating Cost metric.

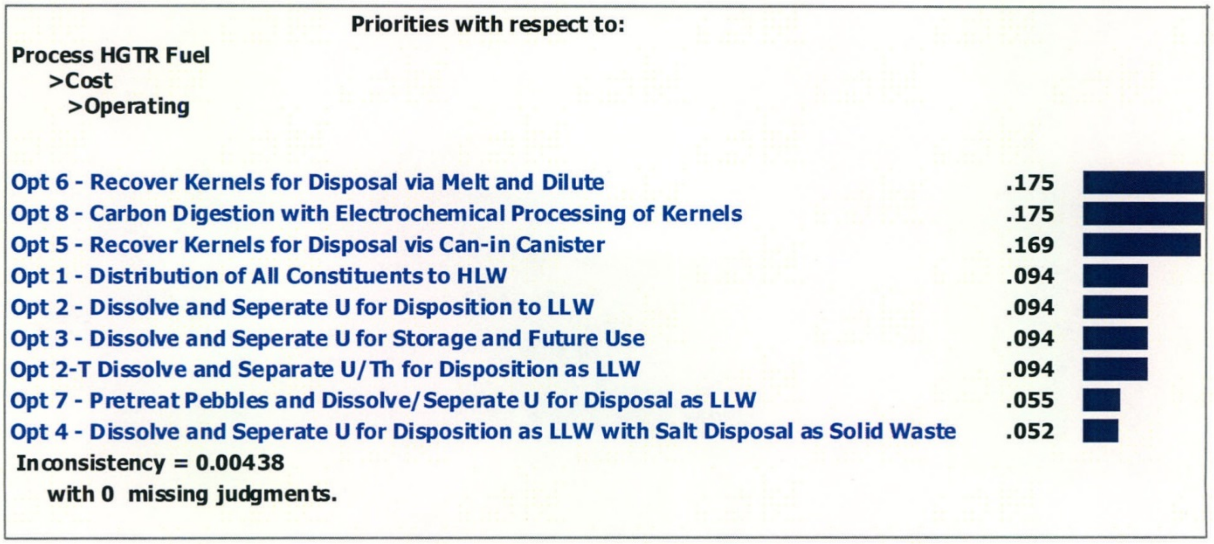

Figure 20: Cost Criterion (Operation) metric

- Options 6, 8, and 5 were equally the most preferred options because they have lower operating cost. They have the potential to avoid the high overheads associated with operating H-Canyon.
- Options 1, 2, 3, and 2-T are equally moderately preferred because they involve routine use of the H-Canyon with some possible overhead cost.
- Options 4 and 7 are the least preferred because they have higher operating costs. Their processes require two areas: Pretreatment in L-Area and Operations in H-Area (H-Canyon)

3.6.8 Safeguards and Security

Figure 21 shows the rank of the options with respect to the Safeguards and Security criterion.

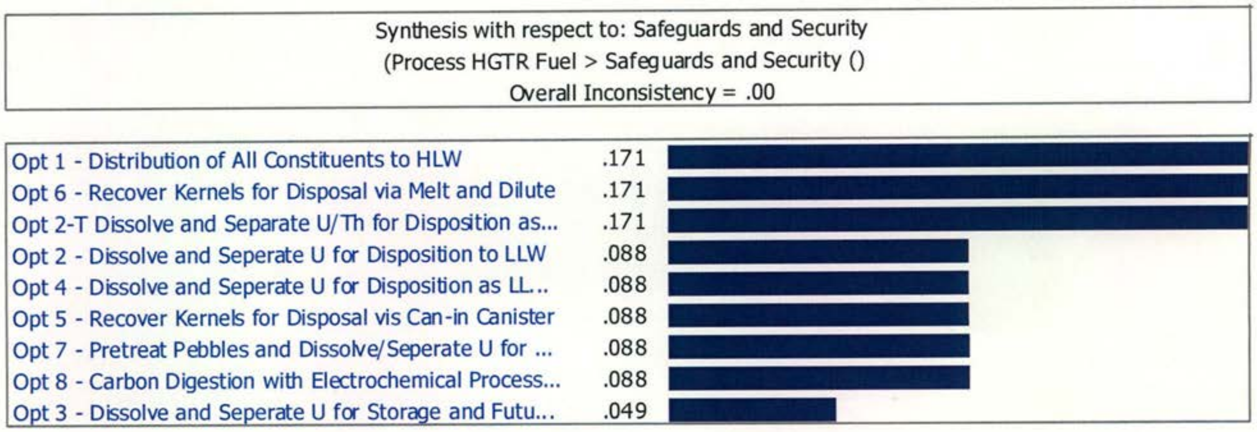

Figure 21: Safeguards and Security Criterion

- Options 1, 6, and 2-T were equally the most preferred options because they do not separate out U. They keep the fission products with U. U separation was considered a proliferation issue. Option 2-T keeps the U and Th together (not a separate U stream).
- Options 4, 5, 7 and 8 were equally least preferred because the U stream would be separated out and made into a LLW form.
- Option 3 was the least preferred because it generates a purified U product requiring continuing S&S measures.

3.6.9 SNM and Waste Stay Time

Figure 22 shows the rank of the options with respect to SNM and Waste Stay Time criterion. This criterion was defined by the following two metrics: 1) Potential for Off-site Disposal 2) Objectionable. The rank of the options with respect to each of the metrics is provided in Figures 23 and 24.

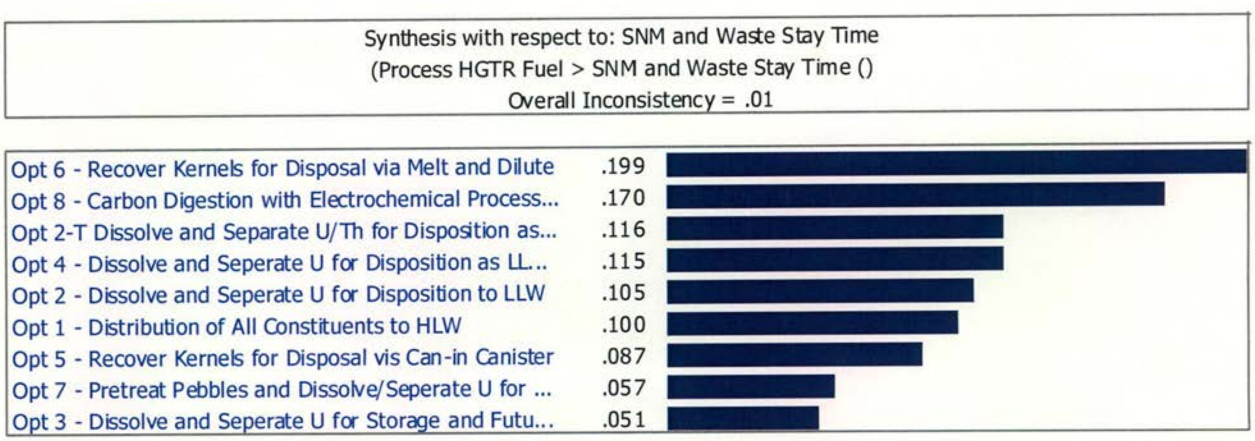

Figure 22: SNM and Waste Stay Time Criterion

3.6.9.1 SNM and Waste Stay Time Time: Potential for Off-site Disposal

Figure 23 provides the rank of the options with respect to the Potential for Off-site Disposal metric.

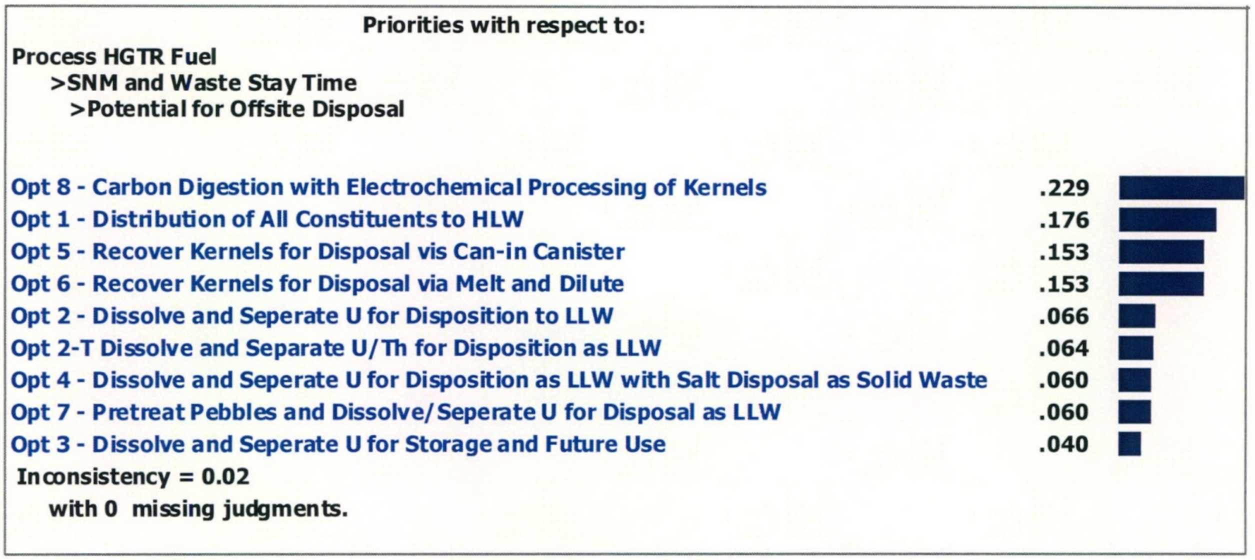

Figure 23: SNM and Waste Time (Potential for Off-site Disposal) Metric

- Option 8 was the most preferred option because it produces a small amount of HLW, and the pyro-chemical process is highly flexible in its ability to produce waste forms compatible with emerging disposal paths.
- Option 1 was the second most preferred because it produces a lower volume of HLW than the other less preferred options and the waste has existing disposal pathways.
- Options 5 and 6 were included with the most preferred options because they produce waste volumes that are lower than the least preferred options. The volumes are not as low as Options 1 and 8. Its waste form is not as established as Options 8 and 1.
- Although it is feasible to dispose of Option 2 and 2-T, 4, and 7 at SRS, it may not be desirable because of the long term leach-ability of U. Shipment off-site is feasible but may prove to be problematic due to the quantity of shipments and stakeholders acceptances.
- Option 3 was the least desirable because there is no known use for the U material.

3.6.9.2 SNM and Waste Stay Time: Objectionable

Figure 24 provides the rank of the options with respect to the Objectionable metric

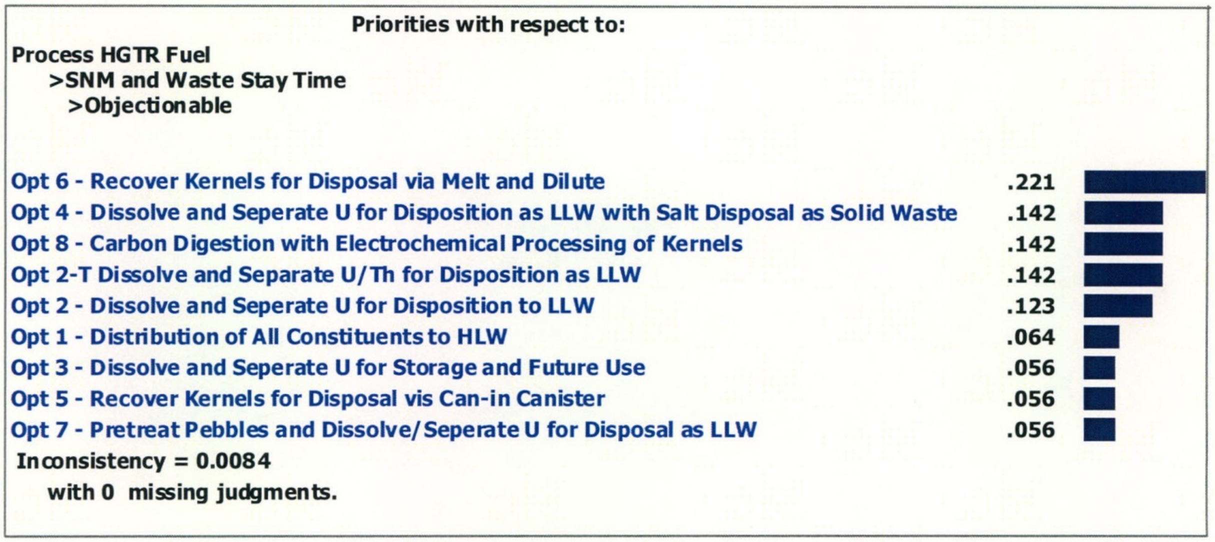

Figure 24 SNM and Waste Stay Time (Objectionable) Metric

- Option 6 was the most preferred options because it doesn't separate U from fission products and it produces waste forms which are consistent with existing L-Area waste forms. It does not impact H-Canyon, DWPF or HLW Systems process. The potential synergy with the use of a previous development program referred to as the "melt and dilute process".
- Option 8 moderately preferred because it minimizes the impacts on the HLW systems and provides useful capability.
- Options 4 and 2-T are moderately preferred because they provide continued use of H-Canyon and potential for future missions.
- Option 1 was less preferred than options 2, 2-T and 4 because it generates more canisters and because it requires blending over a large number of sludge batches.
- Option 3 was included with the three least preferred options because the process separates out a pure U stream. The pure U stream could be viewed as a proliferation risk.
- Option 5 was included with the three least preferred options because it could have a significant impact on DWPF. It would require handling large number of canisters. It would also require modifications to DWPF and associated shutdowns to make modifications.
- Option 7 was the least preferred option because of the concern that many stakeholders have about incineration.

3.6.10 Schedule

Figure 25 shows the rank of the options with respect to the Schedule criterion. This criterion was defined by the following two metrics: 1) Project Schedule and 2) Process Schedule. The rank of the options with respect to each of the metrics is provided in Figures 26 and 27.

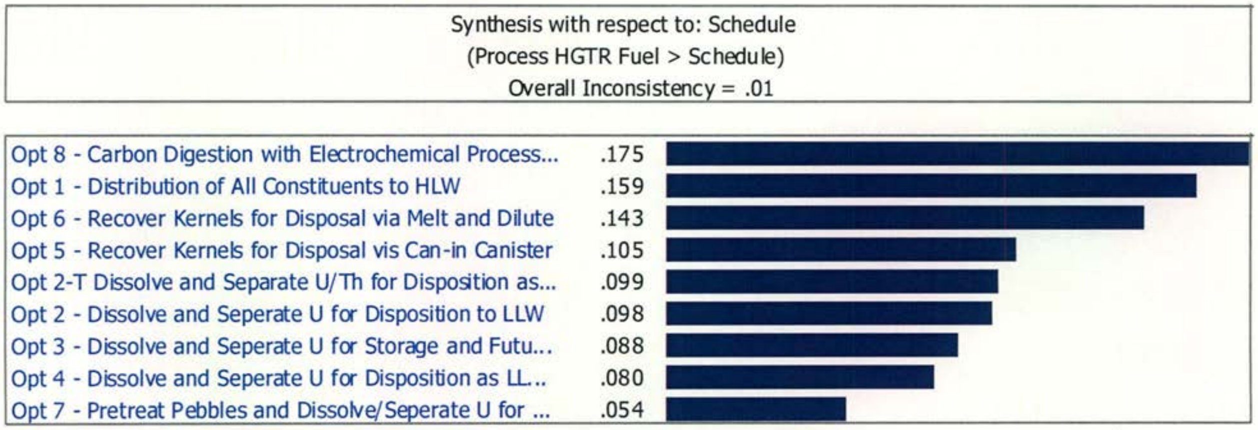

Figure 25: Schedule Criterion.

3.6.10.1 Project Schedule

Figure 26 provides the rank of the options with respect to the Project Schedule metric.

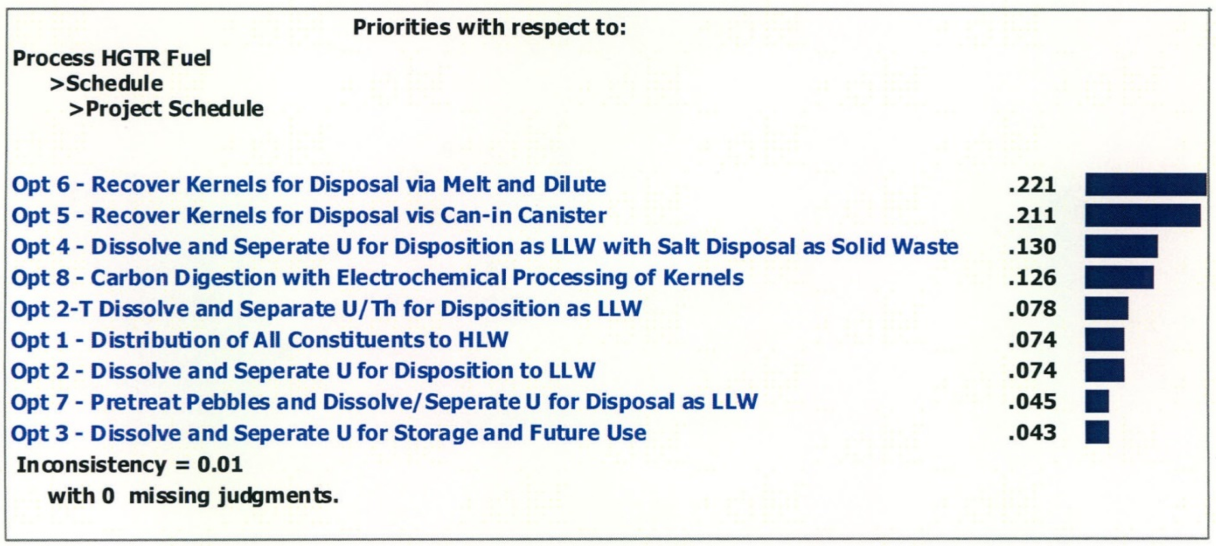

Figure 26: Project Schedule Metric

- Options 6 and 5 were the most preferred option because they can be done in L-Area without impacting H-Area co-occupancy concerns.
- Options 4 and 8 were not as preferred as Option 6 and 5 because they will require minor modifications in the H-Canyon. Option 8 requires an inert facility which may take longer than Options 5 & 6.
- Options 2-T, 1, and 2 were moderately preferred because they require installing complex modifications in H-Canyon during operations.

- Options 7 and 3 were the least preferred options because in addition to requiring installation of complex modifications in H-Canyon during operations, the also require additional unit operations.

3.6.10.2 Process Schedule:

Figure 27 provides the rank of the options with respect to the Process Schedule metric.

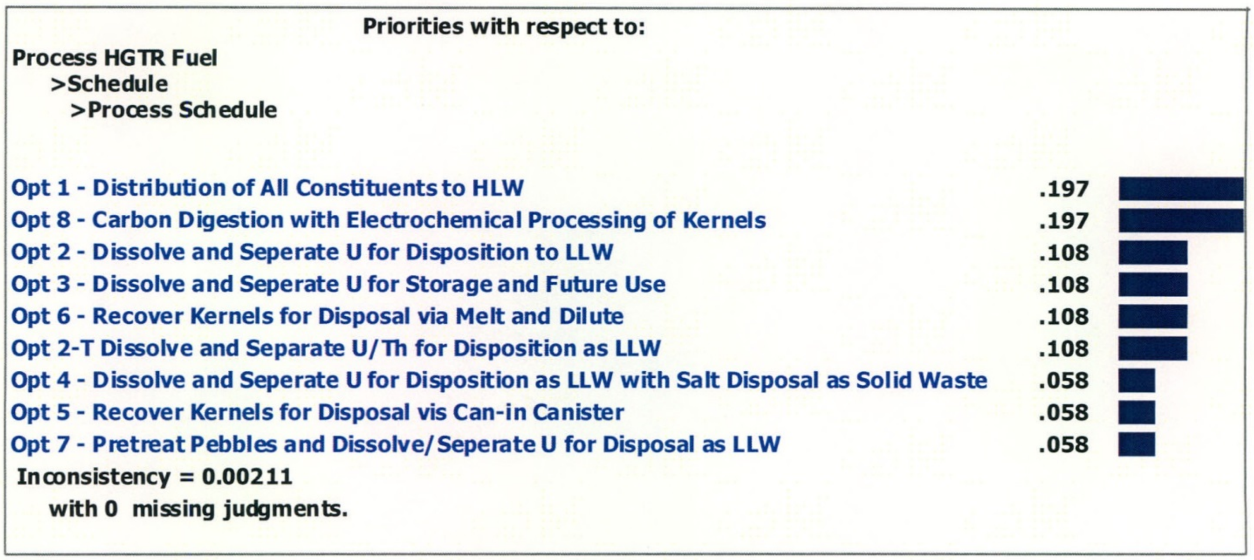

Figure 27: Process Schedule Metric.

- Option 1 was the most preferred option because it has the least number of unit operations.
- Option 8 was equally most preferred as Option 1 because it has the least potential interference with other existing processing.
- Options 2, 3, 6 and 2T were equally less preferred than Options 1 and 8 because they require more unit operations.
- Option 4 is included with the three least preferred options because it utilized two facilities and would require additional time for inter-area transfer of materials.
- Option 5 is included with the three least preferred options because of the potential impact with DWPF.
- Option 7 is the least preferred option because it may result in incomplete and troublesome removal of Carbon from the kernels during the Dissolution Process.

3.7 SENSITIVITY ANALYSIS

An evaluation is considered robust (not sensitive) if up to 10% changes in weights in either direction does not change the position of the highest ranking option. The results of the sensitivity analyses indicated that this evaluation was robust because none of the top 3 options preference changed when the criteria weights were increased or decreased by up to 10%.

However, the results of the sensitivity analyses did show a change in the rank of Option 6 (4th Ranked) and Option 3 (5th Ranked) weights when the environmental permitting criterion was increased by +10%. The results of increasing the environmental permitting criterion by +10% (from 20.9% to 23.8%) are shown in Figures 28 and 29.

Figure 28 shows the original ranking of Option 6 (11.8%) and Option 3 (11.4%) when the original environmental criteria weight was 20.9%.

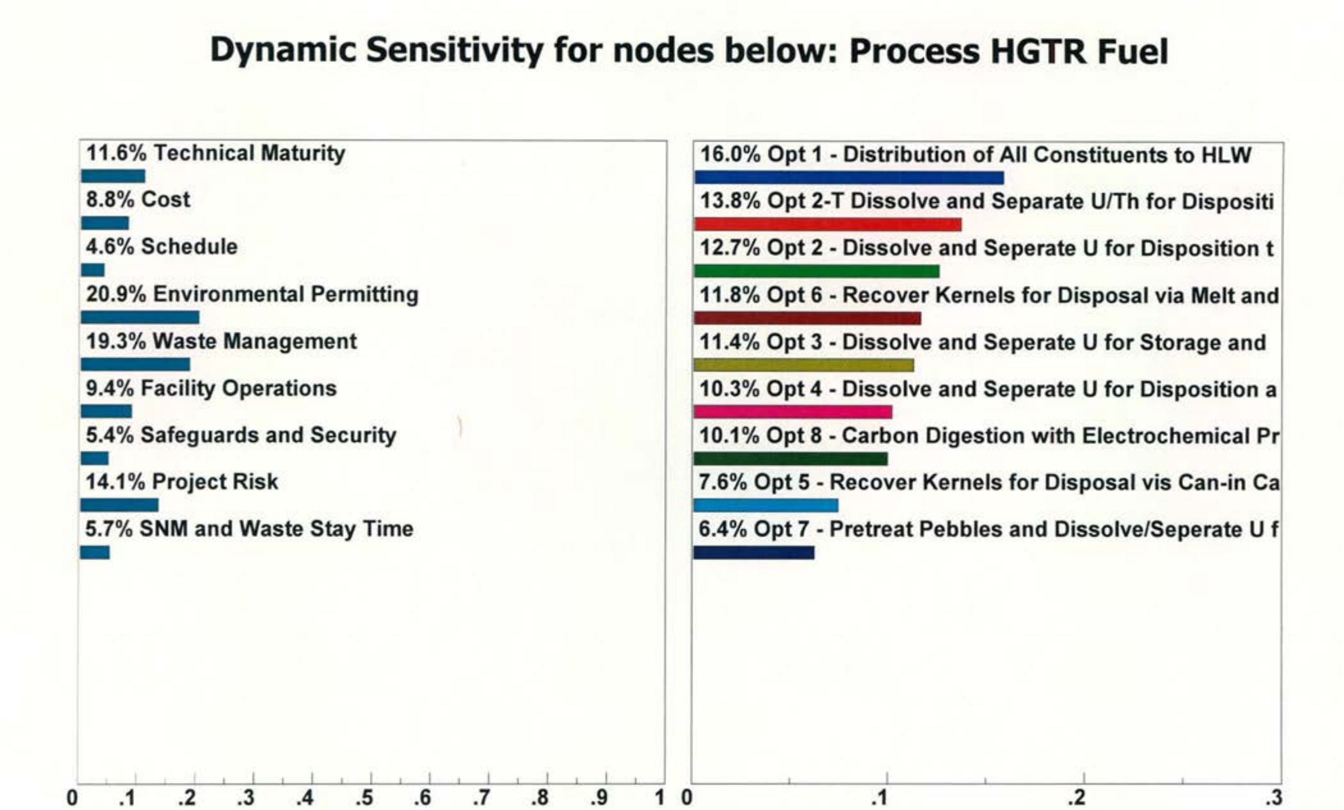

Figure 28: Sensitivity Results - Baseline

Figure 29 shows the changes in Option 6 (4th Ranked) and Option 3 (5th Ranked) weights when the environmental permitting criterion was increased by +10% to 23.8%. Option 6 and Option 3 weights became equal (11.6%).

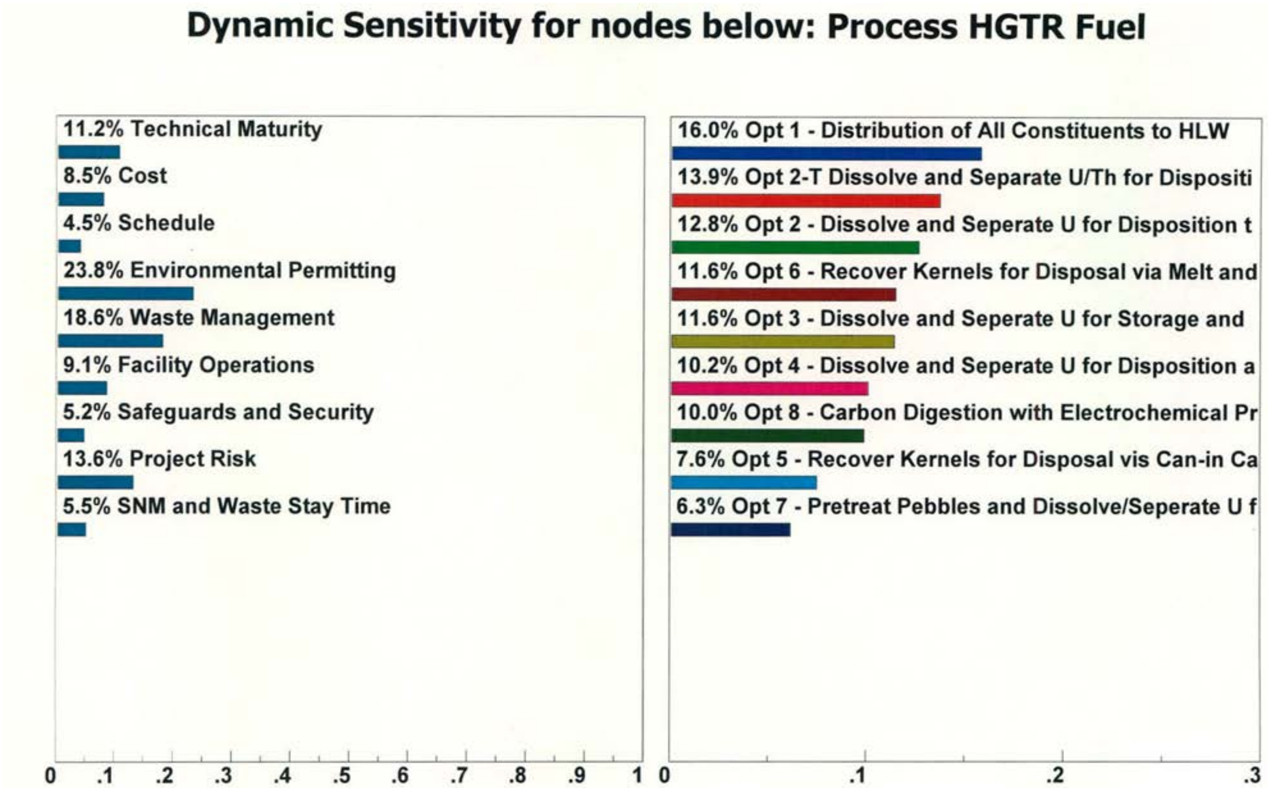

Figure 29: Sensitivity Results – Increased Environmental Criteria Weight.

4. CONCLUSION

Figure 30 provides the result of the Alternative Evaluations. The data shows a minor break between the top three most preferred options (1, 2-T, and 2) and the 4th most preferred option (6). Option 6 was included with option 1, 2-T and 2 as the most preferred options for completion. Option 6 is the only one of the top four options with the proposed process located in an L-Area (105-L Facility) versus the H-Area (H-Canyon).

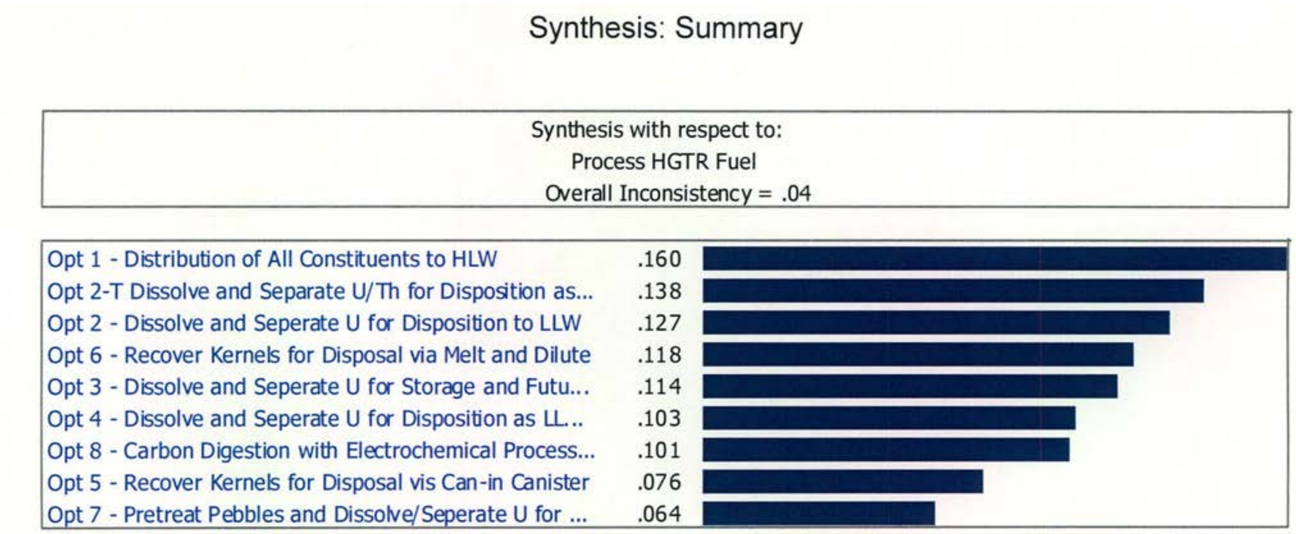

Figure 30: Alternative Evaluation Results - Conclusion

- Options 1, 2T, and 2 were the most preferred options because they all involve implementation in an existing, operating facility (H Canyon) with supporting infrastructure (utilities, ventilation, environmental monitoring).

  For Option 1, an assumption was made that the high level waste stream could be managed in the Tank Farm to allow blending with existing waste and to minimize the incremental number of HLW canisters produced. The production and disposal of HLW canisters resulting from direct conversion of the HTGR liquid waste (containing substantial quantities of thorium and down blended uranium) without blending was considered during the evaluation.

  Options 2T and 2 eliminate the major actinides from the high level waste, reducing the impact on the HLW disposal systems. Implementation of these options assumes that the E-Area Performance Assessment can be modified to allow disposal of the LLW streams that could be generated by these processes.

- Options 6 is the 4th most preferred option because of the potential synergy with the use of a previous program referred to as the “melt and dilute process”. Implementation in L- Area eliminates co-occupancy issues with construction and operations in an existing facility.

- Option 3 has advantages similar to Options 1, 2T, and 2, but was less preferred because it requires: (1) a new LEU conversion process, (2) uranium packaging, and (3) storage. The lack of an identified end-use for the material also contributed to this option being less preferred.

- Option 4 provides the uranium separation for waste disposal benefits as described in option 2, but it utilizes L Area for processing the kernels. By using L-Area for the front-end of the process, the processing schedule would be accelerated and some co-occupancy issues would be eliminated. However, this option was moderately preferred with respect to the other options because it requires inter-area shipments of kernels, salt, and liquid waste. This option would also require operations and support staffing for two facilities.
- Option 5 "can in canister" vitrification and can handling operations were deemed to be more compatible with the proposed 105-L facility layout than with the H-Canyon facility layout. Therefore, during the evaluation, it was assumed that all of the unit operations would be performed in 105-L. This option was included with the three least preferred options because it would difficult to construct and operate the large number of unit operations, and provide the lag storage space for the kernels, glass cans, and loaded DWPF canisters.

The seven options discussed above all share the graphite digestion and kernel recovery process currently under development. Options 8 and 7 are based on alternate technologies, and were considered to balance the technology risk inherent in a new process.

- Option 8 uses electrochemical technology to sequentially separate carbon and then actinides from fission products in a salt matrix; the process is completely dry. However, this option was included with the least preferred options because of the metallic TRU waste form that would be produced by actinide recovery, and the glass waste that would be produced from spent salt processing.
- Option 7 was the least preferred option because it thermally decomposing the carbon using a fluidized bed. Although the technology is mature, disposition of ash residues and volatilization of fission products present significant engineering and regulatory challenges not present in other options.

5. REFERENES

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 –RP-2014-00184 "*Report on Feasibility and Alternatives for Receipt, Storage and Processing of HTGR Pebble Fuel at SRS"* , Revision 0 (Draft), September 2014
3. SRNS-U1000-2014-00156, *"The Savannah River M&O Contract No. DE-AC09-08SR22470; Deliverables of Work For Others Agreement (WFO)-WFO-13-021"*, August 6, 2014
4. SRNL-TR-2014-00291, *Report on Feasibility and Alternatives for Receipt, Storage and Processing of HTGR Pebble Fuel at SRS", Appendix A: High Level Objectives, Functions, and Requirements Document* (WFO Task 1), Revision 0 (Draft), September 2014.
5. SRNL –TR-2014-00214 – Down-selection to Nine Options for Processing of HTGR Pebble Fuel at SRS – Revision 0 (Draft), September 2014.

A-1. Alternatives Description

A "brainstormed" list of potential alternatives is documented in Reference 5. This "brainstormed" list was condensed into the nine credible options listed in Table A-1 for development and evaluation. The bases for their selection included historical experience, assumptions on salt regeneration or reuse, off gas treatment requirements, chemical compatibility, treatment requirements for waste streams, and volume of waste produced. As these options were developed, minor modifications were identified and incorporated to improve material recovery, reduce cycle time, or minimize waste. The advantages and disadvantages associated with each alternative are discussed in Section A-2. This section describes the nine options.

Table A-1: Alternatives (Options)

Alternative Number	Alternative Name	Alternative Description
1	Distribution of All Constituents to HLW	Digest pebbles and dissolve kernels and salt for direct disposal to the HLW system
2	Dissolve and Separate U for Disposition to LLW	Digest pebbles, dissolve kernels and salt, separate and blend-down uranium as LLW grout, and dispose of salt, Th, and fission products to the HLW system
2-T	Dissolve and Separate U/Th for Disposition as LLW	Digest pebbles, dissolve kernels and salt, separate and blend-down U and Th as LLW grout, and dispose of salt and fission products to the HLW system
3	Dissolve and Separate U for Storage and Future Use	Digest pebbles, dissolve kernels and salt, separate and blend-down U to oxide for reuse, and dispose of salt, Th, and fission products to the HLW system
4	Dissolve and Separate U for Disposition as LLW with Salt Disposal as Solid Waste	Same as option 2 but do pretreatment in L-Area
5	Recover Kernels and Disposal via Can in Canister	Digest pebbles, blend-down and vitrify kernels for can-in-canisters disposal as HLW glass, and process salt for direct disposal to Saltstone
6	Recover Kernels for Disposal via Melt and Dilute	Digest pebbles, and melt-dilute kernels for dry storage pending disposal with SNF , and process salt for direct disposal to Saltstone
7	Pretreat Pebbles and Dissolve/Separate U for Disposal as LLW	Grind pebbles and burn carbon, dissolve kernels, separate and blend-down uranium as LLW grout, and dispose of offgas salt, Th, and fission products to the HLW system

Alternative Number	Alternative Name	Alternative Description
8	Carbon Digestion with Electrochemical Processing of Kernels	Pyro-chemically digest pebbles, separate U, Pu, Th as TRU waste, and dispose of Cs/Sr and salt as ceramic HLW

<u>Option 1. Disposition of All Constituents via High Level Waste System (Figure A-1)</u>

This option transfers the CASTOR cask from storage to H Canyon, where the inner cans are removed and transferred to an unloading station. The cans are opened, and the pebbles are transferred to the digester for carbon and (where necessary) SiC removal (b)(3)(4) Off gas from the digester is treated to remove Cs, Sr, and entrained salt.

After digestion is complete, the salt is decanted and the kernels, containing a small amount of salt, are drained into a can designed for storage or insertion in the 10-well canyon dissolver insert for dissolution. The salt is regenerated(b)(3)(4), allowing the salt to be reused. The decant step includes filtration of the salt, with the collected solids flushed back into the digester with the salt. (Spent salt that can no longer be regenerated is drained into a can designed for immersion into a washing vessel for salt dissolution.) The filtrate, containing up to 12% of the U and residual quantities of minor actinides, is combined with the dissolver solution and blended with sufficient quantities of poisons (or depleted uranium) to meet liquid waste acceptance criteria. The down blended solution is neutralized and transferred to the waste tanks, using existing waste transfer infrastructure, for processing into HLW glass and saltstone.

Process areas utilized to support this option include the Hot Shop or Swimming Pool (section 3H, 4H) for can opening and fuel unloading, and a major portion of at least one process cell (5H) for carbon digestion equipment. Existing canyon equipment (dissolvers, waste evaporators) will be used for kernel processing. Kernel processing could be concurrent with kernel recovery, or deferred to a separate campaign by providing interim storage (in a canyon cell) for the separated kernels.

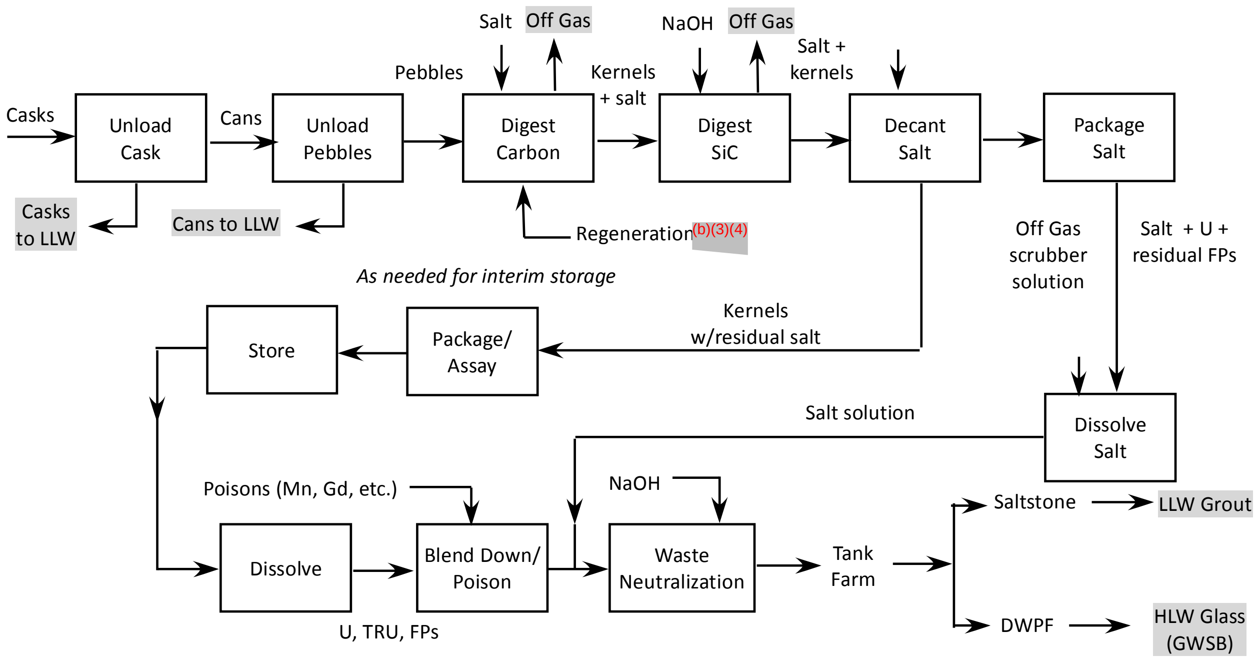

Figure A-1 Option 1 Block Flow Diagram

<u>Option 2. Dissolve and Separate Uranium for Disposition as Low Level Waste</u>

This option receives and processes the fuel pebbles for dissolution as described for option 1. In this option, the dissolver solution is adjusted and fed to solvent extraction for separation and purification of the uranium to meet low level waste acceptance criteria. The product uranium solution is down blended to < 10% fissile (^{233}U + ^{235}U) with DU solution, and poisons (e.g. Gd) are added to increase the allowable package loading. The resultant solution is then mixed with grout in a stainless steel vessel. After curing, the vessel is placed in a CASTOR cask for onsite or offsite disposal.

This option requires a supply of DU solution for blending, using existing equipment provided for the LEU (Can't use existing due to U233 contain) lend down program using natural uranium. It also requires a new facility and equipment for uranium solution grouting.

<u>Option 2T. Dissolve and Separate Uranium and Thorium for Disposition as Low Level Waste</u>

This option is similar to option 2, but recovers both the uranium and the thorium for grouting and disposal as low level waste.

<u>Option 3. Dissolve and Separate Uranium for Reuse</u>

This option is the same as Option #2, with the exception that the recovered uranium is down blended to LEU, converted to an oxide, and packaged for storage pending reuse. New equipment will be required for conversion of the uranium solution to oxide and packaging of the oxide product. Pad storage within a Limited Area boundary is adequate for this material (Attractiveness Level E).

Option 4. Dissolve and Separate Uranium for Disposition as Low Level Waste

This option uses the same process functions as option 2; however, the front end activities, up through kernel packaging, are performed in L-Area to allow for accelerated construction and startup. This option requires packaging and transfer of the kernels, spent salt, and liquid waste to H Area for disposition. Because of the cost and complexity of interarea liquid waste shipments, the volume of liquid waste must be minimized. Implementation of this option requires a minimum salt regeneration ratio of 10:1.

Areas of Building 105-L used to implement this option include the stack area for cask unloading, and the Purification Wing for installation of process equipment. This area contains process cells serviced by an overhead crane, with equipment operated and maintained remotely. The cells are configured for standard jumper connections using Hanford connectors.

Option 5. Recover Kernels for Disposal via Can-in-Canister (Figure A-2)

Receipt, unloading, and front-end processing of the fuel in this option is the same as for Option #1, again using L Area as a basis for implementation. In this option, the separated kernels will be size-reduced and combined with frit to produce a glass form. Because of the low tolerance for sodium, the kernel separation is achieved by dissolution of the salt after digestion. The kernels are dried and packaged for storage to de-couple the front-end from vitrification; the salt solution is combined with off-gas scrubber solution, filtered, and transferred via trailer to H Area for disposition as high level waste. Alternatively, the salt filtrate could be treated (similar to the Salt Waste Processing Facility process) for removal of fission products and actinides, and transferred via trailer for disposal as saltstone. The same restrictions imposed on option 4 for liquid waste generation are applicable for this option.

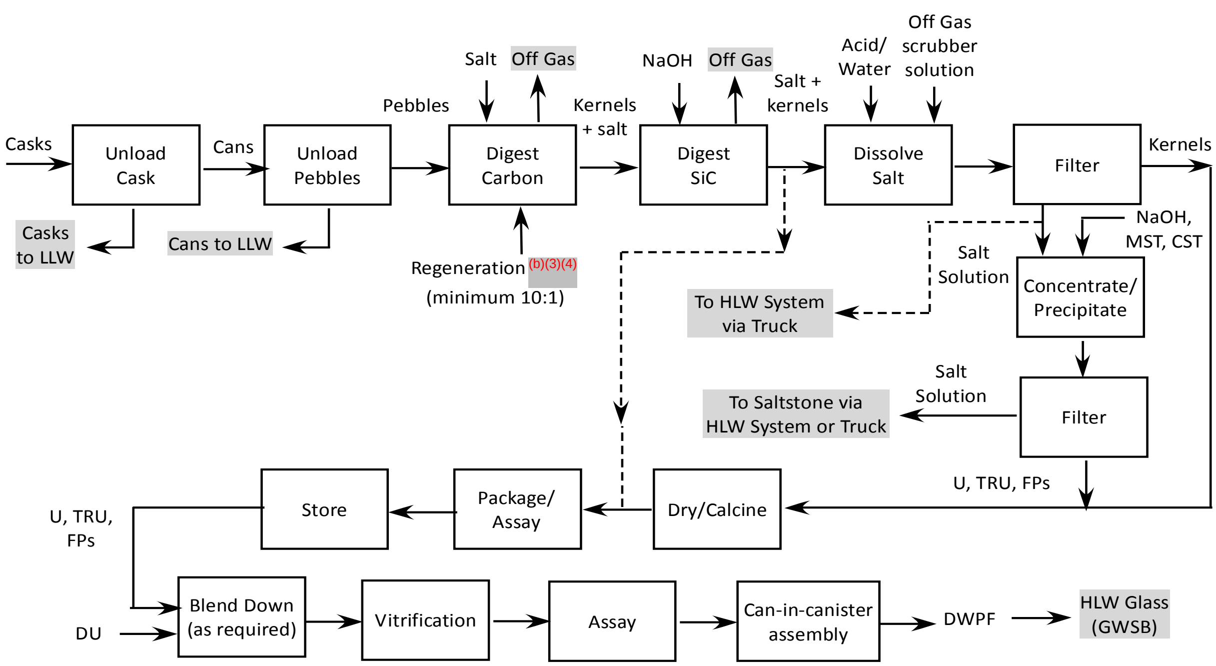

Figure A-2   Option 5 Block Flow Diagram

Option 6. Recover Kernels for Disposal via Melt and Dilute

This option provides for graphite digestion, kernel recovery, salt treatment, and liquid waste disposition as described for option 5. For the melt and dilute process (Adams 2000), the dried kernels are blended with DU, NU, or LEU if required to satisfy safeguards requirements, then combined with aluminum and magnesium metal to produce an alloy that is cast into an ingot. The ingots (4” diameter x 28” high) can be loaded into canisters that can be processed (dried, inerted, welded) and placed in a pad-mounted dry storage cask as previously proposed for L-Basin fuel (SRNL 2012). Alternatively, the ingots can be placed in an L-bundle for storage in L-Basin. Because of the reliance on interarea shipments for liquid waste disposition, the same restrictions imposed on option 4 for liquid waste generation are applicable for this option.

Option 7. Pretreat Pebbles and Dissolve/Separate U for Disposition as Low Level Waste (Figure A-3)

This option provides gross removal of the carbon matrix via thermal decomposition in a fluidized bed (Del Cul 2002, Spencer 2004). The kernels, containing small amounts of carbon, are transferred to the H Canyon dissolver, and processed in a manner described in option #2 The solution from kernel dissolution is adjusted for feeding to solvent extraction, where the uranium is separated, and the thorium, transuranics, and fission products are rejected to waste. The uranium is blended with sufficient poisons or depleted uranium to meet low level waste acceptance criteria, then stabilized by mixing with grout. The waste stream from solvent extraction is processed through the existing liquid waste treatment infrastructure for disposition as HLW glass and saltstone.

This option uses H Canyon for implementation due to need for dissolution and uranium separation. Uranium blend down and grouting equipment will be required.

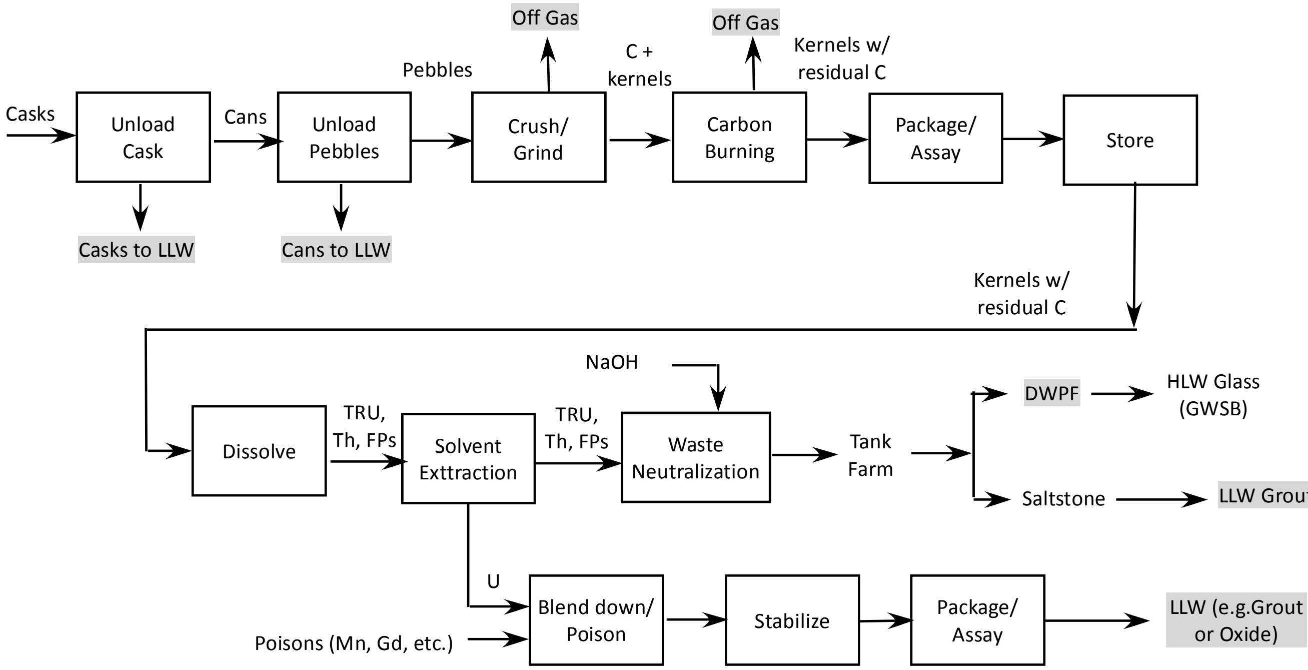

Figure A-3 Option 7 Block Flow Diagram

<u>Option 8. Carbon Digestion with Electrochemical Processing of Kernels (Figure A-4)</u>

This option uses a chloride-based salt for all the operations, even for carbon digestion. Initially, the pebbles are charged to a basket, where the carbon is oxidized in a lithium oxide/lithium chloride salt to form lithium carbonate. The carbon is removed from the salt by electroreduction to elemental carbon, and deposited on a cathode.

The basket containing the kernels is then transferred to an electroreducer, where the oxides are converted to metallic form. Finally, the impure metal undergoes electrorefining, in which the uranium and thorium, along with transuranic minor actinides are sequentially oxidized and reduced to metal at the cathode. After distillation of the salt, the uranium mixture is down blended to meet safeguards termination limits, and packaged for disposal as transuranic waste. The fission products and noble metals remain in the salt phase. Salt cleanup is achieved by absorption on zeolite, which is then converted to a glass-bonded sodalite ceramic high level waste form.

This option is more amenable to implementation in L Area because the electrochemical process is chloride-based, and requires an inert atmosphere due to the presence of the molten chloride salts and metallic waste forms.

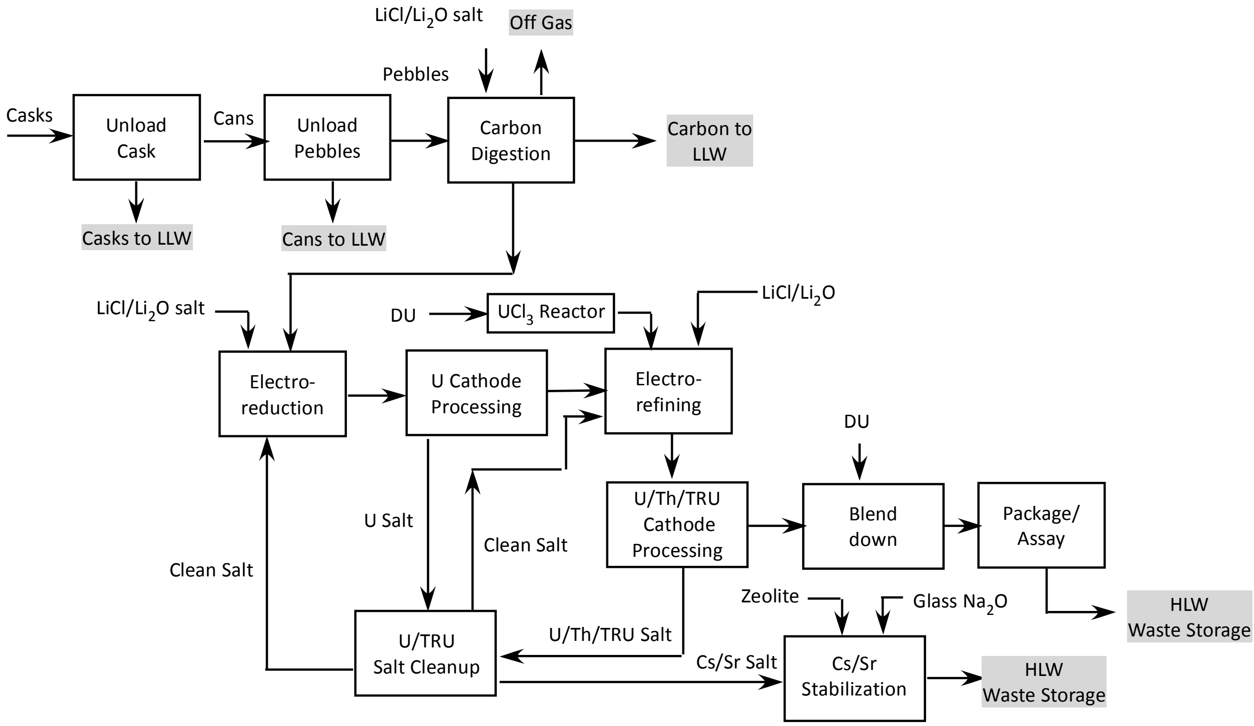

Figure A-4 Option 8 Block Flow Diagram

A-2. Alternatives Advantages/Disadvantages

Table A-2 Alternatives Advantages/Disadvantages

Nos.	Alternative	Pros/Advantages	Cons/Disadvantages
1	All Constituents to HLW	• Proven backend process • H Canyon has established active confinement • Processing in one location • Likely the least capital cost • Interim storage optional not required • Doesn't use solvent extraction (fewer process steps) • Canyon has established off-gas system • Could have less impact on canyon missions/schedule • May be able to stay within existing 897 g Fissile limit/ cu meter for DWPF glass.	• Most HLW canisters • Thorium disposal concerns • Most HLW generation • Most impact to HLW • Non typical canyon operations
2	Dissolve and Separate U for Disposition as LLW. Disposition of U (grout) to LLW	• Proven backend process including separations • Less HLW • H-Canyon has established active confinement • Processing in one location • Less capital cost than option 3 • Re-use CASTOR cask • Interim storage optional not required • Less canisters than Option 1 but more than Option 2T • Canyon has established off- gas system • May be able to stay within existing 897 g Fissile limit/ cu meter for DWPF glass.	• Non typical canyon operations • Need grouting line • U LLW form is not now within PA –requires rev. • Shallow land disposal will result in leaching higher than HLW. Note: U would remain in SC. • Offsite disposal may be required – water table issues (trans. of waste, other state involvement). • Have to demonstrate grout matrix for this form • Would require NCSE 1kg/can (may require dependents on poisons).

Nos.	Alternative	Pros/Advantages	Cons/Disadvantages
2T	Dissolve and Separate U/Th for Disposition as LLW. Disposition of U/Th (grout) to LLW	• Proven backend process including separations • Less HLW • H-canyon has established active confinement • Processing in one location • Less capital cost than option 3 • Re-use CASTOR cask • Interim storage optional not required • U/Th has lower attractiveness concern. This would remain as a Cat. D. • Least HLW canisters • Canyon has established off-gas system • May be able to stay within existing 897 g Fissile limit/ cu meter for DWPF glass.	• Non typical canyon operations • Need grouting line • U/Th LLW form is not now within PA –requires rev. • Shallow land disposal will result in leaching higher than HLW. Note: U would remain in SC. • Offsite disposal may be required – water table issues (trans. Of waste, other state involvement). • May require new equipment 2nd Th cycle • Have to demonstrate grout matrix for this form • Would require NCSE 1kg/canister • Would require NCSE 1kg/can (may require dependents on poisons).
3	Dissolve and Separate U for future use	• Proven backend process including separations • Less HLW • H-Canyon has established active confinement • Processing in one location • Re-use CASTOR cask • Less canisters than Option 1 but more than Option 2T • Canyon has established off-gas system • May be able to stay within existing 897 g Fissile limit/ cu meter for DWPF glass.	• More capital cost (requires oxide capability). • Non typical canyon operations • Need oxide conversion line • Would require NCSE 1kg/can • Extended storage of U • Increase the attractiveness level • Higher operating costs • Higher long term storage costs • May require long term storage • No currently planned future use (e.g. stays in SC)

Nos.	Alternative	Pros/Advantages	Cons/Disadvantages
~~3a~~	~~Using Direct~~ (b)(3)(4)	OPTION DELETED DURING THE ADVANTAGES/DISADVANTAGES DISCUSSION - *Will use (b)(3)(4) as a bounding case for Opt. 3 • ~~Avoids HB Line operating cost~~ • ~~Well established process~~ • ~~Oakridge proven process – real U at these capacities~~ • ~~Equipment available~~ • (b)(3), (4) • ~~Canyon has established off gas system~~	• ~~Availability of equipment~~ • ~~Not designed for remote operation~~ • ~~Cost – capital investment required~~ • ~~No future vendor identified (currently)~~ • ~~Non typical Canyon operations~~
~~3b~~	~~Using HB Line~~	OPTION DELETED DURING THE ADVANTAGES/DISADVANTAGES DISCUSSION - *Will use (b)(3)(4) as a bounding case for Opt. 3 • ~~HB Line previously done~~ • ~~Could be less capital costs~~ • ~~May not need a concentration step~~	• ~~Concentration step needed~~ • ~~More radiation exposure~~ • ~~New shielded transfer container~~ • ~~New can out capability~~ • ~~Requires 2 facilities vs 1~~ • ~~Stored in S&S environment~~ • ~~No future vendor identified~~ • ~~Non typical canyon operations~~

Nos.	Alternative	Pros/Advantages	Cons/Disadvantages
4	Same as Option 2, but with separate lower capacity front end	• Proven backend process including separations • Less HL • H-canyon has established active confinement • Processing in one location • Less capital cost than option 3 • Re-use CASTOR cask • Less canisters than Option 1 but more than Option 2T • Canyon has established off- gas system • May be able to stay within existing 897 g Fissile limit/ cu meter for DWPF glass. • Spread operating costs out over longer period • May have higher capital costs than Option 2 (if in separate facilities). • Have more flexibility in remote handling (design). • Could have lower contamination risks during construction work. • May have lower mission impact	• Non typical canyon operations • Need grouting line • U LLW form is not now within PA –requires rev. • Shallow land disposal will result in leaching higher than HLW. Note: U would remain in SC. • Offsite disposal may be required – water table issues (trans. of waste, other state involvement). • Have to demonstrate grout matrix for this form • Would require NCSE 1kg/can (may require dependents on poisons). • Could require separate facility • More process steps than Option 2 • More onsite shipments • Interim storage is required • Locations other than H-Canyon don't have liquid handling capability. • May require active ventilation and more extensive off gas treatment (no sand filter).
	Dry Options		

Nos.	Alternative	Pros/Advantages	Cons/Disadvantages
5	Can -in- Canister	• Of all the options that create a new HLW form, implementation is easier due to proven process. • India has done work with putting TH in glass using a small scaled melter. Well established concept. • Previously evaluated by SRNL • ~~Relative to option 1, there would be less DWPF Canisters~~ • Less HLW waste volume • Number of canisters is less than Options 1, but more than Options 2-4. • Could potentially minimizing canyon time and impact • Potential allows decoupling from H-Canyon • Both Opt 5&6 reduce co-occupancy to existing facilities	• Need to change HLW form-requires qualification • Requires DWPF modification –possible mission impact. • Higher capital costs than Options 1-4 • Higher technical/project risks than Options 1-4 • Will require numerous DWPF canisters (handling/processing). • Installation of a new melter is a complex challenge. • Would exceed 2.5 kg fissile/ cu meters of glass. • Glass form would not be as tolerant for sodium as silicon borate – would require higher kernel to salt ratios. • May have unresolved S&S issues. • Locations other than H-Canyon don't have liquid handling capability. • May require active ventilation and more extensive off gas treatment (no sand filter). • Permitting issues – no history outside of H-Canyon • Additional permitting issues may be required for Canyon processing. • May generate respirable fines during grinding of kernels. • Some grinding of kernels is necessary • Transport of liquid onsite

Nos.	Alternative	Pros/Advantages	Cons/Disadvantages
6	Melt and Dilute	• Previously been evaluated through NEPA process at SRS. • Melt and dilute form bounded in repository license application. • Oxide fuels were bounded in the repository license application. • Previously evaluated by SRNL and ARGONNE – demonstrated at mini-plate level. • Temp would be lower than the glass melting process • Demonstrated retention and lab strategy for collection of Cs in Zeolite. This could be included in the melt so the Cs would be incorporated. • Relative to option 1, there would be less SNF Canisters than DWPF canisters in Opt. 1. • Totally decouples HLW from DWPF • Potential allows decoupling from H-Canyon • Both this option and option 5 reduces co-occupancy to existing facilities. • Aluminum alloy melting is a much simpler option than Opt. 5 vitrification. • Have a design concept and strategy • Can use LEU and existing SNF as dilution	• A new waste unloading facility and permitting issues • Need to change HLW form-requires qualification • Spent fuel may not be exactly like previously evaluated • Some development would be required to demonstrate the reduction of Cesium and Strontium into the metal. • May require some Zeolite at end to be disposed • Higher capital costs than Options 1-4 • Higher technical/project risks than Options 1-4 • Will require numerous DWPF canisters (handling/processing). • ~~Installation of a new melter is a complex challenge.~~ • (b)(3)(4) • May have unresolved S&S issues. • Locations other than H-Canyon don't have liquid handling capability. • May require active ventilation and more extensive off gas treatment (no sand filter). • Permitting issues – no history outside of H-Canyon • Additional permitting issues may be required for Canyon processing. • Some grinding of kernels may be necessary • Transport of liquid onsite • Add dry storage capability – would require demonstration

Nos.	Alternative	Pros/Advantages	Cons/Disadvantages
7	Crush, Grind and Burn Options	• This process been extensively evaluated • Been operated at pilot scale • This would less high LLW on paper – less salt • Extensive equipment design available	• Considered incineration – Carbon burning (Regulatory Issues). • Kernels more difficult to dissolve – carbon removal isn't complete. • Pilot work for this project was unsuccessful • High stakeholder issues – German experience not good • This results in high carbon heels (fission products) • This process has substantial off gas issues that haven't been resolved. • Grinding of the kernels has proven difficult on equip. • Finely divided carbon safety issues
8	Pyro-chemical	• Would be a small footprint process – continuous process • Could be located outside H- Canyon. • Minimal volume of HLW (liquid and canister wastes) • Tech. has been partially demonstrated under SunShot and LDR • ARGONNE has developed engineered equipment for remote cell for some operations. • Less off gas and carbon captured as a solid • Carbon 14 not released to atmosphere • Less CO2 released to atmosphere • Flexibility of process could partition in different way to make it compatible with other waste streams. • The Lithium Chloride process is a well-established commercial process.	• Require new inert hot cell • Requires new HLW form. Note: some similarity with HLW glass. • Digestion process with chloride not developed as well as NaNO3. • Remote handled TRU waste form would need to be validated. • Little development work done with Th. • Passes through metal state (S&S issues) • Some aux. operations would require development