Consortium for Risk Evaluation with Stakeholder Participation III

Consortium Universities: **Vanderbilt University**, Howard University, Oregon State University, New York University School of Law
Robert Wood Johnson Medical School, Rutgers University, University of Arizona, University of Wisconsin – Madison

CRESP Independent Review of Calcine Disposition Project (CDP) Processing Options and Plans (August 2011)

_________________ Steven L. Krahn, DPA
Review Team Chairman

_____________________ Sanjiv Gokhale, PhD, PE

___________________ R. Bruce Matthews, PhD

VANDERBILT UNIVERSITY

Department of Civil and Environmental Engineering
VU Station B Number 351831
Nashville, TN 37235
Phone: 615-322-2697 Fax: 615-322-3365
www.cresp.org

EXECUTIVE SUMMARY

This report documents an independent technical review, performed by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) at the request of DOE's Office of Environmental Management (DOE-EM), of specific considerations regarding the planned implementation of hot isostatic pressing (HIP) technology for the treatment of calcine waste at the Idaho National Laboratory (INL). The potential use of cold-crucible induction melter (CCIM) technology as a backup treatment process was included in the charter for the review (see Appendix A).

As indicated in the review charter, the CRESP Team focused on three major topics: the relative technical maturity of HIP and CCIM, construction challenges associated with backfitting these technologies into the existing Integrated Waste Treatment Unit (IWTU) facility, and the available nuclear safety-related information for HIP and CCIM. The information for the two options was at different levels of development—HIP, as the selected processing approach for the project, had information that was substantially more complete and comprehensive; whereas the CCIM information was less detailed.

This report provides individual sets of observations regarding each of the three major topics outlined above—no 'show-stoppers' were identified for either HIP or CCIM. Therefore, the CRESP Team concluded that CCIM provides a viable backup technology as DOE-EM continues to develop the HIP process for calcine waste. Three cross-cutting observations were identified (and are discussed in detail in the report):

- The chemical complexity of the calcine waste, coupled with the limited knowledge of the physical properties of the stored calcine waste, warrant a comprehensive analysis of the technical and project risks presented by the present knowledge base.
- The CCIM process presented to the CRESP Team assumed that a glass ceramic waste form would be produced; at this stage in the project, it may be more prudent to plan on the use of a proven waste form technology, such as borosilicate glass, as a backup—until technical and regulatory uncertainties with the glass ceramic waste form are closer to resolution.
- Substantial work is known to remain to fully develop the HIP process and its resultant waste form; the CDP is to be congratulated for proactively developing a Technology Maturation Plan to guide its developmental efforts—close technical oversight of this development plan, along with regular adjustments to the project's risk management planning will be needed.

Contents

INTRODUCTION

The Idaho National Laboratory (INL) Calcine Disposition Project (CDP) is preparing a conceptual design for the technology that has been selected to treat high-level waste (HLW) calcine for disposition. 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 will support the critical decision to authorize preliminary design (CD-1).

The Consortium for Risk Evaluation with Stakeholder Participation (CRESP) has been requested by DOE-ID and DOE-EM to carry out an independent technical review of specific considerations regarding the planned implementation of HIP for treatment of calcine waste currently stored at the Idaho site, and the potential for cold-crucible induction melting (CCIM) to be a back up treatment technology—as a project risk reduction strategy should an event arise during further HIP development that warrants consideration of a different technology.

PROJECT BACKGROUND

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, 2010.

PROJECT SCHEDULE

Reduced funding has impacted the project. The critical decision authorizing preliminary design (CD-1) is now planned for a date yet to be determined; however, at some time within the next contract period, 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) will be determined and placed within the scope of the pending request for proposals. A Resource Conservation and Recovery Act (RCRA) Part B Permit Application must be submitted to State by December 1, 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 23, 2009.

TECHNOLOGY READINESS

Department of Energy (DOE) Order 413.3B, 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 subsequent 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 preliminary technology readiness review was conducted, by a DOE-EM headquarters team, of the CDP design plans the week of July 12-15, 2010[3].

This preliminary technology readiness review was based on the technical status as of July 2010, supplemented by a draft Technology Maturation Plan issued in October by the CDP. The DOE-EM Team identified 11 Critical Technology Elements (CTEs) and evaluated their readiness levels and maturation plans. Seven of the 11 CTEs were expected to be at TRL 4 by October 2010; the remaining four CTEs were rated below TRL 4: ceramic additive formulation (TRL 3), HIP can design (TRL 3), HIP can containment (HCC) system (TRL 2), and simulant formulation (TRL 3). The DOE-EM Team recommended a follow up review prior to CD-1 (see Appendix B for more details of this DOE-EM review).

TECHNICAL BACKGROUND

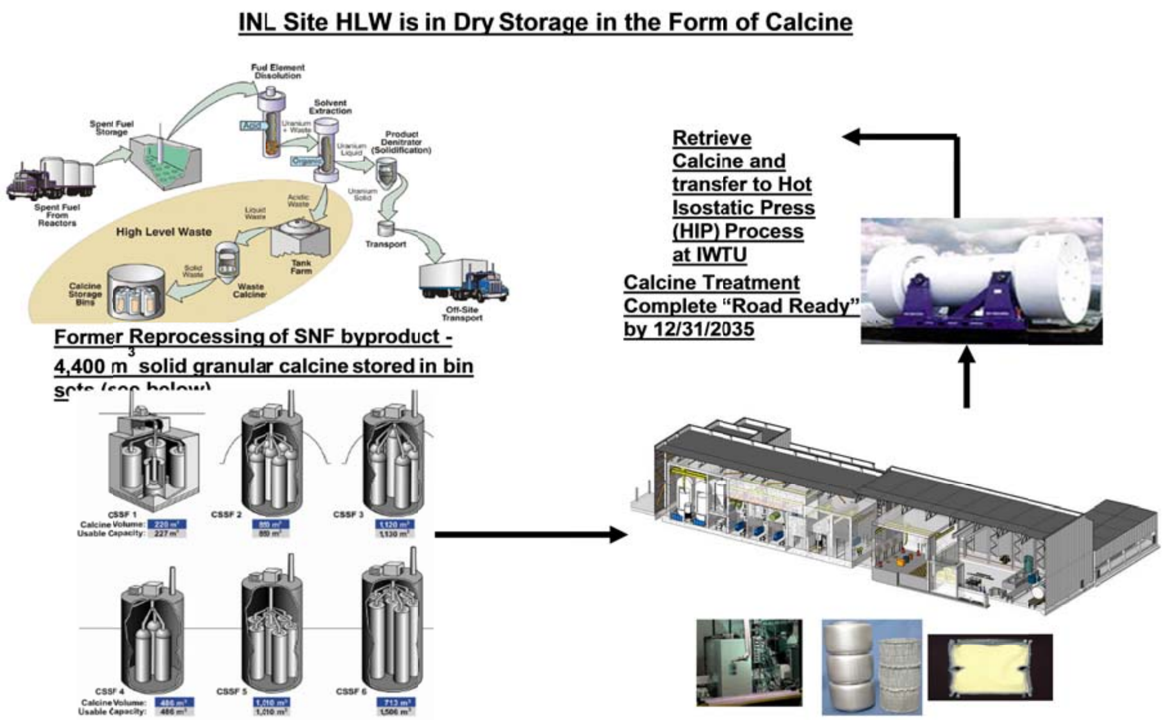
PROCESSING OF SPENT NUCLEAR FUEL AT IDAHO

From 1952 to 1991, spent nuclear fuel (SNF) was reprocessed at the Idaho Chemical Processing Plant (now the Idaho Nuclear Technology Engineering Center, INTEC). 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 waste 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 (6) Calcine Solids Storage Facilities (CSSF, also known as bin sets) under a RCRA permit.

---

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

[3] On November 29, 2010, 413.3B was issued and states “the TRA shall be conducted and the associated Technology Maturation Plan developed prior to CD-2.



THE CALCINE DISPOSITION PROJECT (CDP)

The CDP 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 the CDP will provide a basis for meeting the third milestone:

- Treat the calcine so it is ready to be shipped out of Idaho by a target date of 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 risk guidelines 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, would have had to be delisted prior to disposal in the Yucca Mountain Facility (which was not intended to handle RCRA wastes). Delisting could require additional treatment of the calcine, to remove the characteristic of toxicity as defined in 40 CFR 261. Proof of successful treatment is achieved by passing the Toxicity Characteristic Leaching Procedure (TCLP)[4].

Project milestones include:

- CD-0 approved by DOE June 2007, approve mission need, project initiation;
- 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 realigned to treatment technology selection 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.

Future milestones planned by the CDP include:

- CD-1 approval by the Deputy Secretary planned for TBD.
- CD-2 approval by the Deputy Secretary planned for TBD.

During briefings provided to the DOE-EM in December 2010, there was uncertainty as to whether the equipment to be used for the HIP process would "fit"; that is, would be easily accommodated within the structural envelope provided by the Integrated Waste Treatment Unit (IWTU) facility (which is the planned location for the CDP mission). During this dialogue, cold crucible induction melters (CCIM) were raised by some as a potential alternative to HIP. During the past months the CDP team at DOE-ID has refined its analysis and performed some additional design efforts, yielding a design that does "fit"; therefore, revised planning has HIP continuing as the primary processing technology, with DOE performing additional study of the CCIM option as a backup alternative (should technical or regulatory issues arise).

---

[4] Method 1311 found in SW-846, *Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods* (EPA 2007)

HOT ISOSTATIC PRESSING (HIP)

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

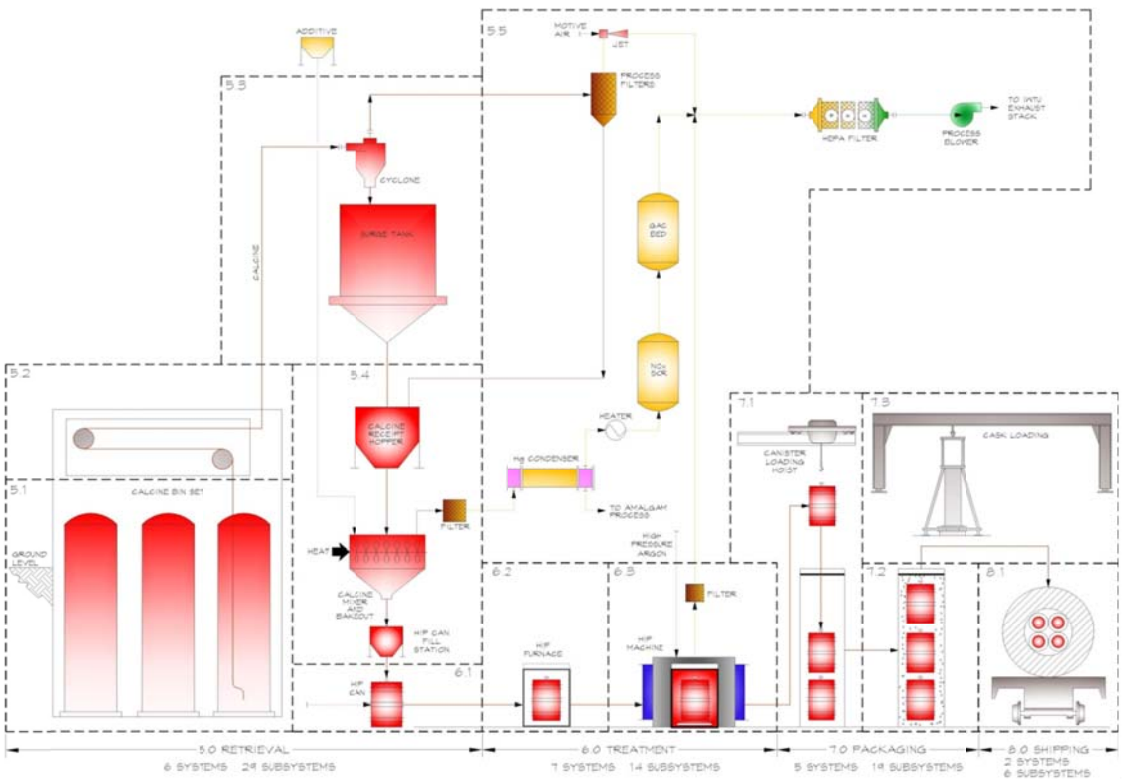


Figure 1 - Simplified Process Flow Diagram – HIP Process[5]

To-date, the HIP process has undergone the following external technical reviews:

- A 30 percent Conceptual Design Review held May 25-28, 2010, and
- A review of HIP technology maturity conducted July 12-15, 2010.

COLD CRUCIBLE INDUCTION MELTING (CCIM)

CCIM derives its name from the nature of energy used to melt the glass forming materials, into which HLW is mixed; rather than direct heating through conduction of heat from a ceramic-lined melter, the materials are exposed to an electromagnetic field—the absorption of the

[5] This diagram represents the design as presented to the CRESP Team during its site trip; since that time, the Team has been informed of changes to the design. These changes are not reflected in this report, however, because the impact of such changes had yet to be determined. Where germane to the discussion, such changes will be mentioned in footnotes, below.

electromagnetic radiation heats the materials directly. The walls of the crucible are cooled, producing a layer of glass directly next to the crucible wall that insulates it from the heat of the melt. This produces the advantage of separating the crucible from potential corrosive materials in the melt and allows for higher melt temperatures, which can be beneficial for waste loading6. The concept is illustrated below.

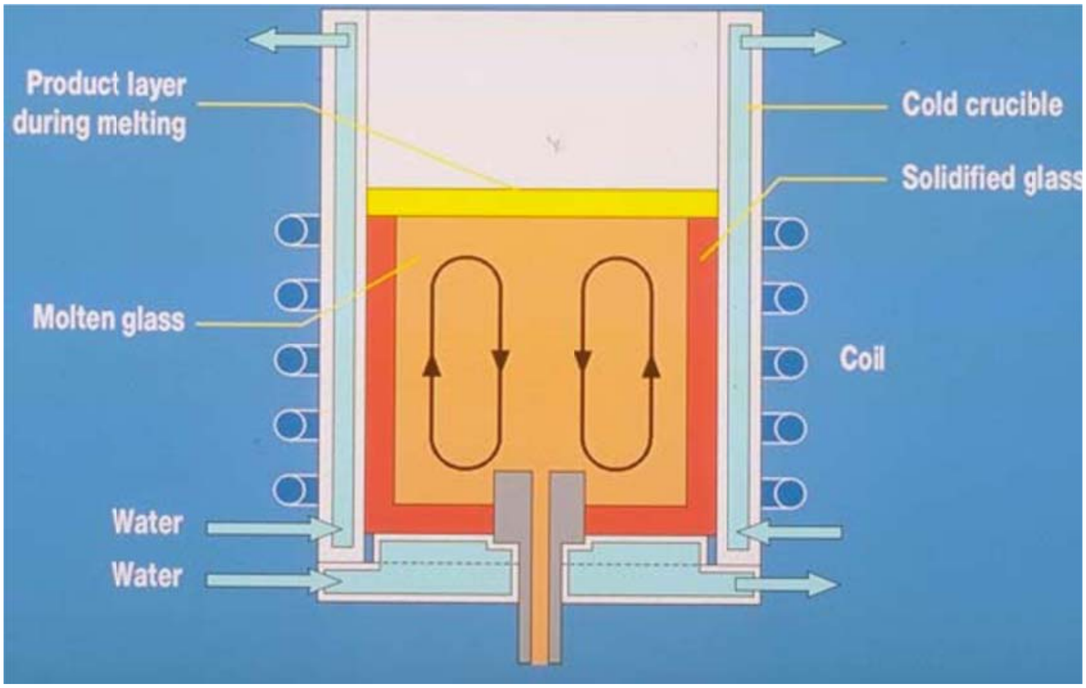


Figure 2 – Schematic of a Cold Crucible Induction Melter

This concept has not been fully developed for application to the calcined waste presently being stored at Idaho; preliminary design studies were performed by URS Corporation and AREVA to support proposing this technology for use. However, CCIM has been in industrial use for the production of a HLW glass product by the French at LaHague since April 2010. During that time period about 1,900 metric tons of HLW glass has been produced[7]. It has also been implemented by the South Koreans for intermediate and low level waste at Ulchin in the Republic of Korea since 2009[8].

---

[6] For a fuller description of the technology, please see Section 2 of AREVA, "U. S. Department of Energy, Advanced Remediation Technologies—Phase I Topical Report: Cold Crucible Induction Melting Project," 2007

[7] Chauvin, E., et al, "A Milestone in Vitrification: The Replacement of a 'Hot Metallic Crucible' with a 'Cold Crucible Induction Melter' in a Hot Cell in Record Time at the LaHague Plant, France," Waste Management 2011

[8] Yang, K., Shin, S. and Moon, C., "Commissioning Tests of the Ulchin LLW Vitrification Facility in Korea," Waste Management 2009

CRESP INDEPENDENT REVIEW OF CALCINE DISPOSITION PROJECT (CDP) PROCESSING OPTIONS AND PLANS

The Consortium for Risk Evaluation with Stakeholder Participation (CRESP) has been requested by DOE-ID and DOE-EM to carry out an independent technical review of specific considerations regarding the planned implementation of Hot Isostatic Pressing (HIP) for treatment of calcine waste currently stored at the Idaho site, and the potential for cold-crucible induction melting (CCIM) to be a back up treatment technology—as a project risk reduction strategy, should an event arise during further HIP development that warrants consideration of a different technology.

To develop the scope for this review, preliminary discussions were held with the DOE-EM and personnel from the DOE's Idaho field office (DOE-ID). Subsequent to these discussions, the CRESP Team Lead conducted a preliminary site visit from February 22 to 24, 2011. After the site visit, a schedule and scope for the review was finalized. This final charter is provided in Appendix A. The CRESP review was to be focused on providing DOE-EM and DOE-ID with an independent review, based on available preliminary data, of:

- The relative maturity of both processing alternatives, taking into account: present industrial scale uses of these technologies, both nuclear and non-nuclear; waste form characteristics and requirements; available and planned testing ("Relative Technical Maturity"' below).
- The compatibility of HIP and CCIM options with currently planning, facility and infrastructure constraints, looking at: available component size information and experience; the interface of planned system installation with the IWTU facility, both building structure and support systems; and available construction planning information ("Constructability", below).
- The safety case for the technologies, including an analysis and assessments completed already and planned under DOE-STD-1189, including facility categorization, and anticipated safety-related systems and requirements ("Safety Case", below).

Subsequent to the development of the charter, several telephone conferences were held among the participants to finalize logistics for the CRESP Team's trip to Idaho, which occurred between April 6 and 8, 2011. A briefing of preliminary observations was provided to the DOE on May 19, 2011. The report was submitted to DOE for factual accuracy checking in late June, comments were received from this review in late July 2011, and the report was then subject to CRESP peer review. These reviews added substantial value to the report. The formal conclusions of the review are documented in this report.

In performing this review, it is important to note that information regarding the two processing alternatives, HIP and CCIM (as applied to the HLW calcine at INL), was at different levels of development. As the primary technology for the CDP, the information associated with HIP is comprehensive and designed to meet the DOE requirements for Critical Decision 1 (CD-1); further, the project is building towards a CD-2 decision, as discussed above. Consideration of the potential to use CCIM has only recently been reinvigorated; as such, the CCIM information available for the CRESP Team to review constituted several programmatic and technical presentations, supplemented by additional technical reports. The CRESP Team has further supplemented that technical information provided on CCIM with the experience of the team members in the construction, nuclear facilities and powder materials industries.

RELATIVE TECHNICAL MATURITY

In this section, the CRESP Team will review available information regarding the relative level of technological maturity of the two processing alternatives. This discussion should not be interpreted as a formal Technology Readiness Assessment[9] or TRA. A "preliminary TRA" has been performed on the HIP technology by DOE-EM in late 2010 to assist in the planning for testing required to further develop the technology; the results of that review can be found in Appendix B (and were summarized in the Introduction).

As already discussed, the available technical information for the two processing options is substantially different for the two technologies; this assessment was based on the high-level concerns outlined in the charter: present industrial scale uses of the two processing options, the characteristics and requirements associated with the two waste forms that are planned, and available testing data and planned testing. With this introduction, the apparent benefits and drawbacks of the processing options are discussed below.

HIP

The CRESP Team identified three notable strengths of the CDP approach to the HIP processing option. First, information presented by the CDP Team indicated that the major component of the system, notably the furnace and its support equipment, was within the experience base of the industry. Next, the CDP has developed an extensive, logically planned testing program, (1) to develop the processing parameters (time, pressure, temperature, etc.) to be used to produce the planned waste form, and (2) to finalize and qualify the canister design to be used to contain the HLW calcine and associated glass forming materials. Finally, and importantly, the planned waste form design—glass-ceramic in a stainless steel canister (can)—has substantial advantages, if successfully developed: while the HIP can provides containment for both

[9]TRA's are formal reviews done to evaluate the maturity of technologies prior to making major project decisions within DOE; the guidance for executing then can be found in DOE Guide 413.3-4 (above).

radiological and RCRA hazards, the waste form substantially reduces the possibility of discharging hazardous materials; also, studies show the potential exists for waste loadings up to 80%, more than double the present industry standard, borosilicate glass.

Several challenges exist to realize the potential discussed above. First, although the HIP processing industry has made large, annular metal parts in the past, the experience shared with the team did not show similar experience in making large monolithic glass or glass-ceramic components; however, as noted above, the project anticipates a comprehensive test program to prove out the technology. The glass-ceramic waste form, which the CDP plans to use, has not been approved by EPA as best-demonstrated available technology (BDAT). Preliminary planning has been done to support regulatory approval and this risk is acknowledged in project risk planning; however, there is an extended, data/testing intensive process to be completed prior to achieving regulatory approval. Several technical uncertainties remain, notably completing the canister design—a design that must combine 'crushability' with structural integrity—and demonstrating that radiological and RCRA containment is achieved.

CCIM

There are several reasons why CCIM presents a viable back-up technology, as the CDP matures the HIP process and technology. First, the CCIM concept presented to the CRESP Team uses industry-proven sub-systems and components. Further, CCIM is presently in use to process radioactive waste into a borosilicate glass product in both France (HLW) and South Korea (Intermediate and Low Level Waste); in addition, the HLW processed in France is calcined prior to vitrification (although the chemistry of the waste is not identical to the Idaho calcines), showing experience with a similar flowsheet as would be used in a potential design for CDP. Finally, the potential exists, if desired, to pursue a borosilicate glass option previously approved by EPA for other DOE HLW[10]—albeit at a reduced waste loading—which would have a high state of technological maturity (discussed further below in "Observations").

Implementing a CCIM process option would not be without its challenges. First and foremost, the CCIM process presented to the CRESP Team would also use the glass-ceramic waste form; as noted above, this waste form has yet to achieve EPA approval for use with HLW containing RCRA constituents—thus the same regulatory risk would obtain. Moving to a borosilicate glass waste form presents the challenge of dealing with a comparative waste loading differential; the limited studies done to-date have only demonstrated satisfactory waste loadings in the 25 – 30% range—significantly lower than that anticipated for the glass ceramic—higher waste loadings glass formulations would need to be demonstrated.

---

[10] It is likely that the specifics of the CCIM process and the final waste form would need to be reviewed by EPA to ensure that its prior BDAT determination remained valid.

Summary

The CDP has developed a Technology Maturation Plan that addresses the known risks in a logical, phased manner to achieve a TRL 4 by CD-1 and a TRL 6 by CD-2 (with the exception of the characterization/sampling issue, discussed in the Cross-cutting Observation section, below). The progress of waste form and canister technology development and qualification bear close monitoring. CCIM is a prudent choice as a backup technology. CDP work on the development and certification of a glass-ceramic waste form for HIP would likely also support its use in a CCIM-based process; however, the use of borosilicate glass with CCIM would provide a more comprehensive backup strategy, as discussed in the Cross-cutting Observations (below).

CONSTRUCTABILITY

To evaluate this area for the two technologies, the overall question was broken down into its three component parts, briefly summarized in the sub-headings below. Under each of these sub-headings the pertinent features of the technology are discussed. After this presentation, overall observations regarding constructability are provided.

Compatibility with IWTU Facility and Consistency with Industry Experience

HIP

Utilization of a pre-HIP treated can, with a diameter of 60-in. and height of 30-in. (holding approx. 3,360 lb of calcine waste form), will not necessitate increasing the existing ceiling height (31’-4 5/8”) of the IWTU hot cells (as was previously a concern). The present design uses pressure vessels and heaters that are “off-the-shelf” items[11]. The design fully utilizes existing PC-3 cells (4 Pack & 2 Pack) and re-uses existing canister fill cells for HIP can fill operations.

Filling the 60-in. diameter canister to a 95%-100% fill (by weight) could be difficult to achieve; however, testing is planned and experience with dry loading will be gained during IWTU operations. Use of the larger canisters will reduce the total number of canisters required, as well as all associated loading, welding, testing, and handling functions. The handling and storage equipment for the larger canisters have previously been developed for use in the Navy and the private sector.

[11] Although presently used in high-temperature and high-pressure applications, it was not clear whether the furnaces had been qualified to the relevant portion of the ASME code for nuclear applications.

CCIM

Proposed application will utilize two, 850 mm (33.5 in.) by 900 mm (35.4 in.), CCIMs working in parallel. Each proposed CCIM is comprised of a) water-cooled, cylindrical stainless steel vessel; b) mechanical stirrer; c) bottom support slab; and d) a dome, to which feeding pipes, and off-gas pipes are connected. Estimated power requirement for each CCIM is 900 kW. Mass of glass/ceramic per canister is 1,400 kg (3,086 lb). 60% waste loading efficiency is assumed, consistent with the lower end of the band of waste loadings shown for the glass-ceramic waste form, to-date.

Extensive experience exists in designing and operating industrial HLW vitrification systems, in general; there is experience in France and South Korea with deploying CCIM-specific processes and equipment for making glass products. The proposed application is within the scope of past experience.

Interface of planned system installation with the IWTU facility, both building structure and support systems

HIP

The surge tank function was moved outside the IWTU in order to fit three HIP machines and, thus, meet the 12-year year processing time constraint. Moving the surge function to the bins set structures, in whatever final configuration is finally determined by the project, may increase certain costs of the bin retrieval system and will incur the challenges associated with modifying an existing facility[12]. However, moving the surge function from the IWTU treatment area to the retrieval system and the CSSF will likely reduce direct project costs, by elimination of the surge tanks, MAR, and associated equipment.

Planned Modifications:

- Modifications to existing off-gas system are required.
- New wall in PC-3 cell and new Service Corridor Buffer Area will require re-analysis (structural and seismic) of base matt and foundation system.
- New Argon Equipment Building; New Electrical Building; and New East Annex to house Wash Down, Packaging/Shipping, and Inspection Buildings are required. These are outside the PC-3 structure of the IWTU.

[12] This section discusses the option of moving the surge tanks to an adjacent facility and the potential impact on the CDP; at the time of the CRESP review, calculations had not been updated to reflect this option selection, thus other impacts (e.g., impact on the safety analysis) could not be evaluated.

CCIM

Calcine retrieval from bin sets was assumed in the presentation to the CRESP Team to be similar to HIP. A surge tank was not part of the design concept. Hoppers for CCIM would be fully contained within the 4 Pack cells without modifications to the roof height. A 10-year time frame is assumed to process all calcine waste; however, further details of the feed and sampling system for CCIM were not provided. The CCIM equipment is of a size that can be introduced using the existing facility crane (30 T capacity).

Planned Modifications:

- *First Level Enhancements*
  - Significant modifications to 4 Pack and 2 Pack (removal of walls, addition of walls, removal of wall openings, ventilation changes)
  - Construction of new air lock (canister introduction) and enclosure for high frequency power supply
- *Second Level Enhancements*
  - Demolition of portion of IWTU cell structure
  - Construction of a new second level covering the 2 Pack and canister fill cells.

Available construction planning information

HIP

The Calcine Disposition Project (CDP) is organized and managed into five 'areas' based on systems engineering functions. These functional areas are: calcine retrieval; HIP treatment; packaging; shipping; and plant facility support. A 3-D model of the existing IWTU facility is available. At the current time no construction planning information for modifications to existing facilities of construction of new facilities is available. It is not expected to be available until 2015.

CCIM

Preliminary analysis and design has been conducted for IWTU building modifications (based on revised mass distribution and total building mass). Preliminary analysis indicates that: (1) seismic demands may reduce by 15%-25%; (2) existing wall and base slab capacities are sufficient; (3) overturning and sliding effect has to be evaluated but expected to be lower; and (4) low D/C ratios of structural members (<0.9) will help simplify cutting, welding, and anchoring of new construction into existing building.

A presentation detailing the CCIM retrofit into the R7 line B at La Hague was made13; in that presentation, it was stated that a 5-year time period (2005-2010) had been required to complete the final design and installation. Similar time frame appears reasonable for the IWTU CCIM retrofit project.

Summary

Modifications to the IWTU are significant for the CCIM retrofit, impacting substantial portions of the cell structure, and will pose challenges. However the vendor (AREVA) has a successful track record with backfitting a similar system into the HLW processing plant at LaHague. In comparison, the modifications to IWTU for HIP are less complex. Provided that the new seismic analysis can ascertain the adequacy of the modified IWTU facility and the existing foundation and slab, from a constructability stand point, the retrofit of IWTU for HIP and CCIM are within the normal bounds of construction, and with proper front-end planning can be achieved with minimum risk.

SAFETY CASE

The CDP has adhered to DOE-STD-1189[14] protocols during the development of the safety case for the HIP process, and the project team has completed a Preliminary Hazard Review[15] and a Conceptual Safety Design Report[16]. The CCIM safety case presented refers to the 2009 authorization by French Authorities to operate CCIM in the La Hague R7 HLW vitrification facility; in addition, some engineering information developed during a DOE Advanced Remediation Technologies project during 2007 through 2010 was also provided17. Because the La Hague safety report was not provided and certain design features may differ (e.g., final feed and sampling system designs), direct, safety-related comparisons between the two technologies cannot be made. The following draws relative conclusions based: on the information presented at the CRESP review, available documents and the experience of the Team.

HIP

A hazard categorization of Hazard Category 2 (HAZ CAT 2) was determined for the CDP with HIP operations, the IWTU facility has a Seismic Design Category PC-3. No accident scenarios

[13] "Application of CCIM Technology Developed by AREVA for Direct Vitrification of Idaho Calcine, Part 1 (April 7, 2011)

[14] DOE-STD-1189-2008, 2008, "Integration of Safety into the Design Process," U. S. Department of Energy, March 2008.

[15] EDF-7748 - "Preliminary Hazard and Operability Review for the Calcine Disposition Project," Rev 2, August 23, 2010.

[16] "Conceptual Safety Design Report for the Calcine Disposition Project (Draft)," RPT-366, Rev. 2 Draft, Idaho Cleanup Project.

[17] AREVA studied the potential to backfit a CCIM into the existing facility at the Defense Waste Processing Facility (DWPF) at the Savannah River Site.

challenge the off-site evaluation guideline, and no safety-class structures, systems, or components were determined necessary.

Major Hazards:

Radiation levels near the surface of a volume of calcine can be up to several thousand rem/hr, depending on the volume and configuration of the calcine. The HIP furnace is a cylindrical confinement vessel that contains three HIP can; the HIP can will be heated to 1200 to 1250^{o}C under an argon atmosphere of 4,300 to 7,200 psi. A large pressure release from the HIP system accompanied by failure of the HIP can and HIP furnace could lead to a rapid and energetic release of calcine to the surrounding cell, resulting in a worst-case accident. An additional bounding accident could be a breach in the surge tank that contains approximately 600 ft^3 of calcine under normal conditions. Additional accidents analyzed for HIP CDSR include: a calcine transfer line breach, a calcine mixer breach, an off-gas system failure, and a design-basis earthquake.

The bounding MAR in the three HIP can in the HIP Can Confinement (HCC) is 76.8 ft^3 of calcine and the radionuclide content of the calcine has been established based on historical sampling of liquid waste and use of the HPM to calculate the calcine composition and previous sampling of the bins in the Calcined Solids Storage Facility. The calculated Total Effective Dose (TED) to a collocated worker 100 m from the release from the HCC is 850 rem, and the calculated TED to an off-Site individual is 0.68 rem. [18] The DOE-STD-1189-2008 criteria are exceeded for the collocated worker. Furthermore, the calculated concentration of cadmium and mercury exceed the safety guideline for the collocated worker. The guideline criteria are not exceeded for either the collocated worker or the off-site public for a breach in the surge tank that contains 600 ft^3 of calcine. The calculated TED to a collocated worker from the release from the surge tank is only 16 rem[19]. Apparently because the surge tank is at atmospheric pressure and the Airborne Release Fractions and Respirable Fractions are low[20].

---

[18] These values are based on a previous design and on conservative assumptions. In the current design, the MAR is reduced (by about 40%) from the previous design. In addition, these values assume that the HIP can is pressurized from within while the actual pressure is on the outside of the can and assume that the HIP system fails catastrophically while the system is designed to leak before failure. The assumptions used in the original analysis will be refined in later revisions to the hazard analysis.

[19] RPT-366 Revision 3 Design Report for the Calcine Disposition Project, September 2010. NOTE: The charts in the April, 2011 CRESP review state a 220 rem collocated worker dose from a breach in the surge tanks. The release assumptions appear to be evolving.

[20] Note: There has been an on-going technical dialogue between the DNFSB and the Waste Treatment Plant (WTP) project at Hanford regarding modeling and use of release fractions as they are applied in accident analysis; the CDP should monitor this ongoing discussion.

Preventive Measures:

The HIP confinement system in the IWTU facility will consist of primary, secondary, and tertiary passive confinements and active confinement provided by the facility HVAC system.

- The primary confinement consists of the storage bins, calcine transfer lines, cyclones, surge tanks, calcine mixer, batch hopper, HIP cans, HIP processed waste form cans, filters, off-gas system piping, and high-efficiency particulate air (HEPA) filter banks.
- The secondary confinements will provide a barrier between the facility workers and releases from the primary confinements. The CSSF vaults, secondary pipes around primary transfer lines, the process cells, the HIP furnace, and the canisters are secondary confinements.
- The building and HEPA filter system provide tertiary confinement.

Potential Mitigating Measures:

- HIP pressure vessel is wrapped with pre-stressed wire; thus, the vessel is designed to reduce pressure gradually, rather than fail catastrophically ('leak before break').
- When processing begins, the calcine is in its dry granular form, which is readily dispersible; however, as temperature increases, the calcine melts and becomes less dispersible
- The vacuum-sealed HIP can containing the calcine is inside a HIP furnace which is inside the HIP pressure vessel. Hydrostatic pressure is on the outside of the HIP can and is not likely to disperse the calcine, at least in the configuration assumed by the present analysis (done in accordance with DOE-HDBK-3010). However, calcine reactants and internally heated gasses do form an internal pressure source that will need to be analyzed.

CCIM

The CCIM safety approach stated that the safety basis established for operations of a hot-wall induction heated melter at La Hague, bounded CCIM operations; they assumed that it would be the same in IWTU. The existing R7 safety report will have to be modified to address specific aspects raised by the change in melter technology and facility-specific modifications for the CDP application. Because the calcine feed material has the same radionuclide and hazardous waste concentrations for both processes, the CCIM process in the IWTU should be bounded by the HAZ CAT 2, PC-3 designations determined by the Calcine Disposition Project CSDR.

Major Hazards:

Radiation levels will be determined by volume of calcine and could be up to several thousand rem/h as in the HIP process. The bounding MAR in the two operating melters will be approximately 27 ft^3 of calcine, approximately one-third of the MAR presently assumed for HIP; however, bounding accidents were not identified, and no offsite or nearby worker dose estimates were provided.

The CCIM glass melt will be heated 1200 to 1500^{o}C (depending on waste loading) under atmospheric pressure so there is not a high-pressure dispersal mechanism. However, vapor explosions have occurred in molten glass/water systems, and a breach in the CCIM furnace cooling coils could potentially cause an energetic reaction and subsequent dispersal of MAR. Fauske & Associates[21] assessed the potential of a steam explosion in Slurry Fed Ceramic Melters (SFCM) for the Defense Waste Processing Facility (DWPF) and concluded that a steam explosion resulting from slurry feeding of the melter would not result in damage to the integrity of the melter. The CCIM review asserted that the conclusions of the Fauske study would apply to the CDP, and, therefore, energetic dispersal of MAR from the melter was not possible.

With respect to seismic hazards, the CCIM case assumes that functions of containment of material at risk and mitigating external exposures applicable at La Hague would be identical for any treatment process housed in IWTU. The melter CCIM vessel at La Hague is not credited – instead the melt cell structure is designed to maintain its containment function (it is stainless steel lined and there is a stainless steel 'drip pan' below the melter).

Preventive Measures:

The R7 containment principles are based on double confinement: (1) a combination of two passive barriers (process equipment and cell structures), both of which are connected to independent active confinement systems (process equipment ventilation and cell ventilation), and (2) the building structure and building ventilation system, presumably identical to the tertiary building and HEPA filter confinement in the ITWU. Additional confinement is provided by active off-gas controls and active melt cell ventilation controls. Safety-related controls include:

- Automatic interlocks to stop electrical power in case of water leak detection;
- A "water deluge tank", which is part of the CCIM cooling loops, will ensure complete freezing of the glass bath upon loss of cooling water;

[21] Steam Explosions in Slurry-Fed Ceramic Melters, Fauske & Associates, 1986

- Redundant pour valve controls; and
- Back-up power supply for safe shutdown functions.

Potential Mitigating Measures:

Industry experience has been that the CCIM can be restarted after loss of electrical power without damage to the melter. Radioactive materials have been shown to be contained in the melt by the glass “skull”, an insulating layer on the inside of the crucible created by cooling system of the CCIM. Tightness of the cooling system is verified by redundant multiple survey/control systems such as pressure measurements. The cell walls are stainless steel lined and a stainless steel drip pan is planned for beneath the CCIM, as is installed at LaHague22.

Summary:

Both processes can be done safely and compliantly in the PC-3, HAZ CAT-2 IWTU facility with an active, safety-related ventilation system. Some safety-related differences between HIP and CCIM could result in cost and schedule impacts as shown in Table 1.

Because of the relatively low MAR and low processing pressures, CCIM appears to the Team to require fewer and/or less costly safety related controls and systems. However, this conclusion may be premature, because the hazards and safety basis for the HIP is better described at present, having been analyzed according to DOE standards. CCIM needs to complete safety analysis following DOE-STD-1189 protocols, identify risks, and required test program in order to “level the playing field.”

[22] Descriptions provided by AREVA and URS during presentations to the CRESP Team.

Table 1. Safety-Related Differences: HIP vs. CCIM

Function	HIP	CCIM	Summary
Safety Basis	DOE-STD-1189 compliant Risks identified and plans to mitigate in place	Licensed and operating at La Hague Not certain that French regulatory process meets US standards	HIP has an edge because safety analysis is based on DOE standards.
Accident initiators	High pressure in HCC	Low operating pressure Potential for vapor explosion	Assuming that the Fauske analysis is correct, CCIM has less potential for an energetic dispersal of calcine.
Preventative Measures	Primary confinement of the calcine throughout the process	No credit is taken for primary containment Glass skull assumed to contain calcine in melt	Lack of credited primary containment in CCIM melter seems to produce unnecessary safety risk.
Consequences	Larger MAR High nearby worker dose	Approximately 1/3 the MAR in the operating cell	CCIM should have lower off site doses because of lower MAR and less energetic dispersal.
Worker safety	Complete confinement of calcine during processing	Frequent sampling More complex off-gas system	CCIM appears to have more opportunities for worker incidents because of sampling frequency and off-gasses.

Both processes require further development. The major uncertainties with CCIM appear to be the potential for a vapor explosion and the ability of the glass skull to contain contamination. The major uncertainties with the HIP process is dispersal mechanisms after mechanical failure of the surge tank and failure of the HIP can, HIP furnace, and pressure vessel during the initial stages of the HIP cycle.

Cross-cutting Observations

In completing this review, the CRESP Team developed three observations that did not neatly fit into three areas laid out in the Charter. However, it was believed that they were important enough to be brought to DOE's attention. Therefore, they have been described and developed, below.

Calcine Characteristics and Sampling

The chemical complexities of the Idaho calcine will influence both processes. The HIP process has the advantage of containing all the constituents in the glass ceramic matrix, including mineralized RCRA constituents, within the HIP can. This advantage assumes that the calcine compositional variability, both chemical and physical, can be bounded with one to three formulations and batch sampling is not required. The CDP has an ongoing waste form test program to support BDAT determination under RCRA. An apparent disadvantage of CCIM is the lack of stabilization of volatile toxic metals; however, large-scale melter tests of Hanford wastes suggest that Cd and Pb are not particularly volatile.

It is not clear that the physical characteristics of the calcine can be assumed from previous sampling efforts without significant project risk. Caking, the amount of fines, and segregation of constituents are potential problems that could:

- impact efficiency and radiological safety of retrieval from the bins,
- cause segregation in the HIPed waste, and
- complicate CCIM feed preparation.

Mechanical agitation will likely be needed to aid particle flow. In addition, the presence of fines could cause filter plugging and present difficulty filling HIP cans and CCIM melters. On the other hand, the CRESP Team understands that characterizing each batch could complicate the process flow, increase plant size, and alter plant operations. It appears, however, that a comprehensive analysis of risks presented by the present knowledge level of chemical and physical properties is warranted, along with the development of technical plans that would reduce or eliminate the identified risks. (Additional technical discussion can be found in Appendix C.)

Borosilicate Glass

The CCIM process presented planned on a ceramic waste form consistent with the planned waste form for the HIP process. The CRESP Team believes that such a plan makes the CCIM only a "partial backup", since it will share the technical and regulatory risks of developing and qualifying the glass ceramic waste form. On the other hand, borosilicate glass presents the advantage of being the only waste form that meets the existing repository waste acceptance criteria and has been previously approved for DOE HLW[23]. Moving to a borosilicate waste form does present the challenge of dealing with a comparative waste loading differential; the limited studies done to-date have only demonstrated satisfactory waste loadings in the 25 – 30% range—significantly lower than that anticipated for the glass ceramic—higher waste loadings borosilicate glass formulations would need to be demonstrated if the glass ceramic waste form even approaches the presently planned waste loading of about 80 percent. However, if the waste loading for the glass ceramic does not meet the CDP's expectations, and the waste loading of borosilicate glass can be improved, this apparent advantage begins to narrow. The CRESP Team believes that an important, near-term technology demonstration priority, and risk reduction effort, should be to determine what the true bounds of waste loading in borosilicate glass, produced with CCIM, would be with high level waste calcine constituents.

Resolution of Major HIP Uncertainties

The CDP has developed both a Technology Maturation Plan and risk management tools consistent with the present phase of project development. In fact, the CDP is to be congratulated for taking a proactive approach to the technology development needs of the HIP process. With this said, two overall risks presented themselves to the CRESP Team:

- Substantial work remains to fully develop and qualify the HIP process and its resultant waste form—success of this set of testing is vital to the potential case for a BDAT determination, to fulfill the high waste loading promise presented by the glass ceramic waste form and also to validate the project's "no sampling" assumptions[24].
- A parallel challenge exists in the development of the HIP can design to meet the dual needs of a crushable geometry to allow for volume reduction and a robust design to contain any remaining reaction products or volatiles of concern.

Close technical oversight will be required to ensure that results of the numerous planned tests continue to track with CDP plans and assumptions. The nature and extent of these overall risks fully warrants the phased approach that the CDP is taking to ensure the availability of a backup technology for this waste.

[23] However, see note 10.

[24] During briefings to the CRESP Team, CDP personnel stated that they had discussed the project's "no sampling" approach with EPA staff and received favorable comments.

Appendix A – Review Charter and Concurrence

CRESP INDEPENDENT REVIEW OF CALCINE DISPOSITION PROJECT (CDP) PROCESSING OPTIONS AND PLANS

REVIEW SCOPE

The Consortium for Risk Evaluation with Stakeholder Participation (CRESP) has been requested by DOE-ID and DOE-EM to carry out an independent technical review of specific considerations regarding the planned implementation of Hot Isostatic Pressing (HIP) for treatment of calcine waste currently stored at the Idaho site, and the potential for cold-crucible induction melting (CCIM) to be a back up treatment technology as a project risk reduction strategy in the possible event that results from further HIP development warrant consideration of a different technology.

The mission of the CDP at DOE's Idaho National Laboratory (INL) is to retrieve and treat the high-level waste (HLW), presently stored as calcined powder in underground storage bins, for disposition outside of the State of Idaho. Present planning, documented in the Amended HLW Record of Decision (ROD) dated December 23, 2009, designates Hot Isostatic Pressing (HIP) as the treatment process to be used. During briefings provided to the Office of Environmental Management (EM) in December 2010, there was uncertainty as to whether the equipment to be used for the HIP process would fit within the structural envelope provided by the Integrated Waste Treatment Unit (IWTU) facility—which is the planned location for the CDP mission. At this time Cold-Crucible Induction Melters (CCIM) were raised by some as a potential alternative to HIP.

During the past months the EM team at DOE-ID has refined its analysis and performed some design efforts; therefore, revised planning has HIP continuing as the primary processing technology, with DOE performing additional study of the CCIM option as a backup alternative (should technical or regulatory issues arise). EM requested that CRESP lead a review of the present status of CDP design and planning efforts. This review will be focused on providing EM and DOE-ID with an independent review, based on available preliminary data, of:

- The relative maturity of both processing alternatives, taking into account: present industrial scale uses of these technologies, both nuclear and non-nuclear; waste form characteristics and requirements; available and planned testing.
- Evaluate compatibility of HIP and CCIM options with currently planning, facility and infrastructure constraints, looking at: available component size information and experience; the interface of planned system installation with the IWTU facility, both building structure and support systems; and available construction planning information.

- The safety case for the technologies, including an analysis and assessments completed already and planned under DOE-STD-1189, including facility categorization, and anticipated safety-related systems and requirements.

SCHEDULE

Initiate Review of available background information	March 2011
Meeting in Idaho for Facility Tours & Technical Briefings	April 6 – 8, 20011
Factual Accuracy Review – draft report	June 2011
Final Report Issued	July 2011

CRESP REVIEW TEAM

Steve Krahn, Chair, Sanjiv Gokhale, Bruce Matthews

TEAM BIOGRAPHIES

Steven L. Krahn, DPA

Steve Krahn is Professor of the Practice of Nuclear Environmental Engineering in the Department of Civil and Environmental Engineering at Vanderbilt University. Immediately prior to coming to Vanderbilt, he served in U. S. Department of Energy (DOE) as the Deputy Assistant Secretary for Safety & Security in the Office of Environmental Management (EM). He performs research as part of the Consortium for Risk Evaluation and Stakeholder Participation (CRESP) in the areas of nuclear and environmental risk assessment and risk management and the insertion of advanced technology into nuclear facilities. While at DOE, Dr. Krahn: served as the Deputy Chair of the Nuclear Safety Research and Development Committee which provided oversight and direction to safety-related research; directed the technology development program for the nuclear waste processing; chaired the EM Technical Authority Board, charged with providing final technical approval of new facilities and major modifications to nuclear facilities; and was selected by the Deputy Secretary to serve on the Risk Assessment Working Group, DOE's technical leadership team for overseeing the development of improved quantitative risk analysis in the department. He has led or served on more than dozens technical reviews of nuclear facilities and radioactive waste processing systems for DOE sites including Savannah River, Hanford, Idaho, Oak Ridge and others. He has also provided nuclear/environmental engineering and risk assessment consultation to the U.S. nuclear industry for more than a dozen years and to NASA for five years. He received his Doctorate in Public Administration from the University of Southern California and holds an M.S. in Materials Science from the University of Virginia.

Sanjiv Gokhale, PhD, PE

Dr. Gokhale is Professor of Civil Engineering in the Department of Civil and Environmental Engineering, Vanderbilt University. Dr. Gokhale also serves as the Director of the Graduate Program in Construction Management at Vanderbilt. He has over fourteen years of engineering and consulting experience, related to design and construction. He is a registered Professional Engineer in the State of New York. Dr. Gokhale is the author or co-author of several texts on construction and construction management, most recently: Trenchless Technology: Pipeline and Utility Design, Construction, and Renewal, McGraw-Hill, 2005. He has been recognized for his teaching and research through many awards. He received Distinguished Professor Award, Construction Industry Institute (CII), University of Texas at Austin, 2009; Excellence in Teaching Award, School of Engineering, Vanderbilt University, 2005; Tau Beta Pi - Teacher of the Year, Vanderbilt University, 2004. He was elected Fellow of the American Society of Civil Engineers in 2009. He holds a PhD in Civil Engineering from Columbia University, New York.

R. Bruce Matthews, PhD

Bruce Matthews has forty years of scientific and engineering experience in nuclear technologies with a primary focus on nuclear materials, nuclear reactor fuels, nuclear facility operations, and nuclear safety. Matthews worked at national laboratories as a scientist, line manager, and project leader and has been involved in Department of Energy programs in stockpile stewardship, plutonium technologies, nuclear materials disposition, environmental management, and space and terrestrial nuclear power systems. He has experience in nuclear facilities management including operations, construction, regulatory compliance, integrated safety management, and safeguards and security. He was appointed by President George W. Bush, to be a Member of the Defense Nuclear Facilities Safety Board (DNFSB), where he focused on safety management of high-hazard nuclear facilities and Integrated Safety Management. From 1993 to 2000 Matthews was the Division Director for Nuclear Materials Technology at the Los Alamos National Laboratory. Matthews is the author or co-author of over eighty journal publications, conference proceedings and technical reports. He initiated the international Plutonium Futures Conference, is a Fellow of the American Nuclear Society; in addition, he serves on the National Nuclear Accrediting Board for the Institute of Nuclear Power Operations (INPO) and is a part time Technical Judge for the Atomic Safety Licensing Board at the NRC. He holds a PhD in Materials Science from the University of Wales.

-----Original Message-----
From: Case, Joel T [mailto:casejt@id.doe.gov]
Sent: Friday, April 01, 2011 8:41 AM
To: Krahn, Steven L
Cc: Ramsey, Ronald O
Subject: RE: Idaho trip--CRESP Review of HIP and CCIM

Yes We are very comfortable with it and have no issues Joel

-----Original Message-----

From: Krahn, Steven L [mailto:steve.krahn@vanderbilt.edu]

Sent: Friday, April 01, 2011 7:36 AM

To: Case, Joel T

Subject: FW: Idaho trip--CRESP Review of HIP and CCIM

Joel:

Just to make sure, Shirley has agreed with the Review Charter (below), are you comfortable with it also (copy attached)?

Steven L. Krahn

Professor of the Practice of

Nuclear Environmental Engineering

Civil & Environmental Engineering Dept.

Vanderbilt University

steve.krahn@vanderbilt.edu

From: Olinger, Shirley [Shirley.Olinger@RL.Doe.Gov]

Sent: Friday, March 25, 2011 3:58 PM

To: Krahn, Steven L

Subject: Re: Idaho trip--CRESP Review of HIP and CCIM

Yes, this is good! Txs, sjo

----- Original Message -----

From: Krahn, Steven L <steve.krahn@Vanderbilt.Edu>

To: Olinger, Shirley; Case, Joel (Lex)

Cc: Elizabeth.Sellers@areva.com <Elizabeth.Sellers@areva.com>; james.floerke@icp.doe.gov <james.floerke@icp.doe.gov>; b.matt@cox.net <b.matt@cox.net>; Gokhale, Sanjiv B <s.gokhale@Vanderbilt.Edu>

Sent: Wed Mar 23 13:16:58 2011

Subject: Idaho trip--CRESP Review of HIP and CCIM

Shirley: I understand your situation; however, please take a look at the final draft of the review charter, to make sure that you are comfortable with it.

Joel: I had also sent the draft charter to you, please take a look at this final draft.

Steven L. Krahn

Professor of the Practice of

Nuclear Environmental Engineering

Civil & Environmental Engineering Dept.

Vanderbilt University

steve.krahn@vanderbilt.edu

Appendix B – Summary Results of DOE-EM Preliminary Technology Readiness Assessment

Of The Calcine Disposition Project (Two Volumes)

February 2011

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.[25] (Note: based on the documentation at hand during the week of July 12, 2010, many of the CTEs would have lower TRL values.)

Table B-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

[25] The project is committed to achieving TRL-4 for all CTEs prior to CD-1 approval.

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)[26] 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.

[26] Deferred again by funding cutbacks. The schedule is TBD.

- 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.

Appendix C – Calcine Characteristics and Sampling

Chemical and Radiological Constituents: The chemical constituents and radiological properties of the calcine have been well characterized based on process knowledge and sampling activities during production and more limited sampling since storage commenced[27]. Important constituents include Cs, Sr, and TRU radioisotopes, volatile toxic metals such as Cd and Hg, and stainless steel, zirconium, graphite, and aluminum fuel cladding materials. The calcine from different fuels and reprocessing chemicals are generally layered in the storage bins in chronological order of generation, as a result compositional variability exists in the bins[28]. These chemical characteristics make the Idaho calcine difficult to process and will likely have an effect on both the HIP and CCIM processes.

A 1999 National Academy of Sciences (NAS) review[29] of alternative HLW treatments made the following observations:

- The current chemical, physical, and radiological characterization data for HLW calcine .... are too incomplete and/or inaccurate for any of the stored waste to permit a logical selection from among the several treatment alternatives available.
- Representative sampling and analysis of actual aged calcine in current storage must be done to establish definitive bounds on critical properties.

One of the principle concerns in the NAS report was a lack of knowledge of the calcine composition. That concern was addressed by issuing reports that comprehensively document the chemical content and radioactivity of the calcine. Additional analysis of the radioactive calcine was done in 2003[30] on three different historical calcine samples. These samples, however, had not been stored in conditions found in the CSSF bins; two of those calcine samples had been saved from a 1978 sampling effort, and the third had been saved from the 1993 operation of the New Waste Calcining. The 2003 analysis found that: calcine is correctly classified as a RCRA waste, no PCBs and only minute quantities of organic compounds were detected, and most measured and historic data correlated well.

---

[27] Stables, Pomiak, and Wade, Properties of Radioactive Calcine Retrieved from the Second Calcined Solids Storage Facility, ICP-1189, March 1979, February, Patterson and Prather, D-Cell Calcine Calcine Sampling and Analysis, ICP/EXT-04-00423, August 2004, Swenson, Organic Compounds in INTEC Tank Farm Waste, ICP/EXT-05-00962, September, 2005.

[28] Berreth, *Inventories and Properties of ICPP Calcined High-Level Waste*, WINCO 1050, 1988.

[29] National Research Council. Alternative High-Level Waste Treatments at the Idaho National Engineering and Environmental Laboratory**,** ISBN: 0-309-59364-6, 1999.

[30] Patterson and Prather, D-Cell Calcine Sampling and Analysis, ICP/EXT-04-00423

A potentially important difference between CCIM and HIP is calcine preparation and sampling. The goal of the HIP process is to use only one formulation for all calcine types. The back up is three formulations, one each for each of the three primary calcine types. The HIP process plans to feed calcine directly from the surge tanks into the HIP cans without sampling or prior preparation. The HIP process is designed to retain all contaminants, and the off gas system is largely for moisture removal. HIP treatment of calcine converts the RCRA metals and constituents of concern into low leachable minerals. Small scale conceptual testing with waste simulants[31] has indicated that HIP treatment with additives will convert solid-granule calcine to a monolithic, glass-ceramic waste form that can meet waste acceptance and leachability standards. However, the preliminary Technology Readiness Assessment for the CDP (see Appendix B) still concluded that the assumption that current calcine characterization information is sufficient represents a major risk to the project. RCRA and DOE requirements typically depend on detailed, batch-by-batch analysis of feed material, additives, and process control information; such as batch process, based on sampling and glass certification runs, is presently used at DWPF and is planned for the Waste Treatment Plant (WTP) at Hanford.

The CCIM process presented plans on sampling of the calcine from the storage bin and will re-calcine high nitrate powder feed prior to flow into the melter. Accurate characterization of calcine is planned for each batch of calcine to be processed in the CCIM to maximize waste loading and accurately characterize the canister contents. The process relies on an off-gas treatment system to remove volatiles which may be released during glass melting including Hg, Cd, Cs, and Tc (the volatiles will be determined by melt temperature which in turn will be determined by waste loading requirements). No testing on Idaho calcine materials has yet been done to verify that the CCIM process can produce a waste form that will meet BDAT and RCRA requirements.

<u>Physical Properties</u>: Both processes will require predictable and uniform calcine powder flow, filters to remove dust, and off-gas treatment (particularly for CCIM). Any uncertainty in the

---

[31] Nelson and Vinjamuri, *Results of Intermediate-Scale Hot Isostatic Can Experiments*, INEL-95/0145, May 1995, Raman, *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, Raman, *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.

physical characteristics of the calcine feed material could be an issue for either process. The potential issues are identified in the Risk and Opportunity Assessment for the HIP process:

- There is a risk of unreliable flow of calcine from the surge tank because of plugging or bridging of calcine inside the surge tank. Manned entry to perform maintenance of these systems would result in excessive radiological exposure and/or contamination.
- There is a risk of high solids loading at the high-efficiency particulate air (HEPA) filters and pre-HEPA filters, resulting in excessive radiological exposure/contamination of maintenance personnel, high operations costs and high filter disposal costs.
- In the event the HCC filter plugs, the HCC internal pressure is not relieved during the HIP machine cool-down phase. In this event, the HCC would remain under high internal pressure (7,000 to 10,000 psia), and removal of the processed HIP cans from the HCC would be an off-normal event.

The problem of calcine powder flow comes from potential changes that might have occurred in the calcine that has been stored for over 40 years under pressure and elevated temperatures[32] in the in the center of bins in the Calcined Solids Storage Facility (CSSF). Compositional and particle size variability has been found in the bins; however, sample analyses of calcine that had been stored in the CSSFs for approximately a decade showed no evidence of agglomeration or change in particle size from that when the calcine was originally formed.

The physical properties of the as-calcined liquid waste have been characterized, and studies of the effect of high temperature and pressure on calcine in CSSF storage conditions have been documented; the following are paraphrased statements from some of previously referenced sampling reports. Calcine is a dry, porous, granular solid consisting primarily of small, rounded particles. The fluidized-bed calciner produced two sizes of solids: coarse product particles that were more than 0.2 mm in diameter and stayed in the fluidized bed and calcine fines particles smaller than 0.2 mm that were entrained in the calciner off-gas. The bulk density and particle size of the coarse calcine product are well known, but less data about the properties exist for the calcine fines. All coarse calcine product is a free-flowing granular solid, regardless of the chemical composition of the calcine. Calcine fines do not flow readily and are more difficult to handle. Calcine flow characteristics data from pilot plant calcine can be used to design calcine handling systems for radioactive calcine. However, simulants used in testing are acknowledged to not have identical physical properties as the calcine waste.

---

[32] Most of the calcine has been stored at temperatures lower than that at which it was originally formed during the calcination process.

The 2004 report noted that the Zr-type calcine was easily sampled and flowed effortlessly. The Al-type calcine, however, did not flow readily, required mechanical breakup and shaking to move the calcine, and a fine dust cloud was visible during transfer. The latest direct data from samples taken from the bins is from a 1979 sampling report that stated "The chemical and physical properties of the retrieved calcine after 10-12 years of storage are very similar to freshly prepared simulated calcine." However, some calcine samples required vigorous agitation and prodding to get them to pour, and considerable dust was generated during sieving and pouring.

Summary

The chemical complexities of the Idaho calcine will influence both processes. The HIP process has the advantage of containing all the constituents in the glass ceramic matrix, including mineralized RCRA constituents, within the HIP can. This advantage assumes that the calcine compositional variability can be bounded with one to three formulations and batch sampling is not required. The CDP has an ongoing waste form test program to support data development for BDAT determination under RCRA. An apparent disadvantage of CCIM is the lack of stabilization of volatile toxic metals; however, large-scale melter tests of Hanford wastes suggest that Cd and Pb are not particularly volatile[33].

It is not clear that the characteristics of the calcine can be assumed from previous sampling efforts without significant project risk. Caking, the amount of fines, and segregation of constituents are potential problems that could:

- impact efficiency and radiological safety of retrieval from the bins,
- cause segregation in the HIPed waste, and
- complicate CCIM feed preparation.

Mechanical agitation will likely be needed to aid particle flow. In addition, the uncertain presence of fines could cause filter plugging and present difficulty filling HIP cans and CCIM melters. On the other hand, characterizing each batch could complicate the process flow,

---

[33] Matlack, Gan, and Pegg, *Glass Formulation and DuraMelter™ 10 Testing with Simulated Idaho HLW Calcine*, VSL-08S1540-1, August 2008.

increase plant size, and alter plant operations. It appears, however, that a comprehensive analysis of risks presented by the present knowledge level of chemical and physical properties is warranted, along with the development of technical plans that would reduce or eliminate the identified risks.