PRELIMINARY TECHNOLOGY READINESS ASSESSMENT OF THE CALCINE DISPOSITION PROJECT
VOLUME ONE

Anthony F. Kluk
Hoyt C. Johnson
Clyde Phillip McGinnis
Michael Rinker
Steven L. Ross
Herbert G. Sutter
John Vienna

February 2011

Prepared by the U.S. Department of Energy
Washington, DC

This page intentionally left blank.

SIGNATURES

Anthony F. Kluk, Team Lead	Dec. 16, 2010 *Date*
Hoyt C. Johnson	12-16-2010 Date
Clyde Phillip McGinnis	15 Dec 2010 Date
Michael Rinker	01/13/11 Date
Steven L. Ross	15 December 2010 Date
Herbert G. Sutter	1/13/11 Date
John Vienna	1/20/11 Date

This page intentionally left blank.

ACKNOWLEDGEMENTS

The Review Team thanks Mr. Ron Ramsey and the staff of the DOE Idaho Operations Office (ID) for their excellent support and accommodation in preparing for and holding an accelerated review prior to the time it was originally planned by the Calcine Disposition Project. Outstanding assistance was provided by Messrs. James Floerke and James Beck and the staff of the CDP and the Review Team wishes to express their appreciation for their cooperation and assistance during technical presentations, discussions, and in providing numerous reference documents for the team to review. Lastly, special thanks must go to Roxanne Fournier Stone who provided very capable assistance in editing this report for us.

This page intentionally left blank.

EXECUTIVE SUMMARY

BACKGROUND

The Idaho National Laboratory (INL) Calcine Disposition Project (CDP) is preparing a conceptual design for the selected technology to treat Calcine high-level waste (HLW) for disposition. The conceptual design will support the critical decision to authorize preliminary design (CD-1). The selected technology will convert the granular Calcine into a glass ceramic waste form using hot-isostatic pressing (HIP) with chemical additives.[1] The conceptual design is one document among several that are required to be developed in support of CD-1. Department of Energy (DOE) Order 413.3A Chg 1, Program and Project Management for the Acquisition of Capital Assets, recommends that a Technology Readiness Assessment (TRA) be performed prior to CD-1 along with the development of a Technology Maturation Plan (TMP). Although not a hard requirement, it is recommended that the selected technology be at or above a Technology Readiness Level of 4 at CD-1.[2]

The CDP had planned to hold a TRA in October 2010, but at the request of EM Headquarters, a technology maturation review was conducted of the CDP design plans the week of July 12-15. The team at first planned to conduct the review in two phases with the first phase in July and the second phase of the assessment in October. Based on a revised schedule for the CDP received after the July review, the second phase of the review was cancelled. The review that is the basis of this report, therefore, is based only on the results of the July review and the draft Technology Maturation Plan issued in October by the CDP. The revised schedule for the CDP also identified delayed dates for initiating and completing the project design, including CD-1 and CD-2 approvals. CD-1 is now projected for the fourth quarter 2012 with CD-2 planned for the fourth quarter 2016.

<u>Project Background</u>

Conceptual design approval (CD-0) was authorized in June 2007 by the Deputy Secretary of Energy. An amended ROD, issued in December 2009 (after the date for including funds in the FY 2011 budget submission), designated HIP to treat calcine by converting it to a monolithic solid whose durability and leach rate is comparable to borosilicate glass. (This will be the first use of HIP for HLW treatment.) The CDP was initiated January 2010, and a 30 percent Conceptual Design Review was held May 25-28.

<u>Project Schedule</u>

The critical decision authorizing preliminary design (CD-1) is now planned for fourth quarter 2012, and the State of Idaho had agreed to revise the Site Treatment Plan (STP) milestone to only require DOE assurance of project funding. The critical decision for authorizing final design (CD-2) is scheduled for fourth quarter 2016. A Resource Conservation and Recovery Act (RCRA) Part B Permit Application must be submitted to State by December 31, 2012, per the 1995 Idaho Settlement Agreement.

[1] Amended Record of Decision: Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement (DOE/EIS-0287), December 21, 2009.

[2] DOE G 413.3-4. U.S. Department of Energy Technology Readiness Assessment Guide, (October 2009).

The following table provides a list of calcine HIP process critical technology elements (CTE) and the Technology Readiness Levels (TRL) for each expected upon completion of development work and documentation planned prior to CD-1. (Note: based on the documentation at hand during the week of July 12, 2010, many of the CTEs would have lower TRL values.)

Table E-1. Readiness Levels for Calcine HIP Process Critical Technology Elements to be Achieved by CD-1

Critical Technology Element	Technology Readiness Level by CD-1
Retrieval/Pneumatic Transfer System	4
Batching and Mixing System	4
Ceramic Additive Formulation	3
Hot Isostatic Pressing Can Design	3
Hot Isostatic Pressing Can Containment	2
HIP Can Filling and Closure	4
Bakeout System	4
Canister loading/Closure	4
Remote Operation and Maintenance	4
Characterization (feed, admixture, product)	4
Simulant Formulation	3

Conclusions, Observations, and Recommendations

The team identified 11 CTEs and evaluated their readiness levels and maturation plans. Seven of the 11 CTEs are expected to be at TRL 4 by October 2010, including retrieval/pneumatic transfer; batching/mixing; HIP can filling/closure; HIP can bakeout; canister/loading/closure; remote operation/maintenance; and characterization of feed, admixture and product. The remaining four CTEs are below TRL 4: ceramic additive formulation (TRL 3), HIP can design (the team expects TRL 3 vs TRL 4 proposed by the CDP), HIP can containment (HCC) system (TRL 2), and simulant formulation (TRL 3). It should be noted that significant supporting documentation for several CTEs in particular remote operation/ maintenance was scheduled to be issued in October and provided to the project. A follow up review prior to CD-1 will be necessary.

The Team observed that significant progress had been made since the CDP was initiated in January 2010, with increased supporting staff at CH2M*WG Idaho, LLC (CWI) and the Field Office. The Team questioned whether the recommended TRL 4 could be achieved by CD-1 (now deferred to June, 2012) based on planned efforts of the contractor to mature the HCC System (projected to be at TRL 2) and ceramic additive, HIP can design, and simulant formulation (projected to be at TRL 3). As stipulated in the TRA guidance, the overall level for the Team evaluation of the CDP is TRL 2. The project has proposed a program to achieve TRL 4 for all CTE's to support the planned Critical Decisions in a draft TMP that was issued by the Project in October 2010. The team noted that during their assessment the Project identified about 200 reports and 30 deliverables needed to support CD-1 are identified in the TMP.

The Team identified several concerns during their assessment:

- Construction of a full-scale mockup is necessary to meet project milestones beyond CD-1. The mockup will permit scale up and full-scale testing of most systems and is highly recommended by the Team.
- Significant project risks include:
  - A repository/disposition path and waste acceptance criteria may not be available for several years—a risk that is applicable to all HLW and SNF.
  - Design of the facility is being restricted to the Integrated Waste Treatment Unit (IWTU) footprint for all systems requiring Performance Class (PC)-3 construction; meeting this requirement and the Idaho Settlement Agreement milestone to complete calcine treatment by December 2035 will be a challenge.
  - If it is determined that additional sampling of the calcine is required, i.e., the project's no sampling assumption is rejected by the regulators or it is determined that sampling must be done to meet repository waste acceptance requirements, designing and constructing the treatment facility within the IWTU footprint may be impractical.
  - A process must be initiated as soon as possible among DOE and the regulatory agencies (U.S. Environmental Protection Agency (EPA), U.S. Nuclear Regulatory Commission, and the State of Idaho) to confirm acceptability of the ceramic waste form for repository disposition. Note: an initial step in the process is now underway for meeting Land Disposal Restrictions, e.g., a rule-making, and discussions are being held with EPA Headquarters.

TRA guidance recommends that all CTEs achieve a TRL of 4 prior to CD-1 and TRL 6 prior to CD-2. For those CTEs that do not meet the appropriate TRL, the TMP must identify activities required to achieve proper maturity for each CTE and the proposed work must be completed prior to the appropriate CD. The Project has issued a draft TMP identifying the strategy for bringing technology elements to the proper maturity level. The team has reviewed the draft TMP and supporting documentation and deliverables, provided comments to the Project, and expects to review the revised TMP prior to CD-1.

This page intentionally left blank.

TABLE OF CONTENTS

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

AEA	AEA Technology Engineering Services, Inc.
ANL	Argonne National Laboratory
CDP	Calcine Disposition Project
CTE	Critical Technology Element
CD	Critical Decision
CSSF	Calcine Surface Storage Facility
CWI	CH2M-WG Idaho, LLC.
DoD	Department of Defense
DOE	U. S. Department of Energy
EM	Office of Environmental Management
GAO	U.S. Government Accountability Office
EPA	Environmental Protection Agency
HCC	HIP can containment
HIP	hot-isostatic press
HLW	high-level waste
ICP	Idaho Cleanup Project
ID	Idaho Operations Office
INL	Idaho National Laboratory
IWTU	Integrated Waste Treatment Unit
LDR	Land Disposal Restrictions
MOX	mixed oxide
MTHM	Metric Tons of Heavy Metal
NASA	National Aeronautics and Space Administration
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PC	Performance Class
PCT	Product Consistency Test
PNNL	Pacific Northwest National Laboratory
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
SA	1995 Idaho Settlement Agreement
SBW	sodium-bearing waste
SNF	spent nuclear fuel
STP	Site Treatment Plan
TCLP	Toxicity Characteristic Leaching Procedure
TMP	Technology Maturation Plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TSPA	Total System Performance Assessment
UTS	Universal Treatment Standards
WAPS	Waste Acceptance Product Specification
WASRD	Waste Acceptance System Requirements Document
WBS	Work Breakdown Structure
WPS	Waste Processing System

This page intentionally left blank.

GLOSSARY

Term	Definition
Bakeout	A process to heat the calcine under atmospheric conditions to drive off any volatile substances.
Bin set	A RCRA Permitted facility designed to store calcine; also referred to as Calcine Solids Storage Facility.
Calcine	A treatment process used at Idaho National Laboratory under which liquid HLW was heated, causing loss of moisture, reduction or oxidation, and the decomposition of carbonates and other compounds. If used as a noun, it refers to the granular material that results from treating liquid HLW by the calcine process.
Hot isostatic pressing	A manufacturing process that subjects materials to both elevated temperature and isostatic gas pressure in a containment vessel. The pressurizing gas used is normally argon. In the case of calcine, the process will be used to produce a ceramic waste form.
Canister	A container designed to hold HLW
Ceramic additive	Chemicals which when mixed with calcine, form a ceramic waste
Ceramic Waste Form	The ceramic material incorporating calcine that results from HIP
Critical Decision	The formal process used to approve different project construction phases
Critical Technology Element	A technology element is critical if the system being acquired depends on the technology element to meet operational requirements (with acceptable development cost and schedule and acceptable production and operations costs) and if the technology element or its application is either new or novel.
Performance Class	Design features for construction of structures to allow them to meet specified seismic criteria (ground acceleration levels) without damage.
Simulant	A material designed to replicate calcine, except that radioactivity may not be present.
Technology Readiness Level	A metric used for describing technology maturity and used by U.S. Government agencies to assess the maturity of evolving technologies (materials, components, or devices, etc.) prior to incorporating a technology into a system or subsystem.

This page intentionally left blank.

1 Introduction

From 1952 to 1991, spent nuclear fuel (SNF) was reprocessed at the Idaho Chemical Processing Plant (now the Idaho Nuclear Technology Engineering Center). The reprocessing operations used solvent extraction to recover uranium from the SNF and generated liquid mixed high level waste and other wastes. Between 1963 and 2000, the HLW was treated to convert the liquid form to a dry granular substance called calcine. The calcine, totaling about 4,400 cubic meters in volume and containing about 35 million curies of radioactivity, is stored in six Calcine Solids Storage Facilities (CSSF, also known as bin sets) under a RCRA permit.

Calcine Project Background

The calcine is managed under the Idaho Cleanup Project (ICP) contract awarded in 2005, with the goal of meeting several legal and regulatory requirements. The highest priority requirements are the milestones in the 1995 Idaho Settlement Agreement. The ICP initiated activity to meet the first two Settlement Agreement milestones, which fall within the timeframe of the current contract:

- Amended ROD issued December 31, 2009, and
- Submittal of RCRA Part B Permit application by December 1, 2012.

The planning and design work initiated by CDP will provide a basis for meeting the third milestone:

- Treat the calcine so it is ready to be shipped out of Idaho by December 31, 2035.

In addition, the INL RCRA Site Treatment Plan addresses calcine management and disposition and requires DOE to provide adequate funding to support calcine related Settlement Agreement milestones by December 31, 2010.

Disposal of granular calcine (packaged in DOE standardized spent fuel canisters) and treated calcine in the form of a monolithic solid were evaluated for disposal in a geologic repository by INL. It was determined that untreated calcine would meet repository requirements based on analyses conducted by INL using the Total System Performance Assessment (TSPA) model developed to support the repository license application. However, calcine is a listed hazardous waste and, therefore, had to be delisted prior to disposal in the Yucca Mountain Facility. Delisting could require additional treatment of the calcine to reduce the leachability of toxic metals, such as cadmium and mercury.

Project milestones include:

- CD-0 approved by DOE June 2007;
- Amended ROD issued in December 2009; HIP was selected as a cost-effective treatment to convert granular form to monolithic solid (durability and leach rate comparable to borosilicate glass);
- Calcine Disposition Project initiated in January 2010;

- Under the Idaho National Laboratory STP, DOE is required to request adequate funding to meet the Settlement Agreement milestones for calcine treatment starting in December 2011.

Figure 1.1 below is a simplified schematic of the proposed calcine treatment process using the HIP technology. The diagram shows the retrieval of granular calcine from the bin sets and transfer to the surge tank; batching, mixing, and HIP filling; the bake out and off-gas treatment; the HIP machine; the cooling station; and the canister loading station.

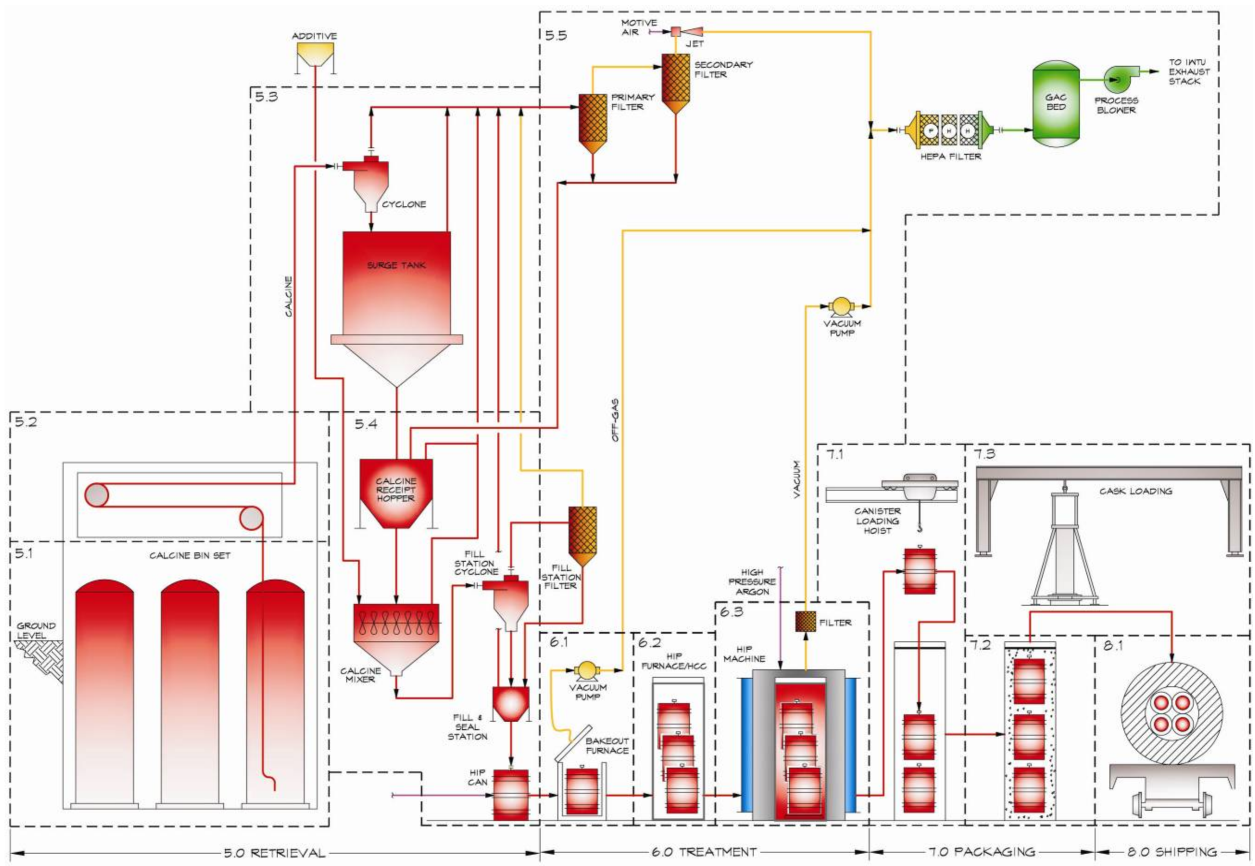


Figure 1.1 Simplified Process Flow Diagram

- A 30 percent Conceptual Design Review held May 25-28
- A review of calcine technology maturity conducted July 12-15, 2010.
- CD-1 approval by the Deputy Secretary planned for the 1st quarter 2013.
- CD-2 approval by the Deputy Secretary planned for the 4^{th} quarter 2016.

1.1 Process Description

The project involves retrieval of granular calcine from the bin sets, pneumatically transferring it to surge storage in the treatment facility, mixing the retrieved calcine with ceramic formers, filling the cans to be treated with a mixture of ceramic formers and calcine, baking out the cans to remove volatiles, placing the cans in a HIP can container (HCC), treating the cans at elevated temperature and pressure in a HIP unit, cooling the treated cans, removing them from the HCC, packaging the treated cans in canisters, closing the canisters and storing them for transfer out of the State of Idaho. Figure 1.2 shows graphically the reprocessing of Spent Nuclear Fuel, calcining of the HLW, and the dry storage configuration of HLW calcine at INL.

1.2 Technology Readiness Assessment Objectives

The scope of the CDP is to design and construct a capability to retrieve, transfer, treat, and package the 4,400 cubic meters of calcine to be ready for shipping out of Idaho by December 31, 2035. The objective of this review was to assess the level of readiness of the technologies proposed to be employed in the facility for treating calcine by HIP using the guidance in the EM TRA/TMP Process Guide.

This page intentionally left blank.

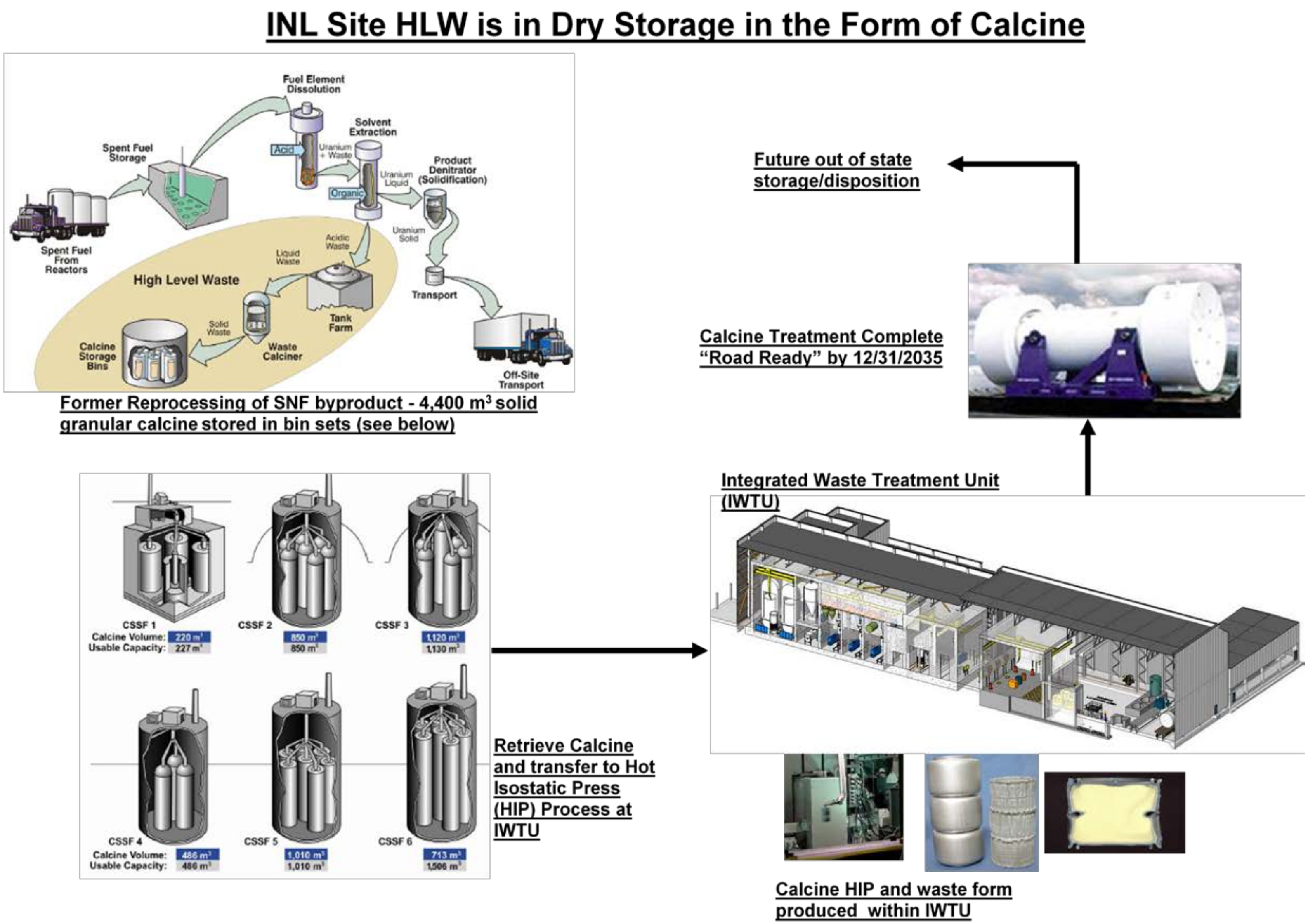


Figure 1.2 Dry Storage Configuration of HLW Calcine at INL

This page intentionally left blank.

2 Technology Readiness Assessment

A TRA is a systematic, metric-based process to assess the maturity of a technology which produces a report documenting the CTEs and their current technology readiness levels (TRL).[3]

2.1 Background

A TRA measures technology maturity using the TRL scale pioneered by the National Aeronautics and Space Administration (NASA) in the 1980s. The TRL scale ranges from one (basic principles observed) through nine (total system used successfully in project operations). The DOE Office of Environmental Management (EM), Department of Defense (DoD), and NASA normally require a TRL 6 for incorporation of a technology into the final design process.

In 1999, the Government Accountability Office (GAO) recommended the DoD adopt NASA's TRLs as a means of assessing technology maturity.[4] In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major programs. Subsequently, the DoD developed detailed guidance for performing TRAs. Recent legislation[5] (2006) has specified that the DoD Milestone Decision Authority must certify to Congress that a technology has been demonstrated in a relevant environment (TRL 6) prior to transition of weapons system technologies to detailed design or justify any waivers.[6]

In March 2007, the GAO recommended DOE adopt the NASA/DoD methodology for evaluating technology maturity.[7] Language supporting the GAO recommendation was incorporated in the House version of the 2008 EM budget legislation. From 2006-2007, EM conducted pilot TRAs on a number of projects, including Hanford's Waste Treatment Plant, Savannah River's Tank 48, and Hanford's K-Basins. In March 2008, EM issued its *Technology Readiness Assessment)/ Technology Maturation Plan Process* Guide[8], which established the TRA process as an integral part of EM's Project Management's Critical Decision Process. In October 2009, DOE generalized EM's TRA/TMP Process Guide into a DOE-wide TRA Guide.[9]

2.2 Description of TRA Process

The TRA process consists of three parts: (1) identifying the CTEs; (2) assessing the TRL of each CTE using an established readiness scale; and (3) preparing the TRA report. If some of the CTEs are judged to be below the desired level of readiness, the TRA is followed by a (TMP) that identifies the additional development required to attain the desired level of readiness. The TRA process is carried out by a group of experts that are independent of the project under consideration.

The CTE identification process involves breaking the project under evaluation into its component systems and subsystems and determining which are essential to project success, and

---

[3] 2003 Department of Defense Technology Readiness Assessment Deskbook, updated May 2005

[4] Best Practices: Better Management of Technology Can Improve Weapon System Outcomes, GAO/NSIAD-99-162, July 1999

[5] National Defense Authorization Act for Fiscal Year 2006 (P.L. 109-163), Title VIII, Sec. 81; Ref to 10 USC 139, Sec. 2366a.

[6] EDF-6980, "Calcine Retrieval, Transport, and Drying Methods for the Calcine Disposition Project"

[7] GAO-07-336, Major Construction Projects Need a Consistent Approach for Assessing Technology Readiness to Help Avoid Cost Increases and Delays, March 2007

[8] U.S. Department of Energy, Office of Environmental Management, Engineering and Technology, Technology Readiness Assessment (TRA) / Technology Maturation Plan (TMP) Process Guide, March 31, 2008

[9] DOE G 413.3-4, U. S. Department of Energy Technology Readiness Assessment Guide, October 12, 2009.

which of them either represent new technologies, are combinations of existing technologies in new or novel ways, or will be used in a new environment. Appendix A describes the CTE determination process for systems employed in retrieval, treating, and packaging calcine.

The TRL scale used in this assessment is shown in Table 2.1. This scale requires that testing of a prototypical design in a relevant environment be completed to achieve TRL 6 for CD-2, which is generally required before incorporation of the technology into the final design of the facility. Note: Some TRLs apply to more than on relative level of technology development, e.g., TRL 5 and 6 apply to technology demonstration.

Table 2.1. Technology Readiness Levels Used in this Assessment

Relative Level of Technology Development	TRL	TRL Definition	TRL Description
System Operations	**9**	Actual system operated over the full range of expected conditions.	The technology is in its final form and operated under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**8**	Actual system completed and qualified through test and demonstration.	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning.
	7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or actual waste and cold commissioning.
Technology Demonstration	**6**	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with actual waste and a range of simulants.
	5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of actual waste and simulants.
Technology Development	**4**	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	2	Technology concept and/or application	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there

Relative Level of Technology Development	TRL	TRL Definition	TRL Description
Basic Technology Research		formulated	may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
	1	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties.

The testing requirements used in this assessment are compared to the TRLs in Table 2.2. These definitions provide a convenient means to further understand the relationship between the scale of testing, fidelity of testing system, testing environment, and the TRL. This scale requires that for TRL 6, testing must be completed at an engineering or pilot scale, with testing of the system fidelity that is similar to the actual application and with a range of simulated waste and/or limited range of actual waste, if applicable.

The assessment of the TRLs is aided by questions based on a TRL Calculator method originally developed by the U.S. Air Force[10] and modified for EM applications. The TRL Calculator questions used in this assessment are described in Appendix C.

Table 2.2. Relationship of Testing Requirements to the TRL

TRL	Scale of Testing[a]	Fidelity[b]	Environment[c]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Laboratory	Similar	Relevant
4	Laboratory	Pieces	Simulated
3	Laboratory	Pieces	Simulated
2	Paper	Paper	Paper
1	Paper	Paper	Paper

a. Full-scale = Full plant scale that matches final application
1/10 Full-scale < Engineering/Pilot Scale < Full-scale (Typical)
Lab Scale < 1/10 Full-scale (Typical)
b. Identical System – configuration matches the final application in all respects
Similar System – configuration matches the final application in almost all respects
Pieces System – matches a piece or pieces of the final application
Paper System – exists on paper (no hardware)
c. Operational (Full Range) – full range of actual waste
Operational (Limited Range) – limited range of actual waste
Relevant – range of simulants + limited range of actual waste
Simulated – range of simulants

2.3 Project TRA Process

The TRA Team used the process described in DOE Guide 413.3-4 as applied modified for use by EM. The Team was comprised of staff from EM Headquarters, national laboratories and a

[10] Nolte, W. L and et al. Technology Readiness Level Calculator. 2003.

technical consultant to DOE. See Appendix D for the TRA Plan, which includes a listing of the Assessment Team and their resumes. The TRA Team members have extensive experience on related nuclear waste treatment technologies. This report describes the technology assessment results and includes tables showing responses to the individual TRL questions. Each response to a specific TRL question was recorded, along with references to the appropriate documents.

The CDP prepared an initial review of the project systems and identified those that were critical and their associated TRL. The Assessment Team reviewed the results of the CDP analysis and completed independent due-diligence reviews and evaluations of the testing and design information to validate the input obtained in the working sessions. Appendix C provides the TRL results for each CTE.

The Assessment Team evaluated the descriptions of the processes and mechanical systems used to treat waste. The Team did not evaluate the software systems used to control the processes and mechanical equipment because these software systems have not been sufficiently developed.

3 Results

The team evaluated 11 CTEs, the results of which are given in this section. It was determined that seven of the 11 CTEs would be at TRL 4 when documentation was provided. These CTE elements include: retrieval/pneumatic transfer, batching/mixing, HIP Can filling/closure, HIP can bake-out, canister/loading/closure, remote operation/maintenance, characterization of feed, admixture, and product. The team found that ceramic additive formulation and simulant formulation will be at TRL 3. The team found the HIP can design would be at TRL 3 vs the TRL 4 proposed by the project, and the HIP can containment system to be at TRL 2. An evaluation of the technologies was conducted by the CDP and the results of those evaluations are presented in Appendices A and B. The list of TRL determination questions and answers are given in Appendix C.

3.1 CTE Determination

Table 3.1 identifies the questions used to determine whether an element or system is critical to the function of the waste treatment process. Table 3.2 identifies the technology elements evaluated by the team and the results of the evaluation.

Table 3.1. Critical Technology Element Questions

Set 1 – Criteria	Yes	No
Does the technology directly impact a functional requirement of the process or facility?		
Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		
Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?		
Are there uncertainties in the definition of the end state requirements for this technology?		
Set 2 – Criteria	Yes	No
Is the technology new or novel?		
Is the technology modified?		
Has the technology been repackaged so a new relevant environment is realized?		
Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		

Table 3.2. Technology Systems Evaluation

Technology system	Technology Readiness Level
Retrieval/Pneumatic Transfer System	4
Batching/Mixing/Sampling System	4
Ceramic Additive Formulation	3
HIP Can	4
HIP Can Container	2
HIP Can Filling/Closure	4
Bake out System	4
Canister Loading and Closure	4
Remote Operation and Maintenance System	4
Characterization of Calcine and Admixture, Product	3
Simulant Formulation	3
Shipping	Not a CTE
Off-gas System	Not a CTE

3.2 Retrieval/Pneumatic Transfer System

The Retrieval and Pneumatic Transfer system is covered under the following CWI elements within Work Breakdown Structure (WBS) 5.0:

- Calcined Solids Storage Facility (CSSF1) Reconfiguration
- Calcined Solids Storage Facility (CSSF2) Reconfiguration
- Calcined Solids Storage Facility (CSSF3) Reconfiguration
- Calcined Solids Storage Facility (CSSF4) Reconfiguration
- Calcined Solids Storage Facility (CSSF5) Reconfiguration
- Calcined Solids Storage Facility (CSSF6) Reconfiguration

- SE 5.2.1 Bin set Interface Subsystem
- SE 5.2.1 Retrieval Nozzle Subsystem
- SE 5.2.3 Slewing Subsystem
- SE 5.2.4 Hose Management Subsystem
- SE 5.2.6 Bin set Camera Subsystem
- SE 5.2.7 Bin set Retrieval Control Room Subsystem

3.2.1 Function of Retrieval/Pneumatic Transfer System

The calcine retrieval system will move the calcine from its storage location in six CSSFs or bin sets through the transport and surge system. In order to do this, the system must perform the following functions:

- retrieve (vacuum) the calcine from multiple individual storage bins within each of the six CSSFs
- provide make up air to the bins as the calcine is being removed
- deliver the calcine to the transport and surge system
- maintain the bins under a small negative pressure at all times to prevent contamination.

The pneumatic transfer system transfers calcine from the calcine retrieval system to the treatment facility where the calcine is disengaged from the carrier air which is filtered prior to release. The calcine is then temporarily stored and metered into the next operational step. The system will perform the following functions:

- interface with the retrieval system
- pneumatically transport the calcine from the retrieval system to one of two surge tanks located in the treatment facility.

3.2.2 Description of Retrieval/Pneumatic Transfer System

The calcine retrieval system will use an articulated arm to remove calcine via pneumatic conveyance from each storage bin within the six CSSFs.[11] Attached to the arm is a retrieval nozzle (end effector) along with the pneumatic conveyance hose. The arm will operate in conjunction with a pneumatic conveyance hose via a slewing device on the arm and the hose management system. Several cameras will be placed on the arm and in the bin set in for operators to remotely view retrieval operations. The operators will be in a control room where these systems can be monitored.

A single arm will be used in each cylindrical bin, and two arms will be used in each annular bin in order to remove calcine from the entire bin cross section. The storage bins will be maintained under a small vacuum at all times to prevent contamination. As calcine is removed from each bin, it will be pneumatically transported to the transport and surge system through two transport lines.

The pneumatic transfer system will use air jets and process blowers to develop the velocity required (and associated pressure drop) to transport the calcine material from the retrieval system to the treatment facility. At the treatment facility, the pneumatic transfer system will deliver the calcine to a cyclone separator, which will separate the calcine from the transport air. From the cyclone, the calcine will enter a surge tank, and the transport air will be treated by an off-gas system within the treatment facility.

3.2.3 Relationship to Other Systems

As calcine is removed from each bin, it will be pneumatically transported to the transport and surge system through two transport lines. The central transport lines for each CSSF will connect to two main headers that service several CSSFs and transport calcine to the processing facility.

The pneumatic transport system major interfaces are with the overall retrieval system, the process off-gas system and the feed canning system. The transport lines are the key physical interface with the retrieval system as well as the bin sets themselves. However, process control and monitoring of the transport system will be performed in the control room. The Process Off-Gas System blowers provide the differential pressure required to convey the calcine from the CSSFs to the cyclone separators. The interface with this system is at the air-outlet of the cyclone separators. The feed canning system interfaces with the transport and surge system at the rotary valve on the bottom of the surge tank.

[11] EDF-6980, "Calcine Retrieval, Transport, and Drying Methods for the Calcine Disposition Project"

3.2.4 Development History and Status

Arm-based retrieval systems have been considered for many years at various DOE waste sites, including Hanford, Savannah River, Idaho, Oak Ridge, and West Valley. To date, the only significant arm-based retrieval system that has been successfully developed and deployed is the Modified Light Duty Utility Arm at Oak Ridge, which was used to retrieve waste from the Gunite Tanks as part of a Treatability Study in the 1990s. The Modified Light Duty Utility Arm was developed by a team of engineers from Pacific Northwest National Laboratory, Oak Ridge National Laboratory, INL, and Sandia National Laboratory. It was tested at Hanford prior to being deployed for retrieval at Oak Ridge and a similar arm was deployed for characterization at Idaho.

AEA Technology Engineering Services, Inc. (AEA) received funding from DOE to conduct a feasibility study of pneumatic retrieval methods for calcined type waste. AEA performed extensive testing on the retrieval of calcine out of bin set VI using a surrogate. In addition, further testing was performed by both INL and outside engineering groups. Findings in the AEA final report and "Calcine Disposition Project Calcine Retrieval Rate Evaluation" (EDF-8182) show achievable retrieval rates of 500 lb/hr and interactions between key subsystems when using the vacuum nozzle and articulating retrieval arm concept. These findings are currently being used as a basis for the project.

3.2.5 Operational Environment

The retrieval system and the pneumatic transport system will be required to operate in a high radiation environment with the capability to convey 500 lb/hr of calcine from the retrieval system through the transfer lines and into the surge tanks. Radioactive density of the calcine ranges from 3,210 to 13,500 Ci/m3. The temperature of the calcine in the bin sets ranges from 85 to 347º C; however, the temperature of the calcine is expected to be significantly lowered during transport due to the air introduced to convey and the distance the calcine is travelling.

3.2.6 Comparison of the Operational Environment and Demonstrated Environment

The operational environment of the arm-based retrieval system for the bin set retrieval is significantly different from the only other arm-based deployment at Oak Ridge. The bin sets have a significantly different geometry from the Gunite tanks at Oak Ridge. Additionally, the waste in the bin sets is expected to be dry, especially in comparisons with the liquids and hard crusts that were encountered at Oak Ridge.

The simulant used in pneumatic testing done by the INL, AEA, and other outside engineering organizations was produced in the same process as the calcine to be retrieved prior to the calcining process going hot. However, the simulant used did not exhibit all the physical characteristics potentially seen when retrieving from the bins. Adaptations to the design will need to be made to account for the thermal and radioactive properties of the calcine in the different bin sets.

3.2.7 TRL Determination

The Retrieval and Pneumatic Transfer System, as defined by the contractor WBS elements described above, is at TRL 4.

During the evaluation of the Calcine Solids Storage Facilities, the only technology within the various CSSF sub-elements that is considered to be a CTE is the remote equipment that will be used in the core drilling of new holes and installation of access risers within any of the various bin sets. There is documentation from Gessner and Jackson 1988[12] that provides West Valley experience in core drilling and riser installation. Additional documentation from Oak Ridge, Hanford, and Savannah River regarding additions of risers to underground storage tanks is also available, but not referenced by the contractor. The technical review team opinion is that while not all the CSSF sub-elements are CTEs, the core drilling and riser installation is a CTE and, therefore, should be covered under WBS 5.0.

The following remaining retrieval system WBS elements were evaluated individually based upon information received from the contactor during the TRL review: SE 5.2.1 Bin set Interface Subsystem; SE 5.2.1 Retrieval Nozzle Subsystem; SE 5.2.3 Slewing Subsystem; SE 5.2.4 Hose Management Subsystem; SE 5.2.6 Bin set Camera Subsystem; SE 5.2.7 Bin set Retrieval Control Room Subsystem; and the pneumatic conveyance system, SE 5.3.

The retrieval system was determined to be TRL 4 because of the full-scale tests recently completed at AEA, as well as other reports of pneumatic conveyance studies in support of the calcine retrieval over the years as documented. The findings in the AEA report and EDF-8182 show it is possible to retrieve calcine waste from the bins at 500 lb/hr.

TRL 5 was not obtained due to the prototypical nature of the testing, which does not replicate all aspects of the full-scale system. Additional full-scale integrated cold tests will need to be conducted after the modifications are complete. This will be a significant undertaking and will take a major commitment by the project in order to accommodate this type of testing. During these tests a higher fidelity simulant should be used that is based upon what is expected to be the current condition of the calcine. While previous process knowledge is well documented, the current physical state of the calcine is not well characterized.

Observations and Recommendations

The bin sets themselves are not CTEs. They are part of the facility; therefore, they should not be evaluated as CTEs. It is noted that the simulants used in testing are acknowledged to have similar, but not identical, physical properties as the calcine waste does (see Section 1.5 of the TMP). However, there are no plans to provide additional characterization data, which is limited, of the calcined waste in its current state.

The coordination of the pneumatic conveyance line and the arm in the bin sets will be difficult, especially during startup and shutdown operations.

The pneumatic hose has a significant unsupported length and may have a dynamic effect on the arm operation. Additionally, the project needs to pay close attention to cameras and where they are located within the bin sets as it will be difficult to see under remote operational conditions. This will be exacerbated by the possibility dust and other particulate getting stirred up during retrieval operations.

[12] J. P. Jackson, R.F. Gessner, *Remote Installation of Risers on Underground Nuclear Waste Storage Tanks*, March 1988.

It was noted during the review that nearly all of the retrieval system and pneumatic transfer system are heavily dependent upon the AEA tests that were conducted in 2005 and 2006. It is recommended that the contractor team evaluate other systems that have been tested and deployed elsewhere that include lessons learned from real operational environments of systems developed to retrieve waste.

3.3 Batching/Mixing System

3.3.1 Function of the Batching/Mixing System

The function of the batching/mixing system is to receive the prescribed amount of calcine from the surge vessel by weight, add the prescribed amount of ceramic forming additives by weight per procedure, and mix the batch to ensure complete blending.

Existing data was obtained from sampling the liquid HLW prior to calcining and limited sampling of the granular solid after calcining. Additional samples may need to be analyzed before the processing, or concurrent with the processing, or be held in archives, but are believed to be required to demonstrate that the waste form meets acceptance requirements when investigated. Project management currently believes that sampling will not be required and is planning to undertake discussions with the regulatory authorities. Relying on existing characterizational data will result in added risk for the project.

3.3.2 Description of the Batching/Mixing System

The mixer is a robust solids mixer with mechanical agitation to provide a thorough mixing. Mixers such as the Littleford Day mixer or the Jaygo mixer has been used for several EM projects. The Jaygo Mixer was used by Fernald to blend the silo residue with grout formers to produce the waste form. This same mixer was used at the Oak Ridge Transuranic Waste Processing Complex to blend concentrated supernatant from the storage tanks with waste formers to produce a waste suitable for disposal at the Nevada Test Site. The Littleford Day mixer has been used for several grout projects and is the mixer of choice for the U233 treatment project at Oak Ridge. These two mixers are similar and either would work.

In addition, the mixed oxide (MOX) program is building a mixing process that blends plutonium oxide and uranium oxide in a very exacting and thorough mixing process to manufacture fuel for commercial power plants. The mixing requirements for blending are more strenuous than the blending required for the Calcine Disposition Project. Conversations should be held between CWI and MOX Services on the mixing.

Mixing dry mixtures historically leads to wear issues and erosion. An evaluation of the hardness and other physical properties that can impact the performance of a dry mixer should be performed. Review team discussions indicated the solidification process is proposed to set up an internal mixing regime, but this has not been proven. The degree of homogenization required is not known.

The mixer receives calcine from the surge tank metering device and additive from the Additive Feed Hopper and mixes the two constituents to form a homogeneous bled that will allow a successful HIP process. The mixer will discharge its batch into the Fill and Seal Station Feed Hopper.

3.3.3 Relationship to Other Systems

The Batching/Mixing function is part of the treatment train. This operation takes the calcine from the surge tank, weighs it into the mixer, adds the required amount of ceramic formers, blends the mixture, and then transfers the mixed feed to the can loading station. This activity is required to operate efficiently and quickly to allow processing of the approximately 12,000 HIP containers over the 12-year operational period of the facility.

3.3.4 Development History and Status

Mixing of dry solids is not new or unique. Commercially available mixers are available for evaluation. The mixing requirements are not fully defined, and the ability to maintain and perform maintenance in case of a failure in the high radiation and contamination environment is not demonstrated.

3.3.5 Operational Environment

The mixer will be required to operate in a high radiation environment with the capability to mix several thousand pounds of calcine and additives. The radiation is significant due to the cesium and other radionuclides, which have a strong radiation field and a fairly short half-life.

3.3.6 Comparison of the Operational Environment and Demonstrated Environment

Mixing of calcine simulant and additive has been performed on a lab scale. No full-scale mixing has been performed in a high-radiation, remotely-maintained and repaired environment.

3.3.7 TRL Determination

The mixer was determined to be TRL 4 as commercially available full-scale equipment is available and capable of performing the operation. The issue of wear and the required degree of homogenization may question the TRL 4, but overall the team agrees with TRL 4. Pilot testing is key to proving this technology can move to the TRL 5 and TRL 6.

TRL 5 was not obtained because the only documented testing on this portion of the process was lab-scale. The testing did not replicate all aspects of the full-scale system, and configuration. Pilot testing will be required.

Observations and Recommendations

The project should consider using a mixer with a heat jacket and vacuum capability and use this equipment to bakeout moisture from the calcine. This operation is routinely done at the Oak Ridge Transuranic Waste Processing Center and is planned for the U233 project. This would give better bakeout due to less torturous path for vapor to escape and would free up space in the IWTU.

3.4 Ceramic formulation

3.4.1 Function of Ceramic Formulation

The purpose of ceramic formulation is to immobilize the hazardous components, both radioactive and chemical, from release to the environment. The ceramic formulation is defined as the mix or ratios of individual chemical additives and various types of HLW calcine. It is the ceramic formulation and heat/pressure treatments that control this waste form. So, the ceramic formulation must reliably produce a waste form that meets acceptance requirements over the range of calcine characteristics and process ranges.

3.4.2 Description of Ceramic Formulation

The reference waste form is a glass-ceramic material formed by the HIP of a mixture of additives and calcined HLW. The currently envisioned additives include those previously used in studies with INL calcine as shown in Table 3-3:

Table 3-3 Summary of Previously Studied Ceramic Formulation Additives for Immobilizing INL Calcine

Comp.	Al/Al_2O_3	Si/SiO_2	Na_2O	Li_2O	B_2O_3	Ti/TiO_2	ZrO_2	S	MgO	P_2O_5	Cu	CaO
Currently Planned	x	x			x	x		x			x	
Nelson 1990		x	x	x	x							
Begg et al. 2009		x				x	x				x	
Raman 1998		x						x	x	x		
Nelson 1993		x	x	x	x							
Carter et al. 2007		x				x	x					x
Nelson and Vinjamuri 2005		x			x	x						
Staples 1988		x	x	x	x							
Vinjamuri and Raman 1991	x	x			x	x						

When heated with calcine in the HIP, a series of reactions occur resulting in glassy phase encapsulating a range of different crystalline minerals. The radionuclides and hazardous components are mineralized into the waste form and immobilized.

The waste form must meet a series of requirements as summarized in McKinley (2010)[13]:

1. Delisting of waste form from RCRA regulation which will include, along with other delisting petition requirements, that the waste form toxicity characteristic leaching procedure (TCLP) response below the universal treatment standards (UTS) (40 CFR 268.48).

2. Variance to land disposal restrictions (LDR) for hazardous wastes, which includes demonstrating TCLP responses below UTS limits.

3. Meeting repository waste acceptance criteria and reporting requirements consistent with the Waste Acceptance System Requirements Document (WASRD)…

4. Loading requirements. Although no final waste loading requirements have been established, the cost and schedule of treatment are directly related to loading of waste in the waste form. The key schedule driver of completing all treatment in time to have all waste ready for transportation to a disposal facility by December of 2035 and the facility size requirements (which allow for two treatment trains) set the ultimate limits on waste loading.

5. Use of one additive and loading for all calcine compositions (a desire, but not a requirement).

[13] McKinley, K., *Calcine Disposition Project Waste Form and Technology Readiness Strategy Plan*, PLN-3448, Idaho Cleanup Project, Idaho Falls, ID, 2010.

6. Formulation that does not require calcine or calcine/additive mixture chemical analyses (a desire, but not a requirement).

7. Immobilization of mercury from the calcine into the final waste form that can meet TCLP requirements.

8. Binding of volatiles not removed during the bakeout process into phases that do not cause expansion of the HIP can after treatment and do not cause the canistered waste form to fail any other requirement.

9. A HIP feed that can reliably form HIP cans meeting dimensional requirements for loading waste canisters.

These requirements assume the use of current Yucca Mountain Program requirements for HLW glass as no repository is currently licensed for HLW in the United States.

3.4.3 Relationship to Other Systems

The waste form recipe has close relations to many other systems and processes as highlighted below:

1. Retrieval – the additives and loading must be formulated in fashion that can reliably treat the calcine as retrieved without putting undue constraints on retrieval such as blending between bins. It would be most advantageous if the formulation allowed for the formation of a successful waste form without analysis of the calcine. Ideally, one additive mixture and loading would be sufficient for any calcine mix that may potentially be retrieved.

2. Calcine Mixer – the waste form additives must be mixed with calcine in the calcine mixer. The chemical form of the additives should reliably form a HIP feed that meets all requirements. Of particular interest is the ability to form and maintain a uniform mixture within the calcine mixer without excessive dusting.

3. Fill and Seal Station – the waste form additives, when mixed with the calcine, must be capable of reliably filling the HIP can homogeneously to form waste form phases in the required quantities, compositions, and microstructure while maintaining a fill density/height that meets final HIP can dimensional constraints. The mixture must be compatible with contamination control mechanisms used to maintain the HCC system contamination levels within acceptable ranges.

4. HIP Can – the HIP feed must not react with the HIP can in a way that causes failure of the HIP Can as a containment system or that cause pressurization of the HIP can during HIP treatment.

5. Bakeout System – the HIP feed must meet requirements of the bakeout system that will allow for removal of sufficient volatiles to avoid HIP can pressurization after treatment. The mixture must also be sufficient to reliably immobilize those volatile components that are not removed through the bakeout process (e.g., mercury).

6. HIP Can Containment System – The waste form mixture must reliably allow HIP treatment that doesn't cause a HIP can deformation outside the dimensional tolerance levels or canister breach.

7. HIP Machine – The HIP feed must reliably produce a waste form that meets all product quality, processing, and reporting requirements over the range of likely HIP treatment variations.

8. Canister – The HIP feed must reliably produce HIP cans that meet weight and dimensional requirements for placement into the canister without exceeding dimensional, dose, criticality, heat generation, or weight limits.

9. Off-gas System – The additives and HIP feed must be reliably processed without adverse impacts to the off-gas treatment system due to particle and/or semi-volatile component releases during calcine mixing, can filling, or bakeout.

3.4.4 Development History and Status

HIP waste forms in the titanate, silicate, and zirconate families have been developed for a number of decades with the most prevalent being a synthetic rock (synroc). Synroc includes a number of titanate phases including zirconolite, hollandite, perovskite, and rutile plus minor crystalline phases and a glassy intergranular phase. Although development of these types of waste forms began in the 1950s, the term synroc was coined by Ringwood et al. in 1979 when the most concerted waste form development and testing on these forms began. An excellent review of these forms is offered by Ringwood (1988)[14] and a more recent update by Ojovan and Lee (2005).[15] Waste forms specifically for HIP treatment of INL calcined HLW began in the mid 1980s and continue today (for examples Staples et al. 1986 and 1988; Nelson et al. 1990, 1993, and 1995; Vinjamuri 1990; Vinjamuri and Raman 1991, Raman 1993 and 1998; and Begg et al. 2009a,b).[16] The waste form studies specifically for HIP of INL calcine included multiphase ceramics in a glassy matrix. Typical phases include:

> Alpha Alumina – Al_2O_3, Greenockite - CdS, Fluorite - CaF_2, Zircon - $ZrSiO_4$, Baddeleyite - ZrO_2, Sphene - $CaTiSiO_5$, calcia stabilized Cubic Zirconia - $Ca_{0.15}Zr_{0.85}O_{1.85}$, Apatite - $Ca_5(PO_4)_3(F,Cl)$, Albite-Anorthite solution - $NaAlSi_3O_8$-$CaAl_2Si_2O_8$, Crystobalite - SiO_2, Zirconolite - $CaTiSi_2O_7$, Wollastonite - $CaSiO_3$, Rutile/Anatase - TiO_2, Nepheline - $NaAlSiO_4$, Gehlenite - $Ca_2Al_2SiO_7$, and Enstatite - $MgSiO_3$.

The corrosion resistance of this material is relatively high as measured by the Materials Characterization Center Corrosion Test 1 (now ASTM C-1220). Recent measurements of the response of HIP calcine to the Product Consistency Test (PCT) have been mixed (Begg et al. 2009b)[17]. The toxicity of the material will be partially determined by the ability to bind

---

[14] A.E. Ringwood, S.E. Kesson, K.E. Reeve, D.M. Levins, and E.J. Ramm. 1988. *Radioactive Waste Formsfor the Future,* eds. Werner, Lutze and Ewing, North Holland Physics Publishing, Chapter 4 -SYNROC, pp. 233-334, 1988.

[15] M.I. Ojovan and W.E. Lee. 2005. *An Introduction to Nuclear Waste Immobilization*, Elsevier, London.

[16] See section 5 references for other documents cited here.

[17] B.D. Begg, S. Morica, and K. Bateman. 2009b. *Assessment of HOT Isostatic Pressing (HIP) Project Annual Report 2009*, FY09-71995-V2, Rev. 5, Australian Nuclear Science and Technology Organisation, Lucas Heights NSW Australia.

cadmium and mercury into leach resistant phases such as Greenockite and Cinnabar. Evidence for incorporation of cadmium into CdS was shown (Raman 1998 and Begg et al. 2009b)[18]. However, no evidence has been presented to the panel demonstrating the formation of HgS. Nor has the leachability of HgS in the HIP waste form been conclusively demonstrated. High waste loading samples have shown significant shortcomings in meeting PCT and TCLP constraints.

Limited testing was performed with calcine simulants including variations in the additive composition; calcine particle size (ground vs. unground); temperature, time, and pressure of HIP treatment; mixing amount; waste loading; and scale (not nearly to full-scale). No actual (radioactive) calcine testing was reported, but radioactive testing results of other wastes by HIP treatment were found in literature.

3.4.5 Operational Environment

The waste form must operate under fully radioactive conditions in which sampling and visual inspection capabilities will be limited. There is currently neither sampling capability nor analytical laboratory in the conceptual design. Calcine composition will vary across the entire span of compositions within the bins with little indication of current composition being treated.

3.4.6 Comparison of the Operational Environment and Demonstrated Environment

Limited evaluations of the range of parameters have been investigated. The scale of testing has not exceeded 25 kg (compared to roughly 600 kg full-scale cans). No simulant testing with mercury was presented to the panel. Tests with actual waste have not been performed. The final additive mixture has not been developed or tested. No testing supports the concept of a single additive and loading for all calcine.

3.4.7 TRL Determination

A TRL of 3 has been achieved for the waste form CTE. Key recommendations for achieving TRL 4 are tabulated in Table 3.4, as follows:

[18] S.V. Raman. 1998. " Microstructures and leach rates of glass-ceramic nuclear waste forms developed by partial vitrification in a hot isostatic press," *J. Mater. Sci.* **33**, 1887-1895

Table 3-4. Key recommendations for achieving TRL 4

Recommendation	TRL 4 Questions Addressed
Define system requirements including ability to sample/analyzed calcine, number of additives/loadings can be used, and minimum allowable waste loadings.	6 & 25
Develop laboratory scale simulant data on formulation with range of calcine to be processed (including mercury and cadmium). Measure durability, regulatory compliance, phase characterization, shrinkage, bakeout requirements, and heat treatment requirements.	5, 24, 30
Perform laboratory scale actual calcine tests on selected calcine to confirm formulation based on simulants. Perform test on representative calcines.	30
Perform engineering scale integrated (feed prep, bakeout, can loading, and HIP treatment) testing with simulants representing the calcines to be treated.	26

3.5 HIP Can

3.5.1 Function of the HIP Can

The HIP can performs several functions within the overall system. Its primary function is that of a process vessel and crush membrane. In addition, the HIP can receives the calcine/additive blend and is a transport container until it is placed in the HCC. The HIP can is the bakeout vessel for the calcine when heated to remove water and other low boiling volatiles. Finally, the HIP can serves as a physical and, to a lesser extent, radiological barrier both before and after hot isostatic pressing.[19]

3.5.2 Description of the HIP Can

The HIP can must be sized to contain approximately 1000 kg of the calcine/additive mixture. It must have sufficient structural integrity to serve as a loading and transport container as it moves through the processing system. The HIP can must survive long term exposure to moderately elevated temperatures (100–200˚C) during bakeout. Also, it must be designed to collapse on a predetermined path under elevated pressure and temperature and survive with its physical integrity intact to preserve its function as both a physical barrier and a container. Preliminary designs for the HIP can have not yet been developed.[20]

3.5.3 Relationship to Other Systems

The HIP interfaces with the following other subsystems[21]

- Can Fill and Seal (5.4.7)
- Fill Port Welding (5.4.9)
- Bakeout Oven (6.1)

[19] ICONE-10-22199
[20] Balls, 2010.
[21] Dustin 2010

- HIP Can Containment (6.2)
- Vent Port Welding (6.1.2)
- Hip Can Treatment (6.3)
- Canister Loading (7.1)

3.5.4 Development History and Status

The history of the HIP can and its development is limited. There appears to be no design approaching the dimensions of a HIP can that would be the full size item for this project. Although several designs are contemplated, no documentation was provided to indicate that even conceptual design has begun. The one document that does discuss various HIP can designs[22] mentions four possibilities that were designed and tested. However, the four possibilities disappear from the text of that document, and there is no discussion of test results or even a reference to what the results may be. A more recent study[23] presents some limited test results on very small scale canister designs but apparently tests only single specimens; no statistical analysis of test results are presented. HIP can design must be considered to be in its infancy as scale-up will be a minimum 50:1 and may be as high as approximately 800:1 on a volumetric basis.

3.5.5 Operational Environment

The operational environment of the HIP can is close to a typical plant environment where conditions of elevated temperature and pressure occur. The major difference is that the calcine contains high levels of radioactivity and all manipulations and operations must be performed remotely. As one of the primary concerns is the containment of the radioactive calcine and small particulate control, the environment should be rather clean. Because movement of the HIP can must be done remotely, pathways through the plant will have to be determined prior to operations and maintained free of obstructions as the operators may not have continuous visual contact as the HIP can is moved through the system.

3.5.6 Comparison of the Operational Environment and Demonstrated Environment

The operational environment for the HIP can varies from plant environment (where it is received and inspected) to a hot cell where filling, bakeout, HIP, final inspection, and load out occur (not necessarily all steps happen in the same hot cell; there will be some transport from one unit operation to the next). The project plan includes a provision for a full-scale demonstration facility, which would be non-radioactive but will include all processing steps except retrieval of the calcine from the bin sets. Superficially, there is no obvious reason why the HIP can cannot be scaled up to meet the requirements of the full-scale demonstration.

3.5.7 TRL Determination

A TRL of 4 requires "component and/or system validation in laboratory environment." Although a small amount of this work has been done, the large scale-up factors anticipated suggest that much remains to be done. The TRA team agrees that "analytical and experimental critical function and/or characteristic proof of concept" certainly has been demonstrated based on the extensive laboratory scale experimentation performed to date. However, the team does not believe that basic components have been integrated establishing that the pieces work together, even on a low fidelity basis. In addition the range of simulants is narrow and should be

[22] Nelson and Vinjamuri 1995

[23] Bateman et al, 2003

broadened (the team knows this work is planned but it has not happened yet). For these reasons the team believes that the HIP can is at TRL = 3.

3.6 HIP Can Containment System/Unit Process

3.6.1 Function of the HIP Can Containment System/Unit/Process

3.6.1.1 HIP Can Containment

The HCC is a modified HIP furnace that also functions as a containment vessel during HIP treatment to protect equipment in the event of a breach of the HIP can. Its primary functions are secondary containment and heating of the HIP can. Auxiliary functions include allowing argon to enter and exit during the HIP process, assisting the cooling of the HIP can, and allowing inspection for internal contamination after the HIP process.

3.6.1.2 HIP Unit

The HIP Unit consists of the Hot Isostatic Press and the HCC cooling system. It must process the cans containing the calcine and produce a waste form that can be loaded into the disposal canister and meets disposal requirements. HIP processing requirements are temperatures up to 1,250^{o}C and pressures up to 15,000 PSI (~1,000 atm). It must also cool the cans and HCC after the HIP program is completed.

3.6.1.3 HIP Process

The HIP process is a time/temperature/pressure program that produces the HIP waste form. The project has defined upper limits of 1,250^{o}C and 15,000 PSI.

3.6.2 Description of the HIP Can Containment System/Unit/Process

3.6.2.1 HIP Can Containment

The HCC is a modified furnace that encases the HIP can and is the initial containment barrier in case of HIP can rupture. It sits inside the pressure vessel (another level of containment). Argon is allowed to enter and exit through a condensing filter. Cooling of the furnace and can is assisted by an integrated cooling fan.

3.6.2.2 HIP Unit

A generic schematic of a HIP system is shown in Figure 3.1. Details of an industrial HIP furnace are shown in Figure 3.2. The basic system consists of an inert gas supply (argon for the CDP); a compressor to boost the gas pressure to desired levels; a water cooled pressure vessel to contain the HIP can; an HCC (in place of the ceramic piece in Figure 3.1; a HIP can (inside the HCC); a furnace; a power controller for the furnace; and a temperature controller. The viscous coating shown in Figure 3.1 will not be used in the CDP apparatus. HIP pressure vessels are either forged thick-walled components or thin-walled components that are wire wound for strength. The former are more prone to catastrophic failure, require more frequent inspection than the latter, and are usually limited to smaller, low pressure, low temperature systems. The latter are used for larger systems because they are stronger, easier to heat and cool, and have a better safety record.

3.6.2.3 HIP Process

The HIP can is filled with the calcine/additive mixture and evacuated. It is then place in the HCC and the HCC is placed in the pressure vessel. The pressure vessel lid is then fastened on to the body of the pressure vessel. The time temperature pressure program is then started. Normally the program will include a ramping up of pressure and temperature; a hold at some intermediate temperature and pressure; a ramping up to final temperature and pressure; another hold; and finally, a ramping down of temperature and pressure. During the heating and pressurization process the can and the material inside are compressed and densified. After the HIP program is completed the can is removed from the HIP unit and packaged for disposal.

Figure 3-1. Generic HIP System

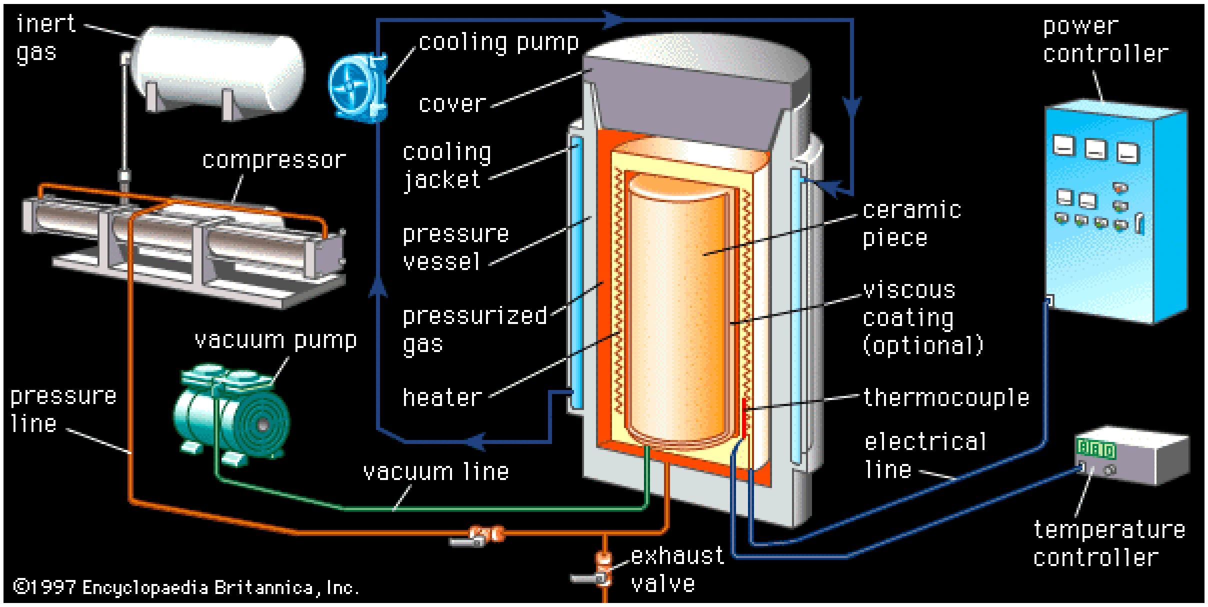
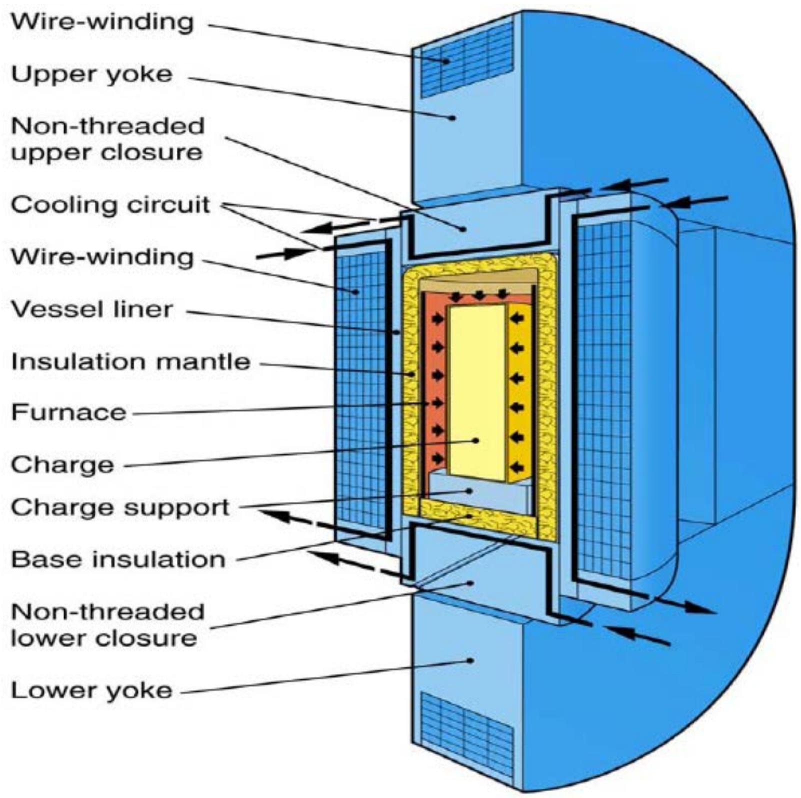


Figure 3-2. Typical HIP Unit



3.6.3 Relationship of the HIP Can Containment System/Unit/Process to Other Systems in the Process

3.6.3.1 HIP Can Containment

Three HIP cans loaded with calcine are baked out and loaded into the HCC. The HCC is loaded into the pressure vessel of the HIP unit, and the HIP process is carried out under a predetermined time, temperature, and pressure program. After the HIP process is completed, the HCC is removed from the HIP unit, the HIP cans removed from the HCC, and the HIP cans loaded into the disposal canister.

3.6.3.2 HIP Unit

The HIP Unit receives an HCC loaded with three HIP cans, processes them according to the HIP program, cools them and passes them on to the HCC unloading system. It receives argon gas from the high pressure argon gas supply system and discharges it to the off-gas handling system. It supplies electric power to the HCC furnace and is connected to the cooling water and vacuum subsystems.

3.6.3.3 HIP Process
The HIP process is the time temperature pressure program that controls the HIP unit. It receives information from the temperature and pressure sensors and drives the power, pressure, and temperature controllers.

3.6.4 Development History and Status

3.6.4.1 HIP Can Containment
The HCC is not part of standard industrial HIP operations and is unique to this project. At the time of this TRA the HCC was still in the early conceptual stage. Very little design information was available.

3.6.4.2 HIP Unit
HIP is a well developed commercial technology. There are several manufacturers of HIP commercial HIP units. The unique feature of the CDP will be the large scale HIP of radioactive materials. Argonne National Laboratory[24] (ANL) modified a small HIP unit for hot cell operation and used it to produce a glass ceramic waste form from spent nuclear fuel processing. The ANL unit used cans with an outside diameter of 4.5 inches (11.5 cm) and height of 6 inches (15 cm). Conceptual design dimensions for the CDP can are have an outside diameter of 22.9 inches (58 cm) and height 102 inches (259cm). The CDP HIP HCC furnace will hold three HIP cans. Commercial HIP units four to five times the size of the units required for the CDP and capable of reaching the CDP processing temperatures and pressures have been used commercially for many years.

ANSTO, Inc. has done small scale testing with non-radioactive calcine and additives that are the basis for the design requirements (temperatures up to 1,250^{o}C and pressures up to 7,200 PSI (~500 atm) for the process.

3.6.4.3 HIP Process
The precise time/temperature/pressure program that will be used by the CDP has yet to be determined. The ANSTO work will be the starting point for determining the final program.

3.6.5 Operational Environment

3.6.5.1 HIP Can Containment
The HCC will operate at temperatures up to 1,250^{o}C and pressures up to 15,000 PSI (~1,000 atm). It will be exposed to the high temperature and high pressure argon gas but will not have any substantial pressure differential across its walls. It will be exposed to the radiation from the calcine filled cans. The HCC will not be exposed to any of the compounds in the HIP can unless the can is breached.

3.6.5.2 HIP Unit
The HIP operating environment includes temperatures up to 1,250^{o}C and pressures up to 15,000 PSI (~1,000 atm). The unit will operate in a high rad environment, but will not be exposed to contamination unless both the HIP can and the HCC fail.

---

[24] Bateman, K.J., Rigg, R.H., Wiest, J.D., *Hot Isostatic Pressing of Ceramic Waste From Spent Nuclear Fuel*, 10th International Conference on Nuclear Engineering, April 14-18, 2002.

3.6.5.3 HIP Process

See section 3.6.5 above for the operating environment.

3.6.6 Comparison of the Operational Environment and Demonstrated Environment

3.6.6.1 HIP Can Containment

At the time of this TRA the HCC was a paper concept. It has not been demonstrated.

3.6.6.2 HIP Unit

Units of the size required for the CDP are commercially available. HIP of radioactive materials has not been carried out at the scale required by the CDP.

3.6.6.3 HIP Process

The temperatures and pressures anticipated for the CDP HIP process are well within the range of commercial operations.

3.6.7 TRL Determination

3.6.7.1 HIP Can Containment

The TRA Team could not evaluate the TRL of the HCC as there was no available documentation on the concept. The project is working on design details, hazard analysis, a safety report and other documents. It expects the HCC to be at TRL 2 by CD-1.

3.6.7.2 HIP Unit

The CDP expects the HIP unit to be at TRL 4 by CD-1. The Team determined that the HIP unit is at TRL 3 at the present time as many documents required by TRL 4 are still in preparation.

3.6.7.3 HIP Process

The Project did not evaluate the HIP Process in its self-evaluation. The Team determined that the HIP Process is at TRL 3, i.e., the specific process parameters are only generally specified.

Observations and Recommendations

- The HCC is a critical piece of equipment and is a very high technology risk at present. It has never been tested or used before. The project expects the HCC to be at TRL 2 by CD-1. If this is the case, the overall project will be at TRL 2. The CDP is well aware of the need to develop the HCC as quickly as possible.
- The time temperature pressure program is a critical design piece, and extensive small scale testing will be required to develop it. The project is aware of this requirement. However, the team believes that the testing will be more extensive than the CDP expects. As noted elsewhere, the WASRD/Waste Acceptance Product Specification (WAPS) requirements for waste form acceptance are very rigorous and require considerable testing.
- The CDP should not submit for CD-4 until all components, including the HCC, are at TRL 4.
- The project, in conjunction with EM, should quickly define the testing requirements waste form acceptance.

3.7 HIP Can Feed System

3.7.1 Function
The function of HIP Can Feed system is to receive calcine from the transport and surge system, blend it with an additive, and feed it from the batch hopper into the HIP can, which is then sealed and surveyed for possible contamination.

3.7.2 Description
Calcine is received from the transport and surge system and is processed through a batch receipt filter that separates the calcine and off-gas prior to mixing operations. Additive for the calcine mixture is measured through a metered hopper at the receipt hopper producing a single batch for each HIP can. The HIP feed blender then mixes the calcine and additive and moves it to a HIP can feed hopper that holds the calcine/additive mix in preparation for filling HIP can. Empty HIP cans awaiting the filling operation are stored inside a hot cell prior to usage.

At the Fill and Seal Station, the HIP can is positioned so that the can is secured, the fill plug is removed, and a vacuum seal is established with the fill line. The calcine/additive mixture is transferred to the can from the fill line and an intermediate plug (a two-piece, push-through plug) is inserted prior to detaching the fill line, sealing the fill tube as well as the can. The filled HIP can is then inspected and swiped for exterior contamination.

3.7.3 Relationship to Other Systems
The HIP Can Feed System has major interfaces with the Calcine Transport and Surge System, as outlined above in 3.6.2 above; the Additive Feed Subsystem; the HIP can from the HIP Can Process Prep system and the Filled HIP to Bakeout System. Conceptually, the calcine flow rate is at 800 lbm/hr (nominal 60% waste) while the additive flow rate is at 528 lbm/hr (nominal 40% additive) with a mixing rate of 2,500 lbm every 60 minutes for the mixer and a 1,320 lbm/hr flow rate for the single batch hopper. There are two minor system interfaces: the Process Off-Gas System and the Secondary Waste System.

3.7.4 Development History and Status
Laboratory scale studies[25] were begun in late 1994 at ANL using a hot isostatic press as the last step in processing a ceramic waste form from a spent fuel treatment process. Temperature, pressure, and other cycle conditions for a hot isostatic press were developed for demonstration scale operations. The demonstration scale tests were first performed using a non-irradiated material on a range of canisters to determine whether the waste form could be treated via HIP on a larger scale. A HIP can was modified to operate in a radioactive environment. The HIP vessel and ancillary components were evaluated and configured to remain in the hot cell with controls located outside the cell. Demonstration HIP cans were loaded with irradiated material for the spent fuel treatment process, and eleven cans were processed using appropriate HIP parameters.

A review of components for the HIP Feed Can System shows that the calcine receipt hoppers[26] to be used in the HIP Can Feed System are commercially available components, and vendor data on radiation environment performance is available. A laboratory scale mixer and supporting data currently exists at the vendor’s facility, and existing laboratory scale equipment at a vendor’s

---

[25] Bateman, et al., 2002.

[26] Project No. 23582, “Calcine Disposition Project Waste-Form and Technology Readiness Strategy Plan (DRAFT)”, PLN-3448, Draft B.

facility will be used to develop full-scale HIP can filling as well as sealing/capping systems design and testing.

3.7.5 Relevant Environment

HIP can feed will be carried out in a highly radioactive environment with the potential for radiation fields up to 6,400 rads. There is a concern that dust and contamination could affect operations and maintenance of remote operating equipment.

3.7.6 Comparison of the Relevant Environment and Demonstrated Environment

Laboratory scale studies were conducted at ANL[27] under similar conditions to the operational environment that the HIP Feed Can System will experience. In addition to tests with surrogate material, in April 1999, one-inch canisters were loaded with irradiated powder and subjected to the HIP cycle. Also, fifteen small canisters (approximately 2½ inches) were filled with plutonium material, evacuated and welded, and subjected to the HIP cycle in May 1999. The studies done on these samples are representative of the conditions that would be encountered in a high radiation environment and techniques employed are comparable to that envisioned for the HIP Can Feed System.

3.7.7 Technology Readiness Level Determination

The HIP Can Feed System was determined to be TRL 4 based on small laboratory scale tests demonstrated at ANL in a radioactive environment. In addition, components of the HIP Can Feed System that need to work together have been identified and conceptually integrated in preparation for system design activities.

3.8 Bakeout System

3.8.1 Function

The function of the HIP Can Bakeout System is to remove excess water and volatiles from the can, evacuate the can and stage it until the HCC is ready.

3.8.2 Description

The filled HIP can is received at the HIP Can Bakeout Station where the can is lowered into a bakeout hot cell and a vent line attached to the HIP can bakeout off-gas system. The can is heated between 100–200ºC for several hours to drive off excess water, volatiles and retain mercury in the calcine mix. During bakeout, a vacuum is established on the HIP can and any off-gas is routed through filters, including in-cell filters and traps, to remove any particulates or gaseous components. After bakeout is complete, a vacuum is maintained on the HIP can through the vent line. Once the vacuum reaches the set point, it is verified, the vent port is closed, and vacuum line removed. Prior to transferring the HIP can to the HCC, the closed vent line is seal-welded and visually inspected. The can is then removed from the bakeout furnace and placed in an HCC.

3.8.3 Relationship to Other Systems

The HIP Can Bakeout System has major interfaces with the HIP Can Feed System, as described in section 3.6 and the HCC Loading Subsystem. There are minor system interfaces with the Bakeout Off-Gas Treatment Subsystem, the Central Vacuum Subsystem, as well as the Utilities and Equipment Instrument and Controls Subsystem. Conceptually, the bakeout time is 24-48 hours and

[27] Bateman, et al., 2002.

the ovens are loaded with multiple cans (3). Time to complete the seal weld is projected to be 2 hours per can.

3.8.4 Development History and Status

Bakeout systems similar to the one proposed for the CDP are prevalent in a large number of industry applications.[28] Equipment for the bakeout system is commercially available and will require minimal design modification for use. An important parameter in the bakeout operation is determination of temperature and time requirements so that excess water and volatiles are driven off and mercury is retained in the calcine waste form.

ANSTO, Inc has performed testing of both alumina and zirconia calcine surrogates to determine the nature of off-gas evolution with respect to the HIP can bakeout cycle.[29] At elevated temperatures (600–900ºC depending on the blended surrogate tested) significant amounts of volatile mercury were collected. The contractor is proposing a bakeout temperature of 100–200ºC for 24–48 hours in order to retain mercury in the waste form. The contractor is evaluating a bakeout temperature of 100–200ºC for 24–48 hours in order to retain mercury in the waste form. Some water of hydration is assumed to be included in the calcine, since the calcine has been exposed to the atmosphere for decades. In addition, some nitrates from the formation of the calcine are assumed to be available. The water of hydration is driven off at about 200ºC, and the nitrate is driven off at temperatures above 200ºC. Testing should be done during preoperational testing to develop the optimum bakeout temperature.

3.8.5 Relevant Environment

The HIP can bakeout will be carried out in a highly radioactive environment with the potential for radiation fields up to 6,400 rads.

3.8.6 Comparison of the Operational Environment and Demonstrated Environment

Laboratory bakeout tests were performed by ANSTO, Inc.[30] using both alumina and zirconia calcine surrogates that were comparable to the operational environment expected.

3.8.7 Technology Readiness Level Determination

The Bakeout System was determined to be TRL 4 as laboratory tests have been demonstrated on surrogate calcine waste. However, the bakeout temperature proposed, 100–200ºC, may not be optimal to achieve desired results as discussed above. It is suggested that laboratory testing of large samples over a range of temperatures be performed.

3.9 Canister Loading/Closure

3.9.1 Function of Canister Loading/Closure

Treated HIP cans are to be loaded into a canister for storage, transportation, and disposal and these canisters will be loaded into shipping casks. This technology element includes the following subsystems: canister, lid removal, canister loading, lid welding, vault storage, canister handling, cask loading, cask handling, and cask storage. Of these subsystems the canister, lid removal, canister loading, and lid welding are critical technologies that make up this critical technology element.

[28] PLN-3448.
[29] INL/ANSTO 2009.
[30] Ibid.

3.9.2 Description of Canister Loading/Closure

The canister described in the current conceptual design is based on the DOE standardized SNF canister design made of 316L with improved top head. The improvement includes full canister opening for insertion of the treated HIP cans with lifting apparatus that would allow movement of the canister before and after lid welding. The canister loading system consists of HIP can hoist to load three HIP cans into a canister. A media fill system will be used to add inert media to reduce motion of the HIP cans within the canister (if necessary based on drop test results).

The canister welding system is based on standard systems used for SNF canister welding. The lids will be stored on the canister to avoid the introduction of foreign objects/material into the canister while waiting for HIP can loading. A system is required to remove the lid before HIP can loading and replace the lid before lid welding. Finally, a helium leak testing system (if deemed necessary), a canister contamination measurement, and a canister weighing system will generate data necessary for canister production records; these will be based on similar existing equipment used for HLW and SNF canister qualification.

The loaded and welded canister must meet disposal requirements for HLW as described in the WASRD (including 4.8.2 through 4.8.12).[31]

3.9.3 Relationship to Other Systems

The canister and closure systems have close relationships to the waste form, HIP can, bakeout, and HIP treatment systems. These systems must reliably produce HIP cans that meet weight and dimensional requirements for placement into the canister without exceeding dimensional, dose, criticality, heat generation, or weight limits. The system will also interface with the HIP can lag storage and the HLW canister lag storage systems.

3.9.4 Development History and Status

Designs of canister, welder, contamination measurement, weighing, and leak testing are based on existing designs for HLW and/or SNF. As this represents a new applications for each of them, they must be tested to confirm effectiveness of changes in design and/or application.

3.9.5 Comparison of the Operational Environment and Demonstrated Environment

The operating environments are nearly identical to those for which the canister and auxiliary equipment were designed and tested. One significant difference is the use of HIP cans as the waste to be loaded and handled within the canister. Canister designs generally were not designed for a few massive solid objects. This difference raises concerns for the ability of the canister to withstand drop testing without breach. Inert media fill could be used as a mitigation strategy if the unfilled canisters fail drop test requirements.

3.9.6 TRL Determination

TRL 4 will be achieved for the canister, lid handling, canister loading, and lid welding CTE subsystems once the draft documents referenced in this study are released prior to CD-1. The list of TRL determination questions and answers are given in Appendix C.

[31] Waste Acceptance System Requirements Document, DOE/RW-0351, Revision 5, ICN-01, March 10, 2008.

3.10 Remote Operations and Maintenance

3.10.1 Function of Remote Operations and Maintenance

The major function of the remote operations and maintenance is to ensure that the remote equipment in the facility can be safely and effectively maintained throughout the operational lifetime of the CDP. At the time of the review, documentation was not provided; it is expected to be available in October 2010.

3.10.2 Description of Remote Operations and Maintenance

Each subsystem within the WBS elements must be designed such that they can be maintained. Each subsystem will have specific remote tools that will be operated via a gantry crane or other remote manipulator systems in order to make the necessary modifications for a subsystem change out, repair, or routine maintenance. Unique and specific tools will be designed for each subsystem depending upon its location and design. At the time of the review, documentation was not provided; it is expected to be available in October 2010.

3.10.3 Relationship to Other Systems

Remote operations and maintenance has interfaces with all of the project CTEs, as well as other WBS elements.

At the time of the review, documentation was not provided; it is expected to be available in October 2010.

3.10.4 Development History and Status

There was limited documentation provided during the CTE evaluation regarding the history of remote operations and maintenance. However, remote operations are ubiquitous throughout the DOE sites in the United States, including Idaho. During the early design phase, the other elements of the CDP will be designed with a requirement to be able to be remotely operated and maintained. Specific tools will then be designed for remote operations and maintenance. At the time of the review, documentation was not provided; it is expected to be available in October 2010.

3.10.5 Operational Environment

Remote operations and maintenance will be required to operate in a high radiation environment. Currently, radioactive density of the calcine ranges from 3,210–13,500 Ci/m^3. The temperature of the calcine in the bin sets range from 85–347ºC. The treatment facility will be an existing facility at the Idaho Cleanup Project site that will be retrofitted to accommodate the CDP. As such, all the systems must generally fit within the existing footprint of the facility. This will create some challenges for remote operations and maintenance. At the time of the review, documentation was not provided, other than a conceptual plant layout. Additional documentation was made available to the Team in October 2010.

3.10.6 Comparison of the Operational Environment and Demonstrated Environment

Remote operations and maintenance activities have been used in very similar environments at Idaho as well as other locations. At the time of the review, documentation was not provided; it is expected to be available in October 2010.

3.10.7 TRL Determination

The TRL level achieved for remote operations and maintenance is TRL 4. The basis of this determination is because of a long history of successful remote operations at the Idaho site, as well as at other DOE sites. Additionally, the TRL 4 level was largely based upon an interview with the remote operations technical point of contact during the review along with assurances that documentation will be completed by October 2010.

TRL 5 was not obtained due to the fact there was no full-scale system to test remote operations and maintenance for this project at the time of the review. Full-scale integrated cold tests are planned and will need to be conducted to achieve TRL 5. This will be a significant undertaking and will take a major commitment by the project in order to accommodate this type of testing.

Observations and Recommendations

At the time of the review, documentation was not provided, other than a conceptual plant layout. Additional documentation is expected to be available in October 2010. At that time, this CTE will need to be re-evaluated to ensure that TRL 4 will be met. During the interview process with the lead technical point of contact for the remote operations and maintenance, it is clear that retrofitting the existing facility for the CDP will result in remote operations and maintenance challenges. Since this is not a "clean sheet" design, equipment in the facility will be placed in the optimal location; however, it may result in logistical operational challenges, as well as physical maintenance challenges due to space limitations and height requirements.

3.11 Characterization (feed, admixture, product)

Characterization is not normally included as a CTE. Waste characterization requirements are driven by processing and waste form requirements. The requirements may change from technology element to technology element. For this reason questions on characterization are included in the standard TRL tables and evaluated for each technology.

CDP has made a fundamental characterization assumption that represents a major risk to the project, namely that the HIP process is robust enough that a single additive, product formulation and time temperature pressure program can be found that will produce a waste form that will meet all RCRA and DOE requirements for all types of calcine. This assumption means that current calcine characterization information is sufficient, and that no further sampling and analysis will be carried out during retrieval or processing. Put another way, CDP is assuming that it can process the waste to an acceptable high level waste form without sampling the waste feed, the mixture of waste plus additive, or the final product.

Existing (DWPF, West Valley) and planned (Hanford) HLW glass processing facilities have rigid waste form qualification programs that involve tight process controls developed from testing various sizes of prototypical melters and the actual plant melters (during cold commissioning) combined with careful sampling and analysis of feed and admixture. CDP's assumption is a major departure from past EM HLW processing and will be carefully scrutinized by the EPA and EM. If existing characterization and HIP process control information can be combined to satisfy EPA and EM, then the current design is acceptable. However, if sampling and analysis similar to what has been carried out at other HLW processing facilities is required, the current design will require major modification.

Available calcine characterization data has been compiled in *Calcine Waste Storage at the Idaho Nuclear Technology and Engineering Center*.[32] Calcine has been produced at two facilities (Waste Calcine Facility and New Waste Calcine Facility) from a variety of feeds. The four major types come from processing different wastes and are generally labeled, aluminum, zirconium, fluorine, and sodium-bearing waste (SBW). The calcine is stored in six bin sets. Although the bin sets generally contain only one type of waste, some of the bins have more than one type of calcine deposited in layers. Retrieval will mix some of the layers.

Very little data from direct analysis of calcine exists. Most characterization information is based on extensive analysis of the feed to the calciner that included analysis for key RCRA and radionuclide components. Estimates for the components not able to be determined by analysis were made from fuel history, including burn-up, dissolution, and subsequent processing.
The following quote is taken from Swenson and Staiger.

> *Individual bin inventories reported here have been estimated from calciner liquid feed information. Some of the information that is of current interest, particularly the concentration of long-lived radionuclides and RCRA metals, was not routinely collected at the time of waste generation. To fill this information gap, the inventories have been estimated on the basis of available information and process knowledge.*[33]

The CDP goal is not to further analyze calcine feed, additives, or final waste form. It is not clear that the existing information will satisfy RCRA and DOE requirements that typically rest on detailed, batch by batch analysis of feed material, additives, and process control information or detailed analysis of the final waste form. A requirement to characterize each HIP batch would substantially complicate the design, increase plant size, and alter plant operations.

3.11.1 TRL Determination for Characterization

The characterization questions included at the various TRLs are given in Table 3-5.

Table 3-5. Characterization Questions
(From EM TRL Question Set 12/02/09)

TRL	Y/N	Criteria	Basis and Supporting Documentation
TRL 1		8. Basic characterization data exists	
TRL 2			
TRL 3		24. Key physical and chemical properties have been characterized for a number of waste samples	
TRL 4		24. Key physical and chemical properties have been characterized for a range of wastes	
TRL 5		18. The range of all relevant physical and chemical properties has been determined (to the extent possible)	
TRL 6			

[32] Swenson, M.D. and Staiger, M.C., *Calcine Waste Storage at the Idaho Nuclear Technology and Engineering Center*[1], INEEL/EXT-98-00455, Revision 2, January 2005.
[33] Swenson and Staiger, 2007.

CDP negotiations with EPA to determine if available characterization information can be combined with proposed process information to satisfy RCRA requirements are in the early stages. The project will have to carry out similar negotiations with EM. If the project assumption that existing characterization and HIP process control information can be combined to satisfy EPA and EM is validated, then characterization would be evaluated as being at TRL 6. However, if the project assumption is not acceptable, characterization would be evaluated at TRL 3 or less.

Observations and Recommendations

- The CDP assumption that no further sampling and analysis of calcine, additive/calcine mixtures, or product will be required represents a major risk.
- The CDP should vet its assumption that additional characterization of calcine, additive/calcine mixtures, or product will not be necessary with EPA and EM as soon as possible.

3.12 Simulants

3.12.1 Function of the Simulant

The simulant must mimic the performance of the calcine for all testing and such mimicry eventually must occur at a relatively “high fidelity.” Nevertheless, the same simulant does not have to be used necessarily for all tests. Whatever the test is intended to demonstrate dictates the properties the simulant should have. For example, tests to demonstrate pneumatic transportability may depend more on the physical properties than on the chemical properties of the simulant, while for tests of glass/ceramic formation, the opposite may be true. Tests of retrievability, mixing and bakeout depend to differing extents on both physical and chemical properties of the simulant. Selection of the appropriate simulant depends mostly on understanding what the test is intended to demonstrate and what simulant characteristics have the most effect on the behavior being tested.

3.12.2 Description of the Simulant

To a first approximation, the simulant must have the same chemical composition as the calcine in the bin sets. The chemical nature of the calcine will most likely be determined from process knowledge of the waste as it was fed into the calciner coupled with a limited amount of analysis of the final product. However, there is more to the preparation of the simulant that just a knowledge of its chemical composition. As noted in the preceding paragraph, physical properties of the calcine are important also. Such characteristics as bulk density, particle density, and particle size distribution (known to be bimodal) affect the ability to mix thoroughly with the additive. The mineralogy and mineral phases of the calcine should be known as these characteristics affect the behavior of the simulant. For example, aluminum oxide can occur as corundum, an extremely hard mineral, or as the hydroxide gibbsite, which is much softer. The tendency for corundum to erode and abrade the internals of pneumatic transport at elbows and other transitions lines is much greater than gibbsite.

The simulant for the ANSTO testing was prepared by making solutions with compositions similar to two basic waste feeds to the calciner: one mimicking aluminum clad fuel waste and another mimicking zirconium clad fuel waste, and processing these solutions through an engineering scale version of the calciner. However, it should be noted the operation of the engineering scale calciner was different from the full-scale device: the level of nitrogen oxides formation was much more carefully controlled at the engineering scale. This difference in operation introduces a difference in chemistry occurring in the calciner and raises the question of how well this surrogate calcine mimics the calcine in the bin sets. Simulant materials require evaluation to adjustment as necessary to support future testing.

One characteristic of the calcine that will be difficult to simulate is its thermal nature. Because the calcine contains decaying radionuclides, it will have above ambient temperatures. How far above ambient the temperature will be depends on the age (decay time) of the calcine and the exact radionuclide composition. Mimicking this aspect of the calcine will be difficult as the heat source of the calcine is internal while the heat source of any simulant is not. The effect of calcine temperature on any of the processes will have to be considered.

3.12.3 Relationship to Other Systems

The simulant interfaces with the following other subsystems:[34]

- Retrieval and pneumatic transport (5.2)
- Surge tank and metering – calcine only (5.3)
- Mixing and metering – calcine plus additive (5.4)
- HIP can Filling (5.4)
- Bakeout Oven (6.1)
- Hip Can Treatment (6.3)

3.12.4 Development History and Status

As noted in section 3.12.2, only a limited amount of development of the simulant has been done. This development has been based primarily on the chemical composition of the calcine (as derived from process knowledge). It virtually ignored both the physical properties and the mineralogical aspects for the simulant and could not be a high fidelity reproduction of the calcine in the bin sets. The best simulant to date is probably that developed for the ANSTO testing, and its properties were varied over a narrow range of chemical compositions. The ANSTO calcine has the advantage of having a thermal processing history similar to the authentic calcine.

3.12.5 Operational Environment

The simulant (and actually the set of simulants) will have to mimic authentic calcine in several different environments: storage tank (retrieval), cyclone (fines removal), surge tank (flow to a metering device), metering device, itself (accuracy of measurement), mixer (uniform blending of calcine and additive), HIP can filling (accuracy of measurement of mixture), bakeout (loss of low boiling volatiles), and HIP treatment (forming the glass/ceramic product). In each of these environments, a different characteristic of the calcine predominates and the simulant will need to duplicate each one. This is why a set of simulants is needed.

3.12.6 Comparison of the Operational Environment and Demonstrated Environment

The difference between the operational and the demonstrated environment for the simulant is that operational environment will be radioactive. The simulant will be exposed to the operational environment only prior to hot start-up. After that, there will be no need for it.

[34] Dustin, 2010.

A possible exception is the continued development of processing equipment after hot start-up but that currently is an unknown.

3.12.7 TRL Determination

The table below presents general requirements to achieve specific Technical Readiness Levels. A TRL of 4 requires "component and/or system validation in laboratory environment." Although a small amount of this work has been done, the large variety of simulants that apparently will be required indicates that much remains to be done. The TRA team agrees that "analytical and experimental critical function and/or characteristic proof of concept" has been demonstrated based on laboratory scale testing with a limited range of simulants which do not mimic all the aspects of authentic calcine. Moreover, the team does not believe that basic operations using a simulant have been demonstrated, even on a low fidelity basis. In addition, the range of simulants is narrow and should be broadened. For these reasons the team believes that the simulant is at TRL = 3.

3.13 Shipping

3.13.1 Function of the Shipping System

The function of the shipping facility is to provide the capability to load the waste canisters into a shipping cask for transport to an out-of-state storage or disposal facility or a repository. Since the plan for the Yucca Mountain facility was to use rail shipment wherever possible because it can accommodate heavier loads, the CDP plans to provide rail access to the storage facility for the canisters of treated calcine.

3.13.2 Description of the Shipping System

The CDP plans to modify the SBW shipping facility (designed to load 2-foot by 10-foot canisters of treated SBW into casks for truck shipment to the Waste Isolation Pilot Plant) to accommodate the larger 2-foot by 15-foot canisters of treated calcine by rail. Lag storage capability will be provided adjacent to the shipping facility.

3.13.3 Relationship to Other Systems

The shipping facility must be capable of handling the large number of 15-foot canisters of calcine. If just-in-time shipping is assumed, the facility will have to be capable of loading and shipping up to two casks per day over a period of 12 years. Otherwise storage capability for a large number of casks will have to be provided.

3.13.4 Development History and Status

Shipment of sources of highly radioactive source, such as SNF has taken place since the beginning of the atomic age by rail, truck and barge. Shipment of the canisters of treated calcine having a maximum dose of 5,000 rem/hr should not be a problem.

3.13.5 Operational Environment

Equipment in the shipping facility must be capable of handling 15' loads of 2 to 3 metric tons and operating in a highly radioactive environment (about 5,000 rad/hr). Workers must operate the equipment remotely from highly shielded locations.

3.13.6 Comparison of Operating to Demonstrated Environment

Equipment for packaging SNF has been operated at INL for years and could easily be adapted to handling the canisters of material treated by HIP.

3.13.7 TRL Determination

The shipping facility was determined not to be a CTE.

3.14 Off-Gas

3.14.1 Function of Off-Gas

The function of the off-gas treatment system is to prevent release of radionuclides and RCRA metals from the stack in unallowable concentrations and condition the gas for release. The intent of the CDP is to use the existing off-gas treatment system in the IWTU. After review of this potential CTE, the review team determined it is not a CTE. However, there are technical issues that should be addressed by the CDP.

These technical issues involve the amount of potential volatiles in the calcine and the impacts this may have on the HIP operations. It is expected that volatiles are contained in the calcine. These consist of the following, in roughly the order of release as the temperature is increased to HIP operating temperature:

- **Waters of Hydration** Heavy metal oxides tend to form compounds with contained waters of hydration. A common compound is uranyl nitrate hexahydrate, or UO2(NO3)2 · 6H2O. Other hydrated metal compounds are expected in the calcine. When the temperature is increased to above approximately 150–200ºC within the bakeout system, this water of hydration is released. This is the expected outcome, and has no impact on the off-gas system. However, if these waters are not released, the residual waters of hydration can cause operational issues during the HIP processing.
- **Nitrate Destruction** Any residual nitrates are broken down thermally to NOx, which is released as a gas. Nitrate destruction is routinely done during thermal processing in operations conducted by DOE and was an attribute of the calcine process. The NOx release generally occurs during the temperature range of 200–400ºC. Some NOx gas will be released during HIP operations, and the resulting potential impacts need to be determined.
- **Mercury and other RCRA metals release** At elevated temperatures of 300ºC or above, the mercury in the calcine is released as a gas and must be treated to prevent release out the stack. This was discussed during the preliminary visit in May but was not included in the flowsheet in the review in July. The metals in the off-gas require a wet scrubber, which produces secondary waste and requires space in the treatment facility. Metals release needs to be recognized, and contingency plans should be in place in the event they are measured in the off-gas during operation.
- **Cesium and other radionuclides** Cesium is known as a volatile species and is an issue in all high-temperature processes, such as vitrification and fluidized bed steam reforming. Cesium volatility generally occurs at elevated temperatures of more than 500ºC.

In order to determine the true impacts of gas release that may impact the off-gas system, samples of each type of calcine should be collected and a thermogravimetric analysis should be performed to determine the observed temperature and quantity of the off-gas released at each temperature. This analysis can be done with limited amounts of calcine and is a routine test that determines the propensity to off-gas upon heating. This data is critical for planning the off-gas system.

3.14.2 Description of Off-Gas

The off-gas treatment system collects the off-gas from all process areas, treats the off-gas via HEPA filtration, dilutes the off-gas, and releases it from the tall stack associated with the IWTU. The off-gas is monitored upon release to determine if there are any releases that are not acceptable. If these occur, corrective action will be required.

3.14.3 Relationship to Other Systems

The off-gas system ties directly into the transfer of the calcine into the surge tank, out of the surge tank into the mixer/blender operation, the bakeout system, and the HIP system where the off-gas contains the inert gas, which is released intentionally as part of the processing.

Characterization of the feeds is required, and is a strong interface. Knowledge of the off-gas from actual calcine during each unit operations is necessary to complete the design.

3.14.4 Development History and Status

Off-gas treatment is routinely done for all chemical processing operations and the system designed for the IWTU should be adequate for the CDP. This is mature technology.

3.14.5 Operational Environment

The off-gas system should not be exposed to high radiation fields, and the temperatures are within the IWTU planned operation.

3.14.6 Comparison of the Operational Environment and Demonstrated Environment

This is a routine processing issue and has been demonstrated at full-scale on several DOE and industry processes.

3.14.7 TRL Determination

The team agreed the off-gas system is not a CTE. The open questions about the type of gas release as the temperature is increased should be determined in laboratory tests with actual calcine. If it is shown that no unacceptable gas is released at the planned operation of the bakeout, and no gas release occurs in HIP operation that impacts the HIP performance, then the off-gas system can be considered ready for final design.

4 Conclusions, Observations, and Recommendations

4.1 Conclusions

The CDP has a dedicated staff who have made significant progress in developing the technology for treating calcine since they first began working as a team in January 2010. During their July visit, the TRA Team found that 8 of the 11 CTE’s are at TRL 4 and that Characterization of Feed, Admixture, Product Simulant Formulation, and Ceramic Additive Formulation were at

TRL 3 and required more work. The HIP Can Container was found to be at level 2; therefore the overall TRL for the CDP was found to be 2. Table 3.2 summarizes the information developed for the individual TRL Determination sections.

4.2 Observations and Recommendations

4.2.1 Observations concerning the TRA

The Team found the CDP staff, including that of both the Field Office and contractor, to be most accommodating and cooperative. While the CDP was clearly in the initial stages of design, the staff had a good handle on where they were in the design process and had a schedule for completing the development work needed to achieve the readiness levels necessary. The Team had concerns, most of which have been previously mentioned including:

- Plans to develop the WPS design without the capability to sample the calcine could limit the ability to collect data that may be needed for acceptance at a repository.
- Development and use of a single ceramic additive for all calcine types could result in less efficient waste loading of the final waste forms.
- Lack of an approved waste form for repository disposition could result in additional developmental work having to be performed.

4.2.2 Observations concerning the Project

- Documentation of WPS TRL requirements was incomplete at the time of the TRA team assessment. Additional documents have since been provided and other essential documents are scheduled for completion prior to CD-1. A second phase of the TRA will be need when they are completed.
- The WPS is a unique application of the HIP process. Substantial testing on a variety of scales (laboratory, bench, demonstration) will be required. CDP has developed a TMP that will details HIP process development plans.

4.2.3 Recommendations for the Project:

- CDP should ensure that all required documentation is complete at the time of future TRAs. (The project does plan to have essential documents ready by the time of CD-1 in June 2012.)
- The Team fully supports the need for a full scale mockup facility to achieve TRL 6 for CD-2 (September 2016).
- CDP should complete discussions of waste form requirements with EPA and EM as soon as possible. (The project has already initiated discussions with EPA on RCRA requirements. It should begin clarifying EM requirements immediately.)
- The CDP TMP should identify all necessary developmental work, including that required for HIP can development, HIP Can containment development, waste form qualification, and simulant formulation. It should also address achieving TRL 6 for all CTEs by CD-2.

5 References

Amended Record of Decision: Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement, DOE/EIS-0287, December 21, 2009.

Arenaz, M.R., Letter to W. John Arthur, *Request for Updated U.S. Department of Energy (DOE) Canister Thermal Output Limits in Support of Repository Design*, (EM-FMDP-06-006), ORD Correspondence Log No. 0210065322. February 6, 2006.

Bateman, K. J., and Rigg, R. H., "Metal Canister Designs for Hot Isostatic Pressing of Ceramic and Glass/Ceramic Matrices for Immobilizing Radioactive Elements," in International Conference on Powder Metallurgy and Particulate Materials.

Bateman, K.J., Rigg, R.H., and Wiest, J.D., "Hot Isostatic Pressing of Ceramic Waste from Spent Nuclear Fuel, ICONE 10-22199, 10th International Conference on Nuclear Engineering, Arlington, VA, April 14-18, 2002.

BEA, "Process ANSTO Can #1133 in Hot Isostatic Press," PWS No. 2-4125, October 20, 2008.

Begg et al., "Assessment of HOT Isostatic Pressing (HIP) Project Annual Report 2009," INL/ANSTO.

Carter, M. L., et.al, "HIPed Tailored Ceramic Waste Forms for the Immobilization of Cs, Sr, and Tc," INL/CON-07-12875, September 2007.

Del Debbio, J. A., "Removal of Cesium from a High-Level Calcined Waste by High Temperature Volatilization," INEL-94/0028, November 1994.

Del Debbio, J. A., "The Use of Tracers for Measurement of Volatiles from High Temperature Calcination," JAD-02-96, June 10, 1996.

EDF-3673, 2003, "Pneumatic Retrieval of Calcined High-Level Waste", Rev 0, Idaho Cleanup Project, July 10, 2003. (This document is OUO and may not be publically available.)

EDF-6185, 2005, "Investigation into Low Aluminum Results Found in Alumina Calcine from Binset 2", Rev 0, Idaho Cleanup Project, November 1, 2005.

EDF-6980, "Calcine Retrieval, Transport, and Drying Methods for the Calcine Disposition Project"

EDF-8182, 2008, "Calcine Disposition Project Calcine Retrieval Rate Evaluation," Rev 2, Idaho Cleanup Project, August 12, 2010.

EDF-9689, "Retrieval Remote Design, Maintenance and Tools for the Calcine Disposition Project", Rev. 0, Draft, Idaho Cleanup Project, 2010.

GAO/NSIAD-99-162, Best Practices: Better Management of Technology Can Improve Weapon System Outcomes, July 1999.

GAO-07-336, Major Construction Projects Need a Consistent Approach for Assessing Technology Readiness to Help Avoid Cost Increases and Delays, March 2007.INL/ANSTO 2009, "Assessment of Hot Isostatic Pressing (HIP), Volume 1, Revision 1, November 2009.

Jackson, J.P. and Gessner, R.F., 1988, *Remote Installation of Risers on Underground Nuclear Waste Storage Tanks*, DOE/NE/44139-45, West Valley Nuclear Services Company, West Valley, NY, March 1988.

Jantzen, C.M. Bibler, N.E., Beam, D.C., Crawford, C.L., and Pickett, M.A., 1933, "Characterization of the Defense Waste Processing Facility Environmental Assessment Glass Standard Reference Material," WSRC-TR- 92-346, Rev. 1, Westinghouse Savannah River Company, Aiken, SC, February 1993.

McKinley, K., *Calcine Disposition Project Waste Form and Technology Readiness Strategy Plan*, PLN-3448, Idaho Cleanup Project, Idaho Falls, ID, 2010.

National Defense Authorization Act of 2006, Public Law 109-163.

Nelson, L. O., 1900, "Progress Report on the Experimental HIP Can Design Study," LON-12-90, Lockheed Idaho Technologies Company, August 10, 1990.

Nelson, L. O., 1993, "Progress Report on HIP Can Design Project," LON-5-93, Lockheed Idaho Technologies Company, November 23, 1993.

Nelson, L. O., Vinjamuri, K., 1995, "Results of Intermediate-Scale Hot Isostatic Can Experiments," INEL-95/0145, Lockheed Idaho Technologies Company, May 1995.

Nevins, P. W., 2005, "Calcine Bins Retrieval and Transfer System: Test Report," ESI Document No 2156-6-004, Rev. 0, AEA Technology Engineering Services Inc., January 2005.

Nevins P. W., 2006 "Calcine Bins Retrieval and Transfer System Final Report," ESI Document No 2223-4-002, Rev. 1, AEA Technology Engineering Services Inc. October 2006.

Nolte, W. L., et al., Technology Readiness Level Calculator, 2003.

Patterson, M. W., "D-Cell Calcine Sampling and Analysis," ICP/EXT-04-00423, August 2004.

PLN-3448, "Calcine Disposition Project Waste-Form and Technology Readiness Strategy Plan ", Rev. 1, September 2010.

PLN-3572, "CDP Process & Facility System Integration," Rev. 0, Draft, Idaho Cleanup Project, 2010.

Raman, S., 1993, "Hot Isostatically-Pressed Aluminosilicate Glass-Ceramic with Natural Crystalline Analogues for Immobilizing the Calcined High-Level Nuclear Waste at the Idaho Chemical Processing Plant," WINCO-1173, Westinghouse Idaho Nuclear Company, December 1993.

Raman, S., 1998, "Microstructures and Leach Rates of Glass-Ceramic Nuclear Waste Forms Developed by Partial Vitrification in a Hot Isostatic Press," *Journal of Material Sciences*, Vol 33, Issue 7, 1998.

RPT-221, 2006, "Comparison of Analytical and Modeled Zirconia Calcine Composition Data," June 2006.

RPT-650, "Calcine Disposition Project Treatment Options Study," September 2009.

SDD-267, "Retrieval Remote Design, Maintenance and Tools for the Calcine Disposition Project," Rev. 0, Draft, Idaho Cleanup Project, 2010.

Staiger, M. D., and M. C. Swenson," Calcined Waste Storage at the Idaho Nuclear Technology and Engineering Center," INEEL/EXT-98-00455, Rev. 3, Idaho Cleanup Project, Idaho National Laboratory, June 2007.

Staples, B. A., S. Pomiak, and E. L. Wade, 1979, "Properties of Radioactive Calcine Retrieved from the Second Calcined Solids Storage Facility at ICPP," ICP-1189, March 1979.

Staples, B.A., 1988, "Statistical Evaluation of Effects of Process Parameters on Properties of ICPP Ceramic Waste Forms," LW-REF-5076/BAS-12-88, September 30, 1988.

Stoller Corporation, "Material Erosion Testing for the Calcine Disposition Project," February 13, 2007.

TFR-401, 2010, "Technical and Functional Requirements for the Calcine Disposition Project," Rev. 4, Idaho Cleanup Project, September 16, 2010.

Tripp, J. and Maio, V., "Evaluation of the Use of Synroc to Solidify the Cesium and Strontium Separations Product from Advanced Aqueous Reprocessing of Spent Nuclear Fuel," INL/EXT-06-01377, March 2006.

Vinjamuri, K. and Raman, R. V., 1991, Progress Report for FY 1991: Glass-Ceramic Waste Form Development *for Immobilization of the ICPP High-Level Waste,* HLW-REF-5059, September 30, 1991.

Waste Acceptance System Requirements Document, DOE/RW-0351, Revision 5, May 31, 2007

Wilding, M. W. and Rhodes, D. W., "Characteristics of Radioactive Zirconia Calcine after Heating to High Temperature," UC-70, June 1971.

U.S. Department of Defense, 2003 Technology Readiness Assessment Deskbook, updated May 2005.

U.S. Department of Energy, Office of Environmental Management, Engineering and Technology, Technology Readiness Assessment (TRA) / Technology Maturation Plan (TMP) Process Guide, March 31, 2008.

U. S. Department of Energy, Technology Readiness Assessment Guide, DOE G 413.3-4, October 12, 2009.

This page intentionally left blank.

Appendix A
CTE Determination

Appendix A summarizes the critical technology systems employed in retrieval, treating, and packaging calcine. The following systems were evaluated:

Retrieval System

- Table A-1. Bin-Set Interface Subsystem
- Table A-2. Retrieval Nozzle Subsystem
- Table A-3. Slewing Subsystem
- Table A-4. Hose Management Subsystem
- Table A-5. Bin-Set Camera Subsystem
- Table A-6. Bin-Set Retrieval Control Room Subsystem

- Transport and Surge System
    - Table A-7. Surge Subsystem

Feed Canning

- Table A-8. HIP Can Fill and Seal
- Table A-9. HIP Can Subsystems
- Table A-10. HIP Feed Blender

Remote Maintenance

- Table A-11. Retrieval Remote Design, Maintenance and Tools
- Table A-12. Transport and Surge Remote Design, Maintenance and Tools
- Table A-13. Feed Canning Remote Design, Maintenance and Tools
- Table A-14. Off-Gas Remote Design, Maintenance and Tools

Treatment: Bakeout

- Table A-15. Bakeout Subsystem
- Table A-16. Inlet and Vent Port Welding Subsystem
- Table A-17. Filled HIP Can Lag Storage
- Table A-18. Bakeout Vacuum System

Treatment: HIP Can Containment

- Table A-19. HCC Storage
- Table A-20. HCC Loading
- Table A-21. HCC Unloading
- Table A-22. HCC Recovery

Table A-1. Retrieval Technology: Binset Interface Sub-System

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-2. Retrieval Technology: Retrieval Nozzle Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-3. Retrieval Technology: Slewing Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-4. Retrieval Technology: Hose Management Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-5. Retrieval Technology: Bin-Set Camera Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-6. Bin-Set Retrieval Control Room Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-7. Surge Subsystem: Transport and Surge System

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?	Y	

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-8. Feed Canning: HIP Can Fill and Sealing Station Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	Y	
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	Y	
• Do limitations in the understanding of the technology impact the safety of the design?	Y	
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?	Y	
• Have the potential hazards of the technology been assessed?	Y	
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-9. Feed Canning: HIP Can Subsystems

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	Y	
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	Y	
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?	Y	

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?	Y	
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-10. HIP Feed Blender Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-11. Retrieval Remote Design, Maintenance and Tools

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-12. Transport and Surge Remote Design, Maintenance and Tools

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-13. Feed Canning Remote Design, Maintenance and Tools

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-14. Off-Gas Remote Design, Maintenance and Tools

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-15. Treatment Technology: Bakeout Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	Y	
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-16. Treatment Technology: Inlet and Vent Port Welding Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-17. Treatment Technology: Filled HIP Can Lag Storage

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?		N
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-18. Treatment Technology: Bakeout Vacuum System

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?	Y	
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-19. Treatment Technology: HIP Can Containment Storage

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-20. Treatment Technology: HIP Can Containment Loading Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	Y	
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-21. Treatment Technology: HIP Can Containment Unloading Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	Y	
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-22. Treatment Technology: HIP Can Containment Recovery Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-23. Treatment Technology: Hot Isostatic Press

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	Y	
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	Y	
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?	Y	
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-24. Treatment Technology: Remote Design–Bakeout

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-25. Treatment Technology: Remote Design–HIP Can Containment

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-26. Treatment Technology: Remote Design–HIP Treatment

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		N
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

**Table A-27. Packaging Technology: Canister Loading–
Canister Analysis, Design and Testing**

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	Y	
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	Y	
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

**Table A-28. Packaging Technology: Canister Loading–
Canister Lid Handling Subsystem**

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	Y	

Table A-29. Packaging Technology: Canister Loading Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-30. Packaging Technology: Canister Welding and Sealing

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?		N
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?	Y	
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-31. Packaging Technology: Canister Loading Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-32.Packaging Technology: Remote Storage Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-33.Packaging Technology: Cask Loading Subsystem

Set 1 - Criteria	Yes	No
• Does the technology directly impact a functional requirement of the process or facility?	Y	
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		N
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		N
• Do limitations in the understanding of the technology impact the safety of the design?		
• Are there uncertainties in the definition of the end state requirements for this technology?		N

Set 2 - Criteria	Yes	No
• Is the technology new or novel?	Y	
• Is the technology modified?		N
• Have the potential hazards of the technology been assessed?		
• Has the technology been repackaged so a new relevant environment is realized?		N
• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		N

Table A-34. Ceramic Formulation

Set 1 - Criteria	Yes	No	Notes
• Does the technology directly impact a functional requirement of the process or facility?	X		The additives are required to make a final waste form that meets performance/acceptance criteria.
• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	X		The additives have been tested, but do not perform as required for Hg and Cd. The additives will require modification to mineralize the Hg and Cd. The additives have not been tested for the bounding calcine waste forms.
• Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	X		The waste loading could decrease increasing the disposition volume which increases the life-cycle costs.
• Do limitations in the understanding of the technology impact the safety of the design?	X		The additives are not hazardous. The quantity does not impact safety. However, the mixing could be hazardous.
• Are there uncertainties in the definition of the end state requirements for this technology?	X		The RCRA LDR UTS TCLP nonwastewater standards and WASRD are the performance/acceptance standards. However, the final disposition and its WAC are undefined.

Appendix B
Documents Cited in Calcine Disposition TRL Tables

1. 10 CFR 71, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations,* Office of the Federal Register, November 18, 2005.
2. 10 CFR 72.236(e), "Specific Requirements for Spent Fuel Storage Cask Approval and Fabrication," *Code of Federal Regulations*, Office of the Federal Register, December 2005.
3. AEA Report 2006, "Calcine Bins Retrieval and Transfer System, Final Report," Rev. 1, AEA Technology Engineering Services, Inc. October 2006.
4. Bateman, K. J., Rigg, R. H., Wiest, J.D. "Hot Isostatic Pressing of Ceramic Waste from Spent Nuclear Fuel," *Proceeding of ICONE10 10th International Conference on Nuclear Engineering*, April 2002.
5. BEA, 2008, "Process ANSTO Can #1133 in Hot Isostatic Press," PWS No. 2-4125, October 20, 2008.
6. Carter, M. L., et.al, "HIPed Tailored Ceramic Waste Forms for the Immobilization of Cs, Sr, and Tc," INL/CON-07-12875, September 2007.
7. Del Debbio, J. A., "Removal of Cesium from a High-Level Calcined Waste by High Temperature Volatilization," INEL-94/0028, November 1994.
8. Del Debbio, J. A., "The Use of Tracers for Measurement of Volatiles from High Temperature Calcination," JAD-02-96, June 10, 1996.
9. "Design Guides for Radioactive Material Handling Facilities & Equipment," 1998. American Nuclear Society (Compiled by D.R. Doman, ISBN: 0-89448-554-7)
10. DOE/RW-0351, *Waste Acceptance System Requirements Document*, Rev. 5, United States Department of Energy, Office of Civilian Radioactive Waste Management, May 2007.
11. DOE/SNF/REP-011, "Preliminary Design Specification for Department of Energy Standardized Spent Nuclear Fuel Canisters," Rev. 3, United States Department of Energy, August 17, 1999.
12. DOE/SNF/REP-091, "NSNFP Activities in Support of Repository Licensing for Disposal of DOE SNF," Rev. 0, United States Department of Energy, September 2004.
13. EDF-4096, "FY2003 Conceptual Design Effort for the High Level Waste Disposal Canister," Rev. 0, T.E. Rahl, August 29, 2003.
14. EDF-6185, 2005, "Investigation into Low Aluminum Results Found in Alumina Calcine from Binset 2", September 20, 2005.
15. EDF-6596, 2006, "High-Level Waste Calcine Canister Design Concept," Rev. 0, Idaho Cleanup Project, Idaho National Laboratory, March, 27, 2006.
16. EDF-7748, 2008, "Hazard and Operability (HAZOP) Review of the Calcine Disposition Project," Rev. 1, Idaho Cleanup Project, Idaho National Laboratory, September 22, 2008.

17. EDF-8182, 2008, “Calcine Disposition Project Retrieval Rate Evaluation,” Rev. 1, Idaho Cleanup Project, Idaho National Laboratory, May 1, 2008.
18. EDF-9659, 2010, “Inlet and Vent Port Welding for use in the Calcine Disposition Project (Draft),” Rev. Draft A, Idaho Cleanup Project.
19. EDF-9678, 2010, “Calcine Disposition Project Bakeout System Design (Draft),” Rev. Draft A, Idaho Cleanup Project.
20. EDF-9679, 2010, “Bakeout Vacuum System Design for use in the Calcine Disposition Project (Draft),” Rev. Draft A, Idaho Cleanup Project.
21. EDF-9681, 2010, “Bakeout System Failure Mode Analysis for use in the Calcine Disposition Project (Draft),” Rev. Draft A, Idaho Cleanup Project.
22. EDF-9687, 2010, “Process Flow Diagram Description for Calcine Disposition Project” (Draft),” Rev. 0, Draft, Idaho Cleanup Project.
23. EDF-9688, 2010, “Block Flow Diagram Description for Calcine Disposition Project” (Draft),” Rev. 0, Draft, Idaho Cleanup Project.
24. EDF-9694, 2010, “Synopsis of the Properties of Calcine for use in the Calcine Disposition Project (Draft),” Rev. Draft A, Idaho Cleanup Project.
25. EDF-9716, 2010, “Calcine Disposition Project Hot Isostatic Pressing Machine Failure Mode and Effects Analysis (Draft),” Rev. Draft A, Idaho Cleanup Project.
26. EDF-9718, 2010, “HIP Can Failure Modes and Effects (Draft),” Rev. Draft A, Idaho Cleanup Project.
27. Federal Register Volume 75, No. 1, Amended Record of Decision: Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement (DOE/EIS-0287), December 21, 2009, published January 4, 2010.
28. ICP, 2009, Calcine Disposition Project Calcine Treatment Options Summary, RPT-650, Rev. 0, Idaho Cleanup Project, Idaho National Laboratory, September 10, 2009. (Note: This document is Official Use Only and may not be publicly available.)
29. ICP/CON-04-00640, “Drop Testing Of DOE Spent Nuclear Fuel Canisters,” D.K. Morton, S. D. Snow, T. E. Rahl, R.K. Blandford, T.J. Hill, July 17, 2005.
30. ICP/EXT-05-00824, “Cost Comparison for the Transfer of Select Calcined Waste Canisters to the Monitored Geologic Repository at Yucca Mountain, Nevada,” M.B. Heiser, C.B. Millet, October 2005.
31. Idaho, 1995, *Settlement Agreement*, State of Idaho, Department of Energy, and Department of the Navy, to resolve all issues in Public Service Co. of Colorado v. Batt, No. CV-91-0035-S-EJL (D. Id.) and United States v. Batt, No. CV-91-0065-S-EJL (D. Id.), U.S. District Court of Idaho, dated October 16, 1995.
32. INL/ANSTO, 2009, “Assessment of HOT Isostatic Pressing (HIP) Project Annual Report 2009,” November 2009.
33. MCE-DPR-DP006-004, Rev.0, “Final Design Review Report, Canister Filling and Decontamination Cell System”, Mid Columbia Engineering, December 2009.
34. MCE-TR-DP006-002, Rev. 1, “Prototype Proof-of-Principle Test, Canister Filling and Decon Cell System Project”, Mid Columbia Engineering, March 2008.

35. Nelson, L. O., 1990, "Progress Report on the Experimental HIP Can Design Study," LON-12-90, August 10, 1990.

36. Nelson, L. O., 1993, "Progress Report on HIP Can Design Project," LON-5-93, November 23, 1993.

37. Nelson, L. O., Vinjamuri, K., "Results of Intermediate-Scale Hot Isostatic Can Experiments," INEL-95/0145, May 1995.

38. Nevinss, P. W., 2005, "Calcine Bins Retrieval and Transfer System: Test Report," ESI Document No 2156-6-004, Rev. 0, January 2005.

39. Nevinss P. W., 2006, "Calcine Bins Retrieval and Transfer System Final Report," ESI Document No 2223-4-002, Rev. 1, October 2006.

40. Patterson, M. W., 2004. "D-Cell Calcine Sampling and Analysis," ICP/EXT-04-00423, August 2004.

41. PLN-2477, 2009, "Calcine Disposition Project Risk Management Plan," Rev. 2, Idaho Cleanup Project, Idaho National Laboratory, September 24 2009.

42. PLN-2478, 2008, "Configuration Management Plan for the Calcine Disposition Project," Rev. 1, Idaho Cleanup Project, Idaho National Laboratory, July 22, 2008.

43. PLN-2478, 2010, "Configuration Management Plan for the Calcine Disposition Project," Rev. 2, Idaho Cleanup Project, Idaho National Laboratory, May 19, 2010.

44. PLN-3448, 2010, "Calcine Disposition Project Waste-Form Delisting Petition and Technology Readiness Strategy Plan (Draft)," Rev. Draft B, Idaho Cleanup Project, June 3, 2010.

45. PLN-3448, 2010, "Calcine Disposition Project Waste-Form Delisting Petition and Technology Readiness Strategy Plan," Rev. 0, Idaho Cleanup Project, June 29, 2010.

46. Raman, S., 1993, "Hot Isostatically-Pressed Aluminosilicate Glass-Ceramic with Natural Crystalline Analogues for Immobilizing the Calcined High-Level Nuclear Waste at the Idaho Chemical Processing Plant," WINCO-1173, December 1993.

47. Raman, S., 1998, "Microstructures and Leach Rates of Glass-Ceramic Nuclear Waste Forms Developed by Partial Vitrification in a Hot Isostatic Press," *Journal of Material Sciences*, 1998.

48. RPT-221, 2006, "Comparison of Analytical and Modeled Zirconia Calcine Composition Data," June 2006.

49. RPT-270, 2009, "Calcine Disposition Project – Conceptual Design Report," Rev. 2, Idaho Cleanup Project, Idaho National Laboratory, October 5, 2009

50. SDD-214, 2008, Calcine Disposition Project Calcine Retrieval, Transport, and Storage Systems – Conceptual Design," Rev. 1, Idaho Cleanup Project, Idaho National Laboratory, September 16, 2008.

51. SE008552, 2007, "Operator's Manual Quintus Hot Isostatic Press," Rev. 0, AVURE Technologies.

52. SO-07 Retrieval System PFD to be completed 10/4/2010

53. SO-09 Feed Canning Process Flow Diagram

54. SOW-8479, 2010, "Statement of Work for Calcine Disposition Project Waste Hazen Research Surrogate Request for Proposal," Rev 0, 16 March 2010.

55. Staiger, M. D., and M. C. Swenson, 2007, *Calcined Waste Storage at the Idaho Nuclear Technology and Engineering Center*, INEEL/EXT-98-00455, Rev. 3, Idaho Cleanup Project, Idaho National Laboratory, June 2007.

56. Staples, B.A., 1988, "Statistical Evaluation of Effects of Process Parameters on Properties of ICPP Ceramic Waste Forms," September 30, 1988.

57. Staples, B. A., S. Pomiak, and E. L. Wade, 1979, "Properties of Radioactive Calcine Retrieved from the Second Calcined Solids Storage Facility at ICPP," ICP-1189, March 1979.

58. Stoller Corporation, 2006, "Material Erosion Testing for the Calcine Disposition Project," February 13, 2007.

59. Tripp, J., Maio, V., 2006, "Evaluation of the Use of Synroc to Solidify the Cesium and Strontium Separations Product from Advanced Aqueous Reprocessing of Spent Nuclear Fuel," INL/EXT-06-01377, March 2006.

60. U.S. NRC, Spent Fuel Storage and Transportation Division, Interim Staff Guidance – 15 (ISG-15), "Materials Evaluation," January, 2001.10 CFR 72.236(e)

61. U.S. NRC, Spent Fuel Storage and Transportation Division, Interim Staff Guidance – 18 (ISG-18), "The Design and Testing of Lid Welds on Austenitic Stainless Steel Canisters as the Confinement Boundary for Spent Fuel Storage," October, 2008.

62. Vinjamuri, K., Raman, R. V., "Progress Report for FY91: Glass-Ceramic Waste Form Development for Immobilization of the ICPP High Level Waste," September 30, 1991.

63. Wilding, M. W., Rhodes, D. W., "Characteristics of Radioactive Zirconia Calcine after Heating to High Temperature," UC-70, June 1971.

64. WSRC-MS-2002-00122, "GTA Welding Research and Development for Plutonium Containment," United States Department of Energy, February 21, 2002.

65. Mixer Manufacturer Operation Manual

References Documents Available After October 4, 2010

1. CDP Process flow Diagrams

2. DDN-015, 2010, "Bakeout Data Needs for Calcine Disposition Project" (Draft)," Rev. 0, Draft, Idaho Cleanup Project.

3. DDN-016, 2010, "Inlet and Vent Port Welder Data Needs for Calcine Disposition Project" (Draft)," Rev. 0, Draft, Idaho Cleanup Project.

4. EDF-9578, HIP Can Trade Studies Completion 10/2/2010.

5. EDF-9633, "HIP Can Fill and Sealing Station", Rev. Draft A, Idaho Cleanup Project.

6. EDF-9638 "Retrieval System FMEA"; preliminary hazard evaluation

7. EDF-9650, “CDP Canister Analysis, Design, and Testing (Draft),” Rev. Draft A, Idaho Cleanup Project.
8. EDF-9652, “CDP Canister Welding, Sealing and Leak Testing,” Rev. Draft A, Idaho Cleanup Project.
9. EDF-9653, HCC Trade Study
10. EDF-9654, “CDP Packaging Methodology (Draft),” Rev. Draft A, Idaho Cleanup Project.
11. EDF-9658, “CDP Trade Study to Compare 10 ft. Versus 15 ft. Canisters (Draft),” Rev. 0, Draft A, Idaho Cleanup Project.
12. EDF-9689, “Retrieval Remote Design, Maintenance and Tools for the Calcine Disposition Project,” Rev. 0, Draft, Idaho Cleanup Project.
13. EDF-9691, “Retrieval Strategy”
14. EDF-9697, “Calcine Metering”
15. EDF-9698, “Transport and Surge System FMEA”; preliminary hazard evaluation
16. EDF-9710, “Calcine Disposition Project Hot Isostatic Pressing Machine Selection Trade Study (Draft),” Rev. Draft A, Idaho Cleanup Project.
17. EDF-9711, 2010, “Calcine Disposition Project Hot Isostatic Pressing Machine Handling Study (Draft),” Rev. Draft A, Idaho Cleanup Project.
18. EDF-9715, “Hot Isostatic Pressing Machine Configuration”
19. EDF-9721, 2010, “Failure Mode and Effects Analysis for Packaging for the Calcine Disposition Project (Draft),” Rev. Draft A, Idaho Cleanup Project.
20. EDF-9757, 2010, “Calcine Disposition Project HIP Can Confinement Failure Modes and Effects Analysis (Draft),” Rev. A, Idaho Cleanup Project.
21. EDF-9758, 2010, “Calcine Disposition Project HIP Can Confinement Loading Station (Draft),” Rev. A, Idaho Cleanup Project.
22. EDF-9759, 2010, “Calcine Disposition Project HIP Can Confinement Unloading Station (Draft),” Rev. A, Idaho Cleanup Project.
23. EDF-9760, 2010, “Calcine Disposition Project HIP Can Confinement Recovery Station (Draft),” Rev. A, Idaho Cleanup Project.
24. EDF-9761, 2012, “Preliminary CDP Process System RAMI Analysis,” Rev. A, Draft, Idaho Cleanup Project.
25. PLN-3572, 2010, “CDP Process & Facility System Integration”, Rev. 0, Draft, Idaho Cleanup Project.
26. RPT-366, 2010,”Conceptual Design Safety Report of the Calcine Disposition Project (Draft),” Rev. A, Idaho Cleanup Project.

27. SDD-267, 2010, “Retrieval Remote Design, Maintenance and Tools for the Calcine Disposition Project (P.1.10.02.02) (Draft),” Rev. 0, Draft, Idaho Cleanup Project.

28. SDD-268, 2010, “Bakeout System for the Calcine Disposition Project (P.1.10.02.02.6.01) (Draft),” Rev. 0, Draft, Idaho Cleanup Project.

29. SDD-269, 2010, “HIP Can Confinement Loading and Unloading System for the Calcine Disposition Project (P.1.10.02.02.6.02) (Draft),” Rev. 0, Draft, Idaho Cleanup Project.

30. SDD-270, 2010, “Hot Isostatic Pressing System for the Calcine Disposition Project (P.1.10.02.02.6.03) (Draft),” Rev. 0, Draft, Idaho Cleanup Project.

31. SDD-290, 2010, “Hot Isostatic Pressing Can Fill Station for the Calcine Disposition Project” (P.1.10.02.02.5.04.07) (Draft),” Rev. 0, Draft, Idaho Cleanup Project.

32. SDD-291, 2010, “Retrieval System for the Calcine Disposition Project” (P.1.10.02.02.5.02) (Draft),” Rev. 0, Draft, Idaho Cleanup Project.

33. SDD-292, 2010, “Hot Isostatic Pressing Can Subsystem for the Calcine Disposition Project (P.1.10.02.02.5.04.05) (Draft),” Rev. 0, Draft, Idaho Cleanup Project.

34. SPC-1272, 2010, “Preliminary Design Specification for the Calcine Disposition Project,” Rev. 0, Draft, Idaho Cleanup Project.

35. TFR-401, 2010, “Technical and Functional Requirements for the Calcine Disposition Project (P.1.10.02.02) (Draft),” Rev. 3, Draft, Idaho Cleanup Project.

36. TFR-401, 2008, “Technical and Functional Requirements for the Calcine Disposition Project – Conceptual Design,” Rev. 2, Idaho Cleanup Project, Idaho National Laboratory, September 30, 2008.

37. WASRD

References Documents Available After FY 2012

1. EDF-9657, 2012, “Canister Handling End Effector,” Rev. Draft A, Idaho Cleanup Project.

2. EDF-9761, 2012, “Preliminary Calcine Disposition Project Process System RAMI Analysis,” Rev. Draft A, Idaho Cleanup Project.

3. ICP, 2009, *Conceptual Design Report for the Calcine Disposition Project*,” RPT-270, Rev. 2, Idaho Cleanup Project, Idaho National Laboratory, October 5, 2009. (Note: This document is Official Use Only and may not be publicly available.

4. CDP Technology Development and Mockup testing planned FY-2011-2012

5. Calcine Disposition Project Waste-form and Technology Readiness Strategy Plan (DRAFT), Plan 3448, Rev. 0 Completion Date: FY 2012

References Documents Available After FY 2014

1. DOE-ID, 2006, *Draft Acquisition Strategy for the Calcine Disposition Project*, DOE/ID-XXX, 2006. (To be prepared)

2. EDF-9762, 2014, “Final Calcine Disposition Project Process System RAMI Analysis,” Rev. Draft A, Idaho Cleanup Project.

3. EDF-9753, 2010, “Calcine Disposition Project HIP Can Confinement Trade Study (Draft)”, Rev. A, Idaho Cleanup Project.

References (in progress)

EDF-7747, 2010, “HAZOP Analysis.”

PLN-2056, 2010, “Systems Engineering Management Plan Calcine Disposition Project.”

PLN-2477, 2008, “Calcine Disposition Project Risk Management Plan,” Rev. 2, Calcine Disposition Project.

RPT-270, 2010, “Calcine Disposition Project Conceptual Design Report.”

The page intentionally left blank.

Appendix C

Technology Readiness Level Results Summary for Calcine Project Critical Technology Elements

Due to its length and file size, Appendix C is not included in volume one of this report.

Appendix C is available on CD (enclosed) as volume two.

This page intentionally left blank.

Appendix D: Review Plan for the Calcine Disposition Project Technology Readiness Assessment

Idaho National Laboratory

Review Plan for the

Calcine Disposition Project

Technology Readiness Assessment

July 12-16, 2010

CDP MISSION

Retrieve, Treat, Package, and Prepare to Ship High-Level Waste Calcine to Interim Storage or Disposal

Table of Contents

1. Introduction

The U.S Department of Energy (DOE), Idaho Operations Office (ID) plans to construct a facility at Idaho National Laboratory to retrieve, treat, package, and prepare 4400 cubic meters of calcine for interim storage or disposition. The technology that will be used to treat the HLW calcine is hot isostatic pressing (HIP). While HIP is a commonly used industrial process, the CDP is the first time it will be used for treating HLW. The CDP is currently in the conceptual design phase and cost estimates for design and construction range from $600 million to $900 million.

The Hot Isostatic Pressing technology was recommended for the treatment of HLW calcine following laboratory tests and completion of a value engineering session conducted by the Idaho Operations Office and was selected for the treatment of HLW calcine with the issuance of an Amended Record of Decision on December 23, 2009.

This Technology Readiness Assessment (TRA) will be conducted according to DOE G 413.3-4, U. S. Department of Energy Technology Readiness Assessment Guide; 10/12/09 using Critical Technology Element (CTE) questions tailored to waste processing (See Appendix A). The TRA will document the technical maturity of all critical technologies employed by the CDP including pneumatic retrieval of the granular HLW calcine, filling and canning processes, HIP treatment, packaging, and preparation of canisters for shipment to interim storage or disposition by December 2035 as required by the 1995 Idaho Settlement Agreement.

The TRA will assess the level of maturity, i.e., Technology Readiness Level (TRL) 1 thru 9, as described in Table 1. The overall score for the project will be the lowest score identified by the Team for any of the CTEs evaluated. The recommended TRL project score for CD-1 is level 4. The range of testing requirements for meeting each TRL are identified in Table 2. Should a score for any of the CTEs evaluated by the Team not meet level 4 during the July assessment, the Team will conduct a further assessment prior to the final CD-1 approval process to determine whether the project has achieved the recommended level 4.

Table 1. Technology Readiness Levels used in this Assessment

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot scale, similar (prototypical) system validation in a relevant environment.	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

Table 2. Relationship of Testing Requirements to the TRL

TRL	**Scale of Testing[1]**	**Fidelity[2]**	**Environment[3]**
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot Scale < Full Scale (Typical)
   Lab Scale < 1/10 Full Scale (Typical)
2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)
3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

<u>Overview of the TRA Process</u>

2.1 Critical Technology Element Selection

Critical Technology Element (CTE) selection will be done by the TRA Team based on the recommendations of the Federal Project Director (FPD).

2.2 Assessing the Technology Readiness Level for each CTE

The TRA will consist of team members participating in the CTE determination, reviewing testing reports, and preparing a report section for each CTE. Applicable test reports for each technology are to be provided to each team member by the FPD and the CDP. The team members will review the reports and determine their relationship to the TRL questions. The questions related to each TRL are provided in Attachment A.
The answers to the TRL questions provided by the FDP and the CDP will be the starting point for Team deliberations. The Team will conduct its own due diligence of the answers provided and incorporate the results recorded for further validation and incorporation in the TRA report.

Based on responses to questions and supporting information provided by the FDP and CDP, the assessment Team will determine the overall project TRL and document the determination in the assessment report. The assessment report outline is provided in Attachment B.

Team Member Assignments

Tony Kluk, EM-43, Lead
Hoyt Johnson, EM-31
Steven Ross, EM-23
Herb Sutter, Consultant to EM-1
Phil McGinnis, ORNL
John Vienna, PNNL
Mike Rinker, PNNL

TRA Assessment Schedule

Task Number	Task Description	Duration	Planned Start	Planned Finish
1	Relevant documentation identified, collected, and made available TRA Team.	1 week	July 5	July 12
2	Identify CTEs	1 day	July 12	
3	Assign TRA Team member lead responsibilities for CTEs	1 hr	July 12	
4	Conduct TRA on CTEs	2 days	July 13	July 14
5	Draft report input for assessment of each CTE	1 day	July 15	
6	Hold closeout briefing	1 hr	July 15/16	
7	Draft TRA Report Prepared	7 days	July 16	July 23
8	ID factual accuracy check	4 days	July 23	July 27
9	TRA report finalized	5 days	July 28	Aug 4
10	Brief EM-1on TRA results*	2 hrs	Aug 6	
11	Follow-up Evaluation (if needed)	2 days	Oct 27	Oct 28
12	Revise or amend TRA Report	10 days	Oct 29	Nov 10
12	Brief EM-1*	1 hr	Nov 15	

*Assumes Report finalization and EM-1 briefing prep occur concurrently.

Appendix A

Technology Readiness Level Calculator

Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix A presents the questions used for assessing the technology maturity of U.S. Department of Energy (DOE) Office of Environmental Management (EM) waste processing and treatment technologies. The TRL Calculator is used to assess the TRL critical technology elements (CTE). The assessment begins by using the top-level questions listed in Figure A.1 to determine the anticipated TRL that will result from the detailed questions. The anticipated TRL is determined from the question with the first “yes” answer from the list in Table A.1. Evaluation of the detailed questions is usually started one level below the anticipated TRL. If it is determined from the detailed questions that the technology has not attained the maturity of the level being evaluated, the next level down will be evaluated in turn until the maturity level can be determined.

The Calculator provides a standardized, repeatable process for evaluating the maturity of the hardware or software technology under development. The questions in Appendix A.1 aid in determining whether the technology element is critical. Appendix A.2, Tables 2 and three assess the TRL for the entire waste processing system. In Appendix A.3, Tables 5 to 9 aid in identifying the readiness level of the critical elements being evaluated. The first column identifies whether it is technical (T), programmatic (P), or manufacturing/ quality requirement (M). A technology is determined to have reached a given TRL if column 3 is judged to be 100% complete for all criteria, i.e., the Team determines that information provided by the FDP support a “yes” response for all criteria).

A.1. CTE Questions

Table 1 CTE Questions			
Technology Element:			
Yes	**No**	**Set 1**	**Notes**
		• Does the technology directly impact a functional requirement of the process or facility?	
		• Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?	
		• Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns?	
		• Are there uncertainties in the definition of the end state requirements for this technology?	
Yes	**No**	**Set 2 - Criteria**	
		• Is the technology new or novel?	
		• Is the technology modified?	
		• Has the technology been repackaged so a new relevant environment is realized?	
		• Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?	

A.2. Process Questions (TRL 4 and 6) For Waste Processing Systems

Table 2
TRL 4 Questions for the Waste Processing System (WPS)

CTE:

	Y/ N	**Questions**	**Basis and Supporting Documents**
Processing		1. Is the WPS, as it appears in the conceptual design, intended to accept the full range of wastes to be processed?	
		2. Is the WPS capable of meeting targets for startup and completion of waste processing?	
		3. Have the target operational and performance requirements for the WPS been determined?	
		4. Have all TEs that require an increase or change in capability been identified as CTEs?	
		5. Has WPS process flow been modeled?	
		6. Have WPS single point failures been identified?	
		7. Can TEs be sized to meet WPS throughput requirements?	
		8. Have all new or novel operating modes of the WPS been modeled and/or tested at lab scale?	
		9. Have all recycle streams been identified and included in the conceptual design process flow models?	
Disposal		10. Will the WPS produce a product or products that can be dispositioned?	
		11. Are all WPS waste streams identified and characterized to the extent necessary for conceptual design?	
		12. Can all WPS waste streams, including, process liquids, off gases, and solids identified in the conceptual design be treated and disposed	
		13. Will the waste streams meet the waste acceptance criteria of the proposed disposition facilities/sites?	
		14. Have the disposition facilities/site been contacted to ensure that the waste forms are compatible with facility/site **<u>operations, procedures, and regulations</u>**?	
Interfaces		15. New or novel interfaces among WPS systems have been identified as CTEs	
		16. Are all WPS technology interfaces and dependencies determined and understood at the conceptual level?	
		17. Can all WPS components be successfully mated?	
		18. Are the processing modes of the TEs (e.g., batch, continuous) compatible?	

Table 3 TRL 6 Questions for the Waste Processing System (WPS)			
CTE:			
	Y/ N	**Questions**	**Basis and Supporting Documents**
Processing		1. Have all TEs that require an increase or change in capability been identified as CTEs?	
		2. Can the WPS accept the full range of wastes to be processed?	
		3. Is the WPS capable of meeting targets for startup and completion of waste processing?	
		4. Have the target operational and performance requirements for the WPS been determined?	
		5. Have major sections of the WPS and their interfaces been modeled and/or piloted?	
		6. Has WPS data collection and data flow been modeled/tested?	
		7. Has WPS process flow and process control been modeled/tested?	
		8. Have WPS single point failures been identified?	
		9. Can TEs be sized to meet WPS throughput requirements?	
		10. Have all new or novel operating modes of the WPS been modeled and/or piloted?	
		11. Are all recycle streams fully characterized?	
		12. Are all WPS recycle streams included in process models?	
Disposal		1. Will the WPS produce a product or products that can be dispositioned?	
		2. Are all WPS waste streams identified?	
		3. Have the waste streams produced by the WPS been fully characterized?	
		4. Has a disposition path been determined for each waste stream, including, process liquids, off gases, and solids?	
		5. Will the waste forms meet the waste acceptance criteria of the proposed disposition facilities?	
		6. Have the disposition facilities/sites been contacted to ensure that the waste streams are compatible with disposal facility/site **operations, procedures, and regulations**?	
Interfaces		7. Are all WPS technology interfaces and dependencies determined and understood?	
		8. New or novel interfaces among WPS systems have been identified as CTEs	
		9. Have all WPS TE interfaces been modeled or piloted?	
		10. Are the processing modes of the TEs (e.g., batch, continuous) compatible?	

A.3: Criteria for Determining the Level of Technology Readiness

Table 4
TRL 1 Criteria for Critical Technical Element

CTE:

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. "Back of envelope" understanding of the environment exists	
T		2. Physical laws and assumptions used in new technologies are defined	
T		3. Paper studies confirm basic principles	
P		4. Initial scientific observations reported in journals/conference proceedings/ technical reports.	
T		5. Basic scientific principles observed and understood.	
P		6. Know who cares about the technology, e.g., sponsor, funding source, etc.	
T		7. Research hypothesis formulated	
T		8. Basic characterization data exists	
P		9. Know who would perform research and where it would be done	

Table 5
TRL 2 Criteria for Critical Technical Elements

CTE:

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P		1. Customer identified and has expressed interest, i.e., know what program the technology would support	
T		2. Potential system or components have been identified	
T		3. Paper studies show that application is feasible	
T		4. An apparent theoretical or empirical design solution identified	
T		5. Basic elements of technology have been identified	
T		6. Components of technology have been partially characterized	
T		7. Performance predictions made for each element	
T		8. Modeling & Simulation used to verify physical principles	
P		9. System architecture defined in terms of major functions to be performed	
T		10. Rigorous analytical studies confirm basic principles	
P		11. Analytical studies reported in scientific journals/conference proceedings/technical reports.	
T		12. Individual parts of the technology work	
T		13. Know what output devices are available	
P		14. Preliminary strategy to obtain TRL Level 6 developed (e.g. scope, schedule, cost)	
P		15. Know capabilities and limitations of researchers and research facilities	
T		16. The scope and scale of the waste problem has been determined	
T		17. Know what experiments are required (research approach)	
P		18. Qualitative idea of risk areas (cost, schedule, performance)	

Table 6 TRL 3 Criteria for Critical Technical Elements			
CTE:			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
P		1. Some key process and safety requirements are identified. Key process parameters/variables and associated hazards have begun to be identified.	
T		2. Predictions of elements of technology capability validated by analytical studies	
P		3. The basic science has been validated at the laboratory scale	
T		4. Science known to extent that mathematical and/or computer models and simulations are possible	
P		5. Preliminary system performance characteristics and measures have been identified and estimated	
T		6. Predictions of elements of technology capability validated by Modeling and Simulation (M&S)	
T		7. Basic laboratory research equipment used to verify physical principles	
T		8. Predictions of elements of technology capability validated by laboratory experiments	
P		9. Customer representative identified to work with development team	
P		10. Customer participates in requirements generation	
P		11. Requirements tracking system defined to manage requirements creep	
M		12. Design techniques have been identified/developed	
T		13. Paper studies indicate that system components ought to work together	
P		14. Customer identifies technology need date.	
T		15. Performance metrics for the system are established (What must it do)	
P		16. Scaling studies have been started	
M		17. Current manufacturability concepts assessed	
M		18. Sources of key components for laboratory testing identified	
T		19. Scientific feasibility fully demonstrated	
T		20. Analysis of present state of the art shows that technology fills a need	
P		21. Risk areas identified in general terms	

Table 6 TRL 3 Criteria for Critical Technical Elements			
CTE:			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
P		22. Risk mitigation strategies identified	
P		23. Rudimentary best value analysis performed for operations	
T		24. Key physical and chemical properties have been characterized for a number of waste samples	
T		25. A simulant has been developed that approximates key waste properties	
T		26. Laboratory scale tests on a simulant have been completed	
T		27. Specific waste(s) and waste site(s) has (have) been defined	
T		28. The individual system components have been tested at the laboratory scale	

Table 7
TRL 4 Questions for Critical Technical Elements

CTE:

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. Key process variables/parameters been fully identified and preliminary hazard evaluations have been performed.	
M		2. Laboratory components tested are surrogates for system components	
T		3. Individual components tested in laboratory/ or by supplier	
T		4. Subsystems composed of multiple components tested at lab scale using simulants	
T		5. Modeling & Simulation used to simulate some components and interfaces between components	
P		6. Overall system requirements for end user's application are known and documented	
P		7. System performance metrics measuring requirements have been established	
P		8. Laboratory testing requirements derived from system requirements are established	
T		9. Laboratory experiments with available components show that they work together	
T		10. Analysis completed to establish component compatibility (Do components work together)	
P		11. Science and Technology Demonstration exit criteria established (S&T targets understood, documented, and agreed to by sponsor)	
T		12. Technology demonstrates basic functionality in simulated environment	
M		13. Scalable technology prototypes have been produced (Can components be made bigger than lab scale)	
P		14. Draft conceptual designs have been documented (system description, process flow diagrams, general arrangement drawings, and material balance)	
M		15. Equipment scale-up relationships are understood/accounted for in technology development program	
T		16. Controlled laboratory environment used in testing	
P		17. Initial cost drivers identified	
T		18. Integration studies have been started	
P		19. Formal risk management program initiated	
M		20. Key manufacturing processes for equipment systems identified	

Table 7
TRL 4 Questions for Critical Technical Elements

CTE:

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P		21. Scaling documents and designs of technology have been completed	
P/T		22. Functional process description developed. (Systems/subsystems identified)	
T		23. Low fidelity technology “system” integration and engineering completed in a lab environment	
T		24. Key physical and chemical properties have been characterized for a range of wastes	
T		25. A limited number of simulants have been developed that approximate the range of waste properties	
T		26. Laboratory-scale tests on a limited range of simulants and real waste have been completed	
T		27. Process/parameter limits and safety control strategies are being explored	
T		28. Test plan documents for prototypical lab-scale tests completed	
P		29. Technology availability dates established	

Table 8 TRL 5 Questions for Critical Technical Elements			
CTE:			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		1. The relationships between major system and sub-system parameters are understood on a laboratory scale.	
T		2. Plant size components available for testing	
T		3. System interface requirements known (How would system be integrated into the plant?)	
P		4. Preliminary design engineering has begun	
T		5. Requirements for technology verification established	
T		6. Interfaces between components/subsystems in testing are realistic (bench top with realistic interfaces)	
M		7. Prototypes of equipment system components have been created (know how to make equipment)	
M		8. Manufacturing techniques have been defined to the point where largest problems defined	
M		9. Availability and reliability (RAMI) target levels identified	
T		10. Laboratory environment for testing modified to approximate operational environment	
T		11. Component integration issues and requirements identified	
P		12. Detailed 3D design drawings and P&IDs have been completed to support specification of a prototypic engineering-scale testing system	
T		13. Requirements definition with performance thresholds and objectives established for final plant design	
P		14. Preliminary technology feasibility engineering report completed	
T		15. Integration of modules/functions demonstrated in a laboratory/bench-scale environment	
T		16. Formal control of all components to be used in final prototypical test system	
P		17. Configuration management plan in place	
T		18. The range of all relevant physical and chemical properties has been determined (to the extent possible)	
T		19. Simulants have been developed that cover the full range of waste properties	

Table 8 TRL 5 Questions for Critical Technical Elements			
CTE:			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		20. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes	
T		21. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	
T		22. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed - results validate design	
T		23. Test results for simulants and real waste are consistent	
T		24. Laboratory to engineering scale scale-up issues are understood and resolved	
T		25. Limits for all process variables/parameters and safety controls are being refined	
P		26. Test plan documents for prototypical engineering-scale tests completed	
P		27. Risk management plan documented	

Table 9 TRL 6 Questions for Critical Technical Elements			
CTE:			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documents**
T		1. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	
M/P		2. Availability and reliability (RAMI) levels established	
P		3. Preliminary design drawings for final plant system are complete	
T		4. Operating environment for final system known	
P		5. Collection of actual maintainability, reliability, and supportability data has been started	
P		6. Performance Baseline (including total project cost, schedule, and scope) has been completed	
T		7. Operating limits for components determined (from design, safety and environmental compliance)	
P		8. Operational requirements document available	
P		9. Off-normal operating responses determined for engineering scale system	
T		10. System technical interfaces defined	
T		11. Component integration demonstrated at an engineering scale	
P		12. Analysis of project timing ensures technology will be available when required	
P		13. Have established an interface control process	
P		14. Acquisition program milestones established for start of final design (CD-2)	
M		15. Critical manufacturing processes prototyped	
M		16. Most pre-production hardware is available to support fabrication of the system	
T		17. Engineering feasibility fully demonstrated	
M		18. Materials, process, design, and integration methods have been employed (e.g. can design be produced?)	
P		19. Technology ”system” design specification complete and ready for detailed design	
T		20. Engineering-scale system is high-fidelity functional prototype of operational system	
P		21. Formal configuration management program defined to control change process	

Table 9 TRL 6 Questions for Critical Technical Elements			
CTE:			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documents**
P		22. Final Technical Report on Technology completed	
M		23. Process and tooling are mature to support fabrication of components/system	
T		24. Engineering-scale tests on the full range of simulants using a prototypical system have been completed - results validate design	
T		25. Engineering to full-scale scale-up issues are understood and resolved	
T		26. Laboratory and engineering-scale experiments are consistent	
T		27. Limits for all process variables/parameters and safety controls are defined	
M		28. Production demonstrations are complete (at least one time)	

Appendix B

Draft TRA Report Outline

(To be finalized after identification of CTEs. Section 3.0 will be modified to reflect agreed upon CTE's.)

Technology Readiness Level Assessment for the Calcine Disposition Project

Table of Contents

Appendix C

Calcine Disposition Project

TRA Team Biographies

Dr. Anthony Kluk. Dr. Kluk currently serves as the high-level waste (HLW) team lead in the Office of Disposal Operations where he is responsible for developing and implementing acceptance requirements for HLW, conducting quality assurance assessments, reviewing compliance documentation, and other oversight activities. He also provided support for developing the Yucca Mountain License Application with respect to DOE HLW and Spent Nuclear Fuel. He is also the Office of Disposal Operations principal liaison for Idaho waste management projects including the Advanced Mixed Waste Treatment Facility, the Accelerated Retrieval Project, and the Sodium Bearing Waste Treatment Project. He has many years experience in nuclear environmental management programs, having served in positions responsible for low-level waste activities, nuclear safety oversight, environmental restoration of contaminated waste sites, decontamination and decommissioning of nuclear facilities, and evaluation of radiation safety programs for workers and the public. Dr. Kluk holds a B.S. in physics and math from St. John's University, Collegeville, Minnesota, and an M.A. and Ph.D. in medium energy nuclear physics from Vanderbilt University, Nashville, Tennessee.
Contact: (301)903-3744 anthony.kluk@em.doe.gov
19901 Germantown Dr, Germantown, MD 20874

Steven L. Ross, PhD. Dr. Ross holds a B.Sc. Chemistry, Central Michigan University, a Ph.D. Biochemistry, Baylor College of Medicine, and has done Post Doctoral Research in Biochemistry, Case Western Reserve University. He is employed by the U.S. Department of Energy, Office of Environmental Management (2008) and has nearly 30 years experience in the fields of high level and low level radioactive waste management, process control, equipment design and fabrication, prototyping, process chemistry and analytical chemistry. For seven years prior to coming to DOE he provided technical support to the Office of Civilian Radioactive Waste Management (RW). This work included development of the Waste Acceptance System Requirements Document, the Integrated Interface Control Document, an analysis of the Accelerator Transmutation of Waste proposal, and analyzed the impacts of a variety of U.S. Nuclear Regulatory Commission regulations on the management of radioactive waste including 10 CFR Parts 60, 61, 63, 72, 73, 74, 835, and 961. Prior to consulting to DOE-RW Dr. Ross was the Manager of the Solidification Laboratory for Stock Equipment Company that manufacturer a cement-based system for the solidification of aqueous low-level radioactive waste (1979–1980). Dr. Ross wrote the Process Control Plan for seven different power plants. He also led the development of a solidification process using a water extendable carbohydrate polymer. Subsequent to Stock Equipment Company, Dr. Ross held several positions within ABB Automation, Inc. (1980 – 1999). These positions include Applications Engineer, Product Line Manager, and Project Manager. In these positions, he developed several process control algorithms for both small and large scale applications, using classical PID and ladder logic controllers as well as state of the art algorithms based on neural networks. Dr. Ross has authored nine journal articles and six patents.
Contact: (202) 586-0973 steven.ross@em.doe.gov
1000 Independence Ave, S.W., Washington, DC, 20585

Dr. Herbert Sutter. Dr. Sutter holds an A.B. in Chemistry from Hamilton College, a Ph.D. Physical Chemistry from Brown University and a Post Doctoral Theoretical Chemistry from Cambridge University, UK. He has more than 30 years experience in the fields of separations science, high and low level radioactive waste treatment, waste water treatment, vitrification, and analytical chemistry. For the past nineteen years he has provided technical and programmatic support to the DOE Office of Environmental Management (EM). Dr. Sutter has provided technical assistance to the DOE programs at Hanford, Savannah River, and other sites in: (1) separation technologies; (2) technology development; (3) high level waste disposal; (4) nuclear waste characterization; (5) vitrification; and (6) analytical laboratory management. From 2007 through the present Dr, Sutter has supported the EM Office of Project Recovery working on technology aspects of Hanford's Waste Treatment Plant. During that time he helped develop the EM Technology Readiness Assessment/Technology Maturation Plan (TMP) Process Guide (March 2008). From 2005 to 2006, Dr. Sutter assisted EM in the development of a long-term, complex-wide Project Plan for Technology Development and Demonstration. From 2002-2004, he was a senior scientist for Kenneth T. Lang Associates, Inc. and provided support to EM in several areas including the evaluation of HLW vitrification technologies at Hanford and pretreatment and separation technologies at Savannah River. He has also been a consultant to private industry on separation technologies. From 1990-2002, as a scientist for Science Applications International Corporation, he supported EM in the areas of nuclear waste treatment and characterization and analytical chemistry. From 1982-1990, Dr. Sutter was Vice President and Chief Scientist at Duratek Corporation and responsible for technical direction of all research and development and commercialization programs in ion exchange, filtration and separation techniques. Relevant experience includes: waste water treatment, bench and pilot testing, and waste treatment studies. Dr. Sutter has authored or co-authored over 30 journal articles and technical reports and is a member of the American Chemical Society and the American Nuclear Society.

Contact: (301) 802-7677 hsutter64@aol.com
910 Laurel Green Drive, NE, North Canton, OH 44720

Dr. Phil McGinnis. Dr. McGinnis is a staff member with 33 years experience at Oak Ridge National Laboratory and holds degrees in Chemical Engineering. Dr. McGinnis was the Tanks Focus Area Technical Integration Manager for the Tanks Focus Area from 1992–2002. He is the programmatic lead for EM Technology Activities for Oak Ridge, and serves as the representative from ORNL to the National Laboratory Advisory Group that works closely with DOE-EM. Dr. McGinnis has been involved in providing technology for all of the EM activities over the past 15 years. He has worked closely with the treatment of Fernald retrieval and processing and with the treatment of U233 in Oak Ridge. He is one of the authors of the recent DOE EM Technical Evaluation for Transforming the Tank Waste System- Tank Waste System Integrated Project Team Final Report. Over the time frame of support to TFA, he worked closely with the staff at INL and other providers to address the technical needs at INL, including treatment of the Calcine and the Sodium Bearing Wastes. Dr. McGinnis has served as a reviewer on expert panels for DOE-EM and is participating in the TRR for this project, for the U233 project at Oak Ridge, and is in discussion with the Office of River Protection Washington River Protection Solutions prime contractor to provide assistance for planning for Technology Readiness documentation.

Contact: 865-548-4692 mcginniscp@ornl.gov
P.O. Box 2008, Oak Ridge, TN 37831

John D. Vienna, Ph.D. Dr. Vienna began his career as a research associate in the Materials Science Division at Argonne National Laboratory. In 1993, he joined the Glass Development Laboratory at Pacific Northwest (National) Laboratory (PNNL) as a Research Scientist. He's been a Senior Research Scientist in PNNL's Materials Science, Environmental Molecular Sciences, and Process Technology Departments and currently serves as Chief Scientist in the Glass Development Laboratory. He conducts research in waste processing and waste form testing. He served as the principal investigator in PNNL's waste glass development projects for the Idaho National Laboratory, Hanford, and Savannah River sites, since 1997. He is an adjunct faculty member of Chemistry at Washington State University where he regularly teaches graduate courses.

Dr. Vienna currently leads waste form technology development projects for the U.S. Department of Energy's Offices of Environmental Management and Nuclear Energy. Dr. Vienna has published over 160 journal articles, conference papers, and technical reports in materials science and it's applications to waste management. He has performed independent research in basic waste form materials chemistry, nucleation and growth kinetics, waste form processing, and thermodynamics of multi-component, multi-phased waste forms. Dr. Vienna had developed waste forms for excess nuclear materials and wastes at several U.S. and international nuclear waste sites. He is a Fellow of the American Ceramic Society, a founding member of the "Nuclear Waste Vitrification" technical committee of the International Commission on Glass, and is an active member of the Materials Research Society, the American Nuclear Society, and the American Society for Testing and Materials.

Chief Scientist
Energy and Environment Directorate
Pacific Northwest National Laboratory

Education:

BS	Ceramic Engineering	Alfred University
MS	Ceramic Engineering	Alfred University
PhD	Materials Sciences	Washington State University

Contact: (509) 372-6201 john.vienna@pnl.gov
902 Battelle Boulevard, Richland, WA, 99352

Michael W. Rinker. *Tank Waste Retrieval Technical Activities* - From 1993 through 1998, Mr. Rinker's provided leadership and management to support the development of technology associated with environmental restoration of underground storage tanks through the DOE's EM50 Tanks Focus Area, Retrieval Process Development and Enhancements (RPD&E) project. Mr. Rinker was the technical and project lead for RPD&E. The project, was valued at over $15 M. RPD&E successfully deployed multiple retrieval technologies into radioactive storage tanks at Oak Ridge. In particular, this included the development of data and equipment to address pneumatic conveyance of nuclear waste from underground storage tanks. Much of the work was centered around two processes. The first process addressed the pneumatic conveyance of three phase flow. The second process addressed the development and deployment of a waterjet pump to motivate three phase nuclear waste material from the outlet of the Confined Sluicing End Effector to the inlet of the jet pump. The project also provided testing and data analysis for systems developed for use at Hanford and Savannah River. Mr. Rinker worked closely with DOE customers at the DOE field office and at Headquarters; the "end users" of technology at Hanford, INEL, and ORNL; the Principal Investigators working for him; and the Tanks Focus Area management team to resolve issues and concerns. Mr. Rinker also was responsible for fiscal year planning, overall project reporting through weekly and monthly reports, fiscal year technical summary documentation, formal technical and media presentations.

Contact: (509) 375-6623 mike.rinker@pnl.gov
Pacific Northwest National Laboratory
902 Battelle Boulevard, Richland, WA, 99352

Hoyt Johnson. Mr. Johnson is the lead for Technical Readiness Assessments and External Technical Reviews in the Office of Waste Processing as a part of Environmental Management's (EM) Office of Technology Innovation and Development Program. He has served as a member of the technical review team during the Construction Project Review of the Salt Waste Processing Facility(SWPF) at the Savannah River Site (SRS), as a member of the independent review team evaluating the Tank 48H technology alternatives selection at SRS and as the EM headquarters lead for the SWPF 30% design review. He has over 36 years experience in nuclear related work including over twenty years of field experience in the design, construction, testing, operation and maintenance of complex plant components systems and structures at three nuclear sites. Mr. Johnson holds a B.S. in Metallurgical Engineering from Virginia Tech and a MBA from the Florida Institute of Technology. He is a registered Professional Engineer in the state of Virginia.

Contact: (202) 586-0191 hoyt.johnson@em.doe.gov
Department of Energy
1000 Independence Ave, S.W., Washington, DC, 20585