APPENDIX A: SCOPE OF THE REPORT

CRESP Evaluation of Management Options for Calcined HLW at INEEL

Objectives:

1. Develop a framework for comparative life-cycle risk evaluation of management options for ultimate disposition of the calcined high level waste stored in bin sets at INEEL.

2. Describe the primary activities, processes and their relationships that are necessary to carry out each of the proposed management options.

3. Identify the major sources of risks, data gaps and uncertainties for each of the primary processes or activities necessary to carry out each of the proposed management options.

4. Identify prior analyses at INEEL or other sites that serve as analogues or prior experience that can serve as a basis for relative comparison of hazards or risks, and provide a qualitative or semi-quantitative characterization of such risks. Characterization of risks will include consideration of expert opinion based on team and other experience, and relative ranking of risks.

This evaluation will not include quantification of risks or recommendations on the preferred waste management approach. Rather the purpose of the document is to serve as technical input for open further discussion and evaluation of the management options. Future discussion needs to include input from the public to the decision making responsible parties and consideration of costs and public policy.

The management options to be considered are:

1. (a) retrieval of the calcined waste, (b) repackaging of waste without modification of chemical or physical form, (c) on-site or off-site interim storage of the repackaged waste, (d) shipment to a HLW geologic repository, (e) internment in a HLW geologic repository.

2. (a) retrieval of the calcined waste, (b) processing (e.g., vitrification or separations) of the calcined waste (c) on-site or off-site interim storage of the processed waste, (d) shipment to a HLW geologic repository, (e) internment in a HLW geologic repository.

With management options (1) and (2) above, the following is to be considered:

A. Retrieval of the calcined waste may be initiated either (i) in the short-term time frame, as soon as practical (i.e., within 10-50 years, independent of availability of a geologic repository and associated waste acceptance criteria), (ii) in the intermediate-term time frame, (assuming a geologic repository, associated waste acceptance criteria and acceptance schedule are defined allowing “just in time” processing; e.g., after 50 years), (iii) in the long-term time frame (assuming a 90% reduction in the specific activity of the calcined wastes; e.g., after 300 years). The stated ranges of time frames are for general classification purposes only. Actual time dependence of risk will depend on when various decisions are made and actual processes occur.

B. Interim storage after waste retrieval may occur either (i) on-site at INEEL, or (ii) off-site at a location independent of the location of final disposition. On-site interim storage would incur 1 set of handling and transportation considerations. Off-site interim storage would incur 2 sets of handling and transportation considerations. Interim storage may be either for either for a brief period (e.g., less than 5 years) if final waste acceptance criteria, location and schedule are defined, or an extended period (e.g., 50 years) if the final disposition pathway is not defined prior to retrieval.

3. (a) continued storage of the calcined waste in the bin sets for the period that allows for contact handling instead of remote handling based on sufficient radioactive decay (ca. 300 yrs) with appropriate site improvements and security, (b) re-evaluation of waste recovery and disposal options.

For each management option identified above, the report will contain:

1. A management flow diagram of major activities, decisions and processes necessary to achieve each option.
2. A material flow diagram that identifies the major processes that incur risk to human health or the environment. Associated conceptual site models for each process step will be included as an appendix.
3. A table listing the primary failure modes and hazards or sources of risk associated with each major process step. This will also identify the populations at risk (e.g.., workers, local public, off-site public) for each of the associated hazards or risks.
4. A table listing the primary data gaps and uncertainties associated with the evaluation of risk for each major process step, based on current information.
5. The available basis and approach for estimating risks associated with each major process step.
6. In appendices, (a) work breakdown structure for each major process step, (b) conceptual site models for each major process step associated with the material flow diagrams (item 2 above).
7. Document will be 10-20 pages of text plus tables and figures identified above, appendices identified above and 2 page executive summary.

The following pages are example tables to illustrate the presentation of information in the report.

NOTE: CRESP has not yet made determinations and therefore risk levels included in the table below are for example purposes only. Actual classifications will be an outcome from our analysis over the next few weeks.

Table 1. Overall classification of risk for different calcine waste management options as a function of the time frame of achieving final waste disposition. Ranges of time frames are for general classification purposes only. Actual time dependence of risk will depend on when various decisions are made and actual processes occur.

	Time Frame		
Overall Risk	**Short-term[1]**	**Intermediate-term[2]**	**Long-term[3]**
High	①		
Medium	②	①②	
Low		③	①②③
Not applicable	③		

① Store in current bin sets/Retrieve/Package/Store/Ship calcined waste to national geologic repository

② Store in current bin sets/Retrieve/<u>Process</u>/Package/Store/Ship calcined waste to national geologic repository

③ Store in current bin sets for extended period/Manage calcined waste in Bin Sets/Reevaluate final disposition options

[1]The **short-term time frame** (< 50 years) analysis assumes that retrieval and subsequent operations are initiated during a period prior to licensing, construction and operation of a national geologic repository and waste acceptance criteria for final internment may not be available.

[2]The **intermediate-term time frame** (50 – 300 years) analysis assumes the availability of waste acceptance criteria, a geologic repository (possibly with waste acceptance and management experience) and an internment schedule that allows “just in time” processing prior to shipment; there will be some (small) reduction in activity through degradation; improved process technology could emerge as well.

[3]The **long-term time frame** (> 300 years) analysis assumes radioactive decay facilitates reduced material handling requirements (e.g., contact vs non-contact handling due to radioactive activity) and perhaps the development and implementation of improved process technology.

DRAFT

Table 2a. Process Risk Analysis for a Short-term Time Frame (< 50 years) [1]

Process	**What can go wrong?**	**How likely is it to occur?**	**What are the consequences?**	**Impacted Population(s)**	**Risk Evaluation Basis**	**Information Gaps**	**Contribution of Process Step to Risk** (Small, Intermediate, Large)
Bin Set Storage							
Characterization[2]							
Retrieval							
Processing							
Packaging							
Interim Storage[3]							
Shipping[3]							
Internment							

[1] The **short time frame** analysis assumes that retrieval and subsequent operations are initiated during a period prior to licensing, construction and operation of a national geologic repository and waste acceptance criteria for final internment may not be available.

[2] This process includes preliminary characterization prior to retrieval and more extensive characterization during retrieval.

[3] Interim storage may be on-site or off-site; off-site storage would require two (2) shipments and associated handling.

DRAFT

Table 2b. Process Risk Analysis for an Intermediate-term Time Frame (50 to 300 yrs) [1]

Process	**What can go wrong?**	**How likely is it to occur?**	**What are the consequences?**	**Impacted Population(s)**	**Risk Evaluation Basis**	**Information Gaps**	**Contribution of Process Step to Risk** (Small, Intermediate, Large)
Bin Set Storage							
Characterization[2]							
Retrieval							
Processing							
Packaging							
Interim Storage[3]							
Shipping[3]							
Internment							

[1] The **intermediate time frame** analysis assumes the availability of waste acceptance criteria, a geologic repository (possibly with waste acceptance and management experience) and an internment schedule that allows "just in time" processing prior to shipment; there will be some (small) reduction in activity through degradation; improved process technology could emerge as well.

[2] This process includes preliminary characterization prior to retrieval and more extensive characterization during retrieval.

[3] Interim storage may be on-site or off-site; off-site storage would require two (2) shipments and associated handling.

Table 2c. Process Risk Analysis for a Long-term Time Frame (>300 yrs) [1]

Process	**What can go wrong?**	**How likely is it to occur?**	**What are the consequences?**	**Impacted Population(s)**	**Risk Evaluation Basis**	**Information Gaps**	**Contribution of Process Step to Risk** (Small, Intermediate, Large)
Bin Set Storage							
Characterization[2]							
Retrieval							
Processing							
Packaging							
Interim Storage[3]							
Shipping[3]							
Internment							

[1]The **long-term time frame** analysis assumes radioactive decay facilitates reduced material handling requirements (e.g., contact vs non-contact handling due to radioactive activity) and perhaps the development and implementation of improved process technology.

[2]This process includes preliminary characterization prior to retrieval and more extensive characterization during retrieval.

[3]Interim storage may be on-site or off-site; off-site storage would require two (2) shipments and associated handling.

Hazard Analysis

Recognition of system hazards and relative consequences is key to both qualitative and quantitative risk assessment. This section divides the three alternatives under consideration into major process steps and component risks for each time frame considered. Major potential failure events are identified and the associated consequences for each event are categorized. This evaluation is derived from the Failure Modes and Effects Analysis (FMEA) technique that is frequently used in qualitative hazard assessment in industry and government. For this evaluation, "Risk-based Decision-making Guidelines," Chapter 7 of Volume 3 of the US Coast Guard guidance manual (http://www.uscg.mil/hq/gm/risk/e-guidlines/rbdm/html/vol3/07/v3-07-cont.htm) was used as a basis document. The complete nine step process includes: defining the system of interest; defining the problems of interest; choosing the type of FMEA approach; subdividing the system by functions for analysis; identifying potential failure modes for elements of the system; evaluating potential failure modes capable of producing accidents; performing a quantitative evaluation (if possible or necessary); transitioning the analysis to a higher level of resolution (if useful); and using the results in decision making. FMEA provides a logical, step-wise framework to comparatively evaluate the major processes involved in each alternative disposition of the calcined HLW powder.

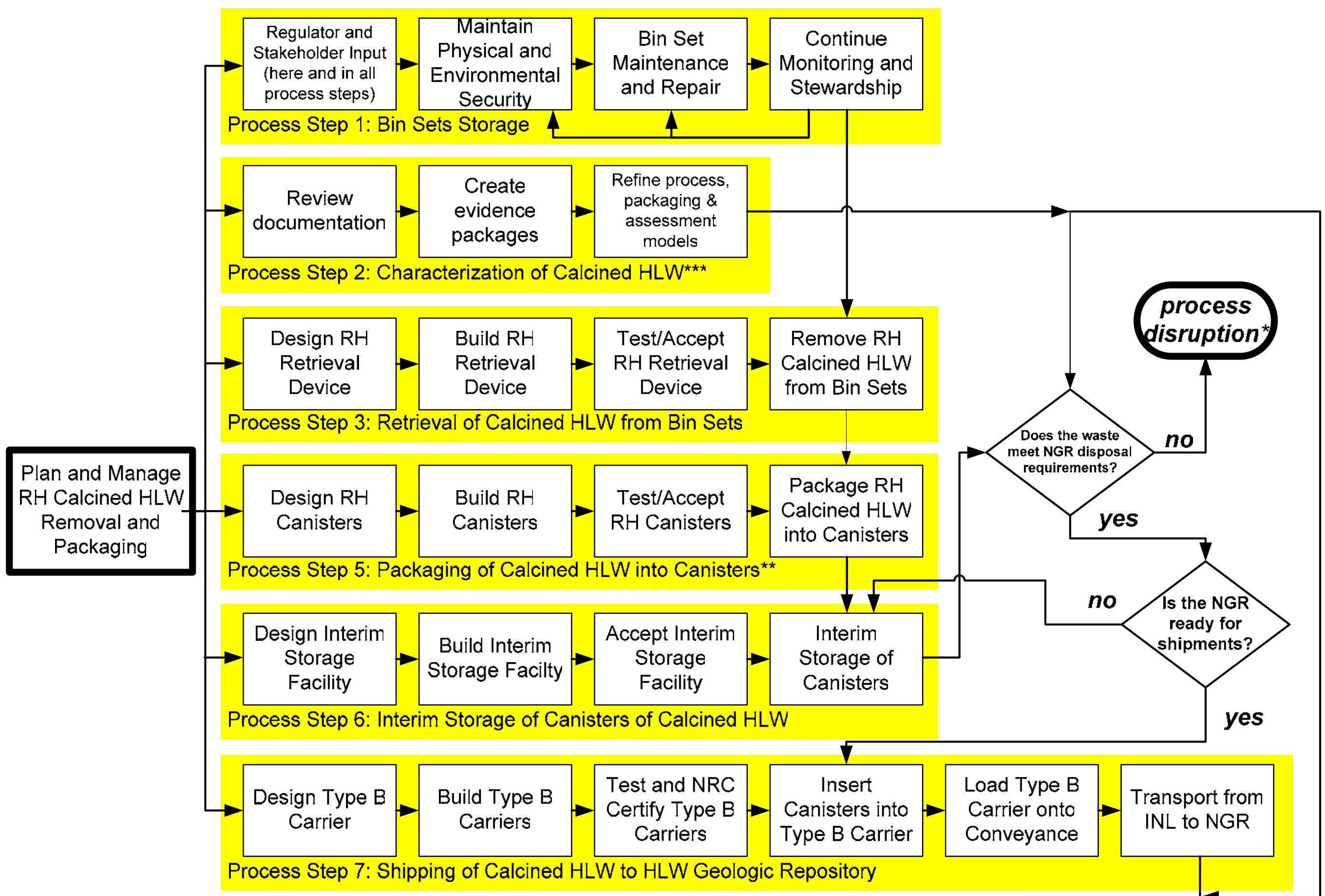
The following page is an example of how the compiled hazard analysis for each process step and evaluation time frame would be presented. These tables would be an appendix to the primary document, providing the basis for summary risk characterization.

Table A. Hazard Evaluation for Process Steps during Short-term Time Frame Analysis.
Process steps evaluated are: Store in current bin sets/Retrieve/Process/Package/Store/Ship calcined waste to national geologic repository

1.0 Storage of calcine waste in existing bin sets (Storage in Current Bin Sets)							
Task	**Task Frequency**	**What can go wrong?** (Failure Mode Event Example; radiological and non-radiological incidents)	**How likely is it?** (Event probability)	**What is the severity of the consequences?**	**Who is the impacted population?**	**Risk evaluation basis**	**Contribution to overall process step risk**
1.1.1 Routine monitoring and inspections	High	A maintenance worker slips on icy metal steps and falls while on-route to replace chart paper in a Bin Set.	Low	Worker Injury Worker Death	On-site workers	Current bin set maintenance history	small
1.1.2 Routine maintenance	Moderate	CAM (air monitoring unit) cart tips over during servicing in a Bin Set.	Low	Worker Injury Worker Death Radiation Dose	On-site workers	Current bin set maintenance history	small
1.1.3 Non-routine maintenance	Low	Bin Sets normally operate under atmospheric pressure, but can operate under negative pressure, if necessary. Contaminated HEPA filter is dropped during replacement.	Low	Worker Injury Worker Death Radiation Dose Radiation Uptake	On-site workers	Current bin set maintenance history	intermediate
1.1.4 Repair or replacement	Low	To correct an erosion problem, during excavation and replacement of fill in the berm surrounding a Bin Set, a worker breeches a fill pipe trench releasing small amount of powdered residue.	Moderate	Worker Injury Worker Death Radiation Dose Radiation Uptake	On-site workers Off-site population	Current bin set maintenance history	intermediate

APPENDIX B: MANAGEMENT FLOW DIAGRAMS

LIST OF FIGURES



**A process disruption could result in increased interim storage, repackaging and/or reprocessing to meet site requirements, or other potential setbacks*

***Process Step 4: Processing.... is not applicable to this Alternative*

****also input to Process Steps 3-7*

Figure B-1. Management flow diagram for Alternative 1 (Retrieve/Package/Ship) for Time Frame A (Near Term)

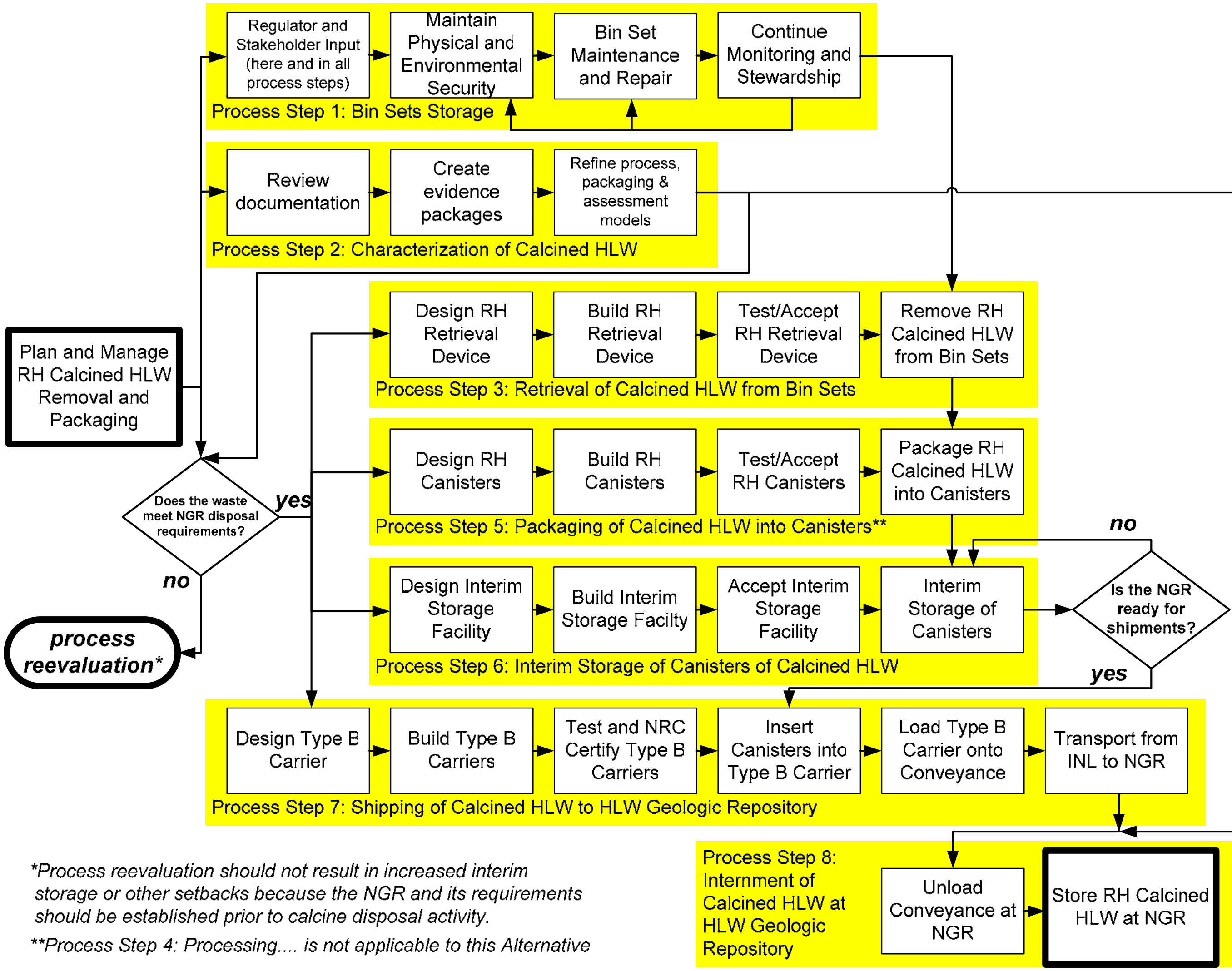
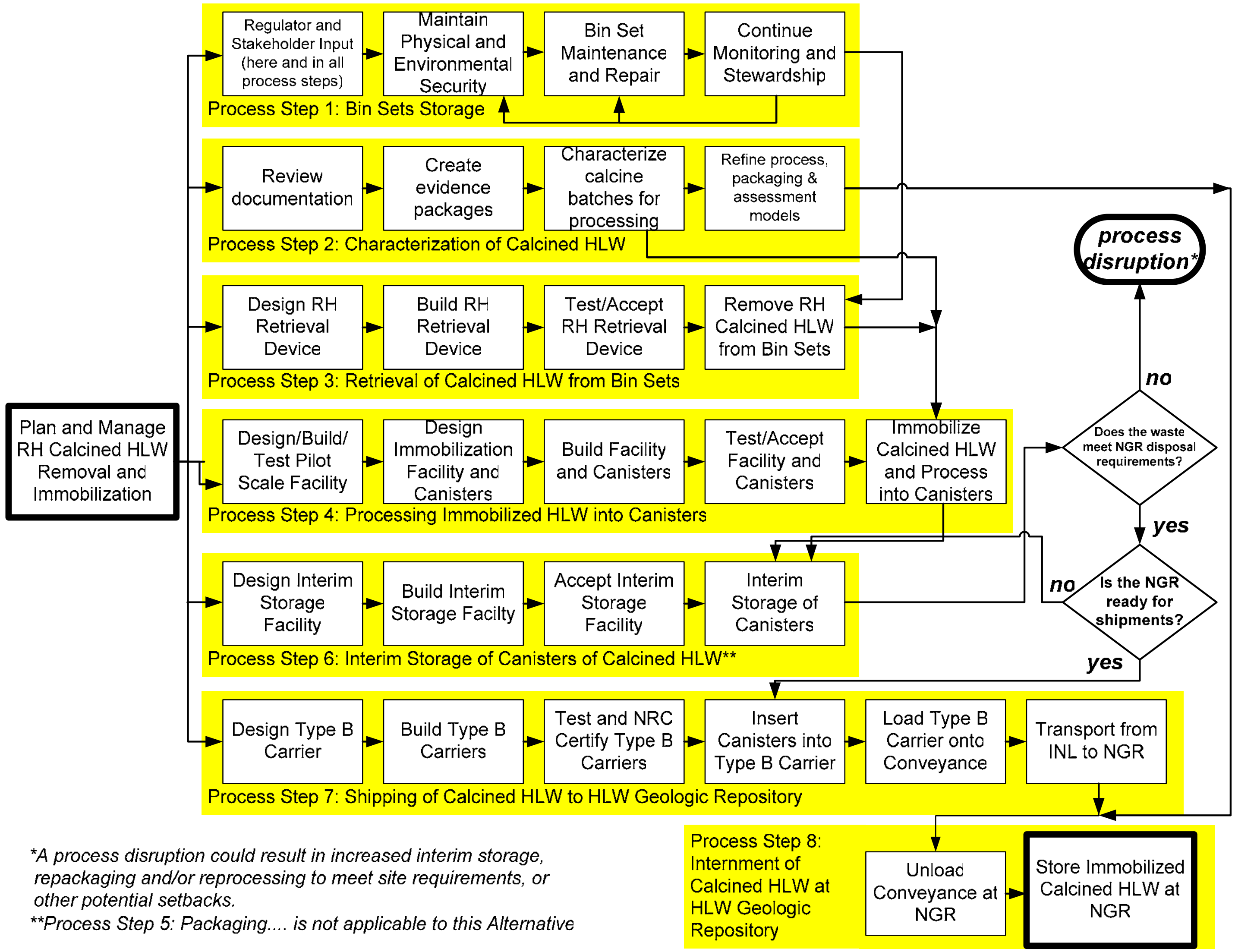
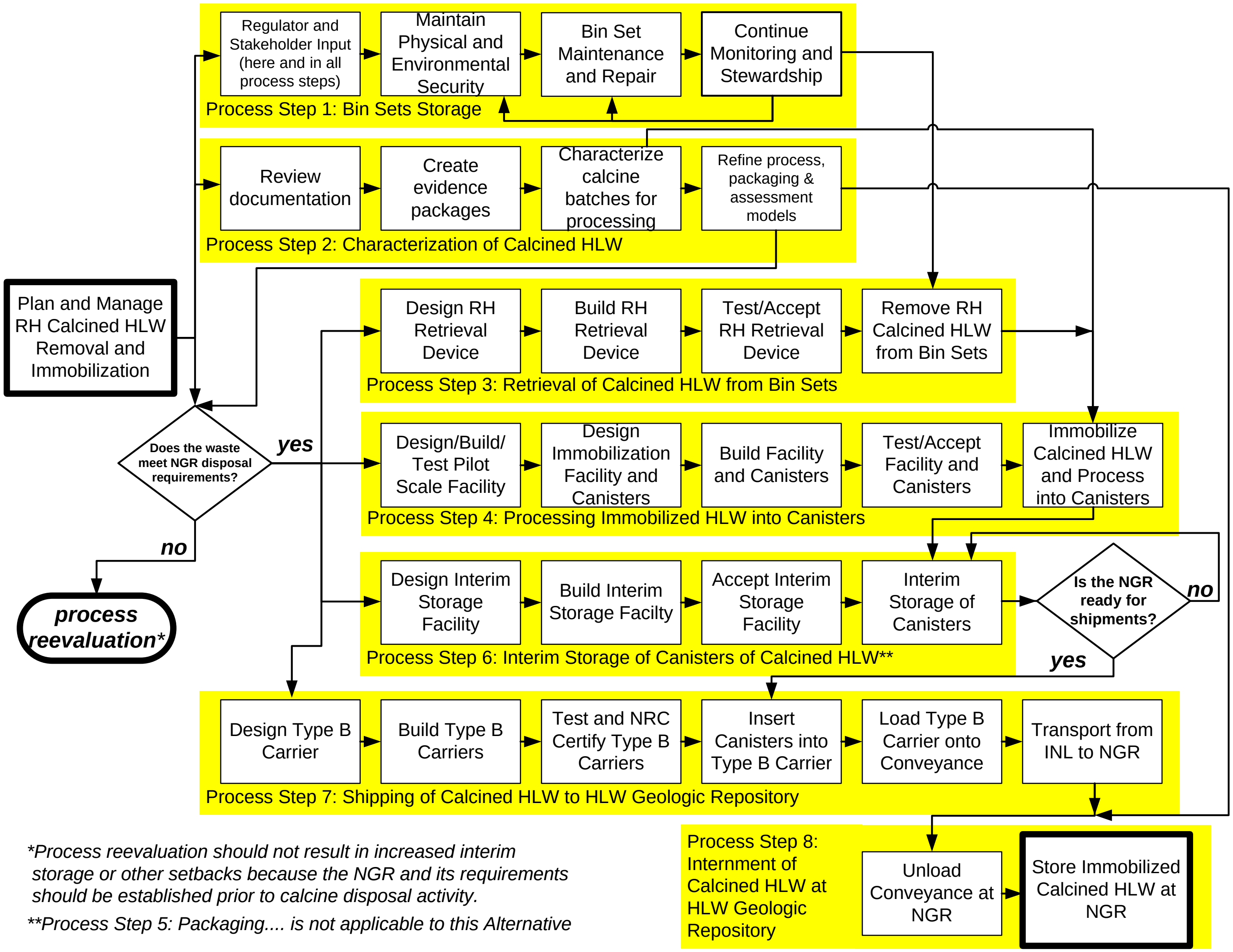


Figure B-2. Management flow diagram for Alternative 1 (Retrieve/Package/Ship) for Time Frame B (Intermediate Term) and Time Frame C (Long Term)



**A process disruption could result in increased interim storage, repackaging and/or reprocessing to meet site requirements, or other potential setbacks.*
***Process Step 5: Packaging.... is not applicable to this Alternative*

Figure B-3. Management flow diagram for Alternative 2 (Retrieve/Immobilize/Package/Ship) for Time Frame A (Near Term)



**Process reevaluation should not result in increased interim storage or other setbacks because the NGR and its requirements should be established prior to calcine disposal activity.*

***Process Step 5: Packaging.... is not applicable to this Alternative*

Figure B-4. Management flow diagram for Alternative 2 (Retrieve/Immobilize/Package/Ship) for Time Frame B (Intermediate Term) and Time Frame C (Long Term)

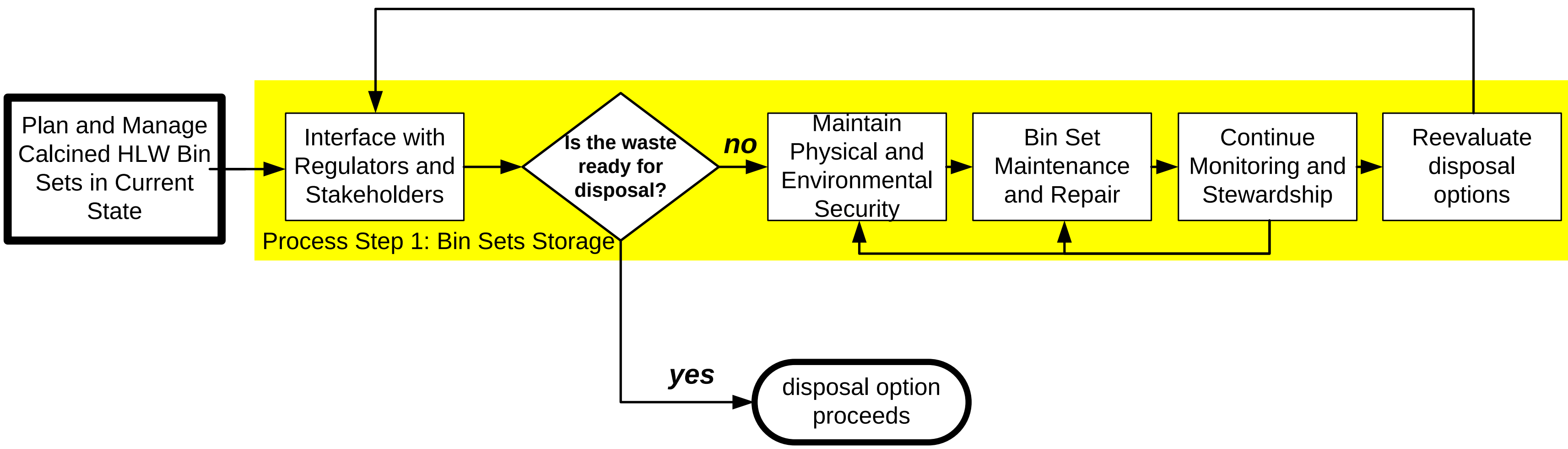


Figure B-5. Management flow diagram for Alternative 3 (Store in Place) for Time Frame A (Near Term), Time Frame B (Intermediate Term) and Time Frame C (Long Term)

APPENDIX C: TASK LIST

Task List[1]

1A.1 Bin Sets Storage

1A.1.1 Management of Bin Set Storage (planning, security, interface with stakeholders, long-term stewardship)
1A.1.2 Routine monitoring and inspections
1A.1.3 Preventive maintenance
1A.1.4 Non-routine maintenance
1A.1.5 Repair or replacement
1A.1.6 Decommission Bin Sets
3A.1.7 Reevaluate waste recovery and disposal options

1A.2. Characterization of Calcined HLW

1A.2.1. Review existing documentation and supplement as needed
1A.2.2 Create evidence packages or other waste acceptance documents
1A.2.3 Refine conceptual site models
2A.2.1 Review existing documentation and supplement as needed
2A.2.2 Characterize batches for processing
2A.2.3 Characterize final waste form for use in evidence packages or other waste acceptance documents
2A.2.4 Refine conceptual site models

1A.3. Retrieval of Calcined HWL from Bin Sets

1A.3.1 Design, fabricate, install calcined HLW remote-handled retrieval device (multiple bin installation)
1A.3.2 Remove 4,400 m^3 of Remote-Handled Calcined HLW from Bin Sets
1A.3.3 Decommission calcined HLW removal equipment

2A.4. Processing Immobilized HLW into Canisters

2A.4.1 Design, test, and build canisters to package immobilized HLW
2A.4.2 Design, build, test, and accept processing facility for immobilization of HLW
2A.4.3 Process calcined HLW into immobilized waste form
2A.4.4 Decommission HLW processing facilities

1A.5. Packaging of Calcined HLW into Canisters

1A.5.1 Design, build, test, and accept canisters to package remote-handled calcined HLW
1A.5.2 Design, build, test and accept calcined HLW remote-handled packaging facilities
1A.5.3 Package 4,400 m^3 of remote-handled calcined HLW
1A.5.4 Decommission calcined HLW packaging facilities and equipment

1A.6. Interim Storage of Canisters of Calcined HLW

1A.6.1 Design and Build Interim Storage Facilities
1A.6.2 Operate Interim Storage Facility
1A.6.3 Decommission interim storage facility

[1] Tasks are listed as applying to all alternatives and time frames. Deviations are *italicized.* In the case of Alternative 3 (all time frames), only the list of tasks under the heading of “Bin Sets Storage” apply.

1A.7. Shipping of Calcined HLW to HLW Geologic Repository
1A.7.1 Design and test shielded shipping casks
1A.7.2 Fabricate shielded shipping casks
1A.7.3 Retrieve canisters from interim storage and load shielded shipping casks
1A.7.4 Secure shielded shipping casks to conveyance
1A.7.5 Transport Calcined HLW to HLW geologic repository
2A.7.5. Transport immobilized HLW to HWL geologic repository

1A.8. Internment of Calcined HLW at HLW Geologic Repository
1A.8.1 Off-load calcined remote-handled shielded casks
1A.8.2 Inter calcined HLW in shielded casks into HLW geologic repository

APPENDIX D: HAZARD ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

Introduction

Hazard and gap analysis tables are provided as part of this report, which evaluates the various calcined HLW disposition alternatives for the Idaho Site. This report provides a *framework* for assessing risks associated with the various remedial alternatives investigated; however, the document provides neither quantitative risk estimates nor recommendations for remedial alternatives. The approach here provides the ability to categorize, at least qualitatively, the known hazards and gaps pertaining to the remedial alternatives considered. Although there is not likely to be unanimous agreement on any set of definitions, a common basis for assessing the tasks in question is essential—this is an attempt to provide such a basis. Furthermore, these definitions allow reviewers to "mean the same thing" when generic terms such as "*low*" or "*high*" are used even though precise values cannot be placed on the risks or gaps. The intent of this report is to provide a *framework* for assessing risks and not to provide quantitative risk estimates. These categories are subject to change as further knowledge is obtained.

The process steps that are relevant to each Alternative in the hazard analysis are shown in Table D-1.

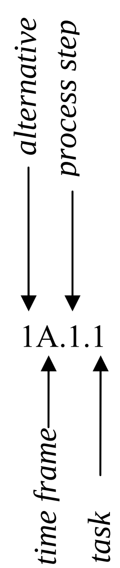
Note

The potential events and consequences for terrorist activities that might threaten the integrity of the calcined HLW storage and disposition have not been considered in this analysis.

Table D-1. Process Steps in Each Hazard Analysis

	Alternative 1			Alternative 2			Alternative 3		
Process Step Description	Time Frame A	Time Frame B	Time Frame C	Time Frame A	Time Frame B	Time Frame C	Time Frame A	Time Frame B	Time Frame C
1. Bin Sets Storage	√	√	√	√	√	√	√	√	√
2. Characterization of Calcined HLW for Processing and Immobilized Waste Form for Disposal	√	√	√	√	√	√			
3. Retrieval of Calcined HLW from Bin Sets	√	√	√	√	√	√			
4. Processing Immobilized HLW into Canisters				√	√	√			
5. Packaging of Calcined HLW into Canisters	√	√	√						
6. Interim Storage of Canisters of Calcined HLW	√	√	√	√	√	√			
7. Shipping of Calcined HLW to HLW Geologic Repository	√	√	√	√	√	√			
8. Internment of Calcined HLW at HLW Geologic Repository	√	√	√	√	√	√			

Numbering scheme



Alternatives
1 – Retrieve, package, ship
2 – Retrieve, immobilize, package, ship
3 – Store in place

Time Frames
A – near term
B – intermediate term
C – long term

ALTERNATIVES

Alternative 1: The calcined HLW will be retrieved from the bin sets, packaged without physical or chemical modification, stored temporarily on-site or off-site and shipped to a HLW geologic repository for permanent internment. This management option will be considered for three time frames.

Alternative 2: The calcined HLW will be retrieved from the bin sets, processed (e.g., separations, immobilization and/or other processes), stored temporarily on-site or off-site, shipped to a HLW geologic repository for permanent internment. This management option will be considered for the same three time frames as described for Alternative 1.

Alternative 3: The calcined waste will continue to be stored in the current bin sets for the period that allows contact handling instead of remote handling based on sufficient radioactive decay (approximately 300 years), with appropriate site improvements and security. This alternative allows for subsequent reevaluation of the waste recovery and disposal options.

TIME FRAMES

A. **Near term:** Retrieval and processing or packaging will be initiated in the near term, within 10-50 years[2], independent of availability of a geologic repository and associated waste acceptance criteria
B. **Intermediate term:** Retrieval and processing or packaging will be initiated once a geologic repository is open, such that the waste acceptance criteria and acceptance schedule allow for "just in time" processing (e.g., after 50 years).
C. **Long term:** Retrieval and processing or packaging will be initiated in the future, after approximately 10 half lives of reduction of the specific activity of the high energy fission products in the calcined wastes has been achieved (e.g., after 300 years).

[2] Specified time periods are used for example purposes. The intermediate term may begin sooner than 50 years, depending on the availability of a final disposition pathway for the calcined HLW.

Hazard Analysis Definitions

A set of hazard analysis tables is provided in the pages that follow this introduction. The purpose of these tables is to identify likely modes of failure and the potentially impacted population for each of the three disposition alternatives for calcined HLW. The basic format that has been agreed upon for the *hazard analysis* tables is illustrated in the pages that follow this introduction. In these tables, there are a number of columns whose definitions were standardized. These columns are

- Task Frequency
- How likely is it? (Event Probability)
- What is the severity of the consequences?
- Overall contribution to risk

where the other columns are considered self-explanatory.

A set of definitions for categorizing the terms in the hazard analysis tables has been provided in Table D-2.

The “Task Frequency” column indicates the frequency with which a task is performed and the “How likely is it?” or event probability column denotes the overall probability of experiencing an adverse event given performance of the task.[3] That is, for *each hazard in a given task in a given process step*, both an adverse event probability (i.e., “How likely is it?”) and a consequence severity can be categorized.

[3] The “How likely is it?” or event probability column indicates the likelihood of the adverse event occurring (or the product of the task frequency and the hazard likelihood).

Table D-2. Definitions for Hazard Analysis Tables

Task Frequency

Frequent: Occurs very often (e.g., more than once per quarter for long-duration tasks) or continuously.

Anticipated: Occurs several times (e.g., on the average of once per year) over the project lifetime or occurs infrequently but with long duration.

Occasional: Occurs sporadically or at a well-defined time (e.g., start-up or closure) or has a remote possibility of occurrence.

Unlikely: One can reasonably assume that this will not occur, but its occurrence is not impossible.

How likely is it? (Event Probability)

Probable: Very likely to occur (e.g., more than 50 times out of 100) during task execution.

Possible: Expected to occur (e.g., between 1 time out of 100 and 50 times out of 100) during task execution.

Unlikely: One can reasonably assume that this hazard will not transpire (e.g., less than one chance out of 100), but its occurrence is not impossible.

Consequence Severity[4]

Severe: Loss of ability to satisfy applicable and relevant design and performance criteria and protect human health (both worker and general public) and the environment (both on- and off-site). Likely to result in death or permanent disability including that from latent cancer effects to a large group of people (e.g., greater than 25 and greater than 5, respectively). Loss of major or safety-critical system or equipment. Major property or facility damage (e.g., greater than $1 million). Severe environmental damage (e.g., significant loss of protected or endangered species habitat).[5]

Critical: Significantly degraded performance versus applicable and relevant design and performance criteria and the ability to protect human health (both worker and the general public) and the environment (both on- and off-site). Likely to result in traumatic injury, illness, and/or disability requiring medical treatment to a moderate-sized group of people (e.g., 10 to 25 and 2 to 5 for injuries and deaths, respectively). Significantly degraded performance of major or safety-critical system or equipment. Significant property damage (of less than $1 million) requiring repairs and replacement and/or environmental damage requiring treatment.

Marginal: Some degraded performance versus applicable and relevant design and/or performance criteria or reduced ability to protect human health (both worker and the general public) as well as the environment (both on- and off-site). Minor damage to equipment, facilities, property, or environment that does not require immediate action. Injury or illness likely to result and will be limited to a small group of people (e.g., less than 10 and less than 2 for injuries and deaths, respectively).

Risk Level (Overall Contribution to Risk)

High: The hazard associated with the alternative has the potential for major on-site and off-site impacts to large numbers of persons or with the potential for major impacts to the environment. There is a high risk of fatality due to traumatic injury or a high probability (e.g., more than one in 10^4) of a latent cancer to either on- or off-site personnel. Highly contaminated area of greater than 10 mi^2.

Significant: The hazard associated with the alternative represents considerable potential on-site impacts to human health or the environment, but at most only minor off-site impacts to human health, or the environment. There is a risk of traumatic injury or a moderate probability (e.g., between one chance in 10^6 and one in 10^4) of a latent cancer to either on- or off-site personnel. Contaminated area of between 1 and 10 mi^2.

Low: The hazard associated with the alternative presents only minor on-site and negligible off-site impacts to human health, the environment, or security. There is negligible risk of injury (i.e., no more than a first-aid treatment case) or a low probability (e.g., less than one chance in 10^6) of a latent cancer developing in either on- or off-site personnel. Impacted area of less than 1 mi^2.

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[4] Direct injuries and deaths are taken into account; psychological damage, economic loss, and stigma are not considered.

[5] It is recognized that this report primarily concerns human health; however, those tasks that involve risks to facilities and property, the environment, and site security will also be noted where appropriate.

For the “consequence severity” category, “Marginal” would be used for injuries or deaths to small groups, say less than 10 and less than 2 for injuries and deaths, respectively. “Critical” denotes injuries or deaths to larger groups, say 10 to 25 and 2 to 5, respectively. “Severe” indicates injuries or deaths to large groups, say greater than 25 and greater than 5, respectively. These numbers are subjective estimates because a rigorous risk analysis has not yet been done and is outside the scope of this report.

The purpose of this exercise is to estimate (and possibly rank order) the contributions to the overall risk for a given alternative of the various process steps (which are comprised of tasks with associated hazards). A possible initial step might be to estimate the contribution of a given hazard to overall process step risk and then “roll up” (and possibly rank order) the process steps risks for a given alternative. However, to determine the contribution to the overall process step risk for a given hazard would require

1) determining the risks for all hazards for tasks within a given process step,
2) aggregating the risks[6] to derive an overall risk for the process step, and finally
3) determining the contribution from each hazard to the overall process step risk.

The resources and/or the level of detail are not available to complete these required tasks in what theoretically would be the desired scientific manner. Therefore, the overall risk from a given hazard will instead be estimated based on expert opinion using a risk-assessment matrix type analysis. That is, given an event probability (e.g., in the “How likely is it?” column) and consequence severity, a risk-assessment matrix can be defined[7] that translates the products of these factors to corresponding overall risk levels given in the “Overall Contribution to Risk” column, which are defined in Table D-2. The proposed scheme is illustrated in Table D-3; where the definitions of *High*, *Significant*, and *Low* are provided in Table D-2.

Table D-3. Example Risk-Assessment Matrix

		How likely is it? (Event Probability)		
		Probable	**Possible**	**Unlikely**
Severity	**Severe**	High	High	Significant
	Critical	High	Significant	Significant
	Marginal	Significant	Significant	Low

6 We recognize that the risks could be synergistic or antagonistic; however, for simplicity we will assume that the risks are additive.

7 The primary reference for the hazard categorization is: “Review of the Army's Technical Guides on Assessing and Managing Chemical Hazards to Deployed Personnel,” Subcommittee on the Toxicological Risks to Deployed Military Personnel, Committee on Toxicology, National Research Council, 2004.

Thus for each hazard associated with a given alternative/process step/task triplet, we can define a risk based upon the consequence severity and event probability information in Table D-3. The information in the individual hazard tables must be "rolled up" for multiple hazards, leading to a single metric representing the overall contribution to alternative risk for a given process step.[8] For simplicity, it is assumed that the minimum risk contribution for a given process step cannot be less than the maximum risk for any hazard for any task in that process step. Furthermore, assuming independence, the maximum risk contribution for a given process step cannot be more than the sum of risk over all hazards.

Because the risk levels (i.e., *high*, *significant*, and *low* from Table D-2) that we require to roll-up into a single metric can be considered as primarily categorical variables[9], there is no simple, mathematical expression that can be derived for use here. Instead the following *criteria* will be used to roll-up the risk information into a single overall contribution to risk metric:

1. If a process step has at least one hazard that is considered *high* risk, then that process step is considered *high* risk in terms of its contribution to the overall risk. There may be a subsequent attempt to rank-order the high risk hazards; however, this will be by its very nature subjective because of the many assumptions already made. For example, one rank-ordering would place the potential for human health effects first (based upon numbers of people impacted, death versus injury, immediate versus latent, off-site versus on-site, etc.) followed by ecological risk, then security and finally property damage. After we complete the analysis, we shall rank order the risks based upon expert opinion and the value judgment of the individual expert. If there is not at least a majority agreement, then the individual rank-ordering will be given with a description of the drivers for their choices.
2. If a process step has only hazards that are considered *low* risk, then the contribution to overall risk from that process step is also *low* risk. This is akin to what should be done when considering cumulative radiological dose estimates.
3. If a process step has hazards that are only considered as *significant* to overall risk, then the minimum risk contribution must also be *significant*. There is a *high* contribution to overall risk from a process step if ten (10) hazards in a process step are deemed *significant*. This is based upon the fact that the best information that we are likely to find for our analyses is on an order of magnitude. For reasons similar to those in Criterion #2 above, the number of low-risk hazards does not factor into this assessment.

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8 We can adopt a process analogous to the Welch-Satterthwaite method for estimating degrees of freedom corresponding to adding a set of variances in quadrature, each having unique degrees of freedom. The resulting degrees of freedom estimate (associated with the total variance) is bounded by the maximum of the individual degrees of freedon and the sum of all.

9 We have, in part, relied upon definitions (i.e., 10^{-4} to 10^{-6}) analogous to those used in CERCLA indicating acceptable "excess upper bound lifetime cancer risk[s] to an individual" (per 40 CFR Part 300.430). Thus, again we must agree on what we consider "acceptable" levels of risk, especially for things other than cancer risks. This is especially important because neither the information nor time exists to develop a quantitative risk estimate for each hazard. Thus our definitions are inherently categorical in nature; however, they should represent our best estimates of risks analogous to 10^{-4} to 10^{-6}.

Process Step Term Definitions

routine monitoring – scheduled observations at the bin sets

preventive maintenance – routine maintenance; scheduled maintenance; operations that are known to the worker and scheduled in advance

non-routine maintenance – unscheduled maintenance; operations that are expected by the worker but not scheduled in advance (e.g., changing a filter, changing a strip chart, etc); repairs are specifically not included in this category.

repair –potentially invasive actions by the worker to correct a failure

evidence package – information about waste (large paper document) to be used in lieu of physical sample from waste container

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame A – near term

Table D-1A.1. Bin Sets Storage, Near Term

Task	Task frequency	What can go wrong? (failure mode event))	How likely is it? (Event probability)	What is the severity of the consequences?*	Who is the impacted population?	What is the risk evaluation basis	Contribution to Overall Process Step Risk
1A.1.1 Management of Bin Set Storage (planning, security, interface with stakeholders, long-term stewardship)	Frequent	Programmatic or regulatory administrative failure.	Unlikely	Marginal[10]	Worker Off site population	Similar operational experience	Low
		Earthquake or severe weather event damages bin set(s).	Unlikely	Severe	Worker and Off-site population		Significant
		Bin set failure due to neglect	Unlikely	Severe	Worker and Off-site population		Significant
1A.1.2 Routine monitoring and inspection	Frequent	Injury during routine monitoring task (without facility damage)	Possible	Marginal	Worker	Similar operational experience	Significant
1A.1.3 Preventive maintenance	Frequent	Injury during preventive maintenance task (with facility damage)	Possible	Critical	Worker	Similar operational experience	Significant
1A.1.4 Non-routine maintenance	Occasional	Injury or radiation exposure during non-routine maintenance	Possible	Critical	Worker	Similar operational experience	Significant

[10] Administrative failure would not cause physical harm to worker or general population; effort would be required to return to compliance. Costs would increase as would time to complete, resulting in greater chances of other events.

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame A – near term

Task	**Task frequency**	**What can go wrong? (failure mode event))**	**How likely is it? (Event probability)**	**What is the severity of the consequences?***	**Who is the impacted population?**	**What is the risk evaluation basis**	**Contribution to Overall Process Step Risk**
1A.1.5 Repair	Occasional	Injury or radiation exposure during repair task	Possible	Critical	Worker	Similar operational experience	Significant
		Release of calcined HLW during repair task (eg., worker breeches a pipe trench during excavation/replacement of fill surrounding a bin set)	Possible	Critical	Worker and Off-site population		Significant
1A.1.6 Decommission of Bin Sets	Occasional	Injury or radiation exposure during decommissioning.	Possible	Critical	Worker	Similar operational experience	Significant

Table D-1A.2. Characterization of Calcined HLW, Near Term

Task	**Task frequency**	**What can go wrong? (radiological and non-radiological incidents)**	**How likely is it?**	**What is the severity of the consequences?**	**Who is the impacted population?**	**Risk evaluation basis**	**Contribution to risk**
1A.2.1 Review historical and other existing documentation	*N/C*[11]	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*
1A.2.2 Create evidence packages or other waste acceptance documents	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*
1A.2.3 Refine conceptual site models	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*	*N/C*

[11] Not considered. For Alternative 1, the tasks in Process Step 1A.2 are considered office tasks. While office injuries do occur, these events are considered outside the scope of this report.

Table D-1A.3. Retrieval of Calcined HLW from Bin Sets, Near Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1A.3.1 Design, fabricate, install calcined HLW remote-handled retrieval device (multiple bin installation)	Occasional[12]	Traumatic injury during installation	Possible	Critical	Worker	Relatively similar operational experience	Significant
		Radiological exposure during installation	Possible	Critical	Worker		Significant
		Release of calcined HLW from engineered controls	Unlikely	Critical	Worker and Off-site population		Significant
1A.3.2 Remove 4,400 m^3 of Remote-Handled Calcined HLW from Bin Sets	Frequent	Release of calcined HLW from engineered controls during material transfer.	Probable	Critical	Worker and Off-site population	Relatively similar operational experience	High
1A.3.3 Decommission calcined HLW removal equipment	Occasional	Radiological exposure during decommisioning	Possible	Critical	Worker	Similar operational experience	Significant

Table D-1A.4. Processing, Near Term (Not Applicable to Alternative 1)

[12] In this instance, "occasional" is defined as occurring at a well-defined time (i.e., startup).

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame A – near term

Table D-1A.5. Packaging of Calcined HLW into Canisters, Near Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1A.5.1 Design, build, test and accept canisters to package remote-handled calcined HLW	Occasional	Injury during package construction and testing	Unlikely	Critical	Worker	Similar operational experience	Significant
1A.5.2 Design, build, test and accept calcined HLW remote-handled packaging facilities	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
1A.5.3 Package 4,400 m^3 of remote-handled calcined HLW	Frequent	Spill of calcined HLW occurs during material transfer. Waste form deemed inappropriate for NGR	Probable Probable	Critical Severe	Worker Worker	Similar operational experience	High **High**[13]
1A.5.4 Decommission calcined HLW packaging facilities and equipment	Occasional	Injury during decommissioning activities Exposure to radioactive materials during decommisioning activities.	Unlikely Possible	Critical Critical	Worker Worker	Similar operational experience	Significant Significant

[13] The rejection of the waste form is deemed "Severe" because of the large impact it would have on other process steps. The consequences of rejection range from minor (e.g., additional paperwork) to considerable (e.g., greatly increased interim storage, required processing/repackaging)

Table D-1A.6. Interim Storage of Canisters of Calcined HLW, Near Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1A.6.1 Design and Build Interim Storage Facilities	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
1A.6.2 Operate Interim Storage Facility[14]	Frequent	Injury during storage facility operation.	Possible	Marginal	Worker	Similar operational experience	Significant
		Canister breeched during storage.	Unlikely	Critical	Worker		Significant
		Radiation exposure during storage.	Possible	Critical	Worker		Significant
		Delay in shipping causes increased storage duration.[15]	Probable	Critical	Worker		High
1A.6.3 Decommission interim storage facility	Occasional	Injury during decommissioning activities	Possible	Marginal	Worker	Similar operational experience	Significant
		Exposure to radioactive materials during decontamination activities.	Possible	Marginal	Worker		Significant

[14] The duration of this process step depends on a number of factors related to the NGR, including the compatibility of the waste with not-yet-established waste criteria.

[15] Delays are normal for most operations; the length of the delay is subject to external factors such as the waste acceptance criteria and schedule of the NGR.

Table D-1A.7. Shipping of Calcined HLW to HLW Geologic Repository, Near Term

Task	Task frequency	What can go wrong? (radiological and non-radiological)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1A.7.1 Design and test shielded shipping casks	Occasional	Injury during cask testing.	Unlikely	Marginal	Worker	Similar operational experience	Low
1A.7.2 Fabricate shielded shipping casks	Frequent	Injury during cask fabrication.	Unlikely	Marginal	Worker	Similar operational experience	Low
1A.7.3 Retrieve canisters from interim storage and load shielded shipping casks	Frequent	Injury during loading of canisters into shipping casks.	Possible[16]	Critical	Worker	Similar operational experience	Significant
		Canister breaks during loading process, causing the release of calcined HLW.	Unlikely	Critical	Worker and Off-site population		Significant

[16] Likelihood is "possible" because of the number of canisters that will require loading/transport. In the HLW EIS estimate, 6100 canisters will be required for this task (1220-6100 shipments). If existing technology was used (SNF canisters), the $4400 m^3$ of calcined HLW would be packaged into approximately 400000 canisters and approximately 16000-80000 shipments would be required, depending on then number of canisters per shipment.

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame A – near term

Task	Task frequency	What can go wrong? (radiological and non-radiological)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1A.7.4 Secure shielded shipping casks to conveyance	Frequent	Injury during the securing process.	Possible	Critical	Worker	Similar operational experience	Significant
1A.7.5 Transport Calcined HLW to HLW geologic repository	Frequent	Radiation exposure during transport	Possible	Critical	Worker and Off-site population	Similar operational experience	Significant
		Traffic accident occurs during transport.[17]	Unlikely[18]	Critical	Worker and Off-site Population		Significant

[17] The assumption is made that each container will be built (legally required) to withstand stresses such as dropping, bumping and impact with a vehicle (i.e., at an ungated crossing). These stresses would have to be coupled with simultaneous failure of both the cask and one or more canisters to cause a release of calcined HLW.

[18] Accident rates for transportation by train and truck are well-studied. The number of accidents depends on the number of shipments. The HLW EIS provides accident rates of 7.7×10^{-4} accidents/shipment and 3.5×10^{-5} fatalities/shipment by truck, as well as 1.0×10^{-4} accidents/shipment and 3.1×10^{-5} fatalities/shipment by train. For the HLW EIS scenarios, 0-5 accidents may occur during transportation, probably not with any fatalities. For the existing technology scenario (SNF canisters, see previous note on number of shipments), 12-62 accidents may occur with 0-3 potential fatalities.

Table D-1A.8. Internment of Calcined HLW at HLW Geologic Repository, Near Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1A.8.1 Off-load calcined remote-handled shielded casks	Frequent	Injury during offloading process.	Possible	Critical	Worker	Similar operational experience	Significant
		Cask is dropped during unloading.	Unlikely[19]	Critical	Worker and Off-site population		Significant
1A.8.2 Inter calcined HLW in shielded casks into HLW geologic repository	Frequent	Cask is dropped during handling.	Unlikely	Critical	Worker and Off-site population	Similar operational experience	Significant

[19] The number of casks varies from 1200 to 80000 depending on the transportation scenario (assuming 1 cask/shipment, see Table D-1A.7 for information on the number of shipments). A large number of task implementations multiplied by a low probability of accidents yields some number of failure events taking place.

Table D-1B.1. Bin Sets Storage, Intermediate Term

Task	Task frequency	What can go wrong? (failure mode event))	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis	Contribution to Overall Process Step Risk
1B.1.1 Management of Bin Set Storage (planning, security, interface with stakeholders, long-term stewardship)	Frequent	Programmatic or regulatory administrative failure.	Unlikely	Marginal[21]	Worker Off site population	Similar operational experience	Low
		Earthquake or severe weather event damages bin set(s).[20]	**Possible**	Severe	Worker and Off-site population		**High**
		Bin set failure due to neglect	Unlikely	Severe	Worker and Off-site population		Significant
1B.1.2 Routine monitoring and inspection	Frequent	Injury during routine monitoring task (without facility damage)	Possible	Marginal	Worker	Similar operational experience	Significant
1B.1.3 Preventive maintenance	Frequent	Injury during preventive maintenance task (with facility damage)	Possible	Critical	Worker	Similar operational experience	Significant
1B.1.4 Non-routine maintenance	Occasional	Injury or radiation exposure during non-routine maintenance	Possible	Critical	Worker	Similar operational experience	Significant

[20] As time increases, the likelihood of a seismic or severe weather event increases. See Mattson et al. (2004) for information related to these events.

[21] Administrative failure would not cause physical harm to worker or general population; effort would be required to return to compliance. Costs would increase as would time to complete, resulting in greater chances of other events.

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame B – intermediate term

Task	Task frequency	What can go wrong? (failure mode event))	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis	Contribution to Overall Process Step Risk
1B.1.5 Repair	Occasional	Injury or radiation exposure during repair task	Possible	Critical	Worker	Similar operational experience	Significant
		Release of calcined HLW during repair task (eg., worker breeches a pipe trench during excavation/replacement of fill surrounding a bin set)	Possible	Critical	Worker and Off-site population		Significant
1B.1.6 Decommission of Bin Sets	Occasional	Injury or radiation exposure during decommissioning.	Possible	Critical	Worker	Similar operational experience	Significant

Table D-1B.2. Characterization of Calcined HLW, Intermediate Term

See Table D-1A.2

Table D-1B.3. Retrieval of Calcined HLW from Bin Sets, Intermediate Term

See Table D-1A.3[22]

Table D-1B.4. Processing, Near Term (Not Applicable to Alternative 1)

[22] Difficulty of retrieval task increases with increasing time frame due to settlement, agglomeration and corrosion. Gamma radiation decay will have occurred, but alpha and beta radiation sources remain hazardous because the inhalation pathway remains.

Table D-1B.5. Packaging of Calcined HLW into Canisters, Intermediate Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1B.5.1 Design, build, test and accept canisters to package remote-handled calcined HLW	Occasional	Injury during package construction	Unlikely	Critical	Worker	Similar operational experience	Significant
1B.5.2 Design, build, test and accept calcined HLW remote-handled packaging facilities	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
1B.5.3 Package 4,400 m^3 of remote-handled calcined HLW	Frequent	Spill of calcined HLW occurs during material transfer.	Probable	Critical	Worker	Similar operational experience	High
		Waste deemed inappropriate for NGR	**Unlikely**	**Marginal**	Worker		**Low**[23]
1B.5.4 Decommission calcined HLW packaging facilities and equipment	Occasional	Injury during decommissioning activities	Unlikely	Critical	Worker	Similar operational experience	Significant
		Exposure to radioactive materials during decontamination activities.	Possible	Critical	Worker		Significant

[23] The question of whether or not the Alternative 1 waste form will be acceptable should be answered before packaging begins in the intermediate term time frame. Therefore, impact on subsequent process step tasks is marginal, so the overall risk reduces to Low.

Table D-1B.6. Interim Storage of Canisters of Calcined HLW, Intermediate Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1B.6.1 Design and Build Interim Storage Facilities	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
1B.6.2 Operate Interim Storage Facility	Frequent	Injury during storage facility operation.	Possible	Critical	Worker	Similar operational experience	Significant
		Canister breeched during storage.	Unlikely	Critical	Worker & Off-site Population		Significant
		Radiation exposure during storage.	**Unlikely**[24]	Critical	Worker		Significant
		Delay in shipping causes increased storage duration.	**Unlikely**[25]	**Marginal**[26]	Worker		**Low**
1B.6.3 Decommission interim storage facility	Occasional	Injury during decommissioning activities	Unlikely	Critical	Worker	Similar operational experience	Significant
		Exposure to radioactive materials during decontamination activities.	Unlikely	Critical	Worker		Significant

[24] Gamma radiation decay decreases the likelihood to Unlikely.

[25] Delay is less likely because NGR should be operational before packaging begins, allowing for "just in time" packaging and shipping. Risk category unchanged.

[26] Gamma radiation decay decreases the severity to Marginal because radiation exposure is non-contact.

Table D-1B.7. Shipping of Calcined HLW to HLW Geologic Repository, Intermediate Term

See Table D-1A.7[27]

Table D-1B.8. Internment of Calcined HLW at HLW Geologic Repository, Intermediate Term

See Table D-1A.8

[27] Changes such as population growth, traffic time and improved technology have not been considered.

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame C – long term

Table D-1C.1. Bin Sets Storage, Long Term

Task	Task frequency	What can go wrong? (failure mode event))	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis	Contribution to Overall Process Step Risk
1C.1.1 Management of Bin Set Storage (planning, security, interface with stakeholders, long-term stewardship)	Frequent	Programmatic or regulatory administrative failure.	Unlikely	Marginal[30]	Worker Off site population	Similar operational experience	Low
		Earthquake or severe weather event damages bin set(s).[28,29]	Possible	Severe	Worker and Off-site population		High
		Bin set failure due to neglect	Unlikely	Severe	Worker and Off-site population		Significant
1C.1.2 Routine monitoring and inspection	Frequent	Injury during routine monitoring task (without facility damage)	**Probable**[31]	Marginal	Worker	Similar operational experience	Significant
1C.1.3 Preventive maintenance	Frequent	Injury during preventive maintenance task (with facility damage)	**Probable**[32]	Critical	Worker	Similar operational experience	**High**

[28] As time increases, the likelihood of a seismic or severe weather event increases. See Mattson et al. (2004) for information related to these events.

[29] The design lifetime of bin sets has been exceeded, so the original seismic certification is no longer applicable and structural integrity of the bin sets may have decreased.

[30] Administrative failure would not cause physical harm to worker or general population; effort would be required to return to compliance. Costs would increase as would time to complete, resulting in greater chances of other events.

[31] Likelihood increases with increased bin set storage duration.

[32] ibid

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame C – long term

Task	Task frequency	What can go wrong? (failure mode event))	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis	Contribution to Overall Process Step Risk
1C.1.4 Non-routine maintenance	Occasional	Injury or radiation exposure during non-routine maintenance	**Probable**[33]	Critical	Worker	Similar operational experience	**High**
1C.1.5 Repair	Occasional	Injury or radiation exposure during repair task	**Probable**[34]	Critical	Worker	Similar operational experience	**High**
		Release of calcined HLW during repair task (eg., worker breeches a pipe trench during excavation/replacement of fill surrounding a bin set)	**Probable**[35]	Critical	Worker and Off-site population		**High**
1C.1.6 Decommission of Bin Sets	Occasional	Injury or radiation exposure during decommissioning.	Possible	Critical	Worker	Similar operational experience	Significant

[33] ibid
[34] ibid
[35] ibid

Table D-1C.2. Characterization of Calcined HLW, Long Term

See Table D-1A.2

Table D-1C.3. Retrieval of Calcined HLW from Bin Sets, Long Term

See Table D-1A.3[36]

Table D-1C.4. Processing, Long Term (Not Applicable to Alternative 1)

[36] Difficulty of retrieval task increases with increasing time frame due to settlement, agglomeration and corrosion. Gamma radiation decay will have occurred, but alpha and beta radiation sources remain hazardous because the inhalation pathway remains.

Alternative 1 – Retrieve, package and ship calcined HLW to geologic repository
Time Frame C – long term

Table D-1C.5. Packaging of Calcined HLW into Canisters, Long Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1C.5.1 Design, build, test and accept **canisters** to package remote-handled calcined HLW	Occasional	Injury during package construction	Unlikely	Critical	Worker	Similar operational experience	Significant
1C.5.2 Design, build, test and accept calcined HLW remote-handled packaging **facilities**	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
1C.5.3 Package 4,400 m^3 of remote-handled calcined HLW	Frequent	Spill of calcined HLW occurs during material transfer. Waste deemed inappropriate for NGR	Probable **Unlikely**	Critical **Marginal**	Worker Worker	Similar operational experience	High **Low**[37]
1C.5.4 Decommission calcined HLW packaging facilities and equipment	Occasional	Injury during decommissioning activities Exposure to radioactive materials during decontamination activities.	Unlikely Possible	Critical Critical	Worker Worker	Similar operational experience	Significant Significant

[37] The question of whether or not the Alternative 1 waste form will be acceptable should be answered before packaging begins in the long term time frame. Therefore, impact on subsequent process step tasks is marginal, so the overall risk reduces to Low.

Table D-1C.6. Interim Storage of Canisters of Calcined HLW

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
1C.6.1 Design and Build Interim Storage Facilities	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
1C.6.2 Operate Interim Storage Facility	Frequent	Injury during storage facility operation.	Possible	Critical	Worker	Similar operational experience	Significant
		Canister breeched during storage.	Unlikely	Critical	Worker & Off-site Population		Significant
		Radiation exposure during storage.	Unlikely	**Marginal**[38]	Worker		**Low**
		Delay in shipping causes increased storage duration.	Unlikely	Marginal	Worker		Low
1C.6.3 Decommission interim storage facility	Occasional	Injury during decommissioning activities	Unlikely	Critical	Worker	Similar operational experience	Significant
		Exposure to radioactive materials during decontamination activities.	Unlikely	Critical	Worker		Significant

Table D-1C.7. Shipping of Calcined HLW to HLW Geologic Repository, Long Term

See Table D-1A.7[39]

Table D-1C.8. Internment of Calcined HLW at HLW Geologic Repository

See Table D-1A.8

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[38] Gamma radiation decay decreases the severity to Marginal because radiation exposure is non-contact.

[39] Changes such as population growth, traffic time and improved technology have not been considered.

Table D-2A.1. Bin Sets Storage, Near Term

See Table D-1A.1

Table D-2A.2. Characterization of Calcined HLW for Processing and Immobilized Waste Form for Disposal, Near Term

Task	Task Frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
2A.2.1 Review historical and other existing characterization documentation	N/C[40]	N/C	N/C	N/C	N/C	N/C	N/C
2.A.2.2 Characterize batches for processing	Occasional	Accident when opening bin	Unlikely	Marginal	Worker	Similar operational experience	Low
		Radiation exposure when opening bin	Possible	Critical	Worker		Significant
		Radiation exposure during sampling	Possible	Critical	Worker		Significant
		Radiation exposure during analyses	Possible	Critical	Worker		Significant
2A.2.3 Characterize final waste form for use in evidence packages or other waste acceptance documents	Occasional	Radiation exposure during sampling	Possible	Critical	Worker	Similar operational experience	Significant
		Radiation exposure during analyses	Possible	Critical	Worker		Significant

[40] For Alternative 2, some of the tasks in Process Step 2A.2 are considered office tasks. While office injuries do occur, these events are considered outside the scope of this report.

Alternative 2 – Retrieve and immobilize calcined HLW from bin sets; ship immobilized HLW to geologic repository
Time Frame A – near term

Task	Task Frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
2A.2.4 Refine conceptual site models	N/C	N/C	N/C	N/C	N/C	N/C	N/C

Table D-2A.3. Retrieval of Calcined HLW from Bin Sets, Near Term

See Table D-1A.3[41]

[41] For Alternative 2, Process Steps 2, 3 and 4 (characterization, retrieval, processing) are integrated.

Table D-2A.4. Processing Immobilized HLW into Canisters, Near Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
2A.4.1 Design, test, and build canisters to package immobilized HLW	Frequent	Injury during canister fabrication	Unlikely	Critical	Worker	Similar operational experience	Significant
2A.4.2 Design, build, test, and accept processing facility for immobilization of HLW	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
2A.4.3 Process calcined HLW into immobilized waste form	Frequent	Remote process failure causes calcine spill; worker must remedy.	Probable	Critical	Worker	Similar operational experience	High
		Waste deemed inappropriate for NGR[42]	Possible[43]	Critical	Worker		Significant
2A.4.4 Decommission HLW processing facilities	Occasional	Injury or radiological exposure during decommisioning	Unlikely	Critical	Worker	Similar operational experience	Significant

[42] Programmatic failure event with potential impact on other process steps

[43] Likelihood is less than that for Alternative 1 if immobilized waste form is similar to those already produced (precedents).

Table D-2A.5. Packaging, Near Term (This process is integrated with in process 2.4 for Alternative 2)

Table D-2A.6. Interim Storage of Canisters of Processed Calcined HLW, Near Term

See Table D-1A.6[44]

[44] Operational tasks relative to interim storage will be unchanged from Alternative 1, except that the facility size may need to be much larger to accommodate the waste generated during immobilization, depending on the immobilization process selected.

Table D-2A.7. Shipping of Processed Calcined HLW to Geologic Repository, Near Term

Task	**Task frequency**	**What can go wrong? (radiological and non-radiological)**	**How likely is it?**	**What is the severity of the consequences?**	**Who is the impacted population?**	**Risk evaluation basis**	**Contribution to risk**
2A.7.1 Design and test shielded shipping casks	Occasional	Injury during cask testing.	Unlikely	Marginal	Worker	Similar operational experience	Low
2A.7.2 Fabricate shielded shipping casks	Frequent	Injury during cask fabrication.	Unlikely	Marginal	Worker	Similar operational experience	Low
2A.7.3 Retrieve canisters from interim storage and load shielded shipping casks	Frequent	Injury during loading of canisters into shipping casks. Canister breaks during loading process	Possible[45] Unlikely	Critical **Marginal**[46]	Worker Worker	Similar operational experience	Significant **Low**
2A.7.4 Secure shielded shipping casks to conveyance	Frequent	Injury during the securing process.	Possible	Critical	Worker	Similar operational experience	Significant

[45] Likelihood is "possible" because of the number of canisters that will require loading/transport. In the HLW EIS estimate for direct vitrification, 12000 canisters will be required for this task (2400-12000 shipments). If existing technology was used (SNF canisters), the 4400m^3 of calcined HLW would be packaged into 1120000 canisters (assumes waste loading of 30% and packing factor of 0.6) and approximately 44800-224000 shipments would be required, depending on then number of canisters per shipment.

[46] Localized radiation exposure and no chemical migration occur because the waste is immobilized.

Alternative 2 – Retrieve and immobilize calcined HLW from bin sets; ship immobilized HLW to geologic repository
Time Frame A – near term

Task	Task frequency	What can go wrong? (radiological and non-radiological)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
2A.7.5 Transport immobilized HLW to HLW geologic repository	Frequent	Radiation exposure during transport	Possible	Critical	Worker and Off-site population	Similar operational experience	Significant
		Traffic accident occurs during transport.[47]	Unlikely[48]	Critical	Worker and Off-site Population		Significant

[47] The assumption is made that each container will be built (legally required) to withstand stresses such as dropping, bumping and impact with a vehicle (i.e., at an ungated crossing). These stresses would have to be coupled with simultaneous failure of both the cask and one or more canisters to cause a release of calcined HLW.

[48] Accident rates for transportation by train and truck are well-studied. The number of accidents depends on the number of shipments. The HLW EIS provides accident rates of $7.7x10^{-4}$ accidents/shipment and $3.5x10^{-5}$ fatalities/shipment by truck, as well as $1.0x10^{-4}$ accidents/shipment and $3.1x10^{-5}$ fatalities/shipment by train. For the HLW EIS direct vitrification scenario, up to 10 accidents may occur during transportation, probably not with any fatalities. For the existing technology scenario (SNF canisters, see previous note on number of shipments), 4-172 accidents may occur with 2-8 potential fatalities. Scenario will differ for other immobilization processes.

Table D-2A.8. Internment of Calcined HLW at HLW Geologic Repository, Near Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
2A.8.1 Off-load calcined remote-handled shielded casks	Frequent	Injury during offloading process.	Possible	Critical	Worker	Similar operational experience	Significant
		Cask is dropped during unloading.	Unlikely[49]	Critical	Worker		Significant
2A.8.2 Inter calcined HLW in shielded casks into HLW geologic repository	Frequent	Cask is dropped during handling.	Unlikely	Critical	Worker	Similar operational experience	Significant

[49] The number of casks varies from 1200 to 80000 depending on the transportation scenario (assuming 1 cask/shipment, see Table D-1A.7 for information on the number of shipments). A large number of task implementations multiplied by a low probability of accidents yields some number of failure events taking place.

Alternative 2 – Retrieve and immobilize calcined HLW from bin sets; ship immobilized HLW to geologic repository
Time Frame B – intermediate term

Table D-2B.1. Bin Sets Storage, Intermediate Term

See Table D-1B.1.

Table D-2B.2. Characterization of Calcined HLW for Processing and Immobilized Waste Form for Disposal, Intermediate Term

See Table D-2A.2

Table D-2B.3. Retrieval of Calcined HLW from Bin Sets, Intermediate Term

See Table D-1A.3[50]

[50] Difficulty of retrieval task increases with increasing time frame due to settlement, agglomeration and corrosion. Gamma radiation decay will have occurred, but alpha and beta radiation sources remain hazardous because the inhalation pathway remains.

Table D-2B.4. Processing Immobilized HLW into Canisters, Intermediate Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
2B.4.1 Design, test, and build canisters to package immobilized HLW	Frequent	Injury during canister fabrication	Unlikely	Critical	Worker	Similar operational experience	Significant
2B.4.2 Design, build, test, and accept processing facility for immobilization of HLW	Occasional	Injury during facility construction	Possible	Critical	Worker	Similar operational experience	Significant
2B.4.3 Process calcined HLW into immobilized waste form	Frequent	Remote process failure causes calcine spill; worker must remedy.	Probable	Critical	Worker	Similar operational experience	High
		Waste form deemed inappropriate for NGR	**Unlikely**	**Marginal**	Worker		**Low**[51]
2B.4.4 Decommission HLW processing facilities	Occasional	Injury or radiological exposure during decommissioning	Unlikely	Critical*	Worker and Off-site population	Similar operational experience	Significant

[51] Waste acceptance criteria for the NGR should be in place by the intermediate time frame, so process changes to meet those criteria can be made before operation begins. This failure event no longer has significant impact on other process steps.

Table D-2B.5. Packaging, Intermediate Term (This process is integrated with in process 2.4 for Alternative 2)

Table D-2B.6. Interim Storage of Canisters of Processed Calcined HLW, Intermediate Term

Task	Task frequency	What can go wrong? (radiological and non-radiological incidents)	How likely is it?	What is the severity of the consequences?	Who is the impacted population?	Risk evaluation basis	Contribution to risk
2B.6.1 Design and Build Interim Storage Facilities	Occasional	Injury during construction activities.	Possible	Critical	Worker	Similar operational experience	Significant
2B.6.2 Operate Interim Storage Facility	Frequent	Injury during storage facility operation.	Possible	Critical	Worker	Similar operational experience	Significant
		Canister breeched during storage.	Unlikely	**Marginal**[52]	Worker		**Low**
		Radiation exposure during storage.	Possible	Critical	Worker		Significant
		Delay in shipping causes increased storage duration	Unlikely	**Marginal**[53]	Worker		**Low**
2B.6.3 Decommission interim storage facility	Occasional	Injury or radiation exposure during decommissioning.	Unlikely	Critical[54]	Worker	Similar operational experience	Significant

[52] Waste form is immobilized and gamma decay reduces the severity of radiation exposure in this scenario.

[53] Gamma decay reduces the severity of increased radiation exposure during excess storage.

[54] Gamma decay reduces the severity of the radiation exposure, but the possibility of injury during decommissioning remains unchanged.

Table D-2B.7. Shipping of Processed Calcined HLW to Geologic Repository, Intermediate Term

See Table D-2A.7

Table D-2B.8. Interment of Processed Calcined HLW at HLW Geologic Repository, Intermediate Term

See Table D-2A.8

Table D-2C.1. Bin Sets Storage, Long Term

See Table D-1C.1

Table D-2C.2. Characterization of Calcined HLW for Processing and Immobilized Waste Form for Disposal, Long Term

See Table D-2A.2[55]

Table D-2C.3. Retrieval of Calcined HLW from Bin Sets, Long Term

See Table D-1A.3[56]

Table D-2C.4. Processing Immobilized HLW into Canisters, Long Term

See Table D-2A.4

Table D-2C.5. Packaging, Long Term (This process is integrated with in process 2.4 for Alternative 2)

Table D-2C.6. Interim Storage of Canisters of Processed Calcined HLW, Long Term

See Table D-2B.6

Table D-2C.7. Shipping of Processed Calcined HLW to Geologic Repository, Long Term

See Table D-2A.7

Table D-2C.8. Internment of Calcined HLW at HLW Geologic Repository, Long Term

See Table D-2A.8

[55] Substantial gamma radiation decay has occurred, but the inhalation pathway remains for the alpha and beta emitters. Risks remain unchanged.

[56] Substantial gamma radiation decay has occurred, but the inhalation pathway remains for the alpha and beta emitters. The retrieval task becomes more difficult over time, as settling and agglomeration increase.

Alternative 3 – Store calcined HLW in current bin sets long-term
Time Frame A – near term

Table D-3A.1. Bin Sets Storage, Near Term

See Table D-1A.1

Table D-3A.2. Characterization, Near Term (Not Applicable to Alternative 3)

Table D-3A.3. Retrieval, Near Term (Not Applicable to Alternative 3)

Table D-3A.4. Processing, Near Term (Not Applicable to Alternative 3)

Table D-3A.5. Packaging, Near Term (Not applicable for Alternative 3)

Table D-3A.6. Interim Storage, Near Term (Not Applicable to Alternative 3)

Table D-3A.7. Shipping, Near Term (Not Applicable to Alternative 3)

Table D-3A.8. Internment, Near Term (Not Applicable to Alternative 3)

Alternative 3 – Store calcined HLW in current bin sets long-term
Time Frame B – intermediate term

Table D-3B.1. Bin Sets Storage, Intermediate Term

See Table D-1B.1

Table D-3B. 2. Characterization, Intermediate Term (Not Applicable to Alternative 3)

Table D-3B.3. Retrieval, Intermediate Term (Not Applicable to Alternative 3)

Table D-3B.4. Processing, Intermediate Term (Not Applicable to Alternative 3)

Table D-3B.5. Packaging, Intermediate Term (Not applicable for Alternative 3)

Table D-3B.6. Interim Storage, Intermediate Term (Not Applicable to Alternative 3)

Table D-3B.7. Shipping, Intermediate Term (Not Applicable to Alternative 3)

Table D-3B.8. Internment, Intermediate Term (Not Applicable to Alternative 3)

Alternative 3 – Store calcined HLW in current bin sets long-term
Time Frame C – long term

Table D-3C.1 Bin Sets Storage, Long Term

See Table D-1C.1

Table D-3C.2. Characterization, Long Term (Not Applicable to Alternative 3)

Table D-3C.3. Retrieval, Long Term (Not Applicable to Alternative 3)

Table D-3C.4. Processing, Long Term (Not Applicable to Alternative 3)

Table D-3C.5. Packaging, Long Term (Not applicable for Alternative 3)

Table D-3C.6. Interim Storage, Long Term (Not Applicable to Alternative 3)

Table D-3C.7. Shipping, Long Term (Not Applicable to Alternative 3)

Table D-3C.8. Internment, Long Term (Not Applicable to Alternative 3)

APPENDIX E: GAP ANALYSIS

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List of Tables

Alternative 1

Alternative 2

Alternative 3

Introduction

Hazard and gap analysis tables are provided as part of this report, which evaluates the various calcined HLW disposition alternatives at the Idaho Site. This report provides a *framework* for assessing risks associated with the various remedial alternatives investigated; however, the document provides neither quantitative risk estimates nor recommendations for remedial alternatives. The approach here provides the ability to categorize, at least qualitatively, the known hazards and gaps pertaining to the remedial alternatives considered. Although there is not likely to be unanimous agreement on any set of definitions, a common basis for assessing the tasks in question is essential—this is an attempt to provide such a basis. Furthermore, these definitions allow reviewers to "mean the same thing" when generic terms such as "*low*" or "*high*" are used even though precise values cannot be placed on the risks or gaps. The intent of this report is to provide a *framework* for assessing risks and not to provide quantitative risk estimates. These categories are subject to change as further knowledge is obtained.

The process steps that are relevant to each Alternative in the gap analysis are shown in Table E-1.

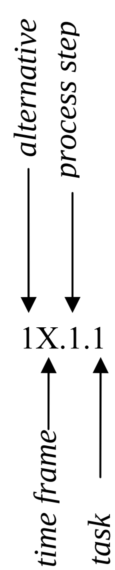
Notation

Each gap table has information related to all three time frames under consideration, as indicated by the X in the heading, where X corresponds to time frame A, B or C. In the table, gaps are listed under the time frame A. If the nature of that gap changes for time frame B or time frame C, that gap is repeated and *italicized* next to the appropriate time frame. A gap that is relevant to a time frame other than time frame A is listed next to the appropriate time frame in normal font. If a gap is listed only under time frame A, then it is relevant to all time frames (A, B and C).

Table E-1. Process Steps in Each Gap Analysis

	Alternative 1			Alternative 2			Alternative 3		
Process Step Description	Time Frame A	Time Frame B	Time Frame C	Time Frame A	Time Frame B	Time Frame C	Time Frame A	Time Frame B	Time Frame C
1. Bin Sets Storage	√	√	√	√	√	√	√	√	√
2. Characterization of Calcined HLW for Processing and Immobilized Waste Form for Disposal	√	√	√	√	√	√			
3. Retrieval of Calcined HLW from Bin Sets	√	√	√	√	√	√			
4. Processing Immobilized HLW into Canisters				√	√	√			
5. Packaging of Calcined HLW into Canisters	√	√	√						
6. Interim Storage of Canisters of Calcined HLW	√	√	√	√	√	√			
7. Shipping of Calcined HLW to HLW Geologic Repository	√	√	√	√	√	√			
8. Internment of Calcined HLW at HLW Geologic Repository	√	√	√	√	√	√			

Numbering scheme



Alternatives
1 – Retrieve, package, ship
2 – Retrieve, immobilize, package, ship
3 – Store in place

Time Frames (X=)
A – near term
B – intermediate term
C – long term

ALTERNATIVES

Alternative 1: The calcined HLW will be retrieved from the bin sets, packaged without physical or chemical modification, stored temporarily on-site or off-site and shipped to a HLW geologic repository for permanent internment. This management option will be considered for three time frames.

Alternative 2: The calcined HLW will be retrieved from the bin sets, processed (e.g., separations, immobilization and/or other processes), stored temporarily on-site or off-site, shipped to a HLW geologic repository for permanent internment. This management option will be considered for the same three time frames as described for Alternative 1.

Alternative 3: The calcined HLW will continue to be stored in the current bin sets for the period that allows contact handling instead of remote handling based on sufficient radioactive decay (approximately 300 years), with appropriate site improvements and security. This alternative allows for subsequent reevaluation of the waste recovery and disposal options.

TIME FRAMES

A. **Near term:** Retrieval and processing or packaging will be initiated in the near term, within 10-50 years[57], independent of availability of a geologic repository and associated waste acceptance criteria.

B. **Intermediate term:** Retrieval and processing or packaging will be initiated once a geologic repository is open, such that the waste acceptance criteria and acceptance schedule allow for "just in time" processing (e.g., after 50 years).

C. **Long term:** Retrieval and processing or packaging will be initiated in the future, after approximately 10 half lives of reduction of the specific activity of the high energy fission products in the calcined wastes has been achieved (e.g., after 300 years).

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[57] Specified time periods are used for example purposes. The intermediate term may begin sooner than 50 years, depending on the availability of a final disposition pathway for the calcined HLW.

Gap Analysis Definitions

The information that is available concerning the necessary tasks, process steps, and alternatives must be categorized to describe the importance each has to protecting human health and the environment. To that end, the information that is not available but is important to protecting human health must be identified and categorized as well. A set of information gap tables has been provided in the pages that follow, analogous to the hazard analysis tables in Appendix D. In the gap analysis tables, column heading definitions were standardized. These columns are

- How important [is the gap]?
- How large a gap?

Other columns are considered self-explanatory. It is realized that there is not likely to be unanimous agreement on any set of definitions for the gap analysis tables; nonetheless, a common basis is necessary for assessing the tasks in question.

A set of definitions for categorizing information gaps is provided in Table E-2. The gaps are considered important because of their ability to jeopardize human health, the environment, or security. Using the categorizations provided in Table E-2 allows the most important information gaps to be identified for summary in the main body in this report. There is not necessarily a one-to-one correspondence between hazards analysis tables and the gap analysis tables; the gap analysis tables include consideration of human health risks as well as programmatic risks.

Table E-2. Definitions for Gap Analysis Tables

How Important (a Gap)?

Critical: Lack of this piece of knowledge is sufficient to provide a high degree of uncertainty in the ability to assess the threat to human health (both worker and the general public), the environment (both on-site and off-site), and/or security; i.e., result in a critical or severe hazard (as defined in Table D-1).

Important: Possession of this knowledge is important to the ability to assess the threat to human health (both worker and the general public), the environment (both on-site and off-site), and/or security. Other information must be lacking to the ability to assess the threat to human health and the environment."

Inconsequential: This knowledge may have localized significance to non-safety-related activities (including routine maintenance, repair, etc.).

Low large a Gap? (Magnitude of Gap or Level of Knowledge)

Large: Little is known or can be reasonably inferred concerning this piece of information (from other sources of information).

Intermediate: Incomplete information is available concerning this piece of information or can only be inferred from other data not necessarily directly related to the missing piece of information.

Small: Nearly complete information is available concerning this piece of information or an adequate, well-known analogue can be established.

Table E-3. Example Information Contribution-Assessment Matrix

		How large a Gap?		
		Large	**Intermediate**	**Small**
Importance	**Critical**	Safety Critical	Safety Significant	Safety Insignificant
	Important	Safety Significant	Safety Significant	Safety Insignificant
	Inconsequential	Safety Insignificant	Safety Insignificant	Safety Insignificant

Alternative 1 – Retrieve, repackage and ship calcined HLW to geologic repository

Table E-1X.1 Bin Sets Storage

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.1.1 Management of Bin Set Storage (planning, security, interface with stakeholders, long-term stewardship)	Appropriate regulatory permits for management and storage	Important	Interm.	eg., RCRA Part B permit not obtained, but may be required. Bin sets are currently operating under the interim status granted by a Part A application.
	Budget planning and adequate funding for stewardship	Critical	Large	
1B.1.1	Security enhancement recommendations or requirements	Important	Small	
	Security enhancement recommendations or requirements	Critical	Interm.	Amount of knowledge required for this task increases with increasing time frame.
1C.1.1	Expected lifetime of bin sets, potential modes of failure.	Critical	Interm.	Design documents describe a bin set lifetime of 100 years. NRC (1999) describes a bin set lifetime of 500+ years. Seismic certification for beyond 100 years?
	Security enhancement recommendations or requirements	Critical	Large	Amount of knowledge required for this task increases with increasing time frame.
	Technology for transfer of calcine from bin set 1 to bin set 6 or 7	Critical	Interm.	As described in the No Action Alternative in the HLW EIS.
1A.1.2 Routine monitoring and inspection	Adequacy of the monitoring plan	Important	Interm.	
1A.1.3 Preventive maintenance	*Not considered*			Usually DOE does not fund this for waste storage. This is usually only included in “nuclear facilities” budgets (i.e. reactors, weapons production plants)

Alternative 1 – Retrieve, repackage and ship calcined HLW to geologic repository

Task	**What information is missing?**	**How important is it?**	**How large a gap?**	**Comments**
1A.1.4 Non-routine maintenance	Potential scenarios for non-routine maintenance (e.g., berm replacement)	Important	Large	
1A.1.5 Repair	Potential scenarios for repair	Important	Large	Repairs are performed on a "run-to-failure" basis. Scheduled maintenance is minimal.
1B.1.5	*Potential scenarios for repair*	Critical	*Large*	"Run to failure" does not seem appropriate
1A.1.6 Decommission of Bin Sets	Method of decommissioning the bin sets	Critical	Large	HLW EIS describes several alternatives, but does not determine the actual method of accomplishment nor provide a detailed analysis sufficient to evaluate risk to human health and the environment.
	Disposition of bin sets and relevant equipment to be in-situ, on-site, or off-site	Important	Interm.	
	Amount of calcine remaining in the bins after removal; amount that would be acceptable.	Critical	Large	
	How to determine the amount of calcine remaining (i.e., incidental waste)	Critical	Interm.	
	Disposition (e.g., grouting) of incidental waste during decommissioning	Important	Interm.	West Valley and SRS have experience in grouting incidental tank wastes.
	Estimates of exposure to workers and general public for different scenarios (including release/transport/exposure mechanisms)	Critical	Interm.	Reasonable assumptions can be made to provide "bad case" scenarios.
	Regulatory requirements related to bin set closure	Important	Large	

Table E-1X.2. Characterization of Calcined HLW

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.2.1 Review existing documentation and supplement as needed	Composition and distribution of calcine	Critical	Large	Existing information has been derived from thermodynamic modeling of the likely composition of different batches of spent nuclear fuel.Two characterization samples were collected (1979 and 1993). The waste is expected to be highly heterogeneous, so the samples should not be considered representative. Sampling may be required during packaging.
1A.2.2 Create evidence packages or other waste acceptance documents	Waste acceptance criteria for the national geologic repository.	Critical	Large	Waste acceptance criteria for the national geologic repository do not exist. Waste acceptance criteria will impact future process steps.
1A.2.3 Refine conceptual site models	Appropriate exposure pathway scenarios	Important	Interm.	Some pathways have been excluded (i.e., water-borne) because the evaluation did not consider long-term scenarios.

Table E-1X.3. Retrieval of Calcined HLW from Bin Sets

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.3.1 Design, fabricate, install calcined HLW remote-handled retrieval device (multiple bin installation)	Specific information about the retrieval system and associated risks	Critical	Large	One technology has passed a "proof-of-concept" test in 1978. An assumption has been made that the removal system is likely to be pneumatic, but many design challenges such as air filtration or ensuring complete recovery of all calcine from the bins have not been considered.
	Effectiveness of retrieval method	Critical	Large	
	Definition of requirements	Critical	Large	
	Pilot testing	Critical	Large	
1A.3.2 Remove 4,400 m^3 of Remote-Handled Calcined HLW from Bin Sets	Method of removal	Critical	Large	The assumption is that removing the material from the bins is essentially like putting the material into the bins; however, removing material remotely has a significantly higher level of difficulty because of settling and agglomeration.
	Adequate dose information (historical operational records)	Critical	Interm.	
	Moisture issues	Critical	Large	In the "proof-of-concept" test, moisture had a significant effect on calcine removal, especially with the alumina type. Over 25 years have passed since that test. How much more severe will the problem with moisture be?

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.3.3 Decommission calcined HLW removal equipment	Method of decommisioning removal equipment	Important	Interm.	The retrieval process will not be 100% efficient. Amount of remaining calcine should be determined based on risk.
	Disposition to be in-situ, on-site, or off-site	Important	Interm.	Would the decommissioning process be carried out remotely?
	Equipment contamination levels; amount that would be acceptable.	Critical	Large	
	Evaluation of exposure to workers and general public for different alternatives.	Important	Interm.	Estimates should be possible for bad case examples.
	Regulatory requirements related to decommissioning	Important	Large	

Table E-1X.4. Processing (Not Applicable to Alternative 1)

Table E-1X.5. Packaging of Calcined HLW into Canisters

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.5.1 Design, build, test and accept **canisters** to package remote-handled calcined HLW	Proof of inter-operability of canisters, transportation casks and interim storage configuration.	Important	Interm.	Design of the canister system needs to begin at the storage activity, then the shipping activity, and finally the canister packaging activity to ensure interoperability of the end members of the calcine waste life cycle. This is especially important for remote-handled packaging.
	Transportation requirements for packages	Critical	Interm.	Appropriateness (availability, design, number of shipments) of conveyances needs to be assessed.
	Waste form and packaging acceptance criteria	Critical	Large	NGR does not exist; waste form may not be acceptable.
1B.5.1	*Waste form and packaging acceptance criteria*	*Critical*	Small	NGR criteria should exist prior to facility and package construction. Process changes can be made.

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.5.2 Design, build, test and accept calcined HLW remote-handled **packaging facilities**	Design concepts for a packaging facility	Critical	Large	Dose and other risk analyses are not possible at this time.
	Packaging facility requirements	Critical	Large	Package requirements are not defined. Facility safety and throughput have not been considered.
	Method of packaging	Critical	Large	Needed for design and risk evaluation.
1B.5.2	*Packaging facility requirements*	Critical	Small	NGR criteria and schedule should exist prior to facility and package construction. Facility safety and throughput can be based on the transportation schedule.
1A.5.3 Package 4,400 m^3 of remote-handled calcined HLW	Effectiveness of packaging process?	Critical	Large	
	Package/conveyance availability	Important	Interm.	Process upsets affect throughput and/or interim storage.
	Method of transportation to interim storage facility	Important	Interm.	
1A.5.4 Decommission calcined HLW packaging facilities and equipment	Method of accomplishment	Important	Interm.	
	Disposition of packaging equipment to be in-situ, on-site, or off-site	Important	Interm.	
	Residual contamination in the packaging facility; amount that would be acceptable.	Critical	Large	
	Disposition of waste during decommissioning	Important	Interm.	
	Evaluation of exposure to workers and general public	Important	Interm.	Estimates should be possible for "bad case" scenarios
	Regulatory requirements for decommissioning packaging equipment	Important	Large	

Table E-1X.6. Interim Storage of Canisters of Calcined HLW

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.6.1 Design and Build Interim Storage Facilities	Information about the storage facility (type of facility, method of storage, shielding, safeguards, etc)	Critical	Interm.[58]	Design of the interim storage system needs to compatible with the canister packaging activity to ensure interoperability. This is especially important for remote-handled packaging and interim storage activities.
	Design lifetime of facility			Design lifetime can be short (eg., if repository begins accepting waste during the packaging process), or can be very long (eg., if shipment to the repository is delayed or if the waste form is rejected according to the waste acceptance criteria).
	Amount of waste to be stored	Critical	Interm.	Will entire contents of bins be packaged and stored? Or, will the Yucca Mountain facility open and begin accepting these waste packages before packaging has been completed?
1B.6.1	*Amount of waste to be stored*	*Critical*	*Interm.*	"Just in time" packaging may enable a smaller interim storage facility and may reduce worker risks.

[58] Assume the Idaho Site and other sites have experience with constructing storage facilities for waste canisters.

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.6.2 Operate Interim Storage Facility	Storage facility configuration	Important	Interm.[59]	This information is needed to evaluate dose to workers and identify potential operational risks for evaluation. One analog that might be used in the risk evaluation of interim storage of packaged calcined HLW is the repackaging of unclad spent nuclear fuel.
	Lifetime of facility	Important	Interm.[60]	
	NGR schedule for waste acceptance	Critical	Large	Premature packaging may result in prolonged interim storage if the NGR is not prepared to accept the waste.
1B.6.2	*NGR schedule for waste acceptance*	*Critical*	Small	NGR should be in place, allowing for "just in time" packaging and brief interim storage on site.
1A.6.3 Decommission interim storage facility	Method of decommissioning	Important	Interm.[61]	Evaluation of exposure to workers and general public for different alternatives
	Residual waste in the facility; amount that would be acceptable	Important	Interm.	Waste present in facility would be the result of accidental release(s).

[59] ibid
[60] ibid
[61] ibid

Table E-1X.7. Shipping of Calcined HLW to HLW Geologic Repository

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.7.1 Design and test shielded shipping casks	Proposed configuration for the canister/shipping cask system	Important	Interm.	Idaho Site HLW EIS discusses shipments for several waste disposition alternatives, but doesn't use existing containers or casks in their discussion.
	Amount per shipment; amount NGR will accept per shipment	Critical	Interm.	Idaho Site HLW EIS describes transportation scenarios including shipment amounts, but the absence of finalized waste criteria and schedule for the NGR maintain this gap.
	Number of shipping casks	Critical	Interm.	Number of shipments and shipment frequency will determine the number of casks.
1A.7.2 Fabricate shielded shipping casks	Specific cask fabrication tasks[62]	Important	Small	A lot of work has been done on what the requirements should be; standards already exist for spent fuel and TRU waste.
1A.7.3 Retrieve canisters from interim storage and load shielded shipping casks	Proposed configuration for the canister/shipping cask system[63]	Important	Interm.	
	Proposed loading process	Important	Small	Analogs with spent fuel and TRU waste
	Schedule for retrieval/loading	Important	Large	NGR waste acceptance schedule not established

[62] Have other sites published sufficient information about cask fabrication for a risk assessment?

[63] Gap is repeated in this and subsequent tasks because configuration would factor into risk assessment for these tasks.

Alternative 1 – Retrieve, repackage and ship calcined HLW to geologic repository

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.7.4 Secure shielded shipping casks to conveyance	Proposed configuration for the canister/shipping cask system	Important	Interm.	
	Worker tasks required for securing shipping casks	Important	Small	Analogs with spent fuel and TRU waste
1A.7.5 Transport Calcined HLW to HLW geologic repository	Proposed configuration for the canister/shipping cask system	Important	Interm.	
	Schedule for NGR	Critical	Large	
	Composition/activity per shipment	Critical	Large	
	Number of shipments	Critical	Large	Idaho Site HLW EIS discusses transportation scenarios; however, given the absence of waste acceptance criteria for the NGR as well as composition information and package configuration, the data are insufficient.
1B.7.5	*Schedule for NGR*	*Critical*	Small	In the intermediate time frame, specific information about the geologic repository acceptance criteria and schedule will be known, so determining this information during process planning will be possible.
	Composition/activity per shipment	*Critical*	Small	
	Number of shipments	*Critical*	Small	

Table E-1X.8. Internment of Calcined HLW at HLW Geologic Repository

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.8.1 Off-load calcined remote-handled shielded casks	Conceptual shielded transportation cask system Estimation of handling risks and worker dose during off-loading	Important Critical	Interm. Interm.	Operating experience at the Nevada Test Site may be useful in evaluating operational risks.
1A.8.2 Inter calcined HLW in shielded casks into HLW geologic repository	Model predictions of calcine behavior in NGR	Critical	Large	The waste forms discussed for Yucca Mountain are spent nuclear fuel encased in canisters and liquid HLW that has been vitrified and encased in canisters. The calcined HLW is not analogous to either of these waste forms.[64] Current work at Idaho Site is underway to determine the appropriateness of the packaged waste form for internment at the Yucca Mountain facility.

[64] DOE/RW-0539 Yucca Mountain Science and Engineering Report, May 2001

Table E-2X.1. Bin Sets Storage

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.1.1 Management of Bin Set Storage (planning, security, interface with stakeholders, long-term stewardship)	Appropriate regulatory permits for management and storage	Important	Interm.	eg., RCRA Part B permit not obtained, but may be required. Bin sets are currently operating under the interim status granted by a Part A application.
	Budget planning and adequate funding for stewardship	Critical	Large	
	Security enhancement recommendations or requirements	Important	Small	
2B.1.1	*Security enhancement recommendations or requirements*	Critical	Interm.	Amount of knowledge required for this task increases with increasing time frame.
	Expected lifetime of bin sets, potential modes of failure.	Critical	Interm.	Design documents describe a bin set lifetime of 100 years. NRC (1999) describes a bin set lifetime of 500+ years. Seismic certification for beyond 100 years?
2C.1.1	*Security enhancement recommendations or requirements*	Critical	Large	Amount of knowledge required for this task increases with increasing time frame.
	Technology for transfer of calcine from bin set 1 to bin set 6 or 7	Critical	Interm.	As described in the No Action Alternative in the HLW EIS.
2A.1.2 Routine monitoring and inspection	Adequacy of the monitoring plan	Important	Interm.	

Alternative 2 – Retrieve, immobilize, package and ship calcined HLW to geologic repository

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.1.3 Preventive maintenance	*Not considered*			Usually DOE does not fund this for waste storage. This is usually only included in "nuclear facilities" budgets (i.e. reactors, weapons production plants)
2A.1.4 Non-routine maintenance	Potential scenarios for non-routine maintenance (e.g., berm replacement)	Important	Large	
2A.1.5 Repair	Potential scenarios for repair	Important	Large	Repairs are performed on a "run-to-failure" basis. Scheduled maintenance is minimal.
2B.1.5	*Potential scenarios for repair*	Critical	*Large*	"Run to failure" does not seem appropriate
2A.1.6 Decommission of Bin Sets	Method of decommissioning the bin sets	Critical	Large	HLW EIS describes several alternatives, but does not determine the actual method of accomplishment nor provide a detailed analysis sufficient to evaluate risk to human health and the environment.
	Disposition of bin sets and relevant equipment to be in-situ, on-site, or off-site	Important	Interm.	
	Amount of calcine remaining in the bins after removal; amount that would be acceptable.	Critical	Large	
	How to determine the amount of calcine remaining (i.e., incidental waste)	Critical	Interm.	
	Disposition (e.g., grouting) of incidental waste during decommissioning	Important	Interm.	West Valley and SRS have experience in grouting incidental tank wastes.
	Estimates of exposure to workers and general public for different scenarios (including release/transport/exposure mechanisms)	Critical	Interm.	Reasonable assumptions can be made to provide "bad case" scenarios.
	Regulatory requirements related to bin set closure	Important	Large	

Table E-2X.2. Characterization of Calcined HLW for Processing and Immobilized Waste Form for Disposal

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.2.1 Review existing documentation and supplement as needed	Composition and distribution of calcine	Critical	Large	Existing information has been derived from thermodynamic modeling of the likely composition of different batches of spent nuclear fuel. Two characterization samples were collected (1979 and 1993). The waste is expected to be highly heterogeneous, so the samples should not be considered representative.
2A.2.2 Characterize batches for processing	Method of accomplishment	Critical	Large	Method determines worker exposure during sampling/testing.
	Feedback ability of sample results to waste processing procedure	Critical	Interm.	Other sites have done this for different waste forms, so although the plans for calcine immobilization are immature, other process analogs may exist for risk evaluation purposes.
2A.2.3 Characterize final waste form for use in evidence packages or other waste acceptance documents	Waste acceptance criteria for the national geologic repository	Critical	Large	Waste acceptance criteria will impact future process steps
2A.2.4 Refine conceptual site models	Appropriate exposure pathway scenarios	Important	Interm.?	Some pathways have been excluded (i.e., water-borne) because the evaluation did not consider long-term scenarios

Table E-2X.3. Retrieval of Calcined HLW from Bin Sets

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.3.1 Design, fabricate, install calcined HLW remote-handled retrieval device (multiple bin installation)	Specific information about the retrieval system and associated risks	Critical	Large	One technology has passed a “proof-of-concept” test in 1978. An assumption has been made that the removal system is likely to be pneumatic, but many design challenges such as air filtration or ensuring complete recovery of all calcine from the bins have not been considered.
	Effectiveness of retrieval method	Critical	Large	
	Definition of requirements	Critical	Large	
	Pilot testing	Critical	Large	
2A.3.2 Remove 4,400 m^3 of Remote-Handled Calcined HLW from Bin Sets	Method of removal	Critical	Large	The assumption is that removing the material from the bins is essentially like putting the material into the bins; however, removing material remotely has a significantly higher level of difficulty because of settling and agglomeration.
	Adequate dose information (historical operational records)	Critical	Interm.	
	Moisture issues	Critical	Large	In the “proof-of-concept” test, moisture had a significant effect on calcine removal, especially with the alumina type. Over 25 years have passed since that test. How much more severe will the problem with moisture be?

Alternative 2 – Retrieve, immobilize, package and ship calcined HLW to geologic repository

Task	**What information is missing?**	**How important is it?**	**How large a gap?**	**Comments**
2A.3.3 Decommission calcined HLW removal equipment	Method of decommisioning removal equipment	Important	Interm.	The retrieval process will not be 100% efficient. Amount of remaining calcine should be determined based on risk.
	Disposition to be in-situ, on-site, or off-site	Important	Interm.	Would the decommissioning process be carried out remotely?
	Equipment contamination levels; amount that would be acceptable.	Critical	Large	
	Evaluation of exposure to workers and general public for different alternatives.	Important	Interm.	Estimates should be possible for bad case examples.
	Regulatory requirements related to decommissioning	Important	Large	

Table E-2X.4. Processing Immobilized HLW into Canisters

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.4.1 Design, test, and build **canisters** to package immobilized HLW	Proof of inter-operability of canisters, transportation casks and interim storage configuration.	Important	Interm.	Design of the canister system needs to begin at the storage activity, then the shipping activity, and finally the canister packaging activity to ensure interoperability of the end members of the calcine waste life cycle. This is especially important for remote-handled packaging.
	Transportation requirements for packages	Critical	Interm.	Appropriateness (availability, design, number of shipments) of conveyances needs to be assessed.
2A.4.2 Design, build, test, and accept processing **facility** for immobilization of HLW	Conceptual designs for an immobilization process and facility	Critical	Large	Dose and other risk analyses are not possible at this time.
	Immobilization process requirements	Critical	Large	Package requirements are not defined. Facility safety and throughput have not been considered.
	Waste acceptance criteria for the national geologic repository	Critical	Interm.	Immobilized calcine meets the preliminary criteria in the regulations (10CFR60, 10CFR63)
	Pilot testing	Critical	Large	
2B.4.2	*Waste acceptance criteria for the national geologic repository*	*Critical*	Small	NGR criteria should exist prior to facility and package construction. Process changes can be made.

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.4.3 Process calcined HLW into immobilized waste form	Unknown immobilization form prevents risk assessment	Critical	Large	West Valley, SRS and Hanford have processes that may be analogous
	Specific process task information (eg., dissolution of batches of calcine in water or nitric acid, processing vessel (separations processes), (post-treatment) processing, packaging)	Critical	Large	
	Effectiveness of immobilization and packaging processes	Critical	Large	
	Package/conveyance availability	Important	Interm.	
	Method of transportation to interim storage facility	Important	Interm.	
2A.4.4 Decommission HLW processing facilities	Method of decommissioning of processing facility	Critical	Interm.	Evaluation of exposure to workers and general public for different alternatives
	Disposition of immobilization process components to be in-situ, on-site, or off-site	Important	Interm.	
	Residual contamination in the processing facility; amount that would be acceptable.	Critical	Large	
	Disposition of waste during decommissioning	Important	Interm.	
	Evaluation of exposure to workers and general public	Important	Interm.	Estimates should be possible for “bad case” scenarios.
	Regulatory requirements related to immobilization process facilities	Important	Large	

Table E-2X.5. Packaging (This process is integrated with in process 2X.4 for Alternative 2)

Table E-2X.6. Interim Storage of Canisters of Immobilized Calcine

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.6.1 Design and Build Interim Storage Facilities	Information about the storage facility (type of facility, method of storage, shielding, safeguards, etc)	Critical	Interm.[65]	Design of the interim storage system needs to compatible with the canister packaging activity to ensure interoperability. This is especially important for remote-handled packaging and interim storage activities.
	Design lifetime of facility			Design lifetime can be short (eg., if repository begins accepting waste during the packaging process), or can be very long (eg., if shipment to the repository is delayed or if the waste form is rejected according to the waste acceptance criteria).
	Amount of waste to be stored	Critical	Interm.	Will entire contents of bins be packaged and stored? Or, will the Yucca Mountain facility open and begin accepting these waste packages before packaging has been completed?
2B.6.1	*Amount of waste to be stored*	*Critical*	*Interm.*	"Just in time" packaging may enable a smaller interim storage facility and may reduce worker risks.

[65] Assume the Idaho Site and other sites have experience with constructing storage facilities for waste canisters.

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.6.2 Operate Interim Storage Facility	Storage facility configuration	Important	Interm.[66]	This information is needed to evaluate dose to workers and identify potential operational risks for evaluation. One analog that might be used in the risk evaluation of interim storage of packaged calcined HLW is the repackaging of unclad spent nuclear fuel.
	Lifetime of facility	Important	Interm.[67]	
	NGR schedule for waste acceptance	Critical	Large	Premature packaging may result in prolonged interim storage if the NGR is not prepared to accept the waste.
2B.6.2	*NGR schedule for waste acceptance*	*Critical*	Small	NGR should be in place, allowing for "just in time" packaging and brief interim storage on site.
2A.6.3 Decommission interim storage facility	Method of decommissioning	Important	Interm.[68]	Evaluation of exposure to workers and general public for different alternatives
	Residual waste in the facility; amount that would be acceptable	Important	Interm.	Waste present in facility would be the result of accidental release(s).

[66] ibid

[67] ibid

[68] ibid

Table E-2X.7. Shipping of Immobilized Calcine to Geologic Repository

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.7.1 Design and test shielded shipping casks	Proposed configuration for the canister/shipping cask system	Important	Intermediate	Idaho Site HLW EIS discusses shipments for several waste disposition alternatives, but doesn't use existing containers or casks in their discussion.
	Amount per shipment; amount NGR will accept per shipment	Critical	Intermediate	Idaho Site HLW EIS describes transportation scenarios including shipment amounts, but the absence of finalized waste criteria and schedule for the NGR maintain this gap.
	Number of shipping casks	Critical	Intermediate	Number of shipments and shipment frequency will determine the number of casks.
1A.7.2 Fabricate shielded shipping casks	Specific cask fabrication tasks[69]	Important	Small	A lot of work has been done on what the requirements should be; standards already exist for spent fuel and TRU waste.
1A.7.3 Retrieve canisters from interim storage and load shielded shipping casks	Proposed configuration for the canister/shipping cask system[70]	Important	Intermediate	
	Proposed loading process	Important	Small	Analogs with spent fuel and TRU waste
	Schedule for retrieval/loading	Important	Large	NGR waste acceptance schedule not established

[69] Have other sites published sufficient information about cask fabrication for a risk assessment?

[70] Gap is repeated in this and subsequent tasks because configuration would factor into risk assessment for these tasks.

Alternative 2 – Retrieve, immobilize, package and ship calcined HLW to geologic repository

Task	What information is missing?	How important is it?	How large a gap?	Comments
1A.7.4 Secure shielded shipping casks to conveyance	Proposed configuration for the canister/shipping cask system	Important	Intermediate	
	Worker tasks required for securing shipping casks	Important	Small	Analogs with spent fuel and TRU waste
1A.7.5 Transport Calcined HLW to HLW geologic repository	Proposed configuration for the canister/shipping cask system	Important	Intermediate	
	Schedule for NGR	Critical	Large	
	Composition/activity per shipment	Critical	Large	
	Number of shipments	Critical	Large	Idaho Site HLW EIS discusses transportation scenarios; however, given the absence of waste acceptance criteria for the NGR as well as composition information and package configuration, the data are insufficient.
1B.7.5	*Schedule for NGR*	*Critical*	Small	In the intermediate time frame, specific information about the geologic repository acceptance criteria and schedule will be known, so determining this information during process planning will be possible.
	Composition/activity per shipment	*Critical*	Small	
	Number of shipments	*Critical*	Small	

Table E-2X.8. Internment of Immobilized Calcine at HLW Geologic Repository

Task	What information is missing?	How important is it?	How large a gap?	Comments
2A.8.1 Off-load calcined remote-handled shielded casks	Conceptual shielded transportation cask system Estimation of handling risks and worker dose during off-loading	Important Critical	Interm. Interm.	Operating experience at the Nevada Test Site may be useful in evaluating operational risks.
2A.8.2 Inter calcined HLW in shielded casks into HLW geologic repository	Model predictions of immobilized calcine behavior in NGR	Critical	Interm.	Model studies may be required to show that the immobilized waste form meets the NGR waste criteria; immobilized calcined HLW may be analogous to previously modeled wastes.

Alternative 3 – Store calcined HLW in the current bin sets

Table E-3X.1. Bin Sets Storage

Task	What information is missing?	How important is it?	How large a gap?	Comments
3A.1.1 Management of Bin Set Storage (planning, security, interface with stakeholders, long-term stewardship)	Appropriate regulatory permits for management and storage	Important	Interm.	eg., RCRA Part B permit not obtained, but may be required. Bin sets are currently operating under the interim status granted by a Part A application.
	Budget planning and adequate funding for stewardship	Critical	Large	
3B.1.1	Security enhancement recommendations or requirements	Important	Small	
	Security enhancement recommendations or requirements	Critical	Interm.	Amount of knowledge required for this task increases with increasing time frame.
3C.1.1	Expected lifetime of bin sets, potential modes of failure.	Critical	Interm.	Design documents describe a bin set lifetime of 100 years. NRC (1999) describes a bin set lifetime of 500+ years. Seismic certification for beyond 100 years?
	Security enhancement recommendations or requirements	Critical	Large	Amount of knowledge required for this task increases with increasing time frame.
	Technology for transfer of calcine from bin set 1 to bin set 6 or 7	Critical	Interm.	As described in the No Action Alternative in the HLW EIS.
3A.1.2 Routine monitoring and inspection	Adequacy of the monitoring plan	Important	Interm.	
3A.1.3 Preventive maintenance	*Not considered*			Usually DOE does not fund this for waste storage. This is usually only included in “nuclear facilities” budgets (i.e. reactors, weapons production plants)

Alternative 3 – Store calcined HLW in the current bin sets

Task	What information is missing?	How important is it?	How large a gap?	Comments
3A.1.4 Non-routine maintenance	Potential scenarios for non-routine maintenance (e.g., berm replacement)	Important	Large	
3A.1.5 Repair	Potential scenarios for repair	Important	Large	Repairs are performed on a "run-to-failure" basis. Scheduled maintenance is minimal.
3B.1.5	*Potential scenarios for repair*	Critical	*Large*	"Run to failure" does not seem appropriate
3A.1.6 Decommission of Bin Sets	Method of decommissioning the bin sets	Critical	Large	HLW EIS describes several alternatives, but does not determine the actual method of accomplishment nor provide a detailed analysis sufficient to evaluate risk to human health and the environment.
	Disposition of bin sets and relevant equipment to be in-situ, on-site, or off-site	Important	Interm.	
	Amount of calcine remaining in the bins after removal; amount that would be acceptable.	Critical	Large	
	How to determine the amount of calcine remaining (i.e., incidental waste)	Critical	Interm.	
	Disposition (e.g., grouting) of incidental waste during decommissioning	Important	Interm.	West Valley and SRS have experience in grouting incidental tank wastes.
	Estimates of exposure to workers and general public for different scenarios (including release/transport/exposure mechanisms)	Critical	Interm.	Reasonable assumptions can be made to provide "bad case" scenarios.
	Regulatory requirements related to bin set closure	Important	Large	
3A.1.7 Re-evaluate waste recovery and disposal options	Appropriate time for reevaluation.	Important	Large	Reevaluation is designated "Important" because reevaluation is not directly a safety critical task.

APPENDIX F: RISK FLOW DIAGRAMS AND CONCEPTUAL SITE MODELS

TABLE OF CONTENTS

LIST OF FIGURES

Introduction

In the pages that follow, risk flow diagrams and the associated conceptual site models are presented. The risk flow diagrams outline the steps involved in the overall process risk assessment. The first diagram is an overview leading to the three Alternatives for calcined HLW disposition. The flow of the risk assessment for each Alternative follows in separate diagrams. Conceptual site models are generalized to be appropriate for both Alternative 1 and 2, and in the case of surveillance and maintenance, Alternative 3 as well. These models are applicable for all three time frames.

The conceptual site models are used to illustrate the exposure pathways within the process steps. Where applicable, barriers are drawn to show how exposure via a certain pathway may be blocked. For example, the Administrative Controls barrier would include limitations on facility access, proper training, etc., so that only well-trained, informed workers will be carrying out the tasks at the site, thus reducing the likelihood of accidents and injuries significantly. A list of barriers including brief descriptions of the barriers follows this discussion.

ALTERNATIVES

Alternative 1: The calcined waste will be retrieved from the bin sets, packaged without physical or chemical modification, stored temporarily on-site or off-site and shipped to a HLW geologic repository for permanent internment. This management option will be considered for three time frames.

Alternative 2: The calcined waste will be retrieved from the bin sets, processed (e.g., separations, immobilization and/or other processes), stored temporarily on-site or off-site, shipped to a HLW geologic repository for permanent internment. This management option will be considered for the same three time frames as described for Alternative 1.

Alternative 3: The calcined waste will continue to be stored in the current bin sets for the period that allows contact handling instead of remote handling based on sufficient radioactive decay (approximately 300 years), with appropriate site improvements and security. This alternative allows for subsequent reevaluation of the waste recovery and disposal options.

TIMEFRAMES

A. **Near term:** Retrieval and processing or packaging will be initiated in the near term, within 10-50 years, independent of availability of a geologic repository and associated waste acceptance criteria
B. **Intermediate term:** Retrieval and processing or packaging will be initiated once a geologic repository is open, such that the waste acceptance criteria and acceptance schedule allow for “just in time” processing (e.g., after 50 years).
C. **Long term:** Retrieval and processing or packaging will be initiated in the future, after approximately 10 half lives of reduction of the specific activity of the high energy fission products in the calcined wastes has been achieved (e.g., after 300 years).

List of Barriers

1. Administrative Controls. Limited worker access to facilities/activities and adequate worker training can prevent or reduce worker injuries, chemical exposure and radiation exposure.

2. Engineering Controls. Physical barriers (fences, reinforcement of structures, etc.) can prevent or reduce worker injuries, chemical exposure and radiation exposure.

3. Spill Response and Cleanup. Prompt remedial action can prevent or reduce migration of calcined HLW into the subsurface in the event of a release.

4. Water Use Restrictions. Downgradient restrictions on water use, if followed, can block certain exposure pathways to the general population.

5. Air Pollution Controls. Air pollution controls are expected components of both the packaging and immobilization facilities designs.

6. Waste Form. The immobilized waste form acts as a barrier to release and/or transport. This barrier would not be applicable to the packaged waste form.

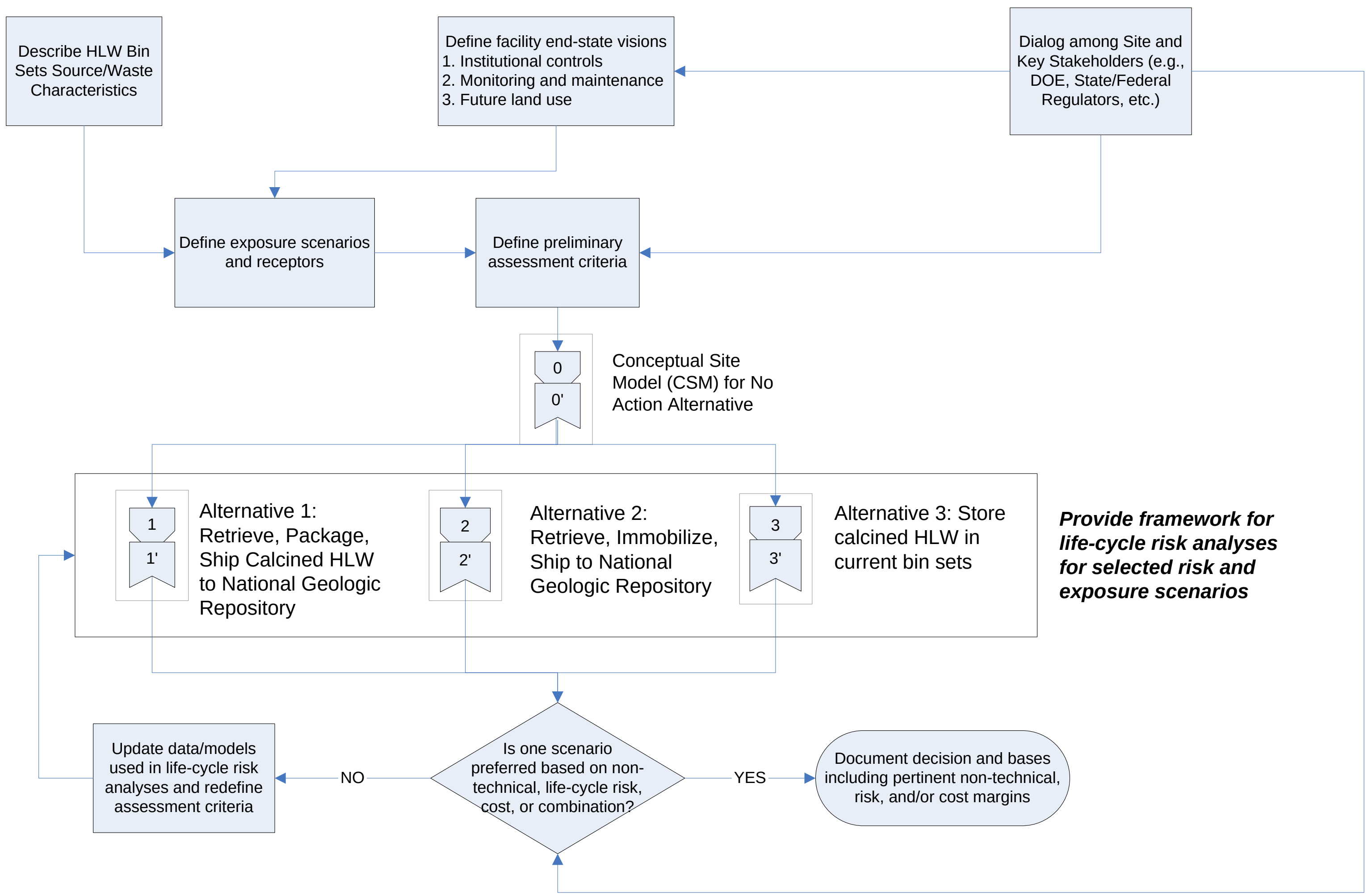


Figure F-1. Overall risk flow diagram for the calcined HLW bin sets.

Alternative 1

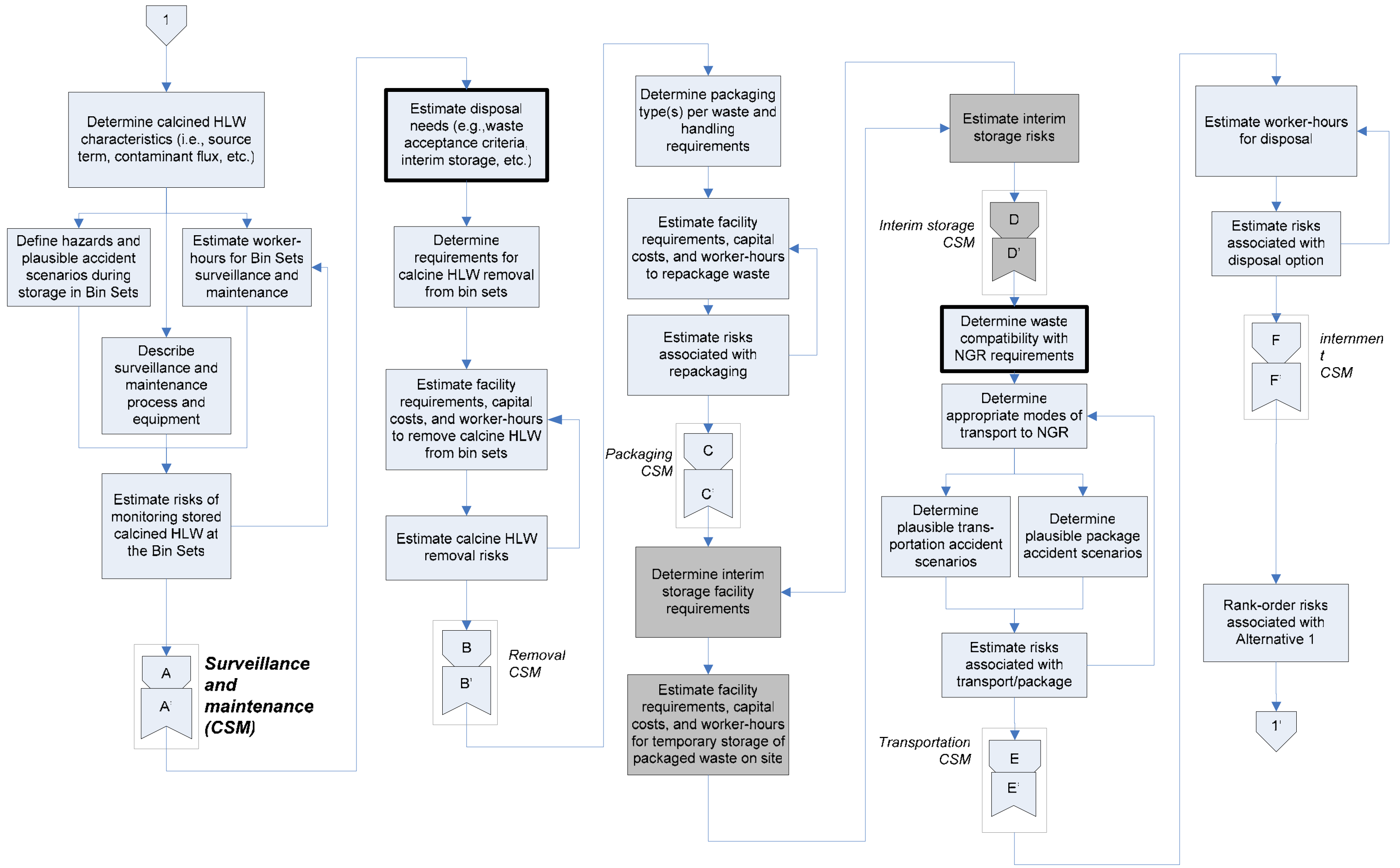


Figure F-2. Risk flow diagram for Alternative 1 (Retrieve/Package/Ship). Deviation points from Time Frame A to either B or C are the boxes with bold outline and the risk flow events that are impacted are highlighted by the dark grey shading.

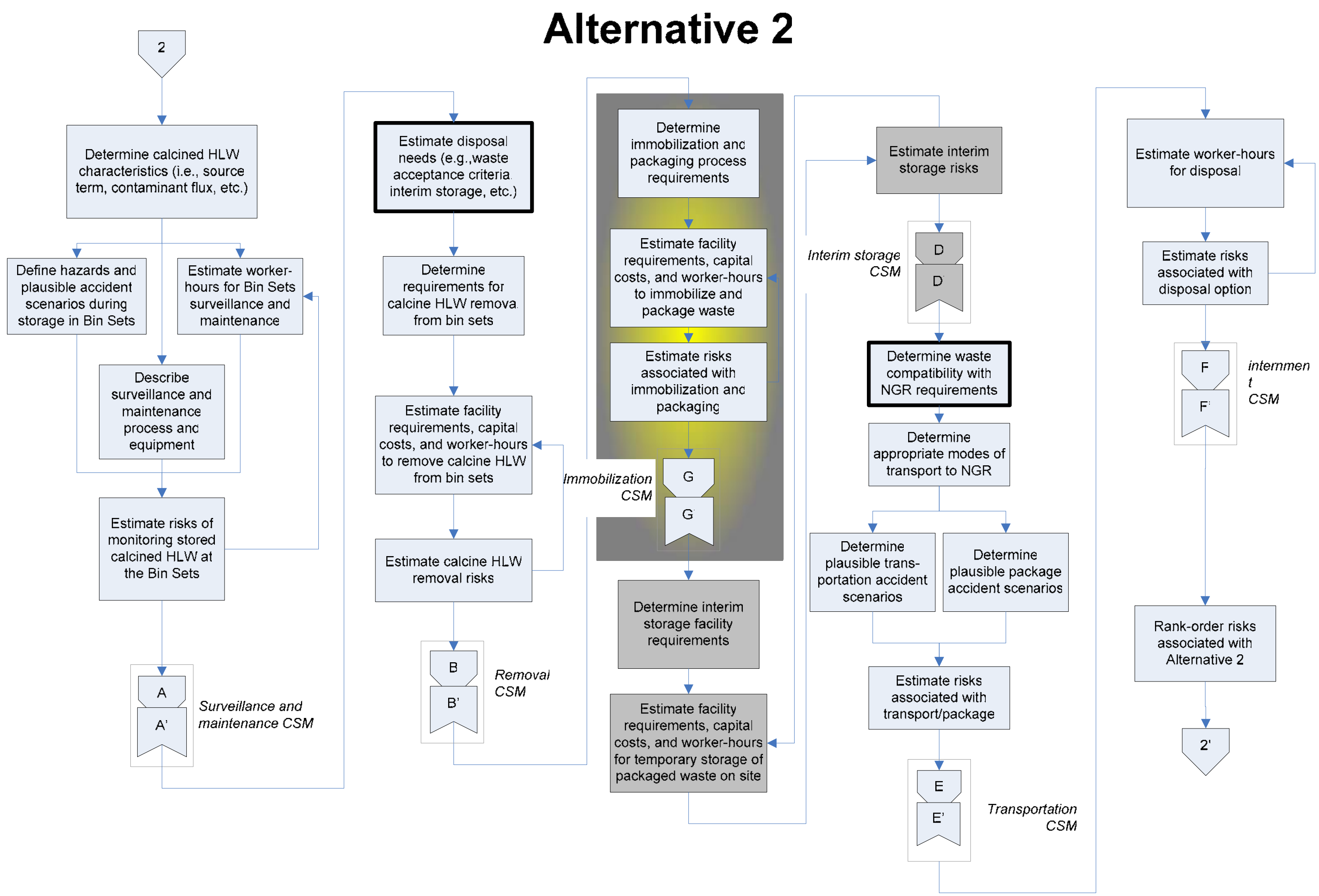


Figure F-3. Risk flow diagram for Alternative 2 (Retrieve/Immobilize/Package/Ship). Divergence from Alternative 1 risk flow (Figure F-2.) is highlighted by the dual-tone box. Deviation points from Time Frame A to either B or C are the boxes with bold outline and the risk flow events that are impacted are highlighted by the dark grey shading.

Alternative 3

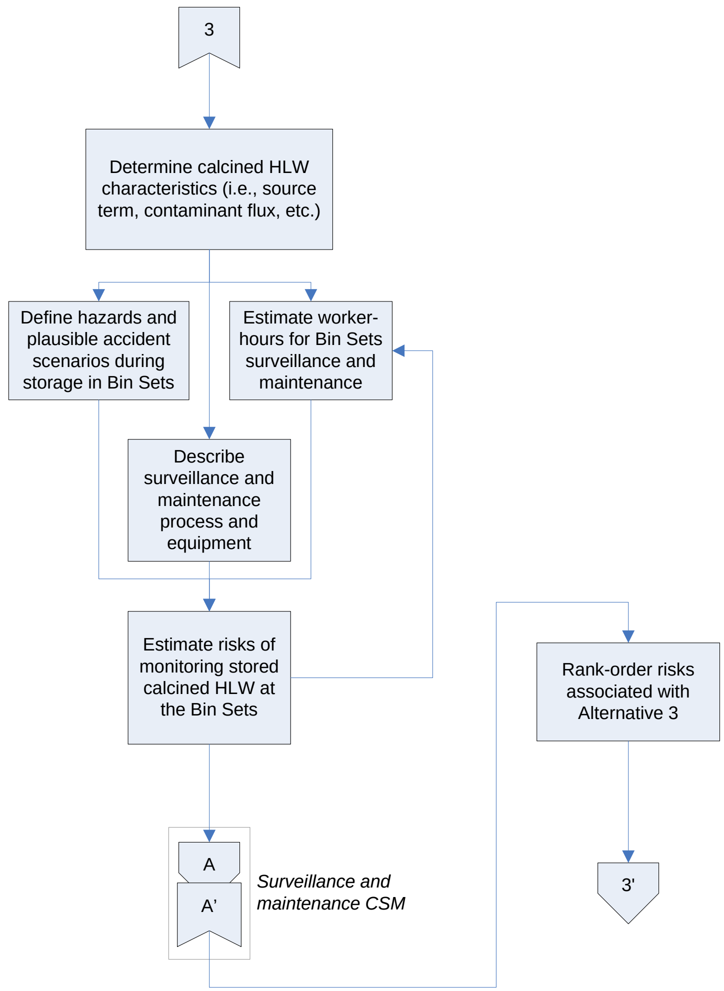
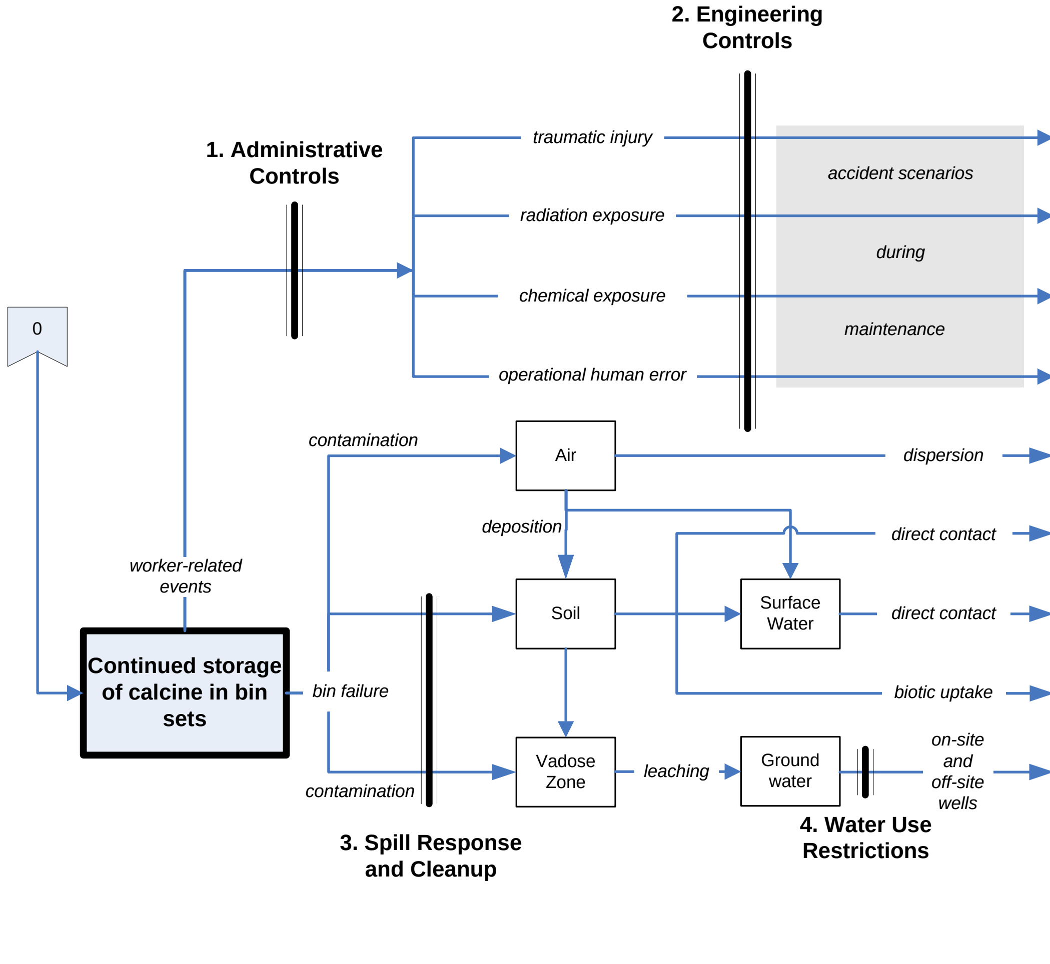


Figure F-4. Risk flow diagram for Alternative 3 (Store in Place).

No Action Alternative

Calcine transferred from bin set #1 to bin set #6 or #7



Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
I	I	I	I	
I/F/D/R	I/F/D	I/F/D	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

I – Inhalation
F – Ingestion
D – Dermal Contact
R – Radiation (Non-contact)
A – Accident

Figure F-5. Conceptual site model for the no action alternative as a baseline for comparison of the management alternatives.

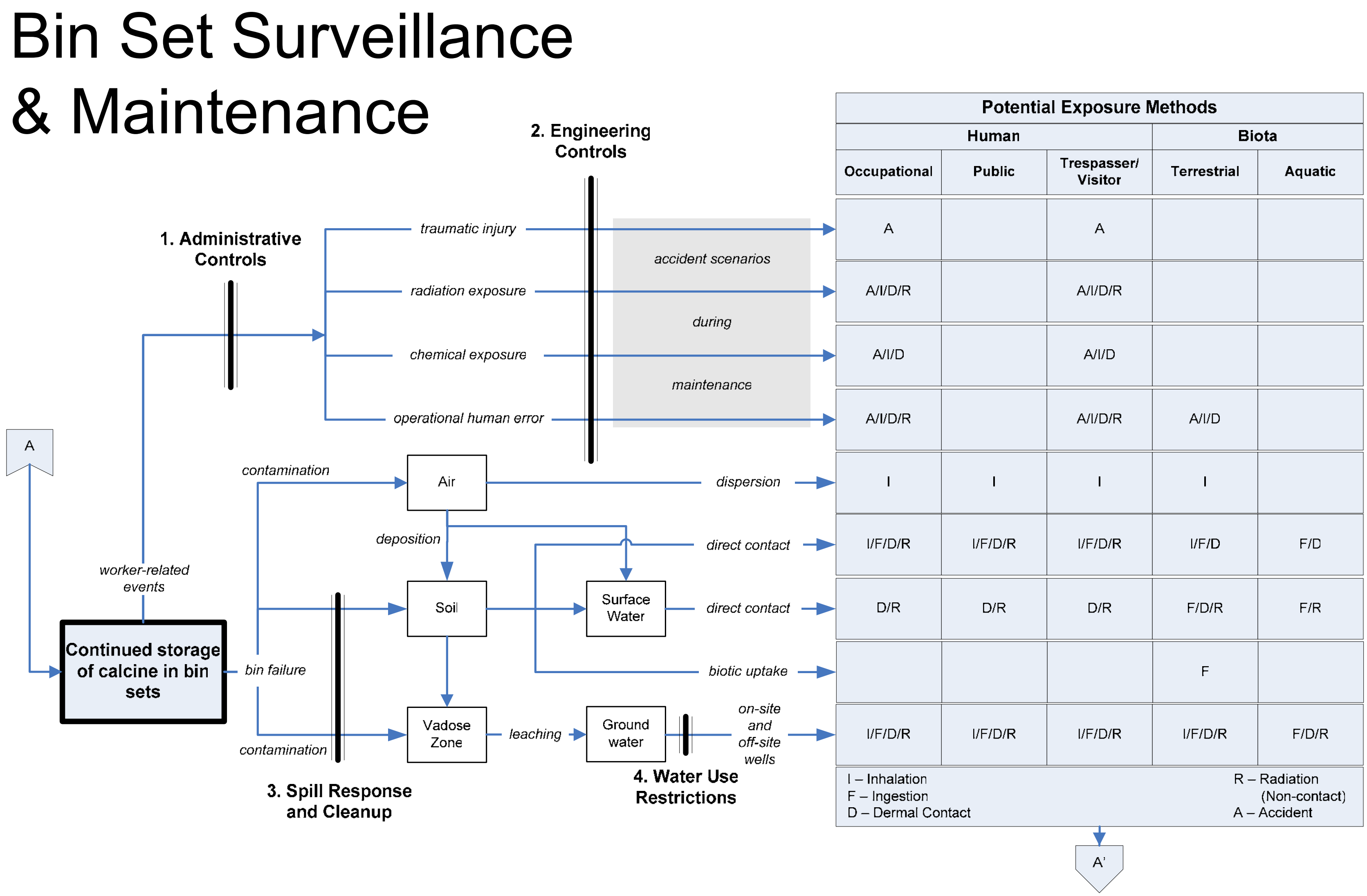
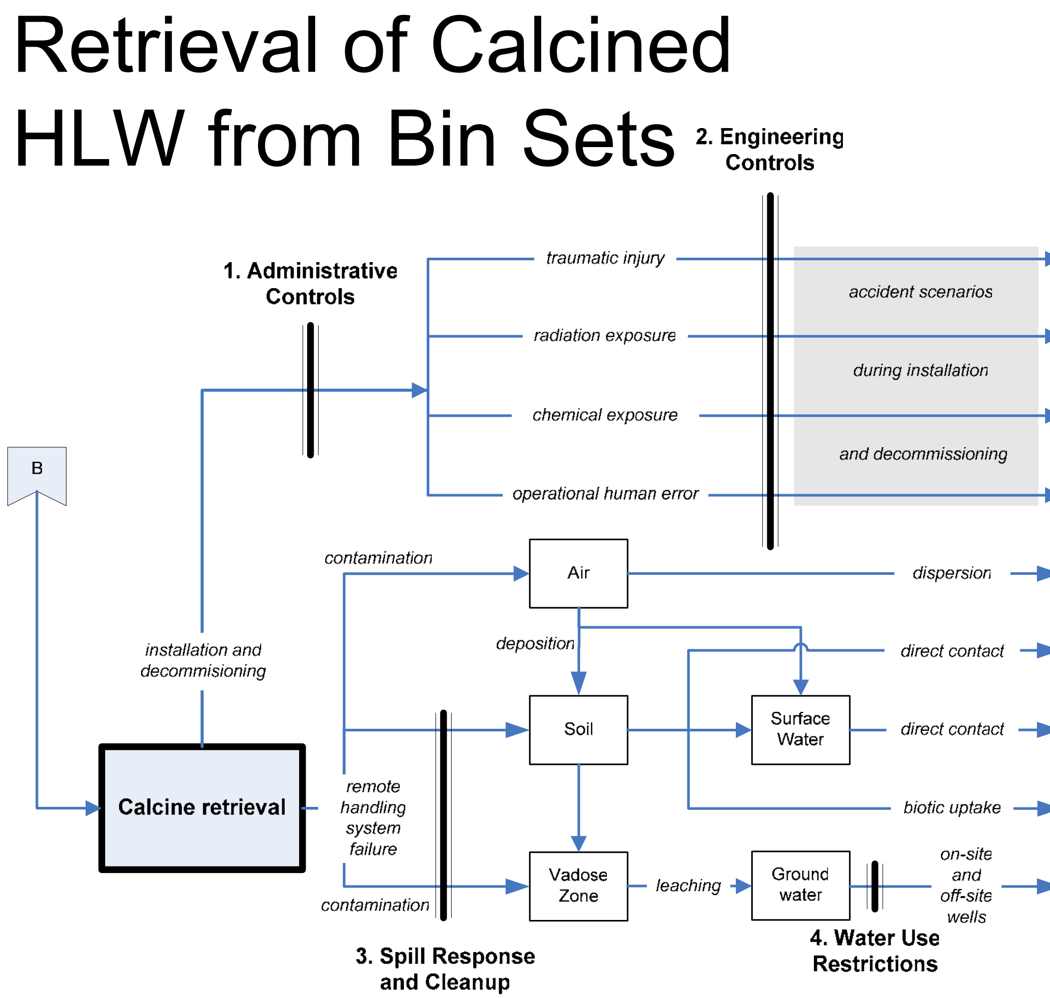


Figure F-6. Conceptual site model for bin set surveillance and maintenance.



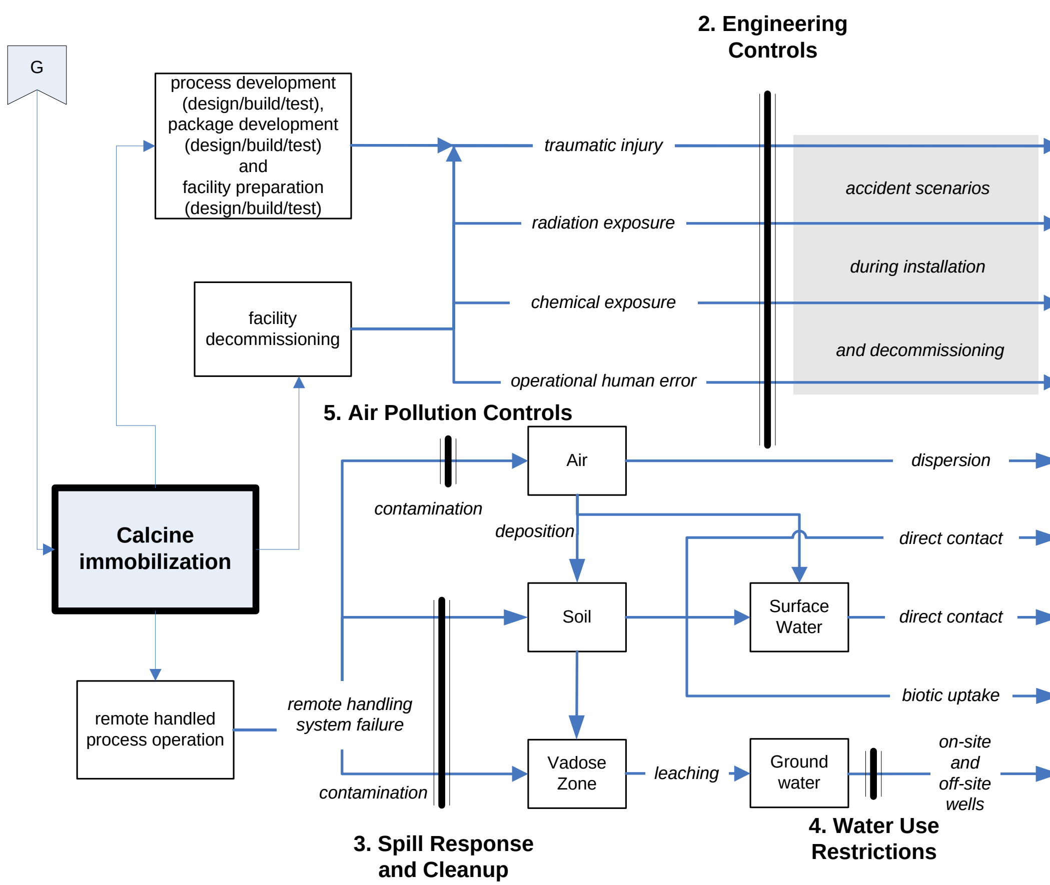
Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
I	I	I	I	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

I – Inhalation
F – Ingestion
D – Dermal Contact
R – Radiation (Non-contact)
A – Accident

B'

Figure F-7. Conceptual site model for retrieval of calcined HLW from the bin sets.

Immobilization of Calcined HLW



Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
I	I	I	I	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

I – Inhalation
F – Ingestion
D – Dermal Contact
R – Radiation (Non-contact)
A – Accident

G'

Figure F-8. Conceptual site model for immobilization of the calcined HLW.

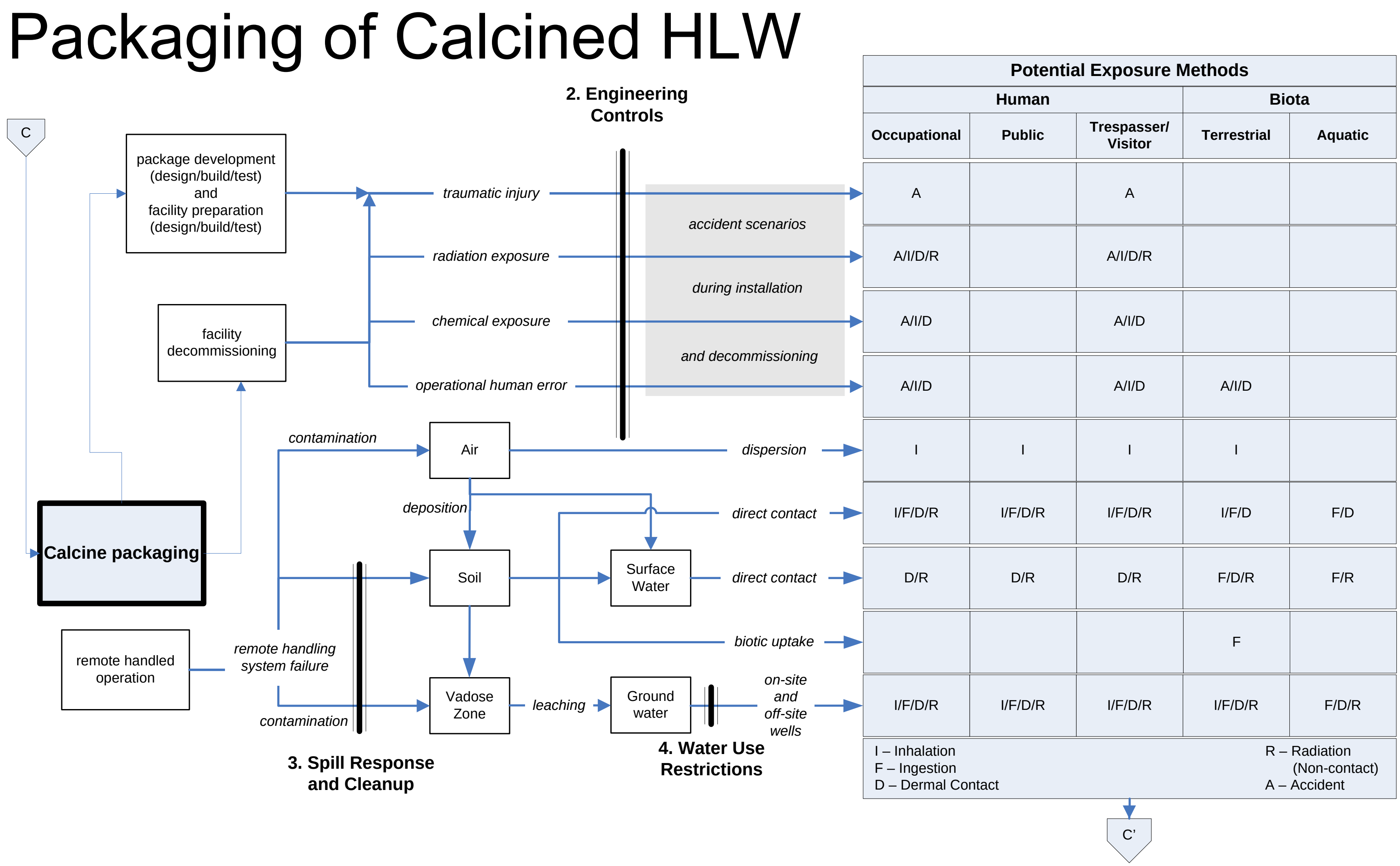
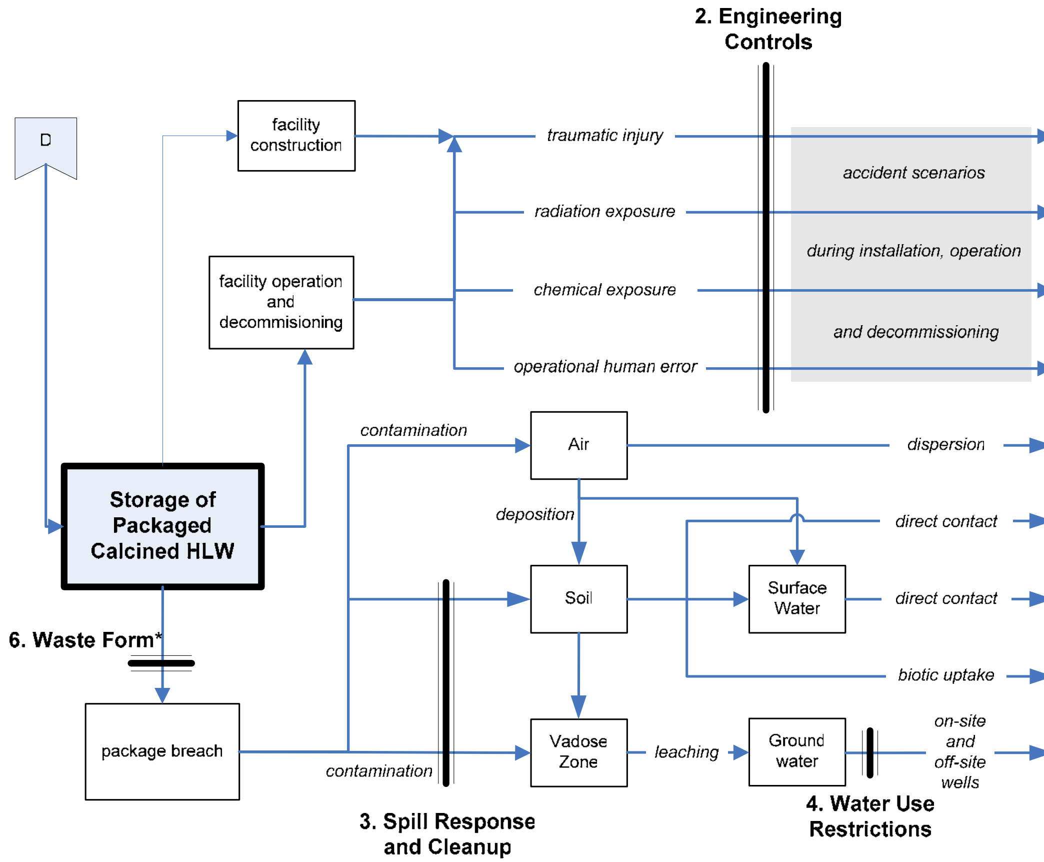


Figure F-9. Conceptual site model for calcined HLW packaging.

Interim Storage of Packages



Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D/R	
I	I	I	I	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

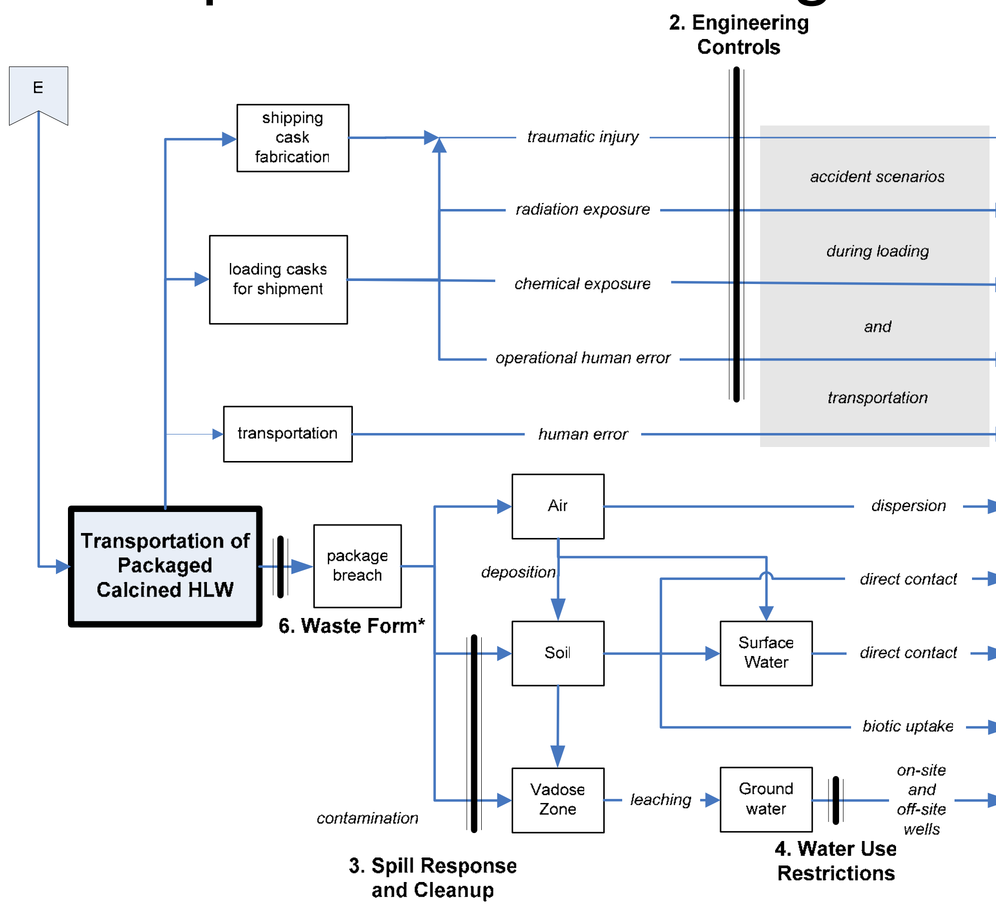
I – Inhalation
F – Ingestion
D – Dermal Contact
R – Radiation (Non-contact)
A – Accident

D

**waste form barrier applies to immobilized waste only*

Figure F-10. Conceptual site model for the interim storage of the calcined HLW packages.

Transportation of Packages



Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
A/R	A/R	A/R	A/R	
I	I	I	I	
I/F/D	I/F/D	I/F/D	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

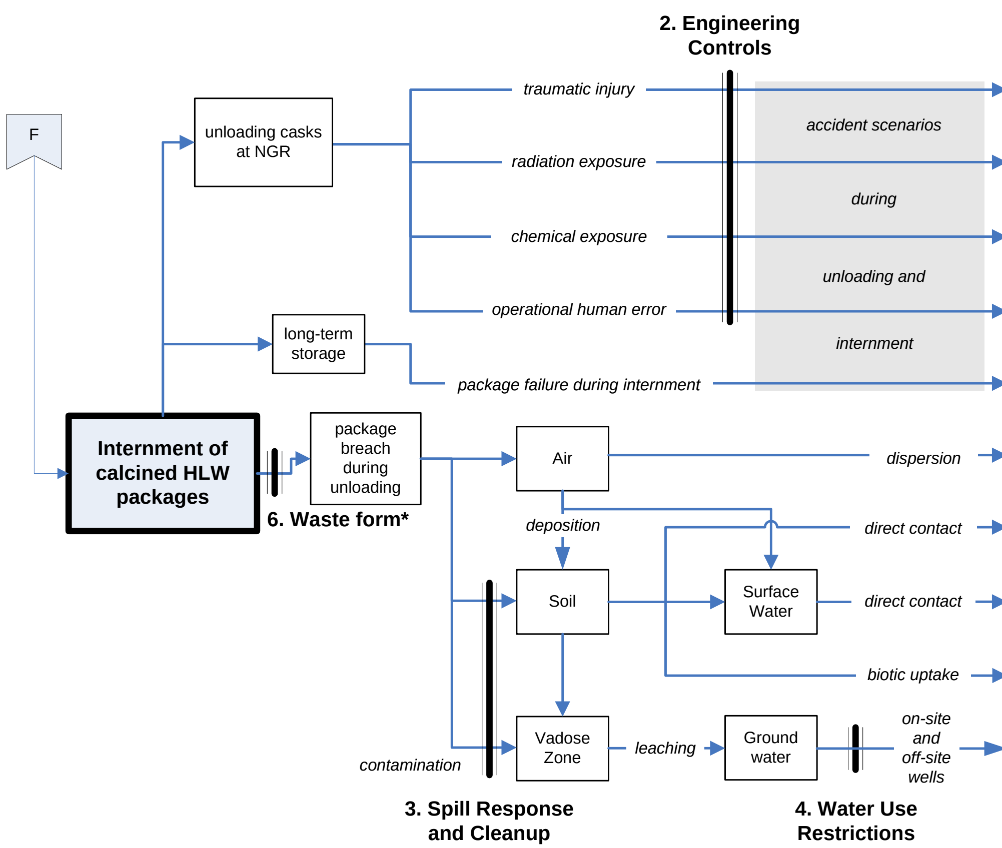
I – Inhalation
F – Ingestion
D – Dermal Contact
R – Radiation (Non-contact)
A – Accident

E'

*waste form barrier applies to immobilized waste only

Figure F-11. Conceptual site model for transportation of calcined HLW packages.

Internment of Packages at NGR



Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
I/F/D/R	F/D	I/F/D/R	F/D	F/D
I	I	I	I	
I/F/D	I/F/D	I/F/D	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

I – Inhalation
F – Ingestion
D – Dermal Contact
R – Radiation (Non-contact)
A – Accident

F'

*waste form barrier applies to immobilized waste only

Figure F-12. Conceptual site model for the internment of calcined HLW packages at the NGR.