PRELIMINARY RISK EVALUATION OF CALCINED HIGH-LEVEL WASTE DISPOSITION AT THE IDAHO SITE

Revision 0

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Consortium for Risk Evaluation with Stakeholder Participation (CRESP)

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ABOUT CRESP

CRESP began operation in 1995 after receiving a competitive cooperative agreement from the Department of Energy.

A key purpose of CRESP is to implement the 1994 National Academy of Sciences' recommendation that the Environmental Management Office of DOE enable the establishment of an independent institutional mechanism to develop data and methodology to make risk a key part of its decision making. (See *Building Consensus through Risk Assessment and Management of the Department of Energy's Environmental Remediation Program*). Consistent with this purpose, the form of federal assistance for CRESP II is a grant and the independence of the granting agency which that form of assistance involves.

CRESP works to fulfill its mission by improving the scientific and technical basis of environmental management decisions that will

- advance protective and cost-effective cleanup of the nation's nuclear weapons sites
- enhance stakeholder understanding of the conditions at the nation's nuclear weapons production facility waste sites

CRESP pursues this mission through a unique institutional model:

1. Its primary mode of operation is an unprecedented program of interdisciplinary university research;
2. It is independent and its beneficiaries are those who have a stake in effective cleanup of federal facilities;
3. It is organized to provide both guidance to and peer review of the evolving effort to utilize risk methods and evaluations to help guide cleanup decisions at DOE sites.

For more information, please visit http://www.cresp.org.

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Kevin G. Brown is currently a second-year Ph.D. student in the Integrative Graduate Education and Research Traineeship (IGERT) program in the Vanderbilt Environmental Engineering Department. Prior to coming to Vanderbilt University, he spent more than 16 years at Savannah River Site in Aiken, South Carolina where his primary responsibilities were to provide the necessary technical bases and product control system allowing the Defense Waste Processing Facility (DWPF) to generate quality vitrified product from high-level waste to a high degree of confidence in an environment offering no possibility of product rework or recycle.

James H. Clarke, Ph.D., is a Professor of the Practice of Civil & Environmental Engineering at Vanderbilt University where he teaches courses on Environmental Assessment and Environmental Characterization and Analysis and conducts research on the long-term management of legacy hazardous and radioactive waste sites. He has served on National Academies committees and independent peer review panels for the Department of Energy and is a member of the Nuclear Regulatory Commission Advisory Committee on Nuclear Waste.

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PREFACE

This document is not the first independent study to examine what should be done to address the calcined wastes currently stored in bins at the Idaho National Laboratory. We are confident that it will not be the last. Two predecessor studies, both conducted by the National Research Council of the National Academy of Sciences have importantly shaped the way in which we have proceeded and what we have produced.

The first was a study focused directly and solely on the HLW problems at Idaho. In 1999 the National Research Council published its review of Alternative High-level Waste Treatments at the Idaho National Engineering and Environmental Laboratory. That important report was broader in scope than this CRESP report and makes specific recommendations. It deserves careful rereading by any student of this extraordinarily challenging technical and social policy problem as its technical evaluations and reasoning are quite compelling – although, as will emerge, our work has revealed more technical reasons to be concerned with the very long-term disposition of the calcined wastes in their current form and location than does that report. The NRC report is unequivocal in calling for what it argued was most lacking to guide the INL decision process:

> *"A driving consideration in deciding upon a radioactive waste management strategy should be identification, definition and evaluation of the "trade-offs" (i.e., comparative risks) for the alternatives being considered… A sufficiently rigorous analysis should be performed to establish current risks and to assess changes in risk due to treatment options" (NRC, 1999)*

The second, and very recent (February 2005) Academy study addresses disposition of transuranic and high-level radioactive wastes in a report entitled *Risk and Decisions* (NRC 2005). In contrast to the 1999 report, no specific recommendations are made about the calcined wastes at Idaho National Laboratory. The report, in complete continuity with the earlier 1999 NRC report, finds after substantial review of Department of Energy assessments and regulatory submissions that the Department lacks, or, at the least, does not regularly employ an effective template either for helping it reach objective bases for decisions or for making its work on complex problems transparent and traceable (NRC 2005, p. 92) -- and, as a consequence, does not get participatory consensus. This new report recommends strongly that the Department and its regulators regularly and consistent utilize a six-step process for risk-informed decision making. That process would be to initiate the decision process by laying out viable options and potential decisions; scope the information and analysis; collect data and refine models; prepare refined risk assessments; develop additional analyses and data collection, as needed, to support decisions; and finalize the decision. CRESP believes that this analysis should provide explicit consideration of all human health risks during the full material life-cycle, including risks to workers during processing, on-site and off-site populations, now and in future generations.

As will become clear in the document that follows, we strongly concur with the NRC that, at least for decisions about calcined high-level waste, a self-consistent basis of design and a conceptual process design for assessing alternatives that include all major processes, from the current storage through final disposition is needed. We do not attempt to achieve all six steps recommended by the NRC. It is not our function, nor (as we will repeatedly stress) is there sufficient information available to exhibit all six of the decision steps. Instead, this document is specifically designed to provide a structured way of laying the foundation for a process such as the NRC suggests. Specifically, we believe that this document will provide to the Department, its regulators and stakeholders the first key steps that will allow all parties to see what is and is not known about what it would take to implement these several alternatives and how to characterize the risks associated with their implementation.

Charles W. Powers, Ph.D.
Principal Investigator
Consortium for Risk Evaluation with Stakeholder Participation

EXECUTIVE SUMMARY

From the 1950's to the 1990's, spent nuclear fuel reprocessing was carried out at the Idaho Site formerly known as the Idaho National Engineering Laboratory (INEL) and the Idaho National Engineering and Environmental Laboratory (INEEL), near Idaho Falls, Idaho. Liquid waste that was generated was stored in tanks on site and, beginning in the 1960's, converted to solid granular form by a high temperature fluidized bed drying process known as calcination. Because of its origin in spent nuclear fuel reprocessing, the calcined waste is classified as high-level waste (HLW). The calcined HLW was transferred for storage to partially or fully buried stainless steel bins grouped in sets of three to seven bins, with each bin set encased in a thick concrete vault. Seven bin sets are present at the Idaho Nuclear Technology and Engineering Center (INTEC) at the Idaho Site, with six in use for storage of approximately 4400 m^3 of calcined HLW. The current Department of Energy (DOE) baseline assumptions and Settlement Agreement with the State of Idaho anticipate transfer of the calcined HLW to a more permanent geologic repository.

Campaigns to convert certain liquid high-level waste (HLW) to granular solid form were completed prior to June 30, 1998, in accordance with the Settlement Agreement between DOE and the State of Idaho. Also under this agreement, DOE made a commitment to propose alternatives for calcined HLW treatment in a record of decision in 2009 and to complete treatment of high-level waste at the Idaho Site by a target date of 2035.

The Consortium for Risk Evaluation with Stakeholder Participation (CRESP) was asked by DOE to carry out an independent evaluation of the risk characterization for several alternatives for management of the calcined HLW. This report is the result of review by CRESP of three alternatives specified by the Department of Energy for the disposition of the calcined HLW as part of a process to facilitate risk-informed decision making. The objectives of the report are

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 the Idaho Site.
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 the Idaho Site 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 includes consideration of expert opinion based on team and other experience, and relative ranking of risks.

This evaluation does not include quantification of risks or recommendations on the preferred waste management approach. The identification of data gaps includes incompletely defined physical information and inadequately defined conceptual processes and components. The purpose of the document is to serve as technical input for open further discussion and evaluation of the management options.

The three alternatives considered in the analysis are

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.
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.
3. The calcined waste will continue to be stored in the current bin sets with appropriate site improvements and security. This alternative allows for subsequent reevaluation of the waste recovery and disposal options.

These alternatives are generalizations of the alternatives discussed in the *Idaho High-Level Waste (HLW) and Facilities Disposition Final Environmental Impact Statement***.**

Three time frames were selected for evaluation: near term, intermediate term and long term. The critical aspects associated with each time frame are the changes in knowledge and system condition for each time frame. The near term is defined as the disposition alternative proceeding in the near future without a fully defined and approved final disposition pathway and its associated waste acceptance criteria. The intermediate term is defined as the disposition alternative proceeding once an approved final disposition pathway is established, currently anticipated to be the proposed geologic repository at Yucca Mountain, Nevada, such that waste acceptance criteria are known and "just in time" processing of waste may be permitted. The long term is defined as some time after a substantial reduction of the specific activity of the major fission products in the calcined HLW has been achieved and an approved final disposition pathway is established. These time frames allow consideration of the implications of programmatic uncertainties that impact human health risk (e.g., extended interim storage or the need to process material a second time to meet previously incompletely defined standards) and time-dependent processes that impact human health risk (e.g., radionuclide decay, corrosion, etc.). The Idaho Site has relatively little control over many of the programmatic issues (e.g., availability of an approved disposition pathway for the calcined HLW and associated acceptance criteria), but these issues have a direct bearing on the feasibility and human health risks associated with the three alternatives and three time frames. Thus, the linkages between programmatic uncertainties and human health risks cannot be overlooked in this analysis.

Disposition alternatives carried out in the near term have the potential to comply with the terms of the Settlement Agreement between DOE and the State of Idaho; activities in the intermediate and long terms may require renegotiation of the Settlement Agreement with the State of Idaho in order to proceed. The near term assumes a geologic repository would be available for receipt of the processed and/or packaged calcined HLW (which may or may not be the case) and risks rejection of the waste form since the waste acceptance criteria will be established or an alternate disposition pathway may be defined after calcined HLW processing or packaging begins. The intermediate and long terms would commence after establishment of a final disposition pathway which may or may not be the proposed geologic repository, allowing for necessary process modifications before processing begins. The long term has the benefit of reducing the external hazard through substantial radiological decay of the high energy fission products prior to initiation of material transfer; however, the remaining hazard through alpha activity would necessitate considerable handling precautions during retrieval and subsequent packaging or processing.

Characterizing risk requires identification of each of the activities or events that may result in an adverse outcome (e.g., injury, fatality, etc.), what may go wrong, the affected population, the likelihood of the adverse outcome, and the severity of the adverse outcome (consequences). The preliminary risk characterization was achieved through the following sequence, developing

1. management flow diagrams of the sequences of steps required to implement the alternatives
2. task lists corresponding to the management flow diagrams
3. sets of risk flow diagrams for the alternatives that indicate the sequences of steps that have the potential to pose significant human health risks to workers, the public or the environment
4. conceptual site models indicating risk pathways and receptors for the steps in the risk flow diagrams
5. preliminary hazards analyses of the most important potential upset conditions for the alternatives
6. a gap analysis that describes the key barriers, missing information and uncertainties to assessing the risks of implementing the three alternatives in each of the three time frames
7. a summary table linking the most important hazards and information gaps identified through the steps above.
8. a single table that depicts the relative risk for each alternative and time frame considered.

Uniform terminologies and categories for characterization of risks and information gaps were used to allow for meaningful comparisons. Using these steps, this analysis provides a structure and template for risk evaluation and applies them to the specific risk-related issues associated with determining the ultimate disposition of the Idaho Site calcined HLW.

Each disposition alternative has associated human health and ecological risks that vary significantly with the time frames under consideration. Sufficient information does not exist currently or is not organized in a form suitable to achieve a meaningful *quantitative* comparison of the life-cycle risks associated with the proposed alternatives. This report provides a basis for a qualitative comparison of the alternatives, identifying process analogs when appropriate as well as key gaps in knowledge that need to be addressed to facilitate a meaningful quantitative risk assessment. This approach includes (i) identification of key steps and exposure pathways that may cause significant risk, (ii) a structured approach for subsequent quantitative risk analyses, (iii) identification of important current information limitations, and (iv) linkage of information limitations to relevant hazards to determine a path forward.

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

Currently, a self-consistent basis of design and a conceptual process design for each alternative and time-frame that includes all major processes, from the current storage through final disposition, do not exist.[4] The lack of these design bases and conceptual designs represents the most important knowledge gap for all alternatives and time frames examined. The additional major gaps in knowledge that prevent a quantitative life-cycle risk assessment for each of the alternatives include a defined and approved final disposition pathway for the calcined HLW and related waste acceptance criteria and schedule; composition and distribution of calcined HLW in the bin sets; detailed information on method of retrieval of calcined HLW from the bin sets; specific plans and standards for decommissioning the bin sets and the processing equipment; model predictions of calcined HLW behavior in its final disposition location, currently anticipated to be the proposed geologic repository at Yucca Mountain; adequate planning for bin set management and repair; and process-specific information related to the handling processes (packaging or immobilization) under consideration. These knowledge gaps were identified as safety critical by the analysis in this report because of their implications for human health risks.

In the absence of detailed specification of the processes involved in the alternative requiring treatment prior to final disposition, the major hazards identified through a generalized hazard analysis occur during the bin set management, retrieval, handling (packaging or immobilization) and interim storage process steps. As the time frame transitions from the near term to the intermediate term and long term, the hazard severity increases during the bin set management step because of consideration of accumulated risks from monitoring, maintenance, structural decay and natural hazards (e.g., earthquakes). Conversely, as the time frame transitions from the near term to the intermediate and long terms, the hazard severity for the interim storage step decreases because the absence of a defined and approved final disposition pathway is resolved in the transition between time frames. In the retrieval and handling steps, the severity of the external radiation hazard decreases in the intermediate and long terms, but the severity of the of the internal radiation hazard does not decrease substantially.

Coupling the hazard and gap analyses allows for a qualitative ranking of each of the alternatives that includes both human health and programmatic factors.

<u>Near Term</u>

[4] The alternatives discussed in this report are generalizations of the alternatives presented in the *Idaho High-Level Waste (HLW) and Facilities Disposition Final Environmental Impact Statement.* Self-consistent bases of design and conceptual process designs do not exist for any of the alternatives in that document.

In the near term time frame, Alternative 1 is high risk because of the hazards associated with packaging the waste, the information gaps relative to the waste itself and the absence of a defined and approved final disposition pathway for HLW, currently anticipated to be a geologic repository at Yucca Mountain. Although processing under Alternative 2 faces many of the same hazards as Alternative 1, Alternative 2 is ranked as medium risk because the waste acceptance issues are less severe than those for Alternative 1 and the longer term outcome of immobilization is more protective of human health and the environment. Current waste acceptance criteria for the proposed disposition pathway (not finalized) use the immobilization (vitrification) processes at West Valley and the Savannah River Site as precedents for waste criteria. In the absence of defined and approved disposition pathways for their wastes, decisions were made at West Valley and the Savannah River Site to generate a very conservative waste form (i.e., vitrified material) that would be considered safe for long term on-site storage as well as most likely acceptable at the final disposition site. Alternative 3 is low risk because the near term time frame remains within the design lifetime of the bin sets; no high risk hazards were identified for this alternative.

Intermediate Term

In the intermediate term time frame, an approved final disposition pathway for HLW exists and related criteria and scheduling issues are expected to be resolved, reducing the associated human health risks. Alternative 1 drops to medium risk if the packaged calcined HLW is deemed acceptable for disposal. Alternatives 2 and 3 are deemed low risk because of the coupled reasons of substantial decay of the high energy fission products and the higher level of certainty related to final disposition pathway. Accumulated risks from seismic and severe weather hazards become more severe in this time frame.

Long Term

In the long term time frame, Alternatives 1 and 2 are deemed medium risk and Alternative 3 is deemed high risk. Alternative 1 is medium risk only if it is acceptable for disposal according to established waste acceptance criteria for the final disposition pathway. Although substantial radiological decay will have occurred, reducing the external radiation hazard, the risk of failure of the bin sets is increased and the potential exposure to workers during repair tasks is increased as well. In the long term time frame, structural decay, corrosion and seismic events become more likely. The increased likelihood of failure coupled with the hygroscopic and highly soluble characteristics of the calcined HLW increases the risk associated with all of the alternatives. Substantial contact of water (e.g., infiltration to a failed containment structure) has the potential to impact adversely the underlying aquifer. Decay of the bin sets is likely to result in a number of high risk worker activities, including transfer of material from the oldest bin set (bin set 1) to one or more of the newer bin sets, bin set repairs and bin set reinforcement. These activities have the potential to expose workers and the offsite population to chemical and radiological hazards.

Suggested Path Forward

The results of the hazard analysis identify no clear, ideal choice for calcined HLW disposition from the three alternatives and three time frames under review. The information gaps related to these alternatives suggest that this assessment is preliminary and it is premature to make any recommendations for a path forward on any disposition alternative. The suggested path forward is to resolve as many of the safety critical information gaps highlighted in this report as possible, develop a basis of design and a self-consistent conceptual design for each of the alternatives, refine the risk characterization based on these designs and use the resulting risk insights as an important inputs to the decision process. Given the commitment to propose alternatives in a record of decision in 2009, initiation of the design process as well as reduction or elimination of the safety critical information gaps should begin in the near future. Further, with the legal difficulties surrounding the proposed final disposition pathway for spent nuclear fuel and HLW (the geologic repository at Yucca Mountain), a contingency disposition alternative should be developed in the same manner to address the possibility that this facility may never open.

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LIST OF ACRONYMS

BRA	Baseline Risk Assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Constituent of Concern
CSB	Centennial Tectonic Belts
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
HLW	High-level Waste
ICDF	INL CERCLA Disposal Facility
ICP	Idaho Completion Project
INEEL	Idaho National Engineering and Environmental Laboratory (*former designation*)
INEL	Idaho National Engineering Laboratory (*former designation*)
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
IRA	Interim Risk Assessment
ISB	Intermountain Seismic Belt
LLW	Low-level Waste
MLLW	Mixed Low Level Waste
MCL	Maximum Contaminant Level
NGR	National Geologic Repository
NRC	National Research Council
RCRA	Resource Conservation and Recovery Act
RH	Remote-Handled
RI/FS	Remedial Investigation/Feasibility Study
RTD	Retrieval/Treatment/Disposal
SNF	Spent Nuclear Fuel
SRPA	Snake River Plain Aquifer
STRE	Short-Term Risk Evaluation
TRU	Transuranic
USGS	United States Geological Survey
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant

1. INTRODUCTION

1.1. Purpose, Goals, and Objectives

In its Spring 2005, report *Risk and Decision*, the National Research Council recommended that the Department follow an organized step-by-step process for risk-informed decision-making (NRC, 2005). This process would allow both technical and less technically trained people to follow a transparent process of defining a problem and then tracking the key elements associated with its remediation under different cleanup approaches. In following this process, the steps involved in each approach and the outcomes to be achieved would be well illuminated, the risks associated with the different steps would be highlighted, and the tradeoffs to be made among the options would be clearly seen. There was another fundamental premise underlying the NRC-proposed process: the insistence that the information that is unknown or not known well enough be identified. The identification of this missing information is essential because whenever the fundamental choices are being made, the decision makers and those affected by the decisions should be clearly aware of (i) the known risks inherent in the choice for one or another alternative and (ii) the significance (for risk evaluation and for programmatic success) of what we do not know about each alternative.

Developing a risk-informed decision that considers human health and ecological risks along with other social factors should include explicit consideration of the trade-offs between reductions in human health risk achieved through each remediation option and the additional human health risks incurred as part of achieving that option. Human health risk evaluation should include consideration of risks to remediation workers and other on-site and off-site populations for current and future generations. Often, integrated evaluation of this range of human health risks is not achieved as part of the remedial decision process. This report provides a foundation to achieve such integration.

This report presents a framework for life-cycle[5] risk analysis of the disposition alternatives for the calcined high-level waste (HLW) stored in the bin sets at the Idaho Site formerly known as the Idaho National Engineering Laboratory (INEL) and the Idaho National Engineering and Environmental Laboratory (INEEL). Based on this foundation, a qualitative examination of three disposition alternatives for the calcined HLW over three time frames has been completed. The alternatives are (i) to retrieve, package and ship the calcined HLW to a geologic repository[6], (ii) to retrieve, immobilize, package and ship the calcined HLW to a geologic repository and (iii) to store the calcined HLW in the

[5] In this report, "life-cycle" refers to all actions necessary to achieve and associated with final disposition of the calcined high-level waste. This is in contrast to many "life-cycle" evaluations within DOE that are focused on a single management entity (e.g., DOE-Environmental Management), planning period or contractual period.

[6] The proposed geologic repository at Yucca Mountain is considered the final disposition pathway for the purposes of this evaluation. The ultimate disposition pathway for the calcined HLW may vary significantly from this basis.

current bin sets[7]. The time frames are (a) near term, (b) intermediate term and (c) long term. These alternatives and time frames are discussed in greater detail in section 2.

The specific objectives of this report are to

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 the Idaho Site.

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 the Idaho Site 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 does 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 further open 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 foundation for the life-cycle risk assessment includes

(i) management flow diagrams (in Appendix B) of the sequences of steps required to implement the alternatives,

(ii) task lists (in Appendix C) corresponding to the management flow diagrams,

(iii) sets of risk flow diagrams (in Appendix F) for the alternatives that indicate the sequences of steps that have the potential to pose significant human health risks to workers, the public or the environment,

(iv) conceptual site models (in Appendix F) indicating risk pathways and receptors for the steps in the risk flow diagrams,

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[7] Under the Settlement Agreement with the State of Idaho, the Department of Energy committed to issuing a complete analysis of the alternatives for disposition of the calcine HLW in a Record of Decision by 2009 and completing treatment of the calcine HLW by a target date of 2035. The full text of the Settlement Agreement is available at http://cleanup.inel.gov/1995-settlement-agreement/.

(v) preliminary hazards analyses (in Section 5 and Appendix D) of the most important potential upset conditions for the alternatives, and

(vi) a gap analysis (in Section 6 and Appendix E) that describes the key barriers, missing information and uncertainties to assessing the risks of implementing the three alternatives in each of the three time frames.

Sufficient information does not exist currently or is not organized in a form suitable to achieve a meaningful *quantitative* comparison of life-cycle risks associated with the proposed alternatives. This report provides a basis for a qualitative comparison of the alternatives, identifying process analogs when appropriate as well as key gaps in knowledge that need to be addressed to facilitate a meaningful quantitative risk assessment.

1.2. Alternatives Considered

Before describing the alternatives, it is imperative that the reader recognize that some elements of each alternative are primarily under the control of the Idaho Site, others are under the control of other organizations within the Department of Energy (DOE), and still others are political policy decisions that the DOE has only some control over. The first set of elements can be categorized as site specific and the second programmatic. This distinction is critical. The Idaho Site has relatively little control over many of the programmatic issues (e.g., opening and availability of Yucca Mountain to accept calcined HLW), but these issues have a direct bearing on the feasibility and risks associated with the three alternatives and three different time frames.

The following alternatives will be considered for management of the calcined HLW bin sets at the Idaho National Laboratory.[8]

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.[9] This management option will be considered for three time frames.

- **A.** ***Near term*:** Retrieval and packaging will be initiated without a completely defined and approved pathway for the ultimate disposition of the HLW such as the proposed HLW geologic repository at Yucca Mountain, and associated waste acceptance criteria.
- **B.** ***Intermediate term*:** Retrieval and packaging will be initiated once an approved pathway for the ultimate disposition of the calcined HLW and associated

[8] Numerous alternatives for calcined HLW disposition have been examined in the *Idaho High-Level Waste (HLW) and Facilities Disposition Final Environmental Impact Statement* (DOE/EIS-0287, 2002). The three alternatives discussed here are generalizations of those alternatives.

[9] The proposed geologic repository at Yucca Mountain is considered the final disposition pathway for the purposes of this evaluation. At the present time, the Yucca Mountain facility has not been approved, the licensing process has not been started and waste acceptance criteria have not been established. The ultimate disposition pathway for the calcined HLW may vary significantly from the basis used in this evaluation.

waste acceptance criteria have been established. Proceeding in this time frame may allow for “just in time” packaging of the calcined HLW.

C. ***Long term*****:** Retrieval and packaging will be initiated in the future, after a substantial reduction of the specific activity of the major fission products in the calcined HLW has been achieved (e.g., after approximately 10 half lives of fission product decay) and an approved final disposition pathway has been established.

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 alternative 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. This alternative will allow for subsequent reevaluation of the waste recovery and disposal options and will be considered for the same three time frames as described for Alternative 2.

The terms of the Settlement Agreement between the Department of Energy and the State of Idaho[10] make specific references to the calcined HLW.

> *“**Treatment of Calcined Wastes.** DOE shall accelerate efforts to evaluate alternatives for the treatment of calcined waste so as to put it into a form suitable for transport to a permanent repository or interim storage facility outside Idaho. To support this effort, DOE shall solicit proposals for feasibility studies by July 1, 1997. By December 31, 1999, DOE shall commence negotiating a plan and schedule with the State of Idaho for calcined waste treatment. The plan and schedule shall provide for completion of the treatment of all calcined waste located at INEL[11] by a date established by the Record of Decision for the Environmental Impact Statement that analyzes the alternatives for treatment of such waste. Such Record of Decision shall be issued not later than December 31, 2009. It is presently contemplated by DOE that the plan and schedule shall provide for the completion of the treatment of all calcined waste located at INEL by a target date of December 31, 2035. The State expressly reserves its right to seek appropriate relief from the Court in the event that the date established in the Record of Decision for the Environmental Impact Statement that analyzes the alternatives for treatment of such waste is significantly later than DOE's target date. In support of the effort to treat such waste, DOE shall submit to the State of Idaho its application for a RCRA (or statutory equivalent) Part B permit by December 1, 2012.”*

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[10] The full text of the Settlement Agreement is available at http://cleanup.inel.gov/1995-settlement-agreement/

[11] Management has changed since the Settlement Agreement so that activities at the former INEL are split between the INL and the Idaho Completion Project.

According to the definitions in the Settlement Agreement the term “treat” is defined,

> *“as applied to a waste or spent fuel, as any method, technique, or process designed to change the physical or chemical character of the waste or fuel to render it less hazardous; safer to transport, store, dispose of; or reduce in volume.”*

and a target date for the departure of treated wastes from the Idaho Site is established.

> *“DOE shall treat all high-level waste currently at INEL so that it is ready to be moved out of Idaho for disposal by a target date of 2035.”*

The language of the Settlement Agreement leaves some flexibility for the decision regarding the final disposition of the calcined HLW at the Idaho Site.

2. SITE BACKGROUND

From 1952 to 1992, spent nuclear fuel reprocessing was carried out in what is now the Idaho Nuclear Technology and Engineering Center (INTEC) within the 890 square mile site currently known as the Idaho National Laboratory (INL) and the Idaho Completion Project (ICP) near Idaho Falls, ID (NRC, 1999; DOE/EIS-0287, 2002) (Figure 1). The remote site lies directly above the Snake River Plain Aquifer, and is about 30 miles from Idaho Falls, an urban area of approximately 80,000 people. This aquifer is the primary source of water resources for Southeastern Idaho and has been designated a sole source aquifer by the USEPA (DOE/EIS-0287, 2002).

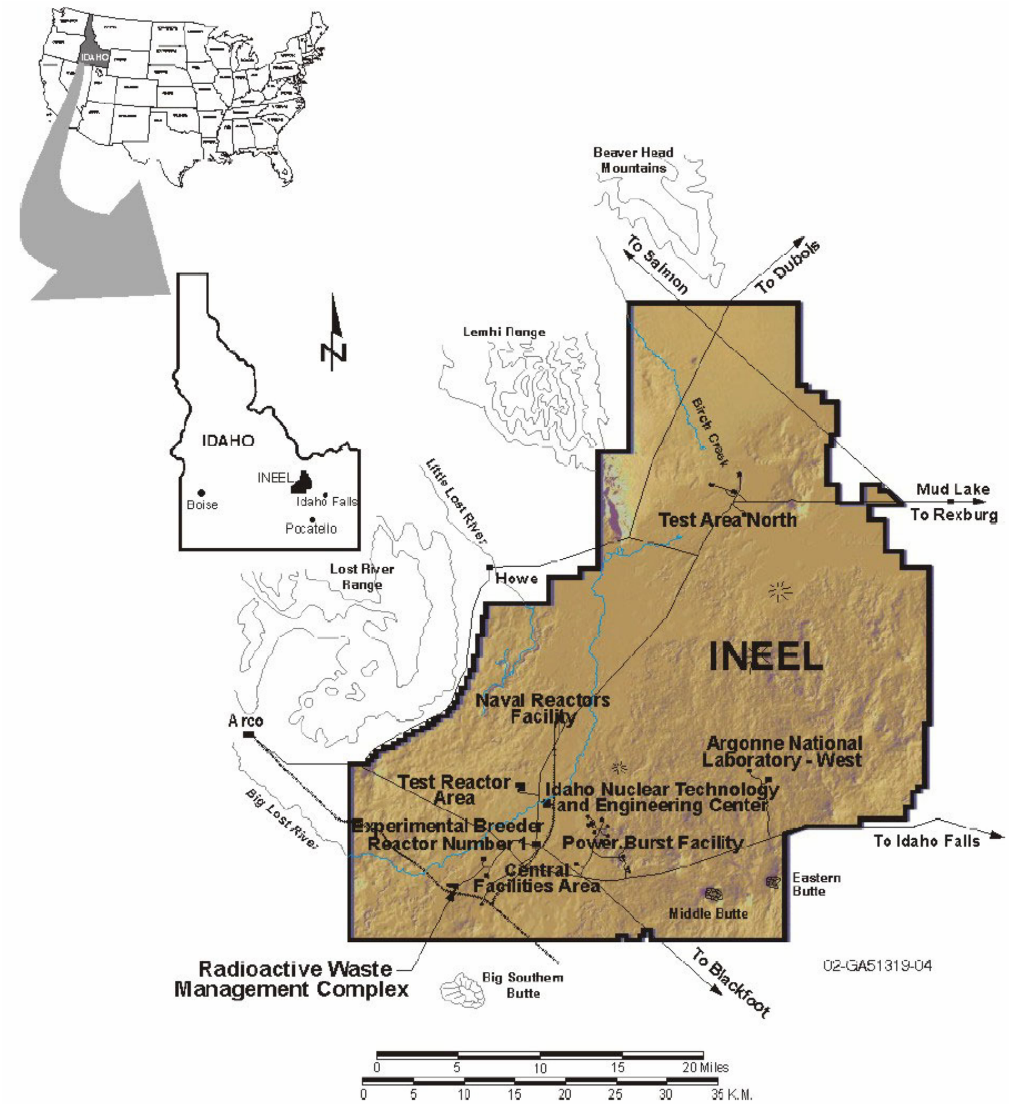

Figure 1. Map of the Idaho Site (formerly INEEL) showing INTEC and other facilities.

The Idaho Site is situated on the Eastern Snake River Plain in the Big Lost Trough sedimentary basin. Three streams drain into the basin. Water does not drain from the basin; it either evaporates or infiltrates into the subsurface. Flooding is infrequent. Studies have shown the probability of a flood that would exceed the capacity of the Mackay Dam is 1 in 5000 years (Mattson et al., 2004).

The subsurface at the Idaho Site is characterized as fractured basalt with interceded sedimentary deposits. The aquifer is present at a depth of approximately 177m (580 ft). The ground surface is not prone to soil erosion. The Idaho Site is proximate to two seismically active areas, the Intermountain Seismic Belt (ISB) and the Centennial Tectonic Belts (CTB). Monitoring by the Idaho Site from 1972 to 2002 detected 29 small magnitude earthquakes (M<1.5) in the area. Historical records show two moderate to large magnitude earthquakes (M>7.0) in the ISB and CTB, in 1959 and 1983, with epicenters less than 150 miles from the Idaho Site. These observations suggest that the region is prone to occasional small magnitude earthquakes with infrequent larger-scale earthquakes. No volcanic eruptions have been documented in the Eastern Snake River Plain, but the region can be described as volcanically active (Mattson et al., 2004).

The liquid waste that was generated during the reprocessing of spent nuclear fuel was stored in tanks on site and, beginning in the early 1960's, certain portions of this waste were converted to solid granular form by a high temperature fluidized bed drying process known as calcination[12]. The calcined HLW was transferred for storage to partially and fully buried stainless steel bins grouped in sets of three to seven bins, with each bin set encased in a concrete vault (Figures 2, 3 and 4). Upon emptying the HLW tanks, other mixed transuranic (TRU) waste was put in the tanks. Some of this waste, which contains sodium in relatively high concentrations (also known as sodium bearing waste (SBW)), was calcined and stored in the same bins as the calcined HLW. Calcining operations ceased in 1998, with all of the HLW calcined and some of the SBW remaining in liquid form in the waste tanks. A total of seven bin sets are present at the Idaho Site, with six in use for storage of approximately 4400 m^3 of calcined HLW (NRC, 1999; DOE/EIS-0287, 2002). The current physical form of the calcined HLW is a particulate solid, which may be partially agglomerated due to settling or moisture uptake, and has been described as analogous to "laundry detergent powder" in physical texture.

Figure 2. Photograph showing the above ground portion of a bin set.

[12] Calcination is a high temperature, non-melting solidification process, typically carried out at temperatures of approximately 800°C (Sax and Lewis, 1987). Higher temperatures may be necessary, depending on the feed composition. The fluidized bed process at the Idaho Site never exceeded 700°C and typically operated at lower temperatures, so a true calcine may not have been achieved.

Figure 3. Aerial view of several bin sets at INTEC.

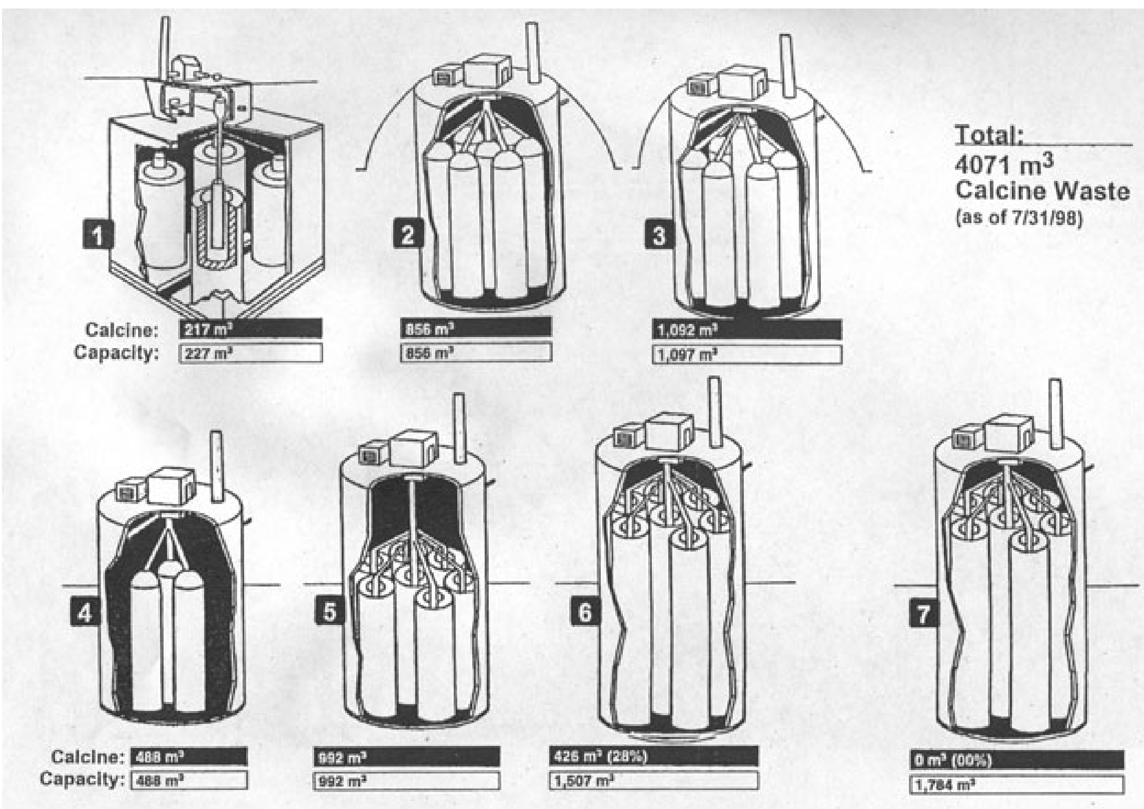

Figure 4. Diagram of the bin set configurations and approximate loading of calcined HLW (reprinted from NRC, 1999).

The calcined HLW is classified as high-level waste because of its origin in the reprocessing of spent nuclear fuel. The sodium bearing waste that has been calcined is considered HLW because it has been commingled with the HLW; the sodium bearing waste that remains in the tanks is considered TRU waste.

The focus of this report is on the disposition of the calcined HLW. The TRU sodium bearing waste is mentioned here because a portion of this waste is commingled in the bins with the HLW and thus impacts the composition of the calcined HLW.

3. SUMMARY OF EXISTING RISK DATA

The Idaho High-Level Waste (HLW) and Facilities Disposition Final Environmental Impact Statement (EIS) (DOE/EIS-0287, 2002) provides preliminary risk data associated with several management alternatives and associated transportation of calcined HLW to the proposed geologic repository at Yucca Mountain, Nevada. The Yucca Mountain Project has been in development for many years and transportation of waste packages from sites across the country has been an important research topic within the project. Transportation is well-characterized for most of the alternatives discussed in the HLW EIS, except for the vitrification alternative. The data assume a waste loading for the vitrified HLW that is substantially higher than loading achieved at other facilities (50% compared to 20-40%, with granular materials potentially skewing toward the lower range of waste loading); the data can be recalculated easily with a more realistic waste loading.

The HLW EIS contains projected estimates of worker radiation exposures and accidents for construction activities through decommissioning activities in Appendix C.3. These numbers are based on historical data and projected number of workers per activity. Radiation doses are extrapolated to increases in latent cancer fatalities relative to the rate of cancer incidence in the general population. Injuries and fatalities were extrapolated to the number of lost work days and recordable cases. In this analysis, all processes are weighted at equal risk, which may not be appropriate for some of the higher risk activities. In the HLW EIS, in order for a process to be considered higher risk, it must involve more workers. A few workers carrying out a high risk task would be weighted less than many workers carrying out a low risk task. In addition, some key process steps are overlooked in the alternatives. For example, the steam reforming alternative in the HLW EIS, whose calcined HLW component corresponds to Alternative 1 here, does not contain an interim storage component even though proceeding with that alternative in the near term time frame would result in the production of HLW packages before a final disposition pathway is established and a facility is prepared to accept them.

The West Valley Demonstration Project and the Savannah River Site have experience with immobilizing HLW through separations and vitrification, relevant to Alternative 2 in this report. An early EIS for West Valley (DOE/EIS-0081, 1982) outlines the process that led to eventual decisions on a treatment alternative for their HLW and a time frame to proceed with treatment. This document contains process outlines for several treatment alternatives and includes contingencies if assumptions such as waste package specifications prove to be incorrect. Subsequent EIS's for West Valley and Savannah

River (DOE/EIS-0337, 2003; DOE/EIS-0217, 1995) have more process-focused data that may be applicable to activities at the Idaho Site. Operational data may be available for risk evaluation purposes as well. West Valley has completed its vitrification process. Although the waste form was different (liquid HLW vs. granular calcined HLW), the accident data from West Valley's processing experience would be a good starting point for evaluating the processing required at the Idaho Site. Also, experience at facilities outside of the United States such as Sellafield in the United Kingdom may be applicable to the processes under consideration for Alternative 2. As a preprocessing step before vitrification, some of the high-level waste at Sellafield was calcined. Current process descriptions refer to the preprocessing as evaporation.[13] Calcination as a preprocessing step will be different from calcination followed by up to several decades of storage, so only portions of the Sellafield experience may be applicable to activities at the Idaho Site.[14] There are no process analogs available for use in the risk evaluation of the process steps in Alternative 1 in these reports.

Airborne and groundwater release information is available for the facilities involved in each of the alternatives under consideration in Appendix C.9 in the HLW EIS. This data is focused on disposition scenarios for each facility. Airborne release information is included as part of the transportation accident scenarios. Brief mention and classification of facility accidents is available in Appendix C.4. These accident scenarios are bounding cases described as (i) abnormal, (ii) within the design basis and (iii) beyond the design basis with accident frequency decreasing in that order.

4. RISK EVALUATION FRAMEWORK

In this section, a framework for evaluating risk, preliminary risk characterization, and the most important information gaps is presented for each of the calcined HLW management alternatives considered. This information has been developed to provide a structure for evaluation and provide insights into the areas where further detailed evaluation is initially most important.

The preliminary risk characterization and the identification of the most important information gaps sections were developed based on review of extensive earlier reports providing information about the calcined HLW at the Idaho Site and management of related materials throughout the DOE nuclear complex (see References and Additional Bibliography). DOE and personnel at the Idaho Site provided additional insights and answered extensive questions. The results of this review, as provided here, reflect the judgment and opinion of the authors, who collectively have extensive relevant experience. However, it is likely that further, more detailed assessment and evolving information will identify additional considerations that impact risk characterization for the management options. Thus, the risk characterization process itself should be viewed

[13] For additional information, see http://www.bnfl.com and http://www.britishnucleargroup.com

[14] Specific data related to accidents at Sellafield may be difficult to find. Most of the reports through IAEA offer anecdotal information only.

as a tool for ongoing gathering, organizing and assessing of information to inform the overall management and decision process.

The discussion provided here was developed to further a broader discussion among DOE, regulators, public representatives and the general public on the most appropriate path forward for management of the calcined HLW. Risk is only one of several aspects that must be considered in decisions regarding protection of the public welfare. Imperfect and incomplete information, inherent variability and uncertainty, and differences in individual values and perspectives undoubtedly lead to different views on what is the appropriate path forward. These differences highlight the need for a clearly defined and engaged stakeholder participation process as part of the on-going decision and management process for these materials.

4.1. Definition of Major Process Components for Each Alternative Considered

The primary alternatives considered in this review are

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.[15]
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 and shipped to a HLW geologic repository for permanent internment.
3. The calcined HLW will continue to be stored in the current bin sets.

Each of these alternatives was broken down into the major process steps that would need to be carried out to achieve successful completion of the designated alternative. Commonality among individual major process steps for each alternative allowed for identification of the primary risk components within each process step. Also, this commonality facilitates highlighting of how these risk components changed from alternative to alternative and as a result of the time frame considered for accomplishing each alternative. The primary process steps are

1. Bin Sets Storage[16]
2. Characterization of Calcined HLW
3. Retrieval of Calcined HLW from the Bin Sets
4. Processing Immobilized HLW into Canisters (Alternative 2 only)
5. Packaging of Calcined HLW into Canisters (Alternative 1 only)
6. Interim Storage of Canisters of Calcined/Immobilized HLW
7. Shipping of Calcined/Immobilized HLW to HLW Geologic Repository
8. Internment of Calcined/Immobilized HLW at HLW Geologic Repository

Not all of the major process steps are required to achieve all of the alternatives. In addition, changes that occur over time with respect to available information, decay of the

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[15] The proposed geologic repository at Yucca Mountain is considered the final disposition pathway for the purposes of this evaluation. The ultimate disposition pathway for the calcined HLW may vary significantly from this basis.

[16] Only the Bin Set Storage process step is relevant to Alternative 3.

radionuclide inventory, and actions necessary to maintain safe storage of the calcined HLW impact the decision logic and risks associated with each alternative and time frame considered. To consider these changes, management flow diagrams were developed for each alternative and time frame evaluated (Appendix B).

4.2. Illustration

For illustration purposes, the management flow diagrams for Alternative 1 (package), which is the currently assumed management option (baseline) for the calcined HLW, are provided for the near term (baseline) and intermediate term as Figures 5 and 6, respectively. Alternative 1 includes all major process steps that are that are listed above except processing (e.g., separations and/or stabilization such as vitrification). The impact of proceeding in the near term versus the intermediate or long term with retrieval and packaging of the calcined HLW in its current form becomes apparent. Proceeding in the near term time frame results in the production and interim storage of waste packages that may not be acceptable for disposal once a final disposition pathway is established. If the waste form is subsequently found to be unacceptable, then disruption of the material management plan occurs. The waste packages may remain in interim storage for a lengthy time period and may need to be removed from the packages and processed before being transported to the facility for final disposition. The impacted workforce and community will be dependent on the location of the interim storage. In contrast, proceeding in the intermediate or long term time frame will insure compatibility with the waste acceptance criteria for the final disposition pathway prior to packaging and may allow "just-in-time" production of calcined HLW packages, minimizing interim storage. Management flow diagrams for all three Alternatives in all three time frames can be found in Appendix B.

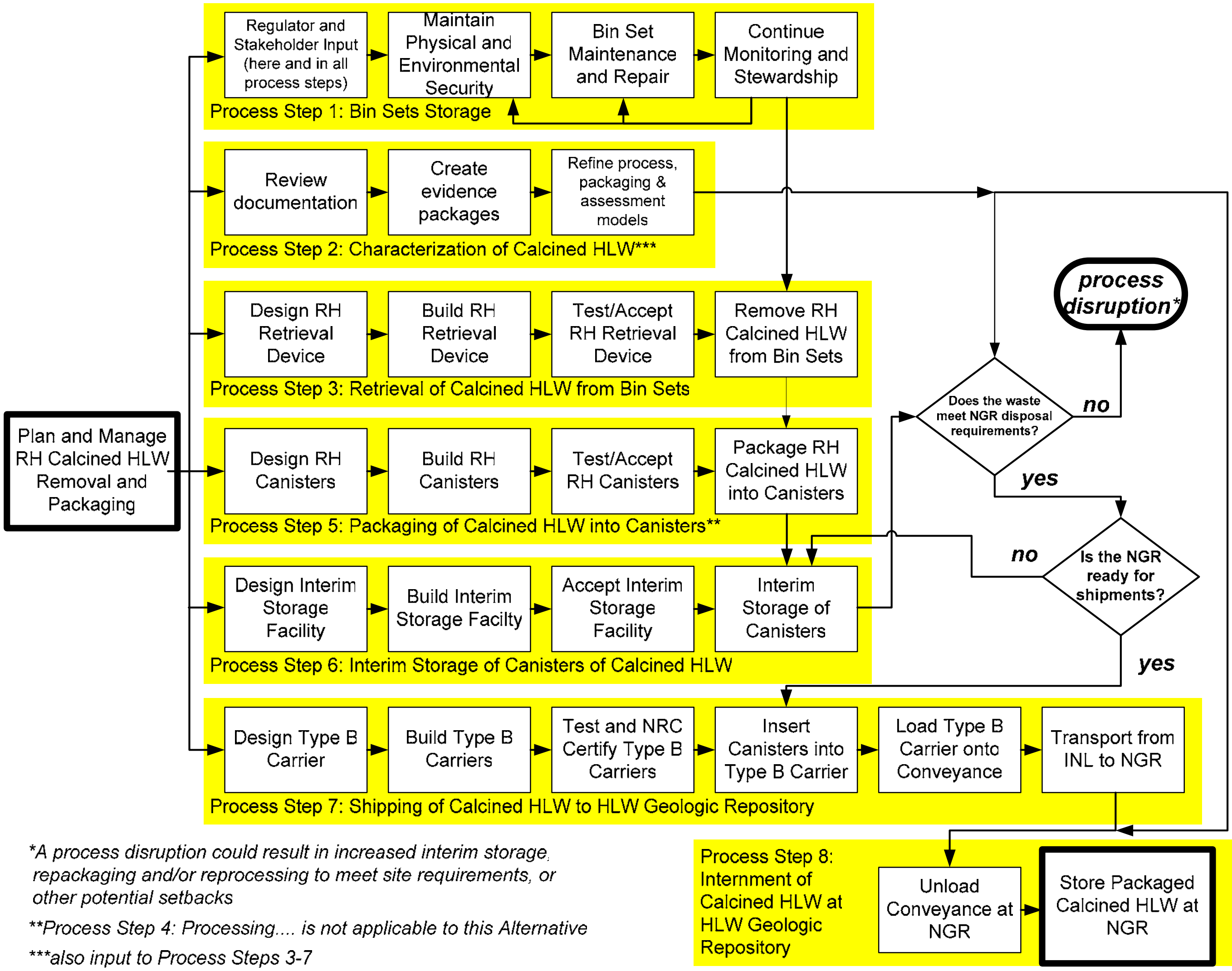

Figure 5. Management flow diagram for Alternative 1A, packaging of calcined HLW in the near term time frame.

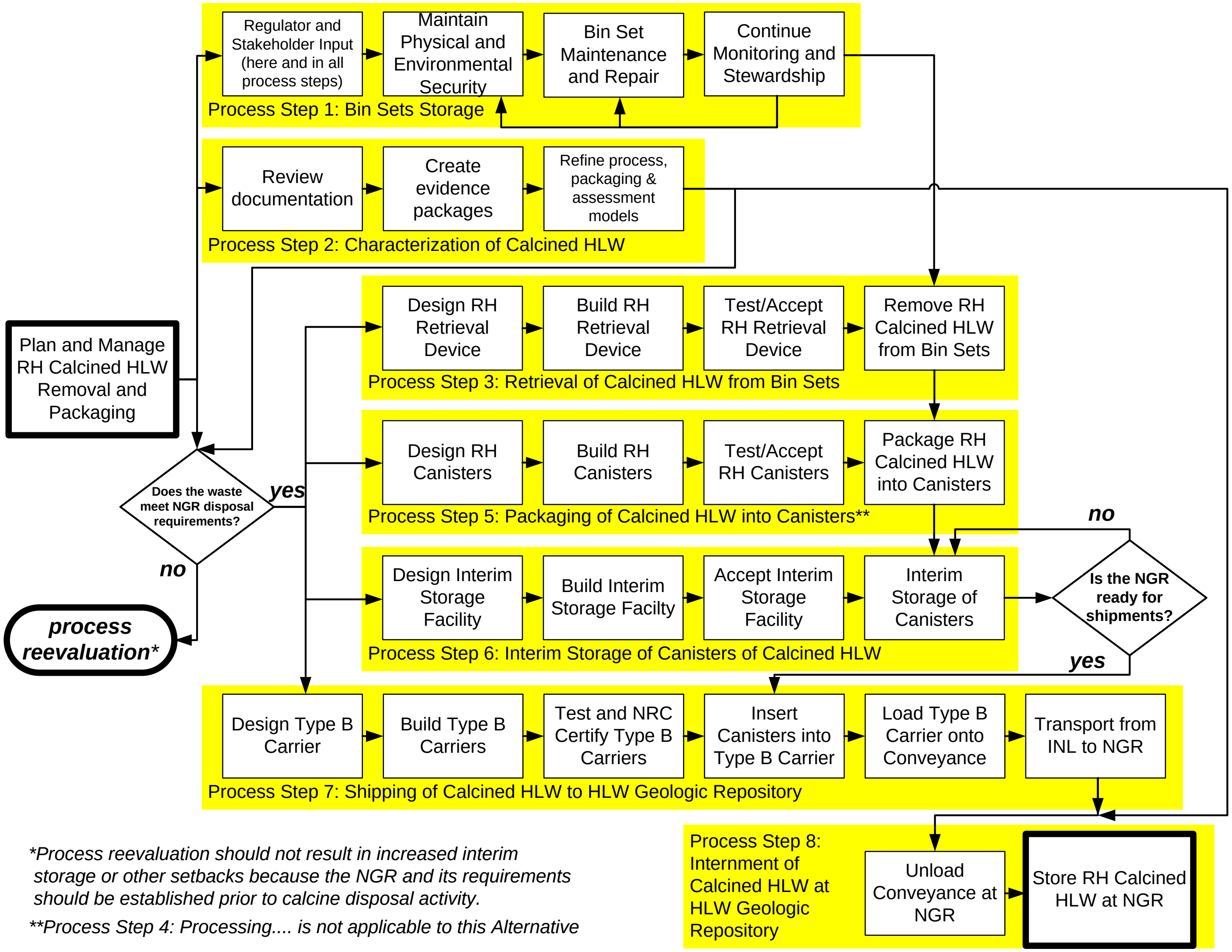

Figure 6. Management flow diagram for Alternatives 1B and 1C, packaging of calcined HLW in the intermediate and long term time frames.

4.3. Risk Characterization

Characterizing risk requires identification of each of the activities or events that may result in an adverse outcome (e.g., injury, fatality), what may go wrong, the affected population, the likelihood of the adverse outcome, and the severity of the adverse outcome (consequences). The preliminary risk characterization was achieved through the following steps:

1. Developing of management flow diagrams (in Appendix B) of the sequences of steps required to implement the alternatives, resulting in a list of primary subtasks for each of the process components for each alternative and time frame considered (Appendix C).
2. Developing of sets of risk flow diagrams (in Appendix F) for the alternatives that indicate the sequences of steps that have the potential to pose significant human health risks to workers or the public.
3. Developing of conceptual site models (in Appendix F) indicating risk pathways and receptors for the steps in the risk flow diagrams.
4. Identifying for each primary subtask, potential failure events and related information, resulting in a series of hazard analysis tables (Appendix D) that identified the most important potential upset conditions for each of the alternatives in each of the time frames (Section 5).
5. Identifying for each primary subtask, the information gaps associated with the characterization of risk, resulting in a series of gap analysis tables (Appendix E) that describes the key barriers, missing information and uncertainties to assessing the risks of implementing each of the three alternatives in each of the three time frames (Section 6).
6. Developing a summary table (Table 2) providing the most important risks and information gaps identified through the steps above, and
7. Developing a single table (Table 1) that depicts the relative risk for each alternative and time frame considered.

Uniform terminologies and categories for characterization of risks and information gaps were necessary to allow for meaningful comparisons. The applicable terminology and definitions used for each evaluation are provided at the beginning of Appendices D and E. Results of the above steps for each alternative and time frame are discussed in the sections that follow.

A recent National Research Council document highlights the importance of balancing human health risk with worker and environmental risks, costs, achievability and site-specific factors in developing a risk-informed approach (NRC, 2005). In that report, the observations are made in the context of exempting certain HLW and TRU wastes from disposal at a geologic repository, but have broader implications and applicability, and are consistent with the framework approach used here.[17]

5. PRELIMINARY CONCEPTUAL-LEVEL RISK ANALYSIS

A preliminary hazard analysis was carried out on the disposition alternatives for the calcined HLW at the Idaho Site with the specific understanding that substantial information gaps exist between the amount of information that is available and the amount of information necessary for a meaningful quantitative risk assessment. Currently, a self-consistent basis of design and a conceptual process design for each alternative and time frame that include all major processes, from the current storage through final disposition, do not exist. The large amount of information that is unknown about the calcined HLW and the treatment options prevents every process hazard from being identified properly. Instead, the goal of this hazard analysis was to identify known risks within the processes and bring forward the risks that form a significant combination of likelihood and consequence. Specifically, failure events that were classified as "probable" and "critical" from a safety perspective, "possible" and "severe", or "probable" and "severe" were identified as high risk hazards. The focus of this discussion is on those high risk hazards. The full hazard analysis, including terminology, definitions and failure events identified for each process step task, can be found in Appendix D.

5.1. Risk Categories

For the purposes of this evaluation, a "*probable*" event is defined as something very likely to occur (50 times in 100) during task execution and a "*possible*" event is defined as something expected to occur (between 1 time in 100 and 50 times in 100). A "*severe*" consequence is defined as the loss of the 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) and a "*critical*" consequence is defined as significantly degraded performance versus applicable and relevant design and performance criteria and the ability to protect human health and the environment. These terms are further defined in terms of injuries, illnesses, fatalities, environmental damage and equipment or property damage in Appendix D. The permutations of probable/critical, possible/severe and probable/severe combine sufficient likelihood of occurrence with significant human health and environmental impact to deem the corresponding hazards high risk.

5.2. Major Hazards

The major hazards occur during the bin set storage, retrieval and handling (packaging or immobilization) and interim storage process steps. Many of these hazards change significantly as a function of time when considering possible physical changes as well as the changes in available knowledge that impact human health risks based on how the time

[17] In the report, the NRC does not recommend for or against consideration of exemption of calcined HLW at the Idaho Site for consideration of exemption from disposal at a geologic repository.

frames are defined and used in this report. For bin set storage, the hazard severity increases as the time frame transitions from the near term to the intermediate term and long term because the lifetime of the process step increases. The increases in hazard severity are based on consideration of accumulated risks from monitoring and maintenance activities, and severe natural events (e.g., earthquakes). For extended time periods (e.g., greater than 100 years), the possibility of decay in the structural integrity of the bin sets (e.g., by corrosion) or system failure through neglect must also be considered. If system failure occurs to the extent that either human intrusion occurs or water infiltration and leaching of calcined HLW occurs, then larger populations beyond the site worker population may be at risk.

The hazard severity does not change for either the retrieval or handling steps, although the nature of the hazard does change because of radiological decay. External hazard reduction through gamma decay becomes significant as the time frames transition beyond the near term, but until the inhalation pathway has been removed (i.e., through waste immobilization) the internal alpha and beta radiation hazards remain, as well as any chemical exposure hazard. Also, consideration must be given to the potential that difficulty of retrieval of the calcined HLW may increase with time resulting from additional settlement, agglomeration from moisture absorption, and containment system corrosion.

The hazard severity decreases for the interim storage process step in the transition beyond the near term, because the hazard is a consequence of the uncertain time that retrieved material (either packaged granular material or immobilized material) will be maintained in interim storage. Without a clearly defined and approved path to final disposition, retrieved calcined HLW may remain in interim storage for decades or indefinitely. In this context, the upset conditions during interim storage that may result in human health impacts need to be considered (e.g., monitoring and maintenance accidents, containment failures). Based on the definitions used in this report, the path to final disposition would be clearly defined and approved for the alternatives in the intermediate term.

The hazard severity for packaging or processing is influenced by the time frame in a compound manner. Significant radioactive decay that occurs for the intermediate term and long term reduces the potential for radiological dose from gamma radiation, and reduces the amount of shielding required for handling operations. Still, substantial handling precautions (e.g., remote handling) will be required prior to placing the material into the final packaging (either in the current granular form or immobilized) because of remaining hazards associated with alpha activity in a friable material. When considering the near term, the potential exists for having to retrieve the material from interim storage and either re-package or process the material because the form the material placed in interim storage is unacceptable for final disposition. By definition, this risk is omitted for the intermediate term and long term time frames.

Coupling the hazard and gap analyses allows for a qualitative ranking of each of the alternatives in terms of risk, taking human health, environmental and programmatic factors into consideration (Table 1).

Table 1. Overall classification of risk for different management options for calcined HLW as a function of the time frame of achieving final waste disposition.[18]

Overall Risk	Time Frame		
	Near Term[19]	**Intermediate Term[20]**	**Long Term[21]**
Alternative 1	HIGH	MEDIUM*	MEDIUM*
Alternative 2	MEDIUM	LOW	MEDIUM
Alternative 3	LOW	LOW	HIGH**

Alternative 1: Store in current bin sets/Retrieve/Package/Store/Ship calcined waste to national geologic repository
Alternative 2: Store in current bin sets/Retrieve/Process/Package/Store/Ship calcined waste to national geologic repository
Alternative 3: Store in current bin sets for extended period/Manage calcined waste in Bin Sets/Reevaluate final disposition options
**Only acceptable if packaged calcined HLW is found to meet waste acceptance criteria for the final disposition pathway*
***Although not intuitively obvious, the deterioration of the bin sets and the calcined HLW as well as the accumulated increase in material events of greater severity warrant this classification*

In the near term time frame, Alternative 1 is high risk because of the hazards associated with packaging the waste as well as the information gaps relative to the waste form itself, transportation of the packaged material, and the absence of a defined and approved final disposition pathway for HLW as well as the related waste acceptance issues and uncertainties surrounding interim storage. Although processing under Alternative 2 faces many of the same hazards as Alternative 1 and is more difficult to carry out, Alternative 2 is ranked as a medium risk because the waste acceptance issues may be less severe than those for Alternative 1 and the end waste product is more protective of human health. Current waste acceptance criteria (not finalized) seem to use the immobilization processes at West Valley and the Savannah River Site as precedents for waste criteria (EM-WAPS Rev. 02, 1996). If the immobilization product selected for the calcined HLW is similar to waste forms that have been produced at the other sites, collectively, the sites may be able to petition for waste acceptance if the finalized waste criteria vary. Alternative 3 is low risk because the near term time frame remains well within the design

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[18] 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.

[19] The **near term time frame** (e.g., < 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.

[20] The **intermediate term time frame** (e.g., 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 decay; improved process technology could emerge as well.

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

lifetime and engineering experience of the bin sets; no high risk hazards were identified for this alternative in the near term time frame.

In the intermediate term time frame, a defined and approved pathway for the final disposition of HLW is expected to be in place. Related acceptance criteria and scheduling issues are expected to be resolved. Alternative 1 drops to medium risk if that waste form is deemed acceptable for final disposition. Alternatives 2 and 3 are deemed low risk because of the coupled reasons of substantial external radiation hazard reduction through decay of the high energy fission products and the higher level of certainty related to the final disposition pathway. Alternative 2 is deemed lower risk than Alternative 1 because although immobilization is a more complicated process with more potential risks to the involved workers, the subsequent benefits of immobilization (e.g., removal of the inhalation exposure pathway, lower radiation exposure during interim storage and transportation, reduction of the mobility of the hazardous constituents in the waste, etc.) are significant as well. It is important to note that accumulated risks from seismic and severe weather hazards become more severe in this time frame.

In the long term time frame, Alternatives 1 and 2 are deemed medium risk and Alternative 3 is deemed high risk because the substantial amount of gamma radiological decay that will have occurred is overshadowed by the likely exceedance of the design lifetime and engineering experience of the bin sets. The probability of bin failure or adverse event, either through worker activities (e.g., repair task) or the effects of aging (e.g., corrosion-related failure, severe seismic event, etc.), becomes more likely in the long term time frame. The bin sets are positioned over a sole-source aquifer and many of the hazardous and radiological components of the calcined HLW are soluble in water, so these failure events have the potential to expose workers and the offsite population to chemical and radiological hazards. A key criterion for Alternative 1 is that it must meet the acceptance criteria for the final disposition pathway in order to be applicable.

5.3. Interpretation

The results of the hazard analysis identify no clear choice for calcined HLW disposition from the three alternatives under review. The terms of the Settlement Agreement with the State of Idaho suggest that either Alternative 1 or 2 should be selected and carried out in the near term; however, the penalties for a premature decision on a disposition alternative may be severe. The proposed timelines in the HLW EIS (DOE/EIS-0287, 2002) suggest that both of these alternatives could meet the terms of the Settlement Agreement; however, the magnitude of the information gaps related to both of these alternatives, discussed in Section 6 of this report, does not support the proposed timelines in the HLW EIS.

Qualitatively, proceeding with retrieval and management of the calcined HLW under Alternative 2 in the intermediate time frame (once the final disposition pathway is established and related issues are resolved) may have the lowest associated risk of all of the permutations presented in this report. However, the information gaps related to this and the other alternatives here suggest that this assessment is preliminary and it is premature to make any recommendations for a path forward on this or any disposition alternative/time frame permutation.

The suggested path forward is to continue to explore the different alternatives for calcined HLW disposition, resolve the issues that are independent of the final disposition pathway and resolve as many issues as possible related to defining the final disposition pathway for the calcined HLW. Further, DOE, the Idaho Site and all of the stakeholders need to consider the contingency of the proposed geologic repository at Yucca Mountain never opening, either by developing a fourth alternative for disposition or by creating an extension to one or more of the current three alternatives. Self-consistent conceptual designs need to be developed to enhance the risk characterization to a level where a quantitative assessment with reasonable uncertainty bounds is possible.[22]

6. GAP ANALYSIS

In order to carry out a rigorous, quantitative risk assessment on the alternatives for the disposition of the calcined HLW at the Idaho Site, a great deal of information related to the nature of the activities involved within each alternative is required. This information may come from the Idaho Site experience directly or it may come from other facilities that have analogous experience. This section seeks to outline the information that is missing from the information that would be necessary for a quantitative risk assessment.

6.1. Gap Categories

A detailed gap analysis, including the definitions of the gap analysis terminology, can be found in Appendix E. Discussion here is restricted to information gaps that are both *critical* (from a safety standpoint) and *large* (little or no information is available), although less critical or less extensive gaps may be mentioned when that information is relevant to the critical, large gaps. These identified gaps are considered to be of the highest priority for resolution. Several of the gaps are programmatic, but the majority of the gaps are site-specific to the Idaho Site. Discussion is divided into two subsections. The first subsection discusses gaps relevant to all waste forms, with the understanding that only the last topic (6.2.8. Planning for Bin Set Management and Repair) is relevant to Alternative 3 (store in-place). The second subsection discusses process-specific gaps. For Alternative 1 (retrieve, package, ship), these gaps will be related to the packaging process. For Alternative 2 (retrieve, immobilize, package, ship), these gaps will be related to the immobilization process.

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[22] The U.S. Army chemical weapons demilitarization program may be of some guidance in developing the self-consistent conceptual designs. Their "ten percent design" concept is a useful preliminary process evaluation tool.

6.2. Gaps in Knowledge Relevant to All Waste Forms

6.2.1. Basis of Design and Conceptual Process Design

The most important knowledge gap identified through this review is the absence of a self-consistent basis of design and a conceptual process design for each of the alternatives evaluated that include every major process step, from the current bin set storage to final disposition. This gap impacts risk evaluation for all alternatives and time frames. Typically, such a basis of design would specify all relevant system requirements, schedule, material quantities and characteristics (e.g., for calcined HLW), general process characteristics (e.g., for retrieval, packaging, transportation, etc.) and development needs. Typically a conceptual process design would include initial system layouts, process flows, major equipment specifications, etc. that would meet the required basis of design. Both the basis of design and conceptual process design then would be used to complete much more specific hazards analysis and risk characterization because they can be used to define upset conditions and accident scenarios. Also, the designs would be used to identify important data and technology gaps in the specific processing steps so that these gaps can be addressed prior to process construction. Evaluation of the currently available information suggests that development of a basis of design and a conceptual process design would require a major effort, but the existence of such information would allow all subsequent process changes and decisions to fall under configuration control and provide clarity during process development and evaluation. Given the commitment to propose alternatives in a record of decision in 2009, initiation of the design process in conjunction with the reduction or elimination of the other safety critical information gaps that follow should begin in the near future.

6.2.2. Waste Acceptance Criteria for the Geologic Repository

The absence of a defined and approved pathway for the final disposition of the calcined HLW and associated waste acceptance criteria is a very large gap that prevents adequate assessment of the risks involved in two of the three alternatives presented in this report. As of the time of this report, the license application (LA) for construction of the proposed final disposition pathway, the National Geologic Repository at Yucca Mountain has not been submitted. Several more milestones must be reached before this facility is approved and the possibility exists that this facility may not be approved. For purposes of this analysis, the Yucca Mountain facility is assumed to be the final disposition site for HLW. If another facility or a different disposition pathway is chosen, this information gap must be resolved for the new site.

Although final waste acceptance criteria do not exist for the Yucca Mountain facility, there are preliminary regulations that may be of some guidance.

The USEPA regulations for the proposed Yucca Mountain facility (40 CFR 197) refer to the Nuclear Regulatory Commission regulations for the waste form and packaging (10 CFR 60 for general repository licensing and 10 CFR 63 for Yucca Mountain specifically). Specific guidance for the waste form has not been issued in 10 CFR 63, but the language in 10 CFR 60 may be of some guidance. For example, it is unclear from the text of 10 CFR 60.135(c) if the packaged waste form presented in Alternative 1 would be acceptable.

> *"(2) Consolidation. Particulate waste forms shall be consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates."*

However, other sections of 10 CFR 60.135 suggest that in its current form, the calcined HLW would be inappropriate.

> *"a) High-level-waste package design in general. (1) Packages for HLW shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages or the performance of the underground facility or the geologic setting. (2) The design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions.*
>
> *"(b) Specific criteria for HLW package design--(1) Explosive, pyrophoric, and chemically reactive materials. The waste package shall not contain explosive or pyrophoric materials or chemically reactive materials in an amount that could compromise the ability of the underground facility to contribute to waste isolation or the ability of the geologic repository to satisfy the performance objectives."*

Several of the components of the calcined HLW are highly soluble in water and may be highly corrosive (acidic) once dissolved in water. The conditions at Yucca Mountain are conducive to minimal infiltration of water; however, many of the constituents of concern in the calcined HLW that comes in contact with water will be dissolved rapidly in that water. The appropriateness of any waste form will depend on the conditions of the repository license, which has not yet been defined.

The models for the proposed Yucca Mountain facility assume waste forms of spent nuclear fuel and vitrified high-level waste (DOE/RW-0539, 2001). The waste acceptance criteria proposed by the Department of Energy (EM-WAPS Rev.02) assume the waste form for high-level waste is borosilicate glass. The calcined HLW is not analogous to either of these waste forms. At the very least, supplemental modeling may be required to show that the calcined HLW form meets the same "no migration" criteria as the vitrified high-level waste. Further study is necessary to establish the ability to of the packaged calcined HLW to remain within the "no migration" criteria.

The waste form presented in Alternative 2 meets both the physical requirements stated in 10 CFR 60.135, as discussed above.

However, since the license for construction has not been submitted and the application for the license to accept waste is several years away, these waste criteria cannot be considered final. Also, pending litigation over the proposed Yucca Mountain facility may impact the waste acceptance criteria. To proceed with either Alternative 1 or 2 in the near time frame in the absence of a defined and approved final disposition pathway risks incompatibility with the finalized waste criteria. Consequences of incompatibility range in severity from low (eg., increased paperwork for a non-standard waste form) to high (eg., rejection of the waste form, required reprocessing, etc.). In the absence of defined and approved disposition pathways for their wastes, decisions were made at West Valley and the Savannah River Site to generate a very conservative waste form (i.e., vitrified material) that would be considered safe for long term on-site storage as well as most likely acceptable at the final disposition site. The intermediate and long term time frames permit waste acceptance criteria to be finalized before proceeding with an alternative and would allow process changes to be implemented in the planning phase, thus eliminating this gap.

The calcined HLW is subject to the Resource Conservation and Recovery Act (RCRA) if it is determined to be a hazardous waste. The Hazardous and Solid Waste Amendments added language to RCRA prohibiting the land disposal of hazardous waste without some form of post-treatment (DOE/EIS-0287, 2002). It is unclear if the packaging process that would be developed under Alternative 1 would meet RCRA requirements. The immobilization process that would be developed under Alternative 2 would be more likely to meet those requirements because in addition to packaging, the waste form itself will be altered to greatly reduce the mobility of the waste constituents. Delisting would be necessary under either Alternative 1 or 2 to remove the waste from RCRA regulations. Under current RCRA regulations, some form of immobilization treatment may be necessary before the waste is allowed to be delisted.

6.2.3. Waste Acceptance Schedule for the Geologic Repository

Because a defined and approved final disposition pathway has not been established for the calcined HLW and the associated waste acceptance criteria have not been finalized, it follows that a waste acceptance schedule has not been established. The waste acceptance schedule is relevant to the interim storage and transportation process steps.

With respect to interim storage, the waste acceptance schedule could impact the duration of storage in the facility. Premature packaging of processed or unprocessed calcined HLW may result in prolonged interim storage if the proposed facility at Yucca Mountain is not prepared to accept the waste. Further, based on the current design, which is capacity constrained by legal authorization, Yucca Mountain is incapable of storing all of the spent nuclear fuel and high-level waste that could be generated by nuclear facilities in the United States. The Nuclear Waste Policy Act limits the first geologic repository at Yucca Mountain to 70,000 metric tons of heavy metal. Of that, 10% or 7,000 metric tons of heavy metal is expected to be available for DOE HLW (NRC, 1999). The priority for disposal of the calcined HLW with respect to all of the other wastes requiring disposal at Yucca Mountain is unclear. If the calcined HLW is affected by the capacity issue when the repository opens, interim storage has the potential to be increased greatly, impacting interim storage design requirements and associated interim storage risks.

With respect to transportation, the waste acceptance schedule and the processing or packaging schedule will determine the size and frequency of shipments and thus risk involved in the transportation process steps, from loading the shipping casks to their arrival at Yucca Mountain.

As with the waste acceptance criteria, the intermediate and long term time frames permit the waste acceptance schedule to be established before proceeding with a process alternative, thus eliminating this gap.

6.2.4. Composition and Distribution of Calcined HLW in the Bin Sets

Approximately 4400 m^3 of calcined HLW resides in six of the seven bin sets at the Idaho Site. The composition of the calcined HLW varies greatly both between bins and within each bin. Existing information about the calcined HLW composition has been derived from thermodynamic modeling of the likely composition of different batches of spent nuclear fuel. Two characterization samples were collected, in 1979 and 1993. The waste is expected to be highly heterogeneous, so the samples should not be considered representative (NRC, 1999). The nature of the filling process suggests that the assumption of horizontal strata of similar calcines is an oversimplification – the strata are more likely to be conical in shape.

NRC (1999) highlights inconsistencies and errors in other documents related to the calcined HLW composition, calling into question the dependability of the published data. The assembly of evidence packages as part of the characterization process step will be difficult with inconsistent data. It is unclear what additional physical characterization may be required (i.e., legally) for disposal if Alternative 1 is selected.

Planning for the tasks involved in the processing step of Alternative 2 is difficult without detailed composition data. Process changes may be required for different batches of calcined HLW as the waste is processed. Characterization may be best achieved as integrated with the processing step for Alternative 2, even though for purposes of discussion, characterization is separate process step. This approach would require design of the treatment process based on the range of composition envelopes for the calcined HLW based on prior process knowledge and minimal early sampling. Post-immobilization process steps in Alternative 2 would be impacted by process changes. Waste loading would affect the number of immobilized waste packages produced, which would affect, in turn, the interim storage, transportation and interment process steps.

Unlike the previous information gaps, the gap related to composition of the calcined HLW does not diminish over time. The calcined HLW composition will change over time because of radiological decay as well as chemical and physical degradation; however, the radiological composition at any time after characterization has occurred can be calculated. Substantial decay of the high energy fission products may occur by the intermediate term time frame and most of this decay will have been completed by the long term time frame.

6.2.5. Method of Retrieval of Calcined HLW from the Bin Sets

Specific information about the retrieval system and associated risks is not available, including the effectiveness of retrieval method, requirements of retrieval method, and planned pilot testing of retrieval method. One vacuum-type technology passed a "proof-of-concept" test in 1978 (PNNL-13268, 2000). Calcined HLW samples that had been aged for approximately 10 years were removed for analysis. Clogging problems were observed with the alumina type calcined HLW during this test. The zirconia type calcined HLW did not cause clogging problems. Similar phenomena were observed in the process of loading the bins (NRC, 1999).

Over 25 years have passed since the test. The clogging problems most likely will be worse, especially with the calcined HLW closest to the bin walls, as the temperature will be lowest there. Several technologies have been discussed to address the clogging issue; however, none have been developed or tested sufficiently to demonstrate potential for success in calcined HLW removal from the bins.

The presence of moisture in the bins will make handling more difficult. As the fission products decay, the temperature in the bins will decrease and the moisture will increase. Several of the components of the calcined HLW are highly soluble in water. Increasing moisture content will increase their mobility as well as increase the likelihood of clogging.

The highest risk involved in the retrieval of the calcined HLW is the potential release of calcined HLW from engineered controls (NRC, 1999), which would affect both the workers involved in the cleanup as well as the general population if the calcined HLW constituents either become airborne or enter the subsurface.

6.2.6. Decommissioning Activities and Standards

Decommissioning standards for the bins, packaging equipment, processing equipment and facilities have not been established. Also, methods for decommissioning have not been proposed. Complete removal from the bins cannot be expected, especially given the clogging issues with the alumina type calcined HLW (discussed above). Further, residual contamination will be present in the processing and/or packaging equipment and piping. Standards must be established for the amount of calcined HLW that can remain in each bin as residual contamination. Sufficient characterization of the calcined HLW would allow for a risk-informed determination of an appropriate standard as well as an appropriate final disposition for the bin sets.

6.2.7. Model Predictions of Calcined HLW Behavior in the Geologic Repository

No modeling analogs exist for the Alternative 1 scenario of disposal at Yucca Mountain.[23] Models have been developed for spent nuclear fuel and vitrified high-level waste (as borosilicate glass) (DOE/RW-0539, 2001). If the immobilization technology selected for Alternative 2 is separations/vitrification or vitrification without separations, the models for Yucca Mountain may be applicable; however, the waste loading discussed in the HLW EIS exceeds the typical waste loading for borosilicate glass (50% compared to 20-40% achieved at the West Valley and Savannah River Site).

Calcined HLW is a mixed high-level waste because it contains both radionuclides as well as RCRA-regulated non-radioactive metals. Calcined HLW disposed at Yucca Mountain under Alternative 1 may be subject to compliance with the Resource Conservation and Recovery Act (RCRA) as well as the not-yet-established standards for Yucca Mountain. If the final disposition pathway changes from the currently proposed Yucca Mountain facility, this information gap must be resolved for the new disposition pathway.

6.2.8. Planning for Bin Set Management and Repair

The gaps related to bin set management and repair range from administrative to operational. Some administrative gaps have direct safety-related consequences, so those gaps are included here.

In all three time frames, budget planning and adequate funding for stewardship remain a large gap. No reports demonstrate that sufficient funding will be available to manage the complete life-cycle of the calcined HLW regardless of the alternative selected.

In the near term time frame, the durability of the bin sets is expected to keep potentially invasive repair scenarios to a minimum; however, repair becomes a much more significant concern in the intermediate and long term time frames as the design lifetime of the bin sets is approached. Estimates for the design life of the bins range from 100 years (design documents) to 500 or more years (NRC, 1999). The Department of Energy operates typically with a "run to failure" approach to maintenance and repair for waste storage. "Run to failure" does not seem appropriate for long term management of the bin sets. Potential scenarios for repair have not been considered, but these scenarios would be important in the longer time frames.

Proactive measures toward bin set management that would increase the security and durability for the longer time frames have not been considered because longer storage periods are not planned currently. The cumulative likelihood of seismic activity and severe weather events increases in the intermediate and long term time frames. The original design specifications included these considerations; however, the design lifetime may be exceeded in the intermediate term time frame and will be exceeded in the long term time frame.

[23] CRESP was informed that modeling of the disposal of calcined HLW in a geologic repository is being carried out, but details and results of this effort were not made available for this study.

6.3. Process-Specific Gaps

6.3.1. Specific Information about Packaging Calcined HLW (Alternative 1)

Aside from the issues raised regarding the absence of a defined and approved final disposition pathway for the calcined HLW, a number of critical and large information gaps exist that are specific to Alternative 1 (packaging). Conceptual designs for a packaging facility, requirements for a packaging facility, method of packaging (i.e., specific tasks involved) and demonstrated effectiveness of the packaging are among the information that is essential to the risk assessment process. Every facility that has begun preparing its HLW for shipment to the proposed geologic repository has selected technologies to immobilize that waste. No process analogs exist for packaging granular HLW. Estimation of worker and environmental risks is difficult without this information.

6.3.2. Specific Information about Immobilizing Calcined HLW (Alternative 2)

The critical and large information gaps that are specific to Alternative 2 (immobilization) include conceptual designs for the processes involved, plans for pilot testing, specific process task information (e.g., dissolution of batches of calcined HLW in water or nitric acid, processing vessel (separations process), (post-treatment) processing, packaging) and effectiveness of post-immobilization packaging process.

Separation and vitrification have been carried out at West Valley and the Savannah River Site, so process analogs exist for those technologies; however, the nature of the calcined HLW differs from the waste treated at these sites. Much process development is required even if these are the technologies selected for immobilization of the waste. Other immobilization techniques have been studied for HLW immobilization, including forms of glass other than borosilicate glass, ceramics, glass-ceramic blends and other encapsulants (Donald et al., 1997). Their application for calcined HLW immobilization has not been studied.

Table 2. Summary of most important human health and programmatic risks and associated highest priority information gaps.

Information Gaps and Their Applicability to Specific Alternatives and Time Frames										**Human Health Risk Characterization**				
Highest Priority Information Gap	**1A (Near Term)**	**1B (Intermediate Term)**	**1C (Long Term)**	**2A (Near Term)**	**2B (Intermediate Term)**	**2C (Long Term)**	**3A (Near Term)**	**3B (Intermediate Term)**	**3C (Long Term)**	**What can go wrong? (radiological and non-radiological failure incidents)**	**How likely is it?**	**What are the consequences?**	**Who is impacted?**	**Contribution to Risk**
Waste Acceptance Criteria for the Geologic Repository	√[24]			√						• Waste form deemed inappropriate for NGR[25] • Delay in shipping causes increased storage duration	• Probable • Probable	• Severe • Critical	• Worker • Worker	• High • High
Waste Acceptance Schedule for the Geologic Repository	√			√						• Delay in shipping causes increased storage duration	• Probable	• Critical	• Worker	• High

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√ Information gap is both *critical* and *large* for the given time frame, resulting in the gap being considered among the highest priorities for resolution because of implications for either human health or programmatic risk.

Information gap is not *critical* and *large* for the given time frame, resulting in the gap not being considered among the highest priorities for resolution

Information gap is not relevant for the given alternative or time frame (eg., waste acceptance criteria do not impact Alternative 3 because the calcine would not be transported to the geologic repository)

[25] 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).

Information Gaps and Their Applicability to Specific Alternatives and Time Frames										Human Health Risk Characterization				
Highest Priority Information Gap	**1A (Near Term)**	**1B (Intermediate Term)**	**1C (Long Term)**	**2A (Near Term)**	**2B (Intermediate Term)**	**2C (Long Term)**	**3A (Near Term)**	**3B (Intermediate Term)**	**3C (Long Term)**	**What can go wrong? (radiological and non-radiological failure incidents)**	**How likely is it?**	**What are the consequences?**	**Who is impacted?**	**Contribution to Risk**
Composition and Distribution of Calcined HLW in the Bin Sets	√	√	√	√	√	√				• *Programmatic failure with human health implications*[26]				
Method of Retrieval of Calcined HLW from the Bin Sets	√	√	√	√	√	√				• Radiological exposure during installation • Release of calcined HLW from engineered controls during material transfer	• Probable • Probable	• Critical • Critical	• Worker • Worker	• High • High
Decommissioning Activities and Standards	√	√	√	√	√	√	√	√	√	• *Programmatic failure with human health implications*				
Modeling Predictions of Calcined HLW Behavior in the Geologic Repository	√	√	√	√	√	√				• *Programmatic failure with human health implications*[27]				

[26] Knowledge of the composition and distribution of the calcined HLW in the bin sets is most relevant to Alternative 2, but may be required for Alternative 1 (eg., in order to justify RCRA delisting).

[27] This knowledge is critical to justify the safety of disposition under Alternative 1, but is relevant to Alternative 2 as well. Absence of this knowledge results in propagation of risks to other process step tasks.

Information Gaps and Their Applicability to Specific Alternatives and Time Frames										**Human Health Risk Characterization**				
Highest Priority Information Gap	**1A (Near Term)**	**1B (Intermediate Term)**	**1C (Long Term)**	**2A (Near Term)**	**2B (Intermediate Term)**	**2C (Long Term)**	**3A (Near Term)**	**3B (Intermediate Term)**	**3C (Long Term)**	**What can go wrong? (radiological and non-radiological failure incidents)**	**How likely is it?**	**What are the consequences?**	**Who is impacted?**	**Contribution to Risk**
Planning for Bin Set Management and Repair		√	√		√	√		√	√	• Earthquake or severe weather event damages bin set(s).[28] • Injury during routine monitoring task[29] • Injury during preventive maintenance task[30] • Injury or radiation exposure during non-routine maintenance[31]	• Possible • Probable • Probable • Probable	• Severe • Critical • Critical • Critical	• Worker & Off-site population • Worker • Worker • Worker	• High • High • High • High
Specific Information about Packaging Calcined HLW	√	√	√							• Release of calcined HLW occurs during packaging	• Probable	• Critical	• Worker	• High
Specific Information about Immobilizing Calcined HLW				√	√	√				• Release of calcined HLW occurs during immobilization	• Probable	• Critical	• Worker	• High

[28] Hazard contribution to risk is High in the Intermediate Term (B) and Long Term (C)

[29] Hazard contribution to risk is High only in the Long Term (C)

[30] ibid

[31] ibid

6.4. Suggestions for Gap Resolution

Several of the gaps listed above are programmatic gaps, outside of the control of the Idaho Site. These gaps, primarily related to the absence of a defined and approved final disposition pathway, have direct impact on the processes to be carried out at the Idaho Site and cannot be overlooked. As discussed in the Preliminary Conceptual Level Risk Analysis, the penalties for a premature decision on a disposition alternative may be severe.

The Risk Analysis suggested a path forward to resolve the process-specific gaps. The development of a basis of design and a self-consistent conceptual design for each alternative would be important first steps toward developing a more thorough risk characterization for each alternative, enabling a more informed decision process. The process outlines in the earlier West Valley EIS (DOE/EIS-0081, 1982) provide examples of good starting points for the development of the basis of design for each alternative. The self-consistent conceptual designs that are developed in subsequent process design steps could be similar to the ten percent designs that the U.S. Army uses. The ten percent designs can be followed by other design intervals such as thirty, fifty and seventy percent, further refining the risk-informed decision process. The progression of designs will help to eliminate several of the other information gaps, because the designs must refine the retrieval method and the plans for sampling to determine composition of the calcined HLW. Resolution of the programmatic information gaps can be facilitated by this type of design process. Information gaps not related to the programmatic issues of the final disposition pathway should be resolved as much as possible. Further, the contingencies of a geologic repository never opening or its availability subject to long delays need to be addressed, specifically by planning for intermediate and long term management of the bin sets and possibly developing a fourth disposition alternative to address this possibility.

7. CONCLUSIONS AND RECOMMENDATIONS

The information provided in this report provides a foundation for improved risk characterization and identifies the most important information gaps that should be resolved to provide both improved risk characterization and decision making. Proceeding with retrieval and either packaging or processing of the calcined HLW prior to clear definition of a complete disposal pathway could result in both increased human health and programmatic risk. This finding is consistent with earlier National Academy observations and recommendations (NRC, 1999). However, in contrast to the earlier National Academy report, perpetual storage of the calcined HLW in the bin sets has long term risks that should not be discounted. Eventual failure of the containment achieved by the bin sets is a probable scenario that may result in impacts either through atmospheric dispersal or release of contaminants to the groundwater.

The primary recommendations stemming from this report are to (i) develop self-consistent bases of design and conceptual process designs for each alternative that merit further consideration, (ii) resolve as many of the information gaps as possible, especially the large and critical gaps that have been highlighted, (iii) use the new information to form improved risk characterization as input to improved decision making. Resolving the identified information gaps will require development of consistent conceptual designs for all of the process steps that integrate effectively to form an overall management alternative. A contingency alternative should be developed to plan for the case where the legal issues surrounding the proposed Yucca Mountain facility are never resolved or the facility is not able to accept the calcined HLW. Some of the required information gathering is currently on-going by DOE.

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APPENDIX A: SCOPE OF THE REPORT

CRESP Evaluation of Management Options for Calcined HLW at INEEL

Objectives:

5. 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.

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

7. 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.

8. 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.

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.

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

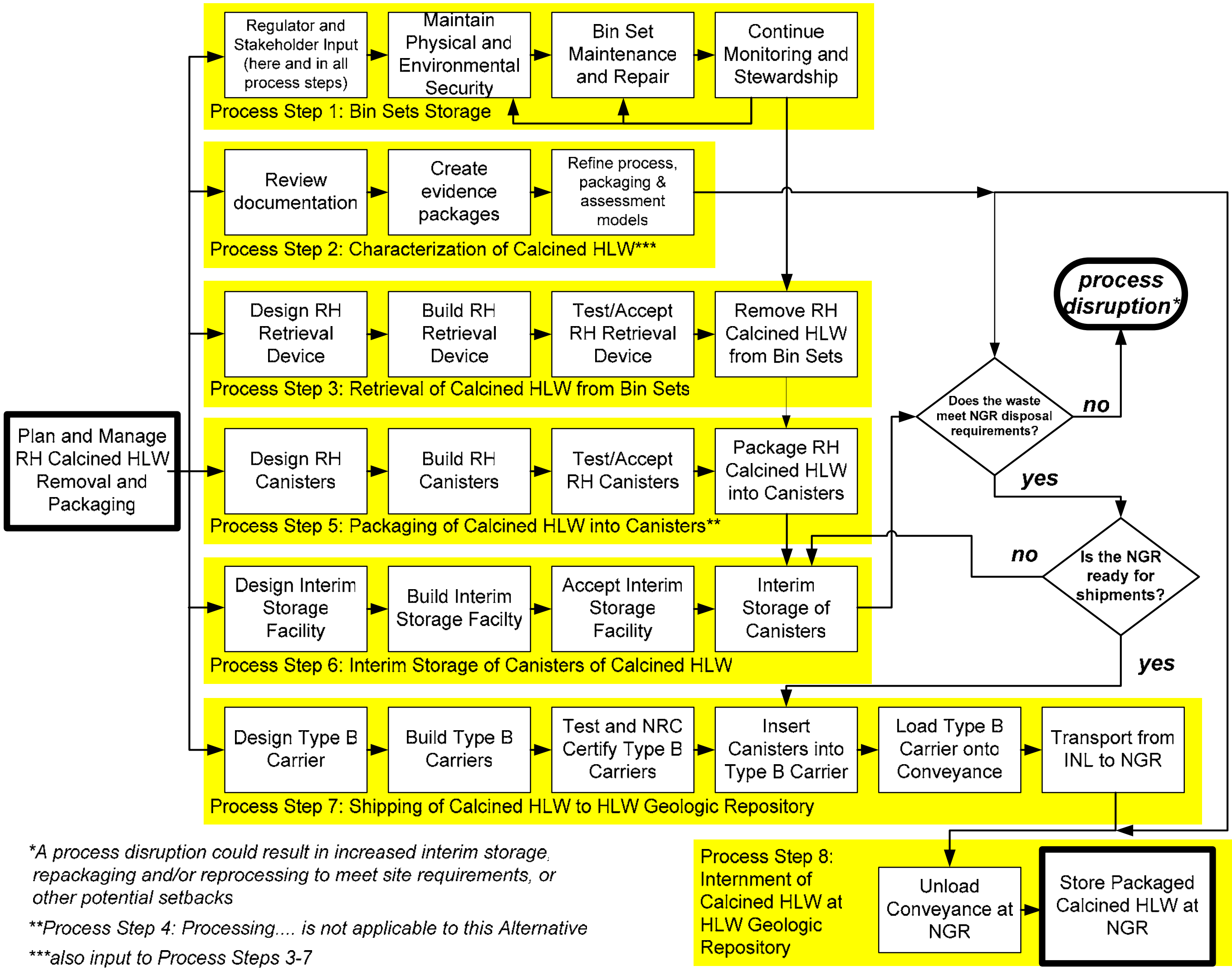


Figure B-1. Management flow diagram for Alternative 1 (Retrieve/Package/Ship) for Time Frame A (Near Term)

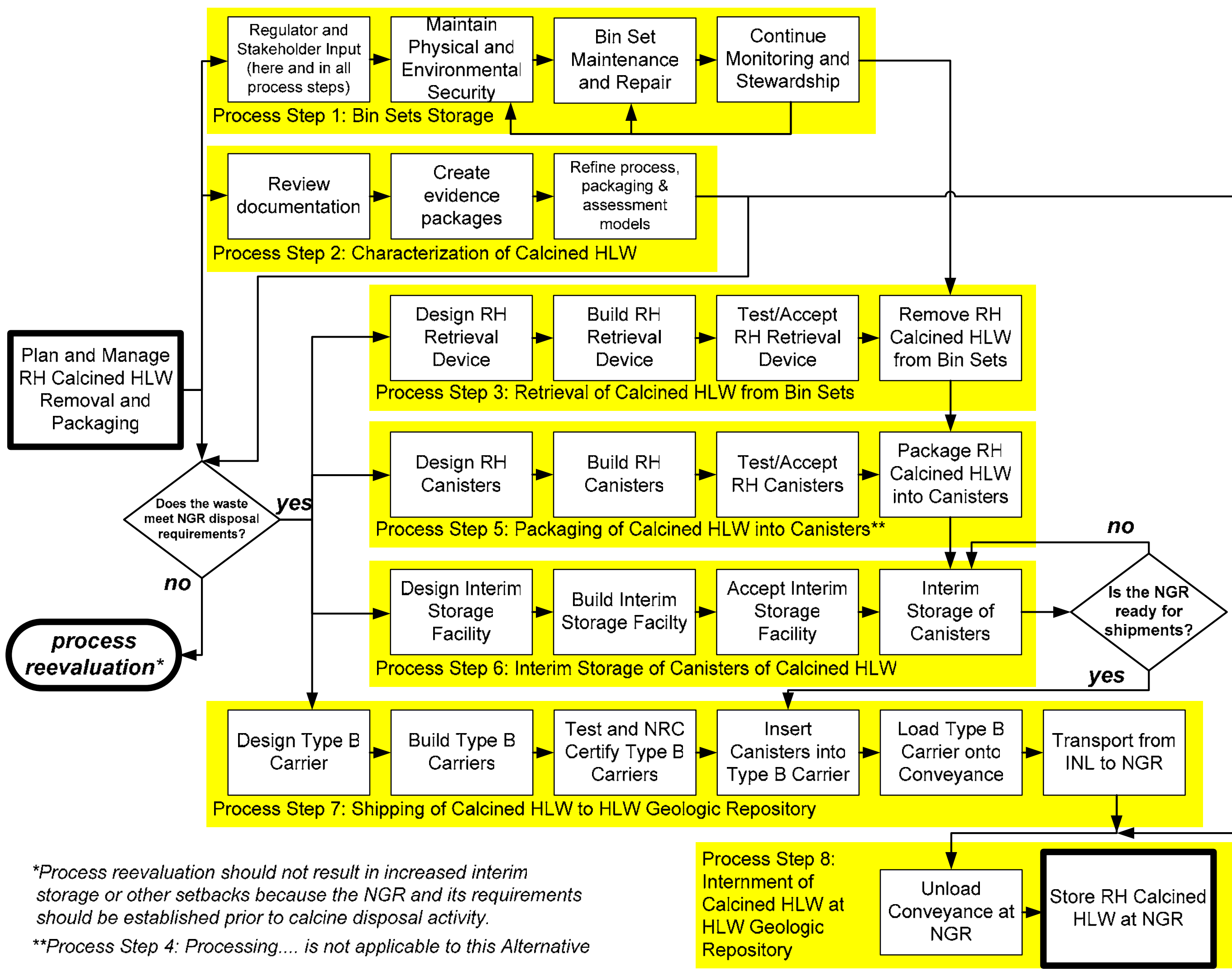
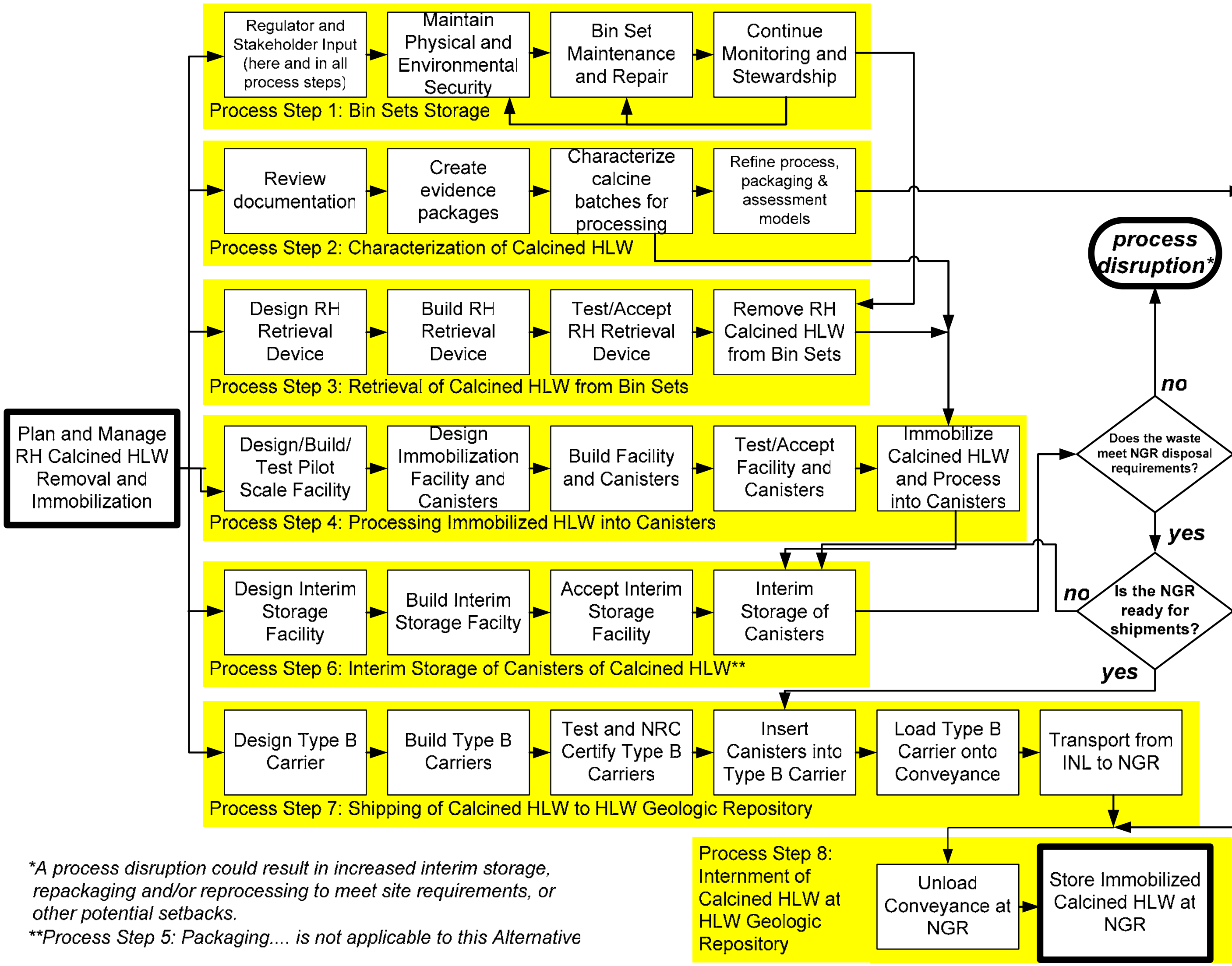


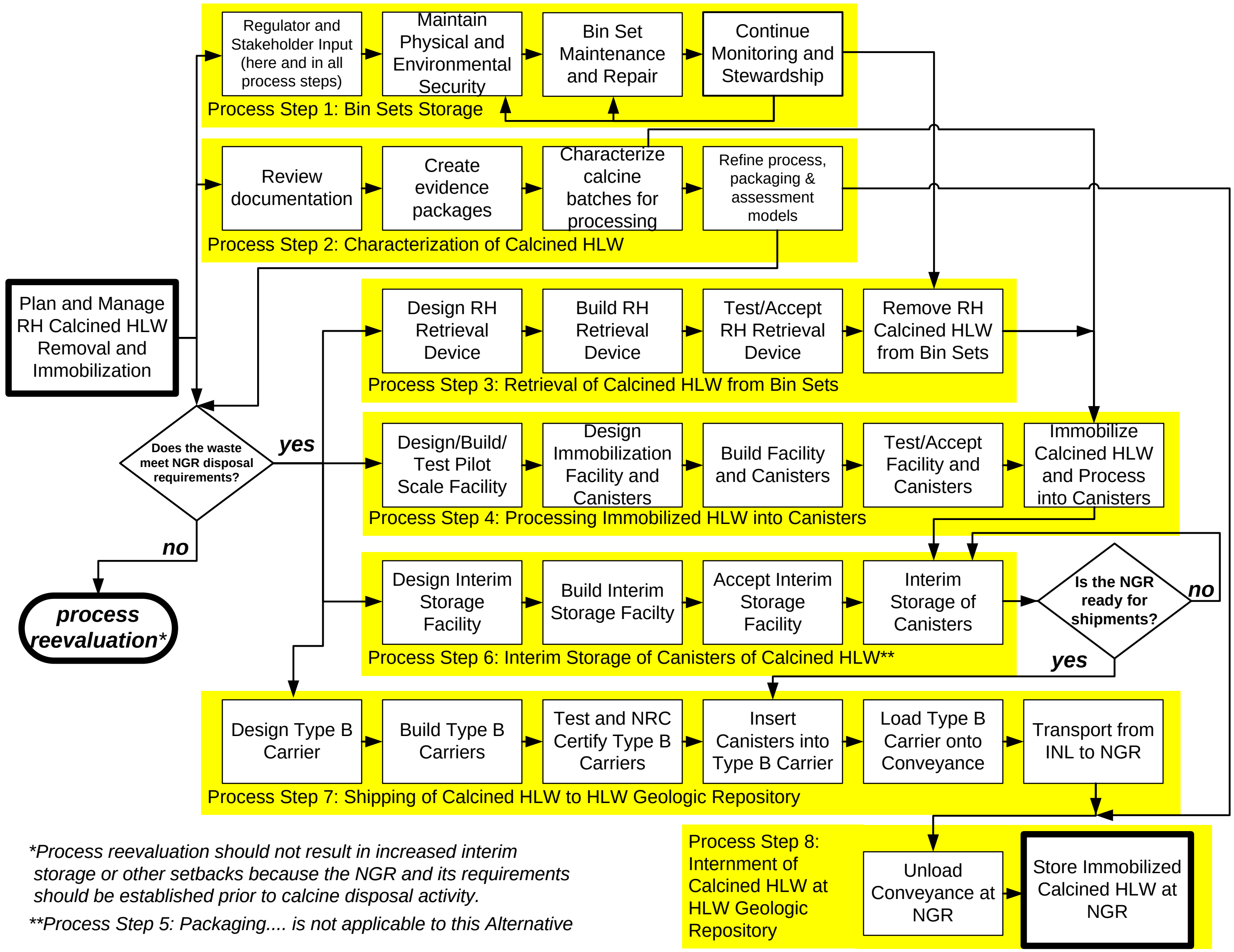
Figure B-2. Management flow diagram for Alternative 1 (Retrieve/Package/Ship) for Time Frame B (Intermediate Term) and Time Frame C (Long Term)



*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)

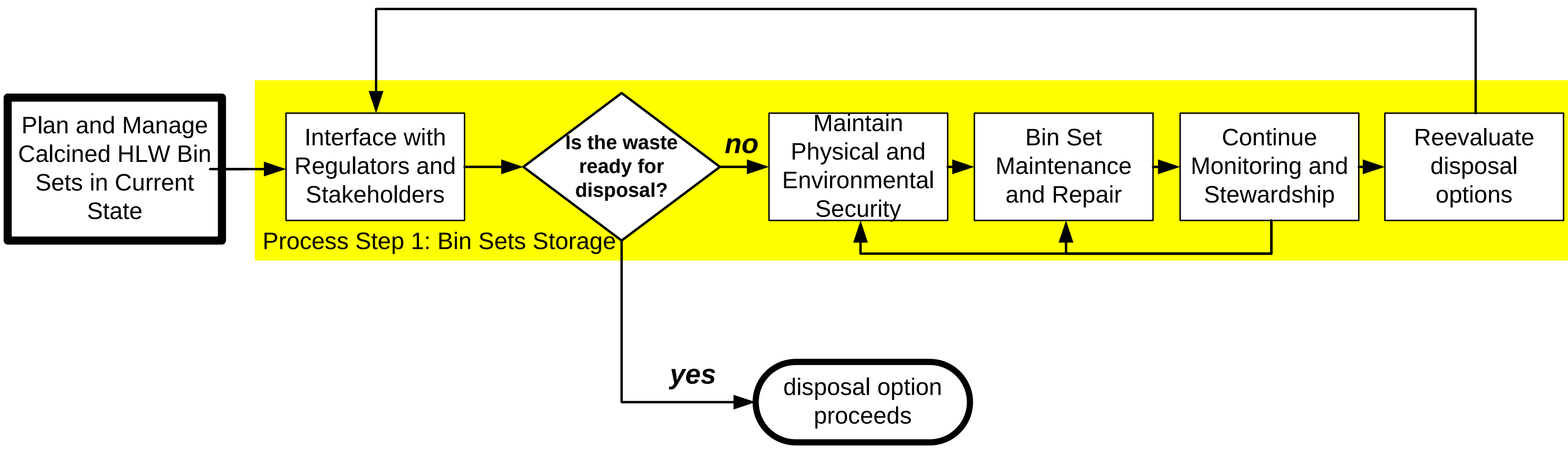


Figure B-5. Management flow diagram for Alternative 3 (Store in Place) for Time Frame A (Near Term), Time Frame B (Intermediate Term) and Time Frame C (Long Term)

APPENDIX C: TASK LIST

Task List[32]

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

[32] 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

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1A.8.1 Off-load calcined remote-handled shielded casks
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APPENDIX D: HAZARD ANALYSIS

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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.

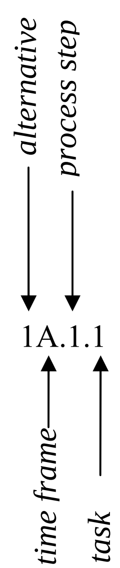
Note

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

Process Step Description	Alternative 1			Alternative 2			Alternative 3		
	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[33], 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).

[33] 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.[34] 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.

[34] 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[35]

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).[36]

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

[36] 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[37] 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[38] 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

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

[38] 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.[39] 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[40], 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.

[39] 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.

[40] 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[41]	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

[41] 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*[42]	*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*

[42] 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[43]	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)

[43] 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**[44]
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

[44] 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[45]	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.[46]	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

[45] 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.

[46] 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[47]	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

[47] 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.[48]	Unlikely[49]	Critical	Worker and Off-site Population		Significant

[48] 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.

[49] 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[50]	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

[50] 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[52]	Worker Off site population	Similar operational experience	Low
		Earthquake or severe weather event damages bin set(s).[51]	**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

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

[52] 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[53]

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

[53] 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. Waste deemed inappropriate for NGR	Probable **Unlikely**	Critical **Marginal**	Worker Worker	Similar operational experience	High **Low**[54]
1B.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

[54] 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**[55]	Critical	Worker		Significant
		Delay in shipping causes increased storage duration.	**Unlikely**[56]	**Marginal**[57]	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

[55] Gamma radiation decay decreases the likelihood to Unlikely.
[56] Delay is less likely because NGR should be operational before packaging begins, allowing for "just in time" packaging and shipping. Risk category unchanged.
[57] 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[58]

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

See Table D-1A.8

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

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[61]	Worker Off site population	Similar operational experience	Low
		Earthquake or severe weather event damages bin set(s).[59,60]	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**[62]	Marginal	Worker	Similar operational experience	Significant
1C.1.3 Preventive maintenance	Frequent	Injury during preventive maintenance task (with facility damage)	**Probable**[63]	Critical	Worker	Similar operational experience	**High**

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

[60] 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.

[61] 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.

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

[63] 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**[64]	Critical	Worker	Similar operational experience	**High**
1C.1.5 Repair	Occasional	Injury or radiation exposure during repair task	**Probable**[65]	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**[66]	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

[64] ibid
[65] ibid
[66] 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[67]

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

[67] 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-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**[68]
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

[68] 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.

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

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**[69]	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[70]

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

See Table D-1A.8

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

[70] 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[71]	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

[71] 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[72]

[72] 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[73]	Possible[74]	Critical	Worker		Significant
2A.4.4 Decommission HLW processing facilities	Occasional	Injury or radiological exposure during decommisioning	Unlikely	Critical	Worker	Similar operational experience	Significant

[73] Programmatic failure event with potential impact on other process steps
[74] 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[75]

[75] 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.	Possible[76]	Critical	Worker	Similar operational experience	Significant
		Canister breaks during loading process	Unlikely	**Marginal**[77]	Worker		**Low**
2A.7.4 Secure shielded shipping casks to conveyance	Frequent	Injury during the securing process.	Possible	Critical	Worker	Similar operational experience	Significant

[76] 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.

[77] 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.[78]	Unlikely[79]	Critical	Worker and Off-site Population		Significant

[78] 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.

[79] 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 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[80]	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

[80] 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-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[81]

[81] 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. Waste form deemed inappropriate for NGR	Probable **Unlikely**	Critical **Marginal**	Worker Worker	Similar operational experience	High **Low**[82]
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

[82] 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**[83]	Worker		**Low**
		Radiation exposure during storage.	Possible	Critical	Worker		Significant
		Delay in shipping causes increased storage duration	Unlikely	**Marginal[84]**	Worker		**Low**
2B.6.3 Decommission interim storage facility	Occasional	Injury or radiation exposure during decommissioning.	Unlikely	Critical[85]	Worker	Similar operational experience	Significant

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

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

[85] 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[86]

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

See Table D-1A.3[87]

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

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

[87] 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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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.

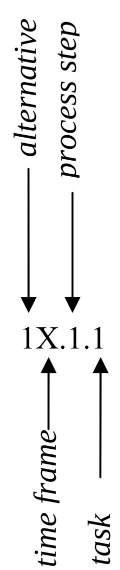
Notation

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[88], 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).

[88] 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.[89]	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.

[89] 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.[90]	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.[91]	
	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.[92]	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).

[90] ibid
[91] ibid
[92] 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[93]	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[94]	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

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

[94] 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.[95] Current work at Idaho Site is underway to determine the appropriateness of the packaged waste form for internment at the Yucca Mountain facility.

[95] 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 Feedback ability of sample results to waste processing procedure	Critical Critical	Large Interm.	Method determines worker exposure during sampling/testing. 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 Effectiveness of retrieval method Definition of requirements Pilot testing	Critical Critical Critical Critical	Large Large Large 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.
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.[96]	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.

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

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.6.2 Operate Interim Storage Facility	Storage facility configuration	Important	Interm.[97]	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.[98]	
	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.[99]	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).

[97] ibid

[98] ibid

[99] 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[100]	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[101]	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

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

[101] 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.

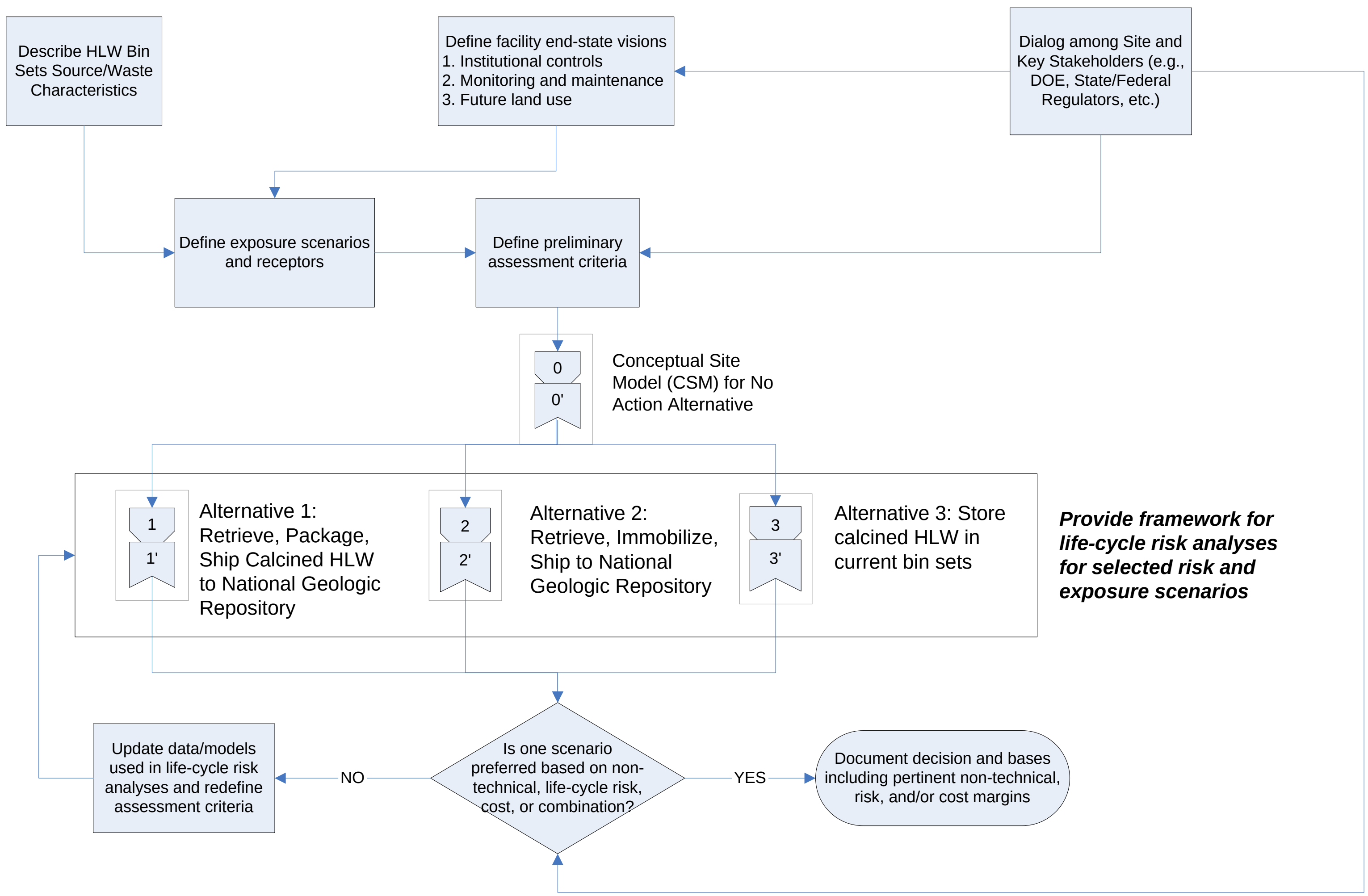


Figure F-1. Overall risk flow diagram for the calcined HLW bin sets.

Alternative 1

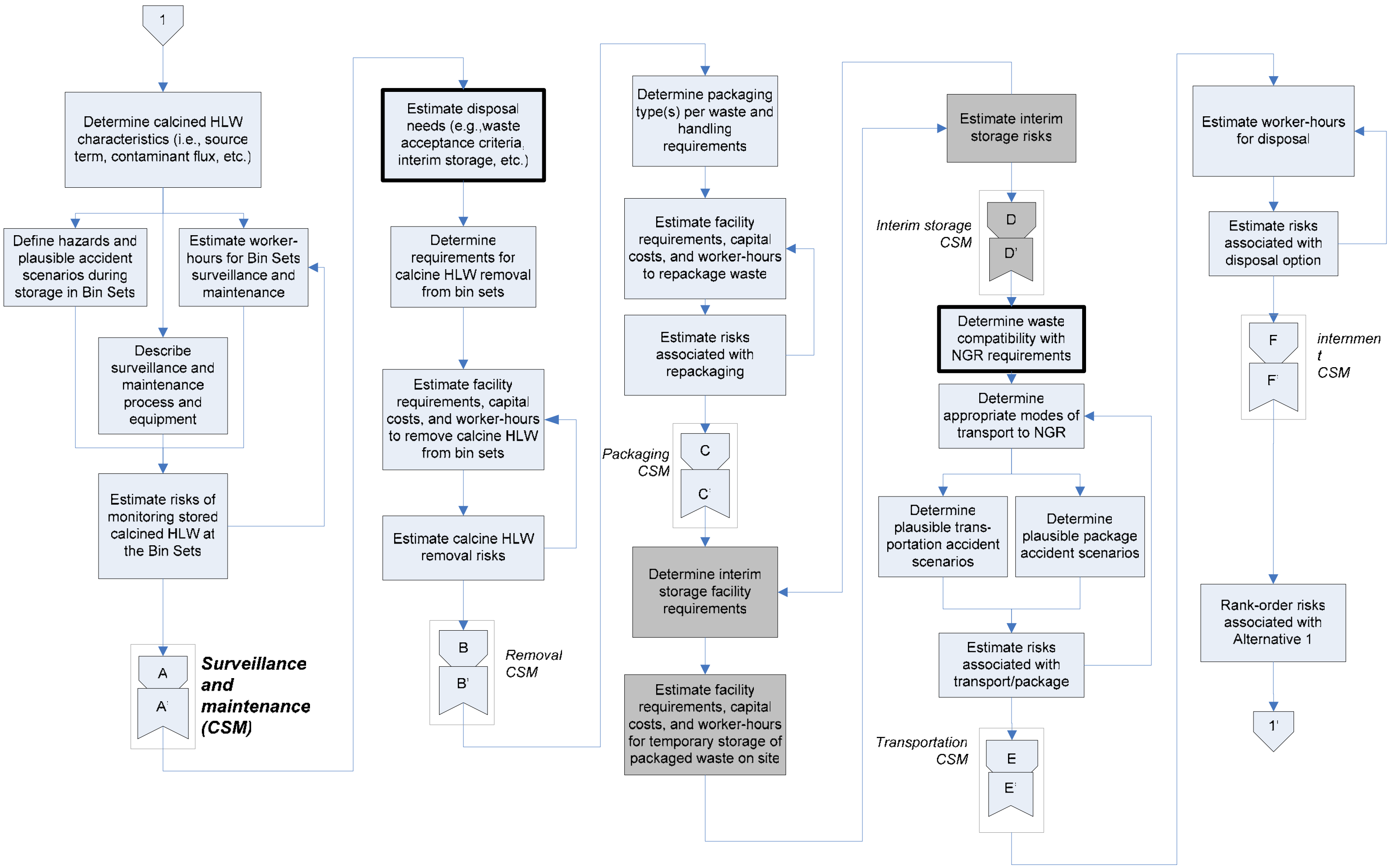


Figure F-2. Risk flow diagram for Alternative 1 (Retrieve/Package/Ship). Deviation points from Time Frame A to either B or C are the boxes with bold outline and the risk flow events that are impacted are highlighted by the dark grey shading.

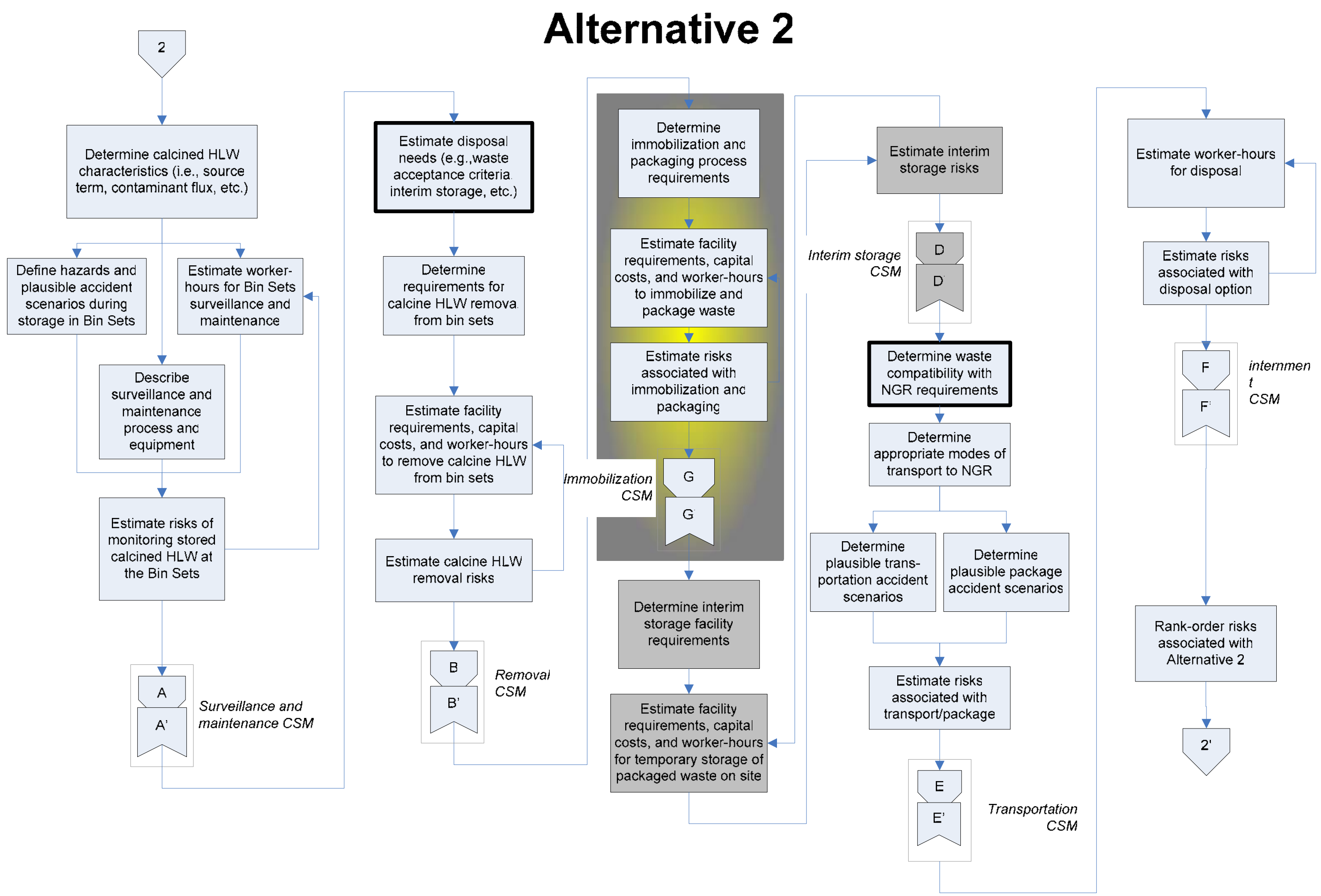


Figure F-3. Risk flow diagram for Alternative 2 (Retrieve/Immobilize/Package/Ship). Divergence from Alternative 1 risk flow (Figure F-2.) is highlighted by the dual-tone box. Deviation points from Time Frame A to either B or C are the boxes with bold outline and the risk flow events that are impacted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

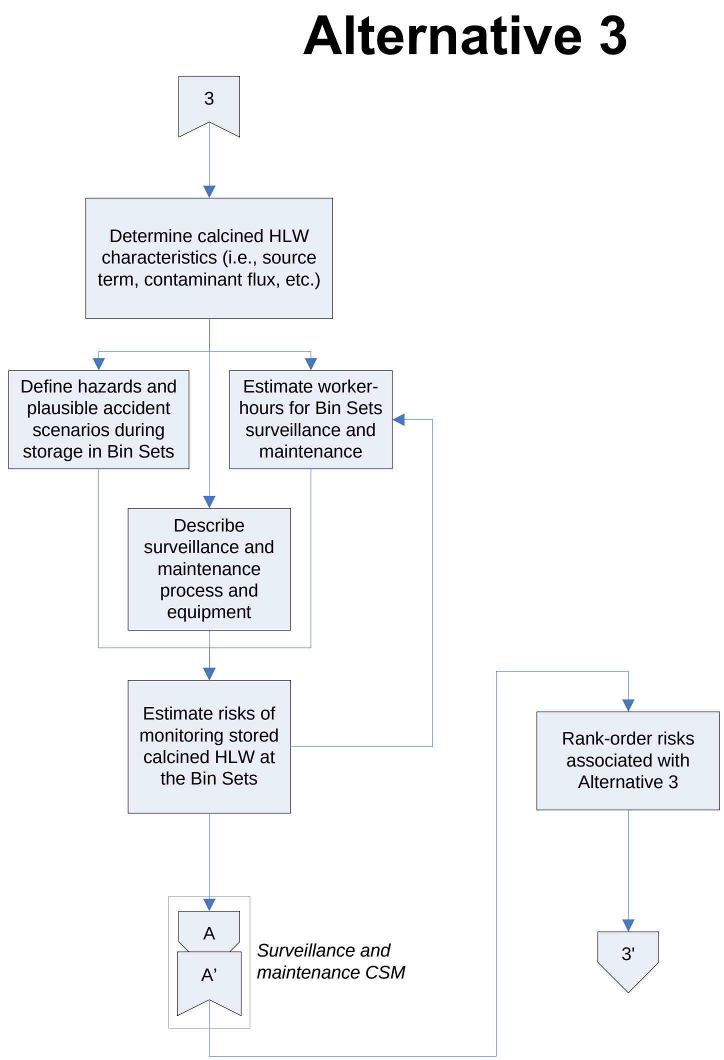
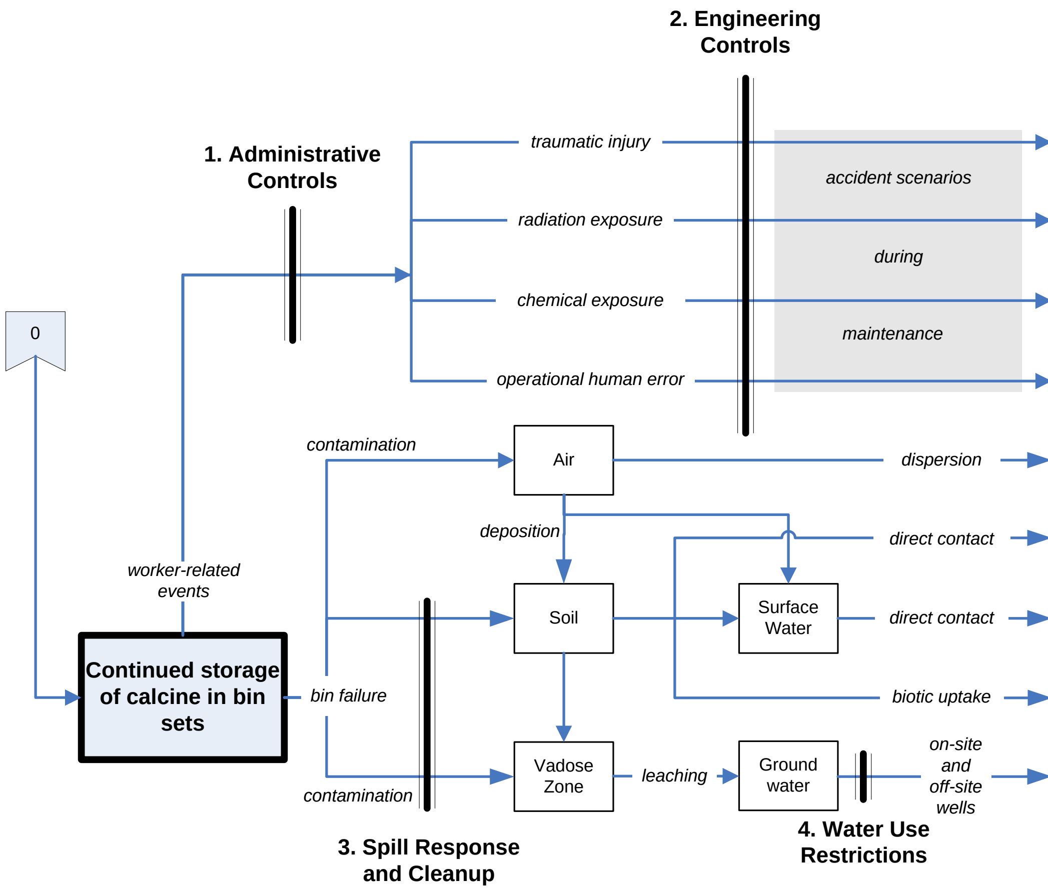


Figure F-4. Risk flow diagram for Alternative 3 (Store in Place).

No Action Alternative

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



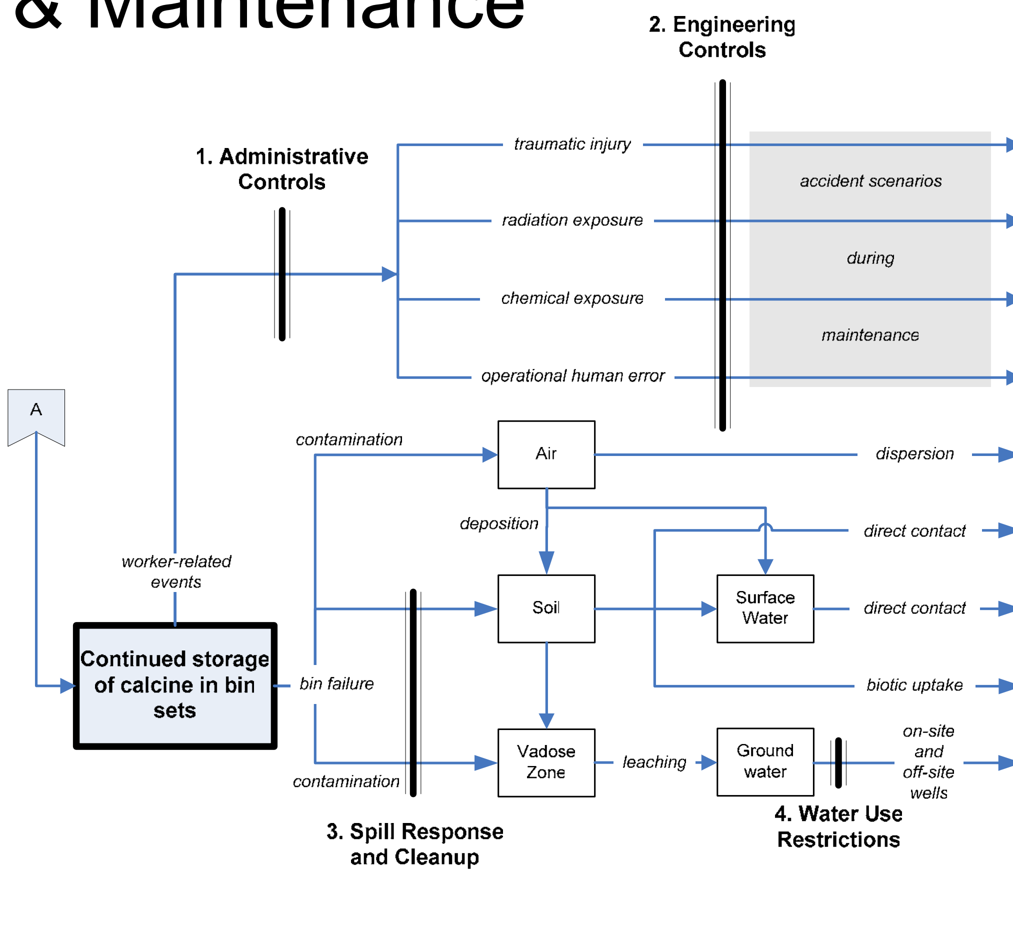
Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
I	I	I	I	
I/F/D/R	I/F/D	I/F/D	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

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

0'

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

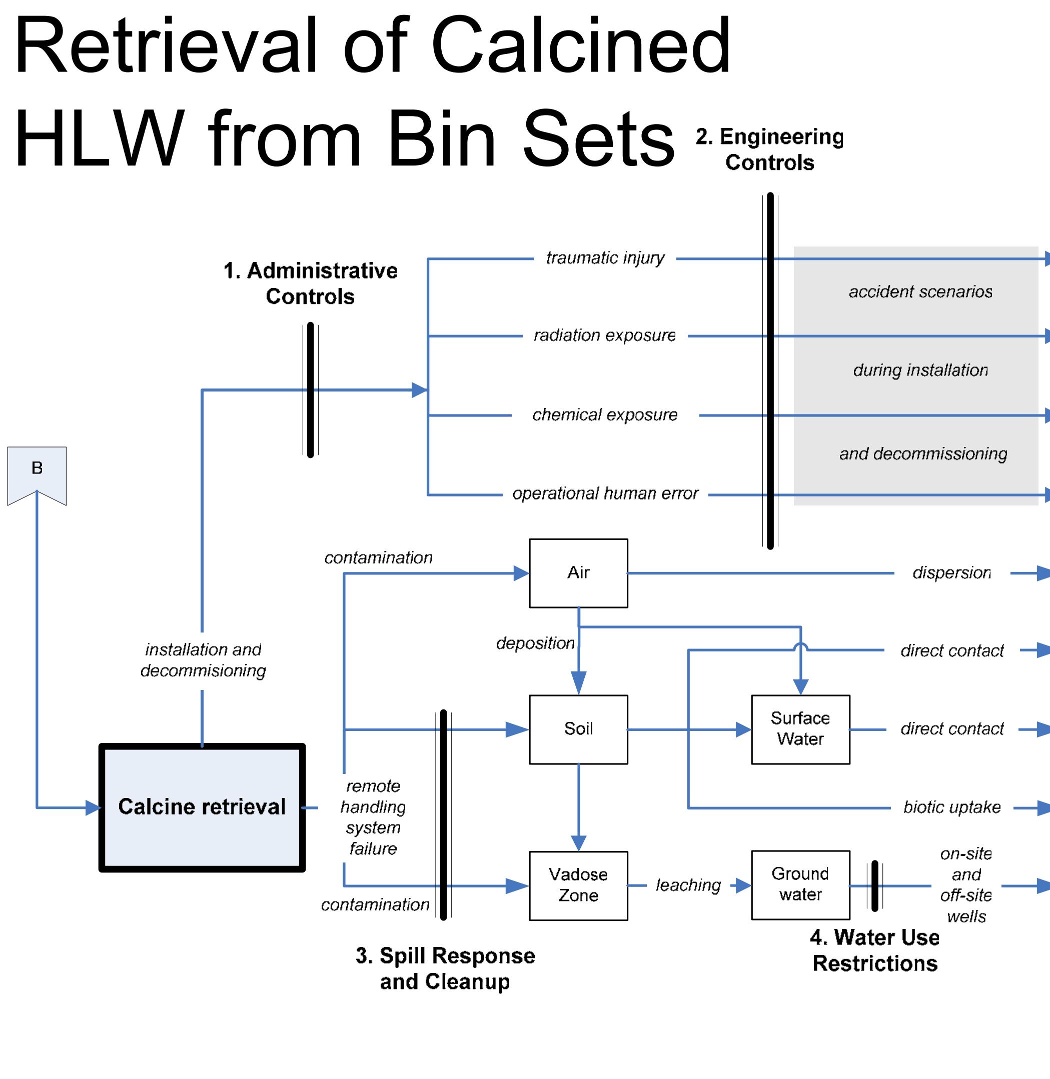
Bin Set Surveillance & Maintenance



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

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



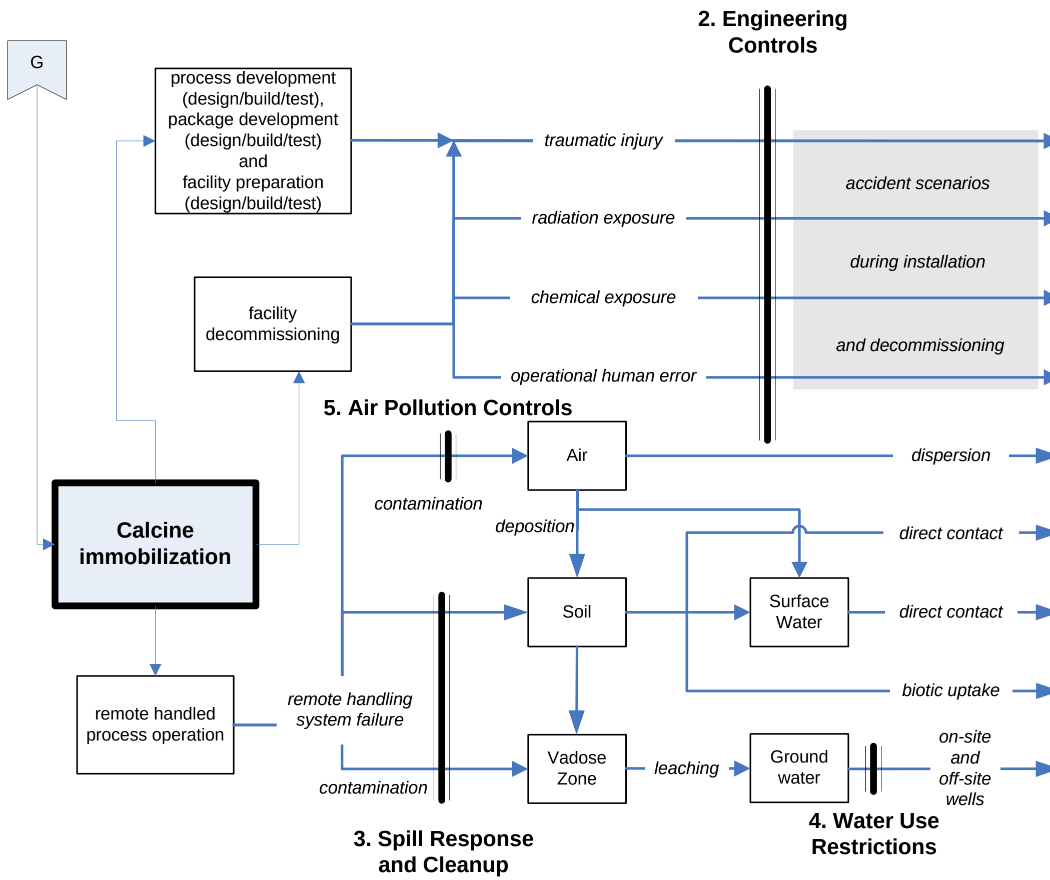
Potential Exposure Methods

Pathway	Human: Occupational	Human: Public	Human: Trespasser/ Visitor	Biota: Terrestrial	Biota: Aquatic
traumatic injury	A		A		
radiation exposure	A/I/D/R		A/I/D/R		
chemical exposure	A/I/D		A/I/D		
operational human error	A/I/D/R		A/I/D/R	A/I/D	
dispersion	I	I	I	I	
direct contact	I/F/D/R	I/F/D/R	I/F/D/R	I/F/D	F/D
direct contact	D/R	D/R	D/R	F/D/R	F/R
biotic uptake				F	
on-site and off-site wells	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-7. Conceptual site model for retrieval of calcined HLW from the bin sets.

Immobilization of Calcined HLW



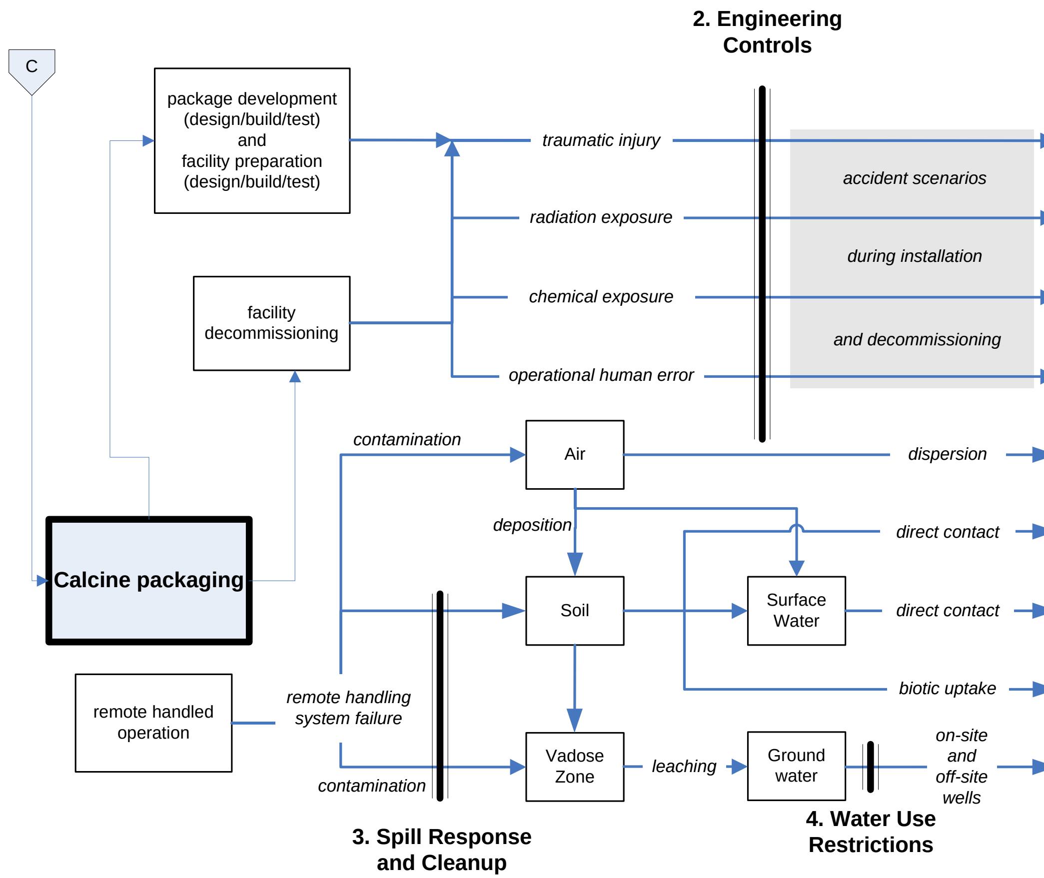
Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
I	I	I	I	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

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.

Packaging of Calcined HLW



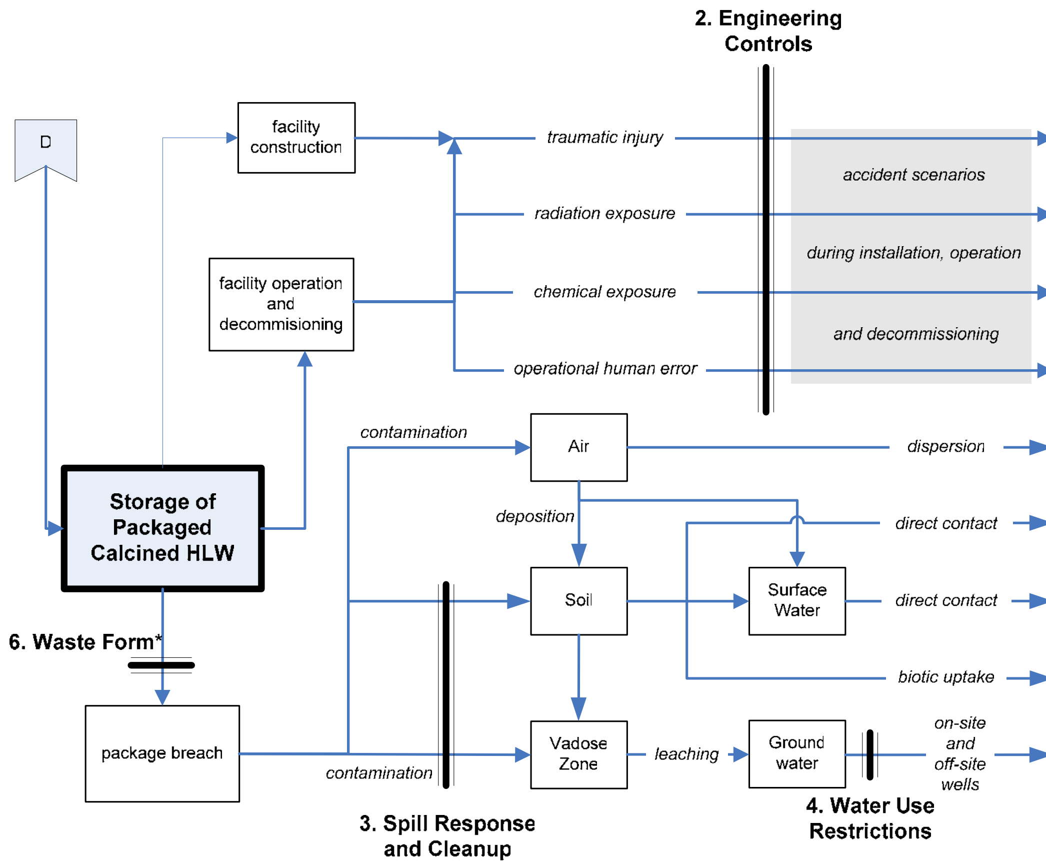
Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D		A/I/D	A/I/D	
I	I	I	I	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

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

C'

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

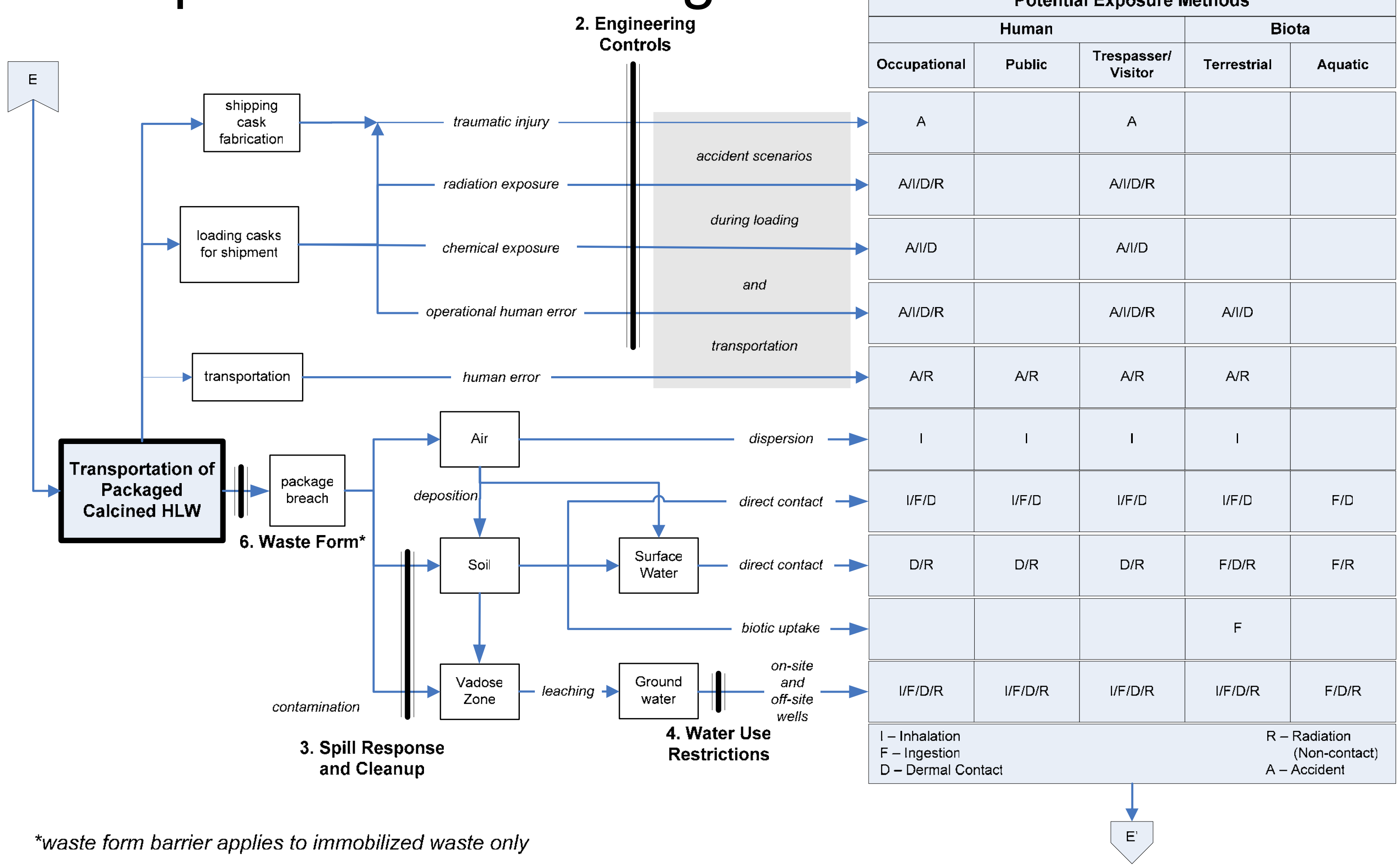
I – Inhalation
F – Ingestion
D – Dermal Contact
R – Radiation (Non-contact)
A – Accident

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



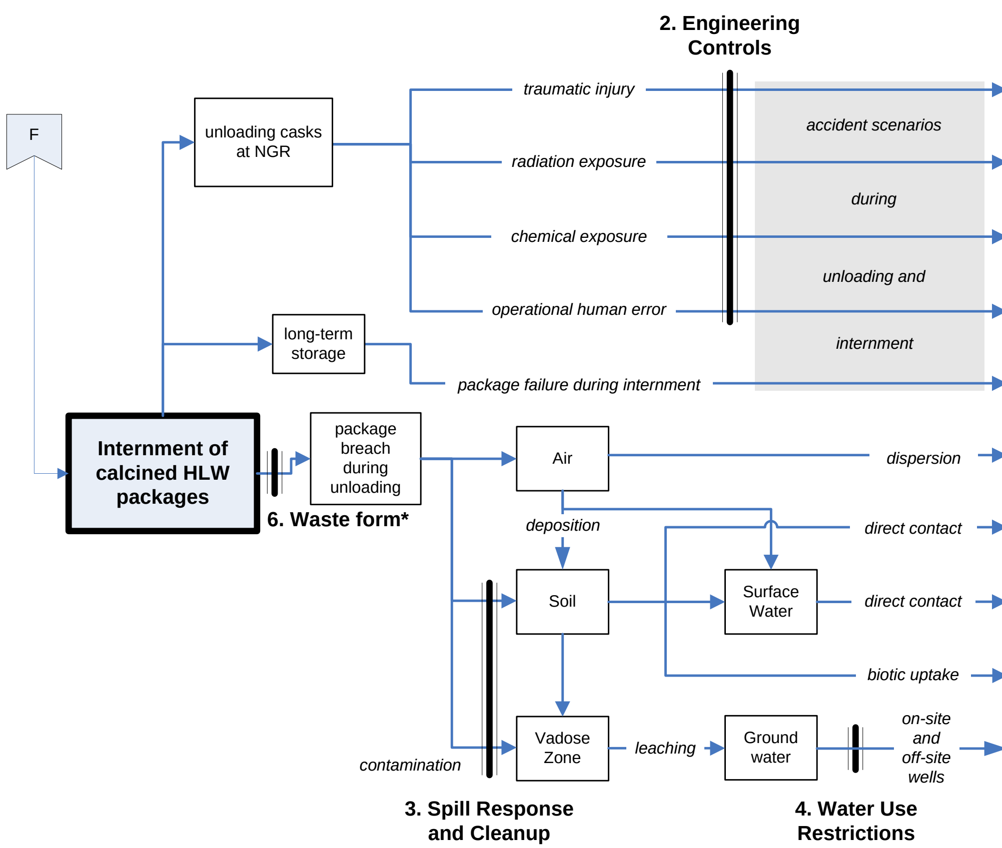
Potential Exposure Methods				
Human			Biota	
Occupational	Public	Trespasser/ Visitor	Terrestrial	Aquatic
A		A		
A/I/D/R		A/I/D/R		
A/I/D		A/I/D		
A/I/D/R		A/I/D/R	A/I/D	
A/R	A/R	A/R	A/R	
I	I	I	I	
I/F/D	I/F/D	I/F/D	I/F/D	F/D
D/R	D/R	D/R	F/D/R	F/R
			F	
I/F/D/R	I/F/D/R	I/F/D/R	I/F/D/R	F/D/R

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

*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.