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Appropriateness and Readiness of Cold Crucible Vitrification of Calcine Solids at the Idaho Site and H-Canyon Effluent at the Savannah River Site

Savannah River National Laboratory

ICP Idaho Cleanup Project CORE

Prepared for
U.S. Department of Energy Office of Environmental Management

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EXECUTIVE SUMMARY

This report summarizes the results from an assessment of the technology readiness and deployment of cold crucible induction melter (CCIM) technology to vitrify high level waste (HLW) calcine solids at the Idaho Site and H-Canyon liquid effluent at the Savannah River Site (SRS). The assessment was requested by the Department of Energy's Office of Environmental Management (DOE-EM), but is not a DOE 413-3-4a assessment for technology deployment. A joint Savannah River National Laboratory (SRNL) and Fluor Idaho Cleanup Project (ICP) team with subject matter experts evaluated the existent literature and experience both within the DOE as well as relevant external experience. The technology assessment focused on the site-specific technology readiness and appropriateness based on a number of system factors including feasibility and appropriateness of the technology for the specific site application, the potential extent of the regulatory and design challenges, and evaluation of the ability to deploy within the treatment needs of each site. This initial assessment provides information to support DOE-EM in making a go/no-go decision to carry out additional work on the technology maturation for critical decisions and planning.

In this assessment, technology appropriateness and readiness were subjectively evaluated for a proposed CCIM system. This report assumes a disposition path for the HLW as canistered borosilicate glass. Any deviation from that baseline or alternative classification of the waste was not compared against the CCIM.

The appropriateness of the CCIM vitrification technology is well established and has been validated through its widespread use internationally and in industry and more than 10 years of successful operational experience processing HLW from commercial nuclear reprocessing at La Hague. The CCIM technology is considered appropriate for vitrification of HLW at both sites.

The readiness of the CCIM technology is dependent on interface and installation constraints for each of the proposed CCIM applications. Although siting the CCIM in a standalone facility is an option, this assessment focused on retrofitting existing infrastructure for the CCIM. No insurmountable barriers were identified to prevent deployment of the technology at either site, in existing infrastructure. However, some technology maturation tasks were identified that will need to be resolved. The greatest challenge for SRS will be installation of electrical upgrades to power the CCIM in the existing H-Canyon and associated permitting changes. The greatest challenge for Idaho Site will likely be the development of a strategy and system for blending, sampling, and transferring of the material prior to vitrification but this challenge is consistent for any treatment technology with the federal repository as a disposition path. The canister dimension was identified as critical to both sites as it will affect all aspects of the process including design, facility, operations, safety, regulatory compliance, and product acceptance. The approved DOE-EM work authorization for this Technology Development effort included performance of a Task 2 Technology Maturation assessment should Task 1 determine that application of the CCIM technology is feasible. The team recommends performing Task 2 to further identify the development needs for each site, as well as the critical system interfaces and overall system robustness. This preliminary Technology Maturation Plan will provide an overview of the critical path needs for development and transitioning to the CCIM for each site.

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LIST OF ABBREVIATIONS

AMWTP	Advanced Mixed Waste Treatment Project
CSSF	Calcined Solids Storage Facility
CRR	Carbon Reduction Reformer
CCIM	Cold Crucible Induction Melter
DEQ	Department of Environmental Quality
DMR	Denitration Mineralization Reformer
DOE	Department of Energy
DOE-RW	DOE Office of Civilian Radioactive Waste Management
DWPF	Defense Waste Processing Facility
EM	Environmental Management
EPAR	Expected Measurement Acceptability Region
HAD	High Activity Drain
HEME	High Efficiency Mist Eliminator
HEPA	High Efficiency Particulate Air
HLW	High Level Waste
HTGR	High Temperature Gas Reactor
ICP	Idaho Cleanup Project
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
IWTU	Integrated Waste Treatment Unit
LAW	Low Activity Waste
LLW	Low Level Waste
MAR	Measurement Acceptance Region
MU	Measurement Uncertainty
NFPA	National Fire Protection Association
NA-SNF	Non-Aluminum Spent Nuclear Fuel
OGC	Off-Gas Cooler
OGF	Off-Gas Filter
PAR	Property Acceptance Region
PGF	Process Gas Filter
PCCS	Product Composition Control System
ROI	Return on Investment
SRNL	Savannah River National Laboratory
SRS	Savannah River Site

SBW	Sodium Bearing Waste
SOA	State of the Art
SAS	Steam Atomized Scrubber
SBS	Submerged Bed Scrubber
T&FR	Technical and Functional Requirements
TRL	Technology Readiness Level
TRU	Transuranic
WAPS	Waste Acceptance Product Specifications
WASRD	Waste Acceptance System Requirements Document
WESP	Wet Electro-Static Precipitator

1.0 Introduction

Cold Crucible Induction Melter (CCIM) technology is a mature commercial technology that has been deployed internationally to stabilize high level waste (HLW) resulting from nuclear processing activities. In fiscal year 2021, the Department of Energy's Office of Environmental Management (DOE-EM) requested a technology assessment of CCIM Technology for vitrifying high level waste (HLW) calcine solids at the Idaho Site and H-Canyon effluent at the Savannah River Site (SRS).[1] The activity aims to assess the technology appropriateness and to develop a technology maturation plan needed to realize validation and system adequacy of cold crucible vitrification technology for treating each of the aforementioned waste streams. The activity has been implemented using a phased approach, the work being performed as successive tasks.

The initial task, for which this report is concerned, was to assess the appropriateness and readiness of CCIM technology for each application. The purpose of this assessment was to evaluate the technology maturation outlook for the aforementioned applications to enable DOE-EM to make a more informed decision to carry out further work on the technology and to proceed with critical decisions and planning.

This task focused on evaluating the CCIM technology for each site based on a number of criteria, including, for example:

- *Vitrification potential of wastes*
- *Operational constraints*
- *Physical space requirements*
- *Product/system mismatch*
- *Material handling systems/Material Regulations & Repository*
- *Regulatory compliance and permitting changes*
- *Product acceptance*
- *Facility safety considerations*
- *Off-gas handling and system components*
- *Flowsheet adaptability*

The assessment also considered missing or critical information, data, and performance criteria needed to achieve validation and system adequacy for each site. The set of assessment criteria listed above were used in combination with baseline assumptions to order to facilitate a like comparison across both sites. Although the unique site requirements limited a common set of design basis assumptions, common technical specifications were assumed wherever practical.

2.0 Background

Cold crucible vitrification technology has matured globally for radioactive waste vitrification applications, but has not been applied across the DOE complex. The technology is currently used to vitrify HLW waste in radioactive and non-radioactive environments outside the US including France and the UK. Russia and South Korea have also performed extensive evaluations for vitrification of their radioactive waste using CCIM technology. Several non-radiological and scaled demonstrations with cold crucible vitrification technology have been performed with DOE waste simulants in the past decade or more. These tests were preliminary in nature and proof-of-concept driven.

There exists potential to develop cold crucible technology for specific use across the DOE to stabilize existent wastes for which the available stabilization strategies are not viable or cost prohibitive. Specifically, an evaluation of cold crucible vitrification to stabilize the Savannah River Site's (SRS) H-Canyon effluent at the point of generation has considerable opportunity to decouple the canyon from the liquid waste system to enable greater operational flexibility and reduce long-term economic and environmental cost associated with existent and future missions. H-Canyon is a production-scale, radiologically-shielded chemical separations facility and is the only DOE operating reprocessing facility in the United States. H-Canyon operations historically recovered material from the SRS nuclear reactors to support the United States' nuclear weapons program. More recently, H-Canyon's mission is focused on nonproliferation and environmental cleanup.

Concurrently, an evaluation of cold crucible vitrification to stabilize HLW calcine solids, stored at the Idaho Site, provides an opportunity to convert the calcine waste into a form that can be safely dispositioned while reducing the long term storage risks. Calcine solids are the result of reprocessing multiple nuclear fuel types from 1953 to 1992 at the Idaho Nuclear Technology and Engineering Center (INTEC). This reprocessing involved multiple cycles of solvent extraction and then calcining of the radioactive liquid raffinates. A total of approximately 8 million gal of liquid high-level tank waste was converted to 4,400 m^3 of granular solid HLW calcine, the current amount in storage. The 1995 Idaho Settlement Agreement requires that the 4,400 m^3 of calcine material must be ready for departure from Idaho by 2035. There is no established treatment process for the calcine waste, and it cannot be transported or dispositioned in its current form. An evaluation of implementing cold crucible vitrification technology will support the establishment of a more reliable waste processing and waste form disposition option and provide greater flexibility to the Department.

A comprehensive evaluation of cold crucible vitrification technology to stabilize calcine waste at the Idaho Site and H-Canyon effluent at SRS remains to be undertaken. Nevertheless, cold crucible vitrification technology is not considered to be the primary limiting factor; the technology is well established as a method to produce borosilicate glass, which is an acceptable waste form, and the technology builds on over 25 years of experience with HLW vitrification in the DOE complex. Rather, the appropriateness of the technology and its implementation into existing process flowsheet and infrastructure constraints at each site is less understood.

3.0 Common Design Basis and Assumptions

This assessment assumes HLW that is vitrified as borosilicate glass and canistered for disposal to be the baseline state of the art (SOA). Table 3-1 summarizes assumptions for the CCIM system and the waste package used to guide this evaluation. The CCIM baseline configuration was based on a proposed retrofit of the Defense Waste Processing Facility (DWPF) for a CCIM conducted in 2007.[2] These assumptions were used to establish a baseline CCIM system and common disposal requirements to facilitate comparison between the sites and DOE-EM decision making. Other site-specific assumptions used to evaluate the CCIM vitrification technology were based on available projections or practical assumptions and are identified in subsequent discussion.

Table 3-1. Summary of baseline specifications.

Item	Assumption
Waste Package	- Canistered borosilicate HLW glass
CCIM melter system	**Crucible System** - 650 mm CCIM (refer to [3] for overall dimensions) - Maximum glass melting rate: 100 kg/h - Operating frequency: 150 kHz - 350 kHz - 600 kW power supply - High Frequency Generator (HFG) (3.5m x 0.6m x 2.2m (l x w x h)) - Impedance Adaptor: 1.5m x 0.6m x 2.2m (l x w x h), located as near as possible to CCIM **Cooling System** - Cooling water required to be between 105°C and 120°C at 2 to 3 bars. - Cooling Loop 1 (shell of the CCIM processing vessel): ~250 gal/min. - Cooling Loop 2 (high-frequency equipment). ~350 gal/min.

4.0 Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60.[4] This document was reviewed by design check. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.[5] Supplementary information for this report is stored in electronic laboratory notebook experiment G2434-00225-10.

Requirements for performing reviews of technical reports and the extent of review are established in manual MCP-135 for the Idaho Cleanup Project (ICP) Core.

5.0 Evaluation of Criteria

5.1 Vitrification Potential of Wastes

Vitrified borosilicate glass is currently the only acceptable HLW form that is in production in the United States. As such, a critical factor in this assessment of the suitability of the CCIM, is whether the waste streams can be expected to readily form acceptable waste glass. Site-specific considerations are described subsequently.

5.1.1 H-Canyon

There is great diversity in the SRS fuel inventory, which is destined to be processed though H-Canyon. It is expected that H-Canyon will process much of this fuel diversity in the later years of operations, regardless of the cleanup approach that is pursued in the coming decade. This is because material that is more diverse, is also more difficult to process and presents greater risk. Four primary waste streams were identified that should be considered when assessing future use of a CCIM to process H-Canyon effluent:

5.1.1.1 Al-Clad Fuel

Flowsheets exist for Al-clad spent nuclear fuel (SNF), and vitrification of those waste streams is not considered problematic as that fuel is currently processed through the DWPF.

5.1.1.2 Non-Al Clad Fuel

The portion of the inventory that poses the greatest challenge to process is non-aluminum SNF (NA-SNF). A description of the NA-SNF inventory, for which many flowsheets are unproven or potentially hazardous, is summarized in Figure 5-1. The waste streams associated with much of the NA- SNF do not exist, and an evaluation of their suitability for vitrification via CCIM is speculative. If a general dissolution flowsheet is assumed, then it is probable that vitrification will be suitable under existing procedures and processes. While it is unlikely that the CCIM would not be able to produce some vitrified product, it is noted that some of the NA- SNF contains high concentrations of Zr and Be, which may be problematic to incorporate into a vitrified product with high waste loading.

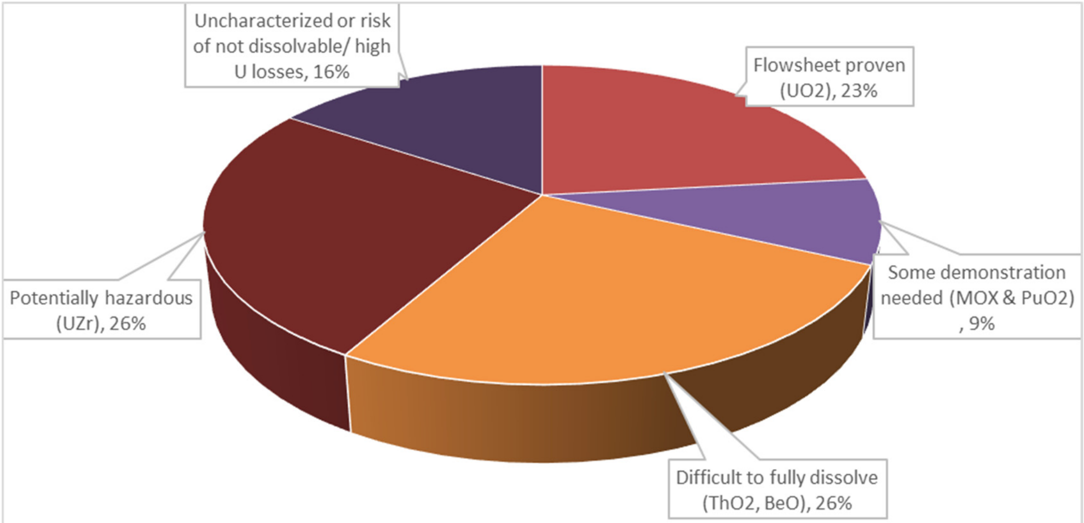

Figure 5-1. Inventory grouping of NA-SNF at SRS.

5.1.1.3 High Temperature Gas Reactor (HTGR) Fuel

Process flowsheets for treating fuel from High Temperature Gas Reactor (HTGR) systems have been developed and are patterned to take advantage of the technical maturity of legacy systems such as the DWPF off-gas system. Engineering-scale testing has been deployed for many of the critical components. Condensate and effluents of the off-gas system for the primary digester would be calcined along with the fuel kernels and shells to reduce carbon and oxidize any metals prior to being fed to a melter.

5.1.1.4 Sample Returns from SRNL to Include the High Activity Drain (HAD)

SRNL currently returns samples (experimental residues) to the SRS tank farm for disposition. Any future change to this arrangement should be considered for the impact to SRNL. The volumes and concentrations of the residues and sample returns from SRNL are not expected to impact the vitrification potential of the above mentioned wastes as the SRNL residues represent but a fraction of a percentage of the total waste and are traditionally sample returns from HLW processing. However, if the tank farm is decoupled from H-Canyon, material movement from SRNL directly to H-Canyon will be needed, or a different disposal route for SRNL residues will need to be assessed. It is noted, that a disruption to directly returned residues to SRS may have a significant impact on SRNL operations.

5.1.2 ICP Core Calcine

Due to the multiple fuel/cladding designs that were reprocessed at INTEC, various chemical compositions of calcine exist within the different Calcined Solids Storage Facility (CSSF) bins and are stratified within each of the bin sets. There are four main types of calcine: aluminum, Zirconium, Fluorinel/sodium bearing waste (SBW) Blend, and Aluminum Nitrate/SBW blend (See Table 6 of [6]). The calcine can be high in alumina, or zirconia and calcium oxide, fluoride, and sulfate, all of which can adversely affect glass properties. The calcine composition varies greatly by CSSF bin set and is layered within each CSSF bin set. Glass-ceramic formulations for non-radioactive pilot-plant Run 78 calcine (zirconia/sodium) and composite blend calcine have been developed that allow waste loadings of up to 45 wt%.[7] In a more recent study,[8] the researchers demonstrated glass waste loadings in a joule-heated ceramic melter of 35 wt% waste oxides for alumina calcines and 30 wt% waste oxides for zirconia calcines. Testing of these formulations in a joule-heated ceramic melter showed glass production rates of over 5000 kg/(m^2/d) for the alumina calcine and over 8500 kg/(m^2/d) for the pilot-plant Run 78 calcine.

Both SRNL and Orano[9] have used a systematic approach for glass formulation development and qualification; however, significant development work, such as use of bench-scale and/or pilot-scale systems, to include feed preparation and delivery with melter off gas system testing, will be required to identify and qualify Idaho Site calcine/frit blends for the different calcine compositions.

Based on the chemical composition of the calcine and the stratification of these different compositions within one bin set, it is expected that batch feeding of the calcine with a custom frit would be required before being sent to the CCIM. Continuous processing of the calcine would have the benefit of requiring less time to process the calcine, but it is unknown how the calcine would be mixed or blended or if a single frit could accommodate the calcine variation.

A high-level assessment of the various calcine chemical compositions paired with an array of 10,647 frit compositions (incremental combinations of the five oxides: Li_2O, Na_2O, Al_2O_3, B_2O_3, and SiO_2) at 1-40 wt% waste loading (WL) was performed using the DWPF Product Composition Control System (PCCS) models and their associated Measurement Acceptance Region (MAR) constraints.[10] The PCCS is a statistical system that has guided acceptability decisions for processing at the DWPF since the start of radioactive operations in 1996.[11] While not directly applicable to the calcine solid processing flowsheet or the CCIM constraints, the MAR assessment provides insight into the ability to formulate acceptable glass compositions based on the calcine solid compositions. This assessment evaluated the acceptability of each projected glass composition with respect to the PCCS processing and product performance criteria. The results of the MAR assessment are summarized in Table 5-1. Table 5-1 indicates the WL for which acceptable frits are available and the failing constraint distribution for the total array of frits. The maximum WL is presented with the accompany percentage point range available to a single frit with the maximum waste loading. For example, for CSSF III with Al_2O_3 @ at 0-2% (in the frit) and no F, the waste loading range is 13 percentage points with a maximum waste loading of 18%. At 18% WL, 19.8% fail Del Gp (energy of hydration term), 14.7% fail low viscosity, and 59.9% fail high viscosity. Note, the percentage of failed and acceptable compositions will not necessarily sum to unity because some compositions fail multiple constraints simultaneously. Based on the results of the MAR assessment, there are frit compositions that can be developed to vitrify the calcine waste; however, the assessment also shows that it is unlikely that one recipe will be sufficient for all of the calcine types. Some of the CSSF bins contain high concentrations of F (>15 wt%) which limits the direct vitrification of calcine from those bins. However, if F is removed from the calcine chemical compositions used for the MAR assessment (designated by "No F" in Table 5-1), maximum WL between 14 and 28 wt% were predicted to be achievable, within existing PCCS constraints. For CSSFs I and VI, high viscosity (process constraint) and nepheline precipitation (waste form affecting) were limiting constraints at higher waste loadings, whereas high viscosity was the primary limiting constraints to higher waste loadings for CSSFs II-V. This result is not unexpected given the concentration of Al_2O_3 in the calcine. High SO_4 was also found to be a limiting constraint to higher WL in the MAR assessment; however, DWPF now imposes the SO_4 constraint administratively (outside of the formal PCCS application)[11] based on sludge-batch specific evaluations and experimental studies. Similarly, applying an administrative SO_4 constraint to this assessment would likely result in acceptable glass compositions at higher WL for most of the bins.

The above analysis was based on average CSSF bin compositions, but the calcine is known to be heterogeneous and compositionally stratified in the bins. Figure 5-2 shows schematically the chemical stratification across one of the calcine bins (calcine bin set 3). The calcine waste has four basic chemical compositions based on the type of cladding in the original fuel rod (e.g., aluminum, zirconium, etc.) and there are other compositional differences depending on the additives (e.g., mercury, chromium, etc.) used during calcination that could have a significant impact on the vitrification process. A process to account for these differences (e.g., a strategy to use more than one glass additive or a method to mix and homogenize the calcine waste prior to vitrification) is needed to determine the flowsheet options for an integrated system

Table 5-1. Summary of the Measurement Acceptance Region (MAR) assessment for calcine.

Assessment Parameters	CSSF ID	Max WL pts (range) (wt%)	Failed Constraint(s) % of glasses @ MAX WL that fail
WL: 0 - 40 (wt%) Al_2O_3: 0-2 (wt%)	CSSF-I	15 (8-22)	lowv:2% highv:88.3% Neph:41.8%
	CSSF-II		NaF: 100%
	CSSF-III		
	CSSF-IV		
	CSSF-V		
	CSSF-VI	24 (5-28)	Del Gp:0.6% lowv:4% highv:82.7% Neph:50.9%
WL: 0 - 40 (wt%) Al_2O_3: 0-2 (wt%) No F	CSSF-I	15 (8-22)	lowv:2% highv:88.3% Neph:41.8%
	CSSF-II	17 (3-19)	Del Gp:8.8% lowv:9.6% highv:69.9% Neph:2.5%
	CSSF-III	13 (6-18)	Del Gp:19.8% lowv:14.7% highv:59.9%
	CSSF-IV	12 (7-18)	Del Gp:22.3% lowv:16% highv:58.1% R2O:6.7%
	CSSF-V	10 (5-14)	Del Gp:24.9% lowv:16.1% highv:56.9% R2O:9.5%
	CSSF-VI	24 (5-28)	Del Gp:0.6% lowv:4% highv:82.7% Neph:50.9%
WL: 0 - 40 (wt%) Al_2O_3: 3-5 (wt%) No F	CSSF-I	14 (7-20)	Del Gp:0% lowv:2.9% highv:86.5% Neph:46.7%
	CSSF-II	19 (1-19)	Del Gp:6.4% lowv:9.7% highv:71.4% Neph:11.2%
	CSSF-III	18 (1-18)	Del Gp:16.2% lowv:14.8% highv:61.5% Neph:1.4%
	CSSF-IV	18 (1-18)	Del Gp:18.4% lowv:16% highv:59.7% Neph:1.1%
	CSSF-V	14 (1-14)	Del Gp:20.8% lowv:16.2% highv:58.6% Neph:0.9%
	CSSF-VI	24 (3-26)	Del Gp:0.7% lowv:4.8% highv:81.6% Neph:56.4%

Del Gp = energy of hydration term (related to durability of glass); lowv = low viscosity; highv = high viscosity; Neph = nepheline constraint (related to durability of glass); SO4 = sulfate limit; NaF = fluorine limit; R2O = sum of alkali

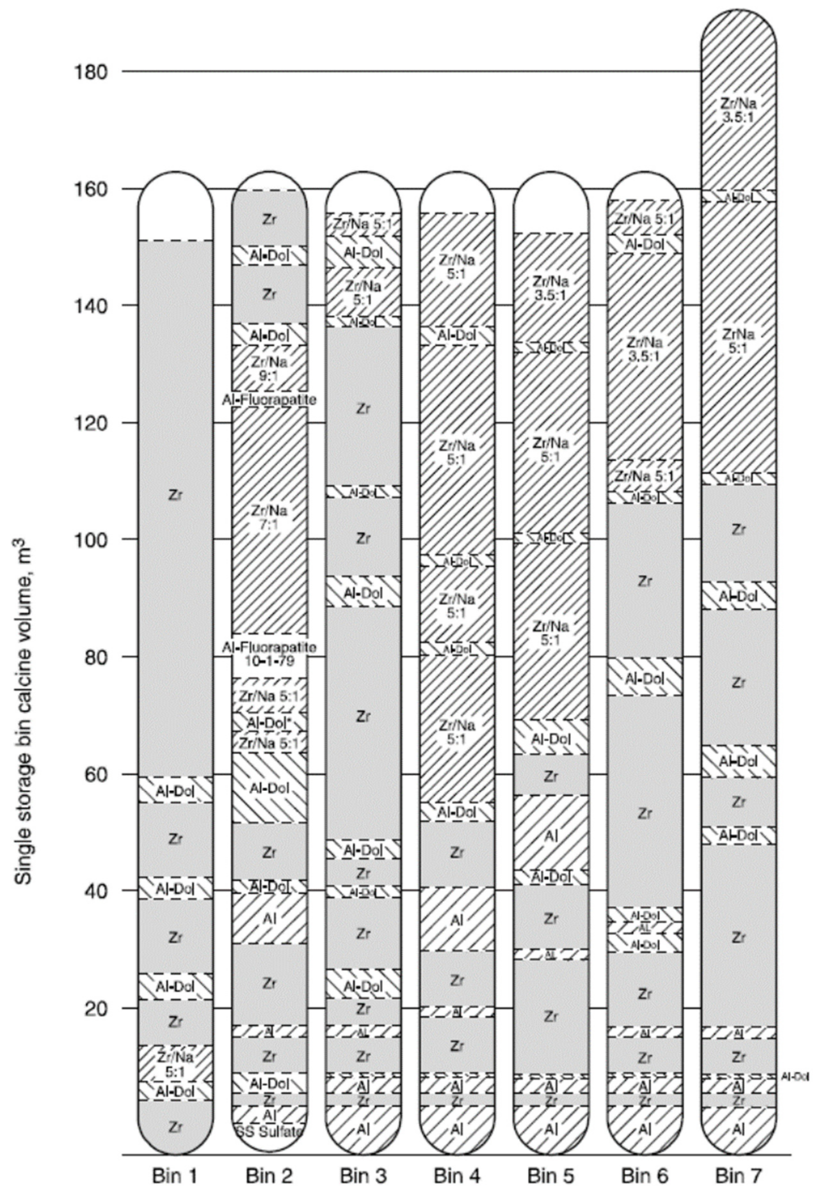

Figure 5-2. Qualitative representation of the chemical stratification in the calcine bins for CSSF III. [6]

5.2 Product Acceptance

For this evaluation it is assumed that both H-Canyon effluent and Idaho calcine solids are vitrified and managed as HLW. Additionally, some discussion is provided on the possible path to dispose of calcine as non-HLW under DOE's recently published interpretation of the HLW definition.

Since the late 1980s, DOE has put forth significant effort to establish the framework to safely dispose of vitrified HLW. The product acceptance and regulatory compliance for HLW producers is documented in the Environmental Management (EM) Waste Acceptance Product Specifications (WAPS).[12, 13] The WAPS are the technical specifications waste form producers are required to meet in order to ensure acceptance of their vitrified HLW into the Civilian Radioactive Waste Management System (CRWMS). The EM-WAPS derive from the acceptance specifications for vitrified waste developed by the DOE Office of Civilian Radioactive Waste Management (DOE-RW) for the SRS Defense Waste Processing Facility and West Valley Demonstration Project[14] and the *Waste Acceptance System Requirements Document (WASRD)*,[15] which included requirements for both SNF and HLW. The DOE Office of Environment Management (DOE-EM) extracted the HLW requirements from the WASRD and put them into the WAPS.

The WAPS governs all elements of vitrified HLW under four technical specifications:

- ***Waste Form Specifications*** *(e.g., chemical, radionuclide inventory, product consistency, and phase stability)*
- ***Canister Specifications*** *(e.g., material, fabrication, identification and labeling, and size)*
- ***Canistered Waste Form Specifications*** *(e.g., waste product, fill height, external contamination, heat generation, dose rates, subcriticality, weight and overall dimensions, drop test, and handling features)*
- ***Quality Assurance Specifications***

Additional specifications relating to documentation and other requirements are also included in the WAPS.

Compliance with the waste acceptance process in the WAPS is demonstrated through four different required documents, each prepared by the producers, reviewed and accepted by DOE-EM, and provided to DOE-RW. These four documents are:

- *Waste Form Compliance Plan*
- *Waste Form Qualification Report*
- *Production Records*
- *Storage and Shipping Records*

Current producers identified in the WAPS are the Defense Waste Processing Facility at SRS, the Waste Treatment and Immobilization Plant at the Hanford Site, and the West Valley Demonstration Project in New York. H-Canyon and Idaho are not listed producers. Considerations specific to H-Canyon effluent and Idaho calcine regarding product acceptance and regulatory compliance are described subsequently.

A program to ensure product acceptance will need to be developed to support any installed CCIM vitrification system at either site. In order to meet the WAPS for the borosilicate glass HLW form produced at DWPF, a Glass Product Control Program (GPCP) was implemented.[16] The GPCP ensures the glass product acceptability and documents that the specifications have been met. A major component of the GPCP is PCCS.[11] Through PCCS, process and product properties are assessed through models that relate each of the properties to the chemical composition of the glass, which is determined from measurements of in-process samples taken during operations that precede the DWPF melter. A set of waste solubility constraints on the resulting glass product involving select elements (e.g., Ti, Cl, F, Cr, S, Cu, and P) also must be satisfied. The PCCS, has evolved over the decades of application at SRS and is currently in Revision 6. The PCCS is continuously evaluated and maintained to update the guiding constraints. Table 5-2 reproduces information from the PCCS reference documents showing the original constraints and the current version of the constraints.[11] Comparison of these two sets indicates that the original alumina and homogeneity constrains were combined into a single homogeneity constraint involving Al_2O_3 and TiO_2. The upper level of melt viscosity was also increased from 100 to 110 poise. The solubility constraint for TiO_2 was increased from 1.0 wt% to 6.0 wt% with concurrent viscosity modeling constraints indicated. The original phosphorous constraint (as either PO_4 or P_2O_5) was removed. Lastly, the nepheline constraint was added in response to high-alumina content of some SRS sludge batches. The nepheline discriminator was found to be a reliable aid in identifying glass compositions that are likely to form this primary crystalline phase in product glass.

PCCS was developed to process legacy HLW that was generally obtained from the dissolution of aluminum-clad SNF from the SRS reactors via the H-area modified plutonium-uranium extraction (PUREX) process. The NA-SNF at SRS would most certainly require revisions to the existing range of PCCS compositions for existing wet-based HLW slurries from either F or H tanks farms at SRS. A program to ensure product acceptance would need to be considered for both the Idaho calcine HLW and some of the proposed H-Canyon effluents for CCIM processing.

Table 5-2. Comparison of original and revision 6 PCCS constraints.

Name	Type	Constraint (1996, Original)	Constraint (2017, Revision 6)
Conservation (sum of oxides)	Laboratory Specification	95% ≤ ∑ (Major Oxides in wt(%)≤ 105%	95% ≤ ∑ (Major Oxides in wt%) High Conservation - ∑ (Major Oxides in wt%) ≤ 105%
Durability	Product Quality	B, Li and Na Leach ≤ EA glass Leach based upon PCT results	B, Li and Na Leach ≤ EA glass Leach based upon PCT results
Alumina	Product Quality	g Al_2O_3 / 100 g glass ≥3.0	
Homogeneity	Product Quality	1.6035 sludge + 5.6478 frit > 216.8092 (Sludge and frit components, each as a wt%)	For TiO_2 ≤ (2 wt% - MU) Al_2O_3 ≥(3.0 wt% + MU) and ∑:alkali ≤ (19.3 wt% - MU) or Al_2O_3 ≥ (4.0 wt% + MU) For TiO_2 > (2 wt% - MU); Al_2O_3 ≥ (4.0 wt% + MU)
Frit Loading	Product Quality	70% ≤ ∑(Frit Oxides in wt%) ≤ 85%	
Liquidus Temperature	Process-ability	Liquidus Temperature (T_L) ≤ 1050ºC	Liquidus Temperature (T_L) ≤ 1050ºC
Melt Viscosity at 1150ºC	Process-ability	20 ≤ Viscosity (η) ≤ 100 poise (P)	20 poise (P) ≤ Viscosity (η) (with TiO_2 ≤ (6.0 wt%- MU) constraint met) Viscosity (η) ≤ 110 poise (P) (with TiO_2 ≤ (6.0 wt%- MU) constraint met)
TiO_2	Waste Solubility	g TiO_2 / 100g glass ≤ 1.0	g TiO_2 / 100g glass ≤ (6.0 wt%-MU)
NaCl	Waste Solubility	g NaCl / 100g glass ≤ 1.0	g NaCl / 100g glass ≤ 1.0
NaF	Waste Solubility	g NaF / 100g glass ≤ 1.0	g NaF / 100g glass ≤ 1.0
Cr_2O_3	Waste Solubility	g Cr_2O_3 / 100g glass ≤ 0.03	g Cr_2O_3 / 100g glass ≤ 0.03
SO_4 or Na_2SO_4	Waste Solubility	g SO_4 / 100 g glass ≤ 0.40 g Na_2SO_4 / 100 g glass ≤ 0.59	g SO_4 / 100 g glass ≤ 0.40 g Na_2SO_4 / 100 g glass ≤ 0.59
Cu	Waste Solubility	g Cu / 100g glass ≤ 0.05	g Cu / 100g glass ≤ 0.05
PO_4 or P_2O_5	Waste Solubility	g PO_4 / 100g glass ≤ 3.0 g P_2O_5 / 100g glass ≤ 2.25	
Nepheline	Product Quality		$(SiO_2) / (SiO_2 + Na_2O + Al_2O_3) > 0.62$

MU= Measurement Uncertainty; EA=Environmental Assessment[17]; PCT=Product Consistency Test (ASTM C1285)

5.2.1 H-Canyon

Vitrification of the H-Canyon effluent would conceptually be similar to the existing DWPF operations. As such, potential changes to the WAPS that might arise from CCIM processing can be expected to be limited. The most likely changes would include potential changes to the canister dimension specification and the canister fissile limit specification. The specified canister dimensions in the WAPS are relatively large, ~4.5x greater by volume, compared to the standard canister used in the CCIM vitrification facilities at La Hague. Furthermore, a smaller canister could make processing operations more manageable given the confined H-Canyon space as well as reducing the weight of each canister. The canister fissile limit may also need to be revised for programmatic or operational reasons. Increased fissile limits (e.g. > 2,500 g/m^3) have already been demonstrated for DWPF glass with no significant impact to the waste form specification.[18] Both of the aforementioned specifications are considered practical and achievable within the WAPS framework.

Several other specifications, in particular related to the canistered waste form may need to be revised. For example, heat generation, removable radioactive contamination on external surfaces, and maximum dose rates, may be affected by the operation and facility constraints related to the CCIM and retrofit capability and if the HLW product has significantly higher radionuclide loading versus the nominal DWPF glass. Changes to these specifications may be more arduous than the fissile loading or the canister dimensions. Alternatively, the existing specifications could be met at the expense of a lower waste loading and more cans being produced.

Revisions needed to other specifications in the WAPS are less likely in the event of vitrification of the H-Canyon effluent using CCIM technology. The standard vitrified HLW produced in a CCIM will be alkali borosilicate glass, which can be expected to meet the existing waste form specifications in the WAPS. However, any alternative waste form, or alkali borosilicate glass not within the composition constraints, would be subject to review by the RW with potential allowance if the waste form complies with the HLW definition listed in the Nuclear Waste Policy Act of 1982.

5.2.2 ICP Core Calcine

Since the initial publication of the WASRD and WAPS, DOE issued DOE O 435.1, “Radioactive Waste Management,” which governs the management of DOE’s radioactive wastes. Section J.(1)(d) of DOE M 435.1-1 Chg 2[19] specifically requires all HLW pretreatment, treatment, storage, packaging, and other operations to be designed and implemented in a manner that complies with the WAPS for vitrified waste or the WASRD for nonvitrified, immobilized HLW. Section K.(2) further addresses waste with no identified path to disposal, and it similarly requires compliance with the WAPS.

At this time, requirements to meet WAPS specifications have not been developed for treatment of Idaho calcine using vitrification, except for some preliminary work that was done in the mid-1990s. As such, requirements will need to be developed and implemented before design and construction of a treatment facility are started.

Progress, however, on some aspects to treat calcine and will support meeting WAPS requirements has been made through initiation of the Calcine Disposition Project.[20] The Calcine Disposition Project mission is to determine and implement the final disposition of calcine including characterization, retrieval, treatment (if necessary), packaging, loading, on-Site interim storage pending shipment to a repository or interim storage facility, and disposition of related facilities. At this time, significant progress has been made in the areas of waste characterization and waste retrieval. With respect to **waste characterization**, a report initially issued in 2005, *Calcine Waste Storage at the Idaho Nuclear Technology Engineering Center*,[6] provides the definitive volume, mass, and composition (chemical and radioactivity) of calcine stored at INTEC in the CSSF bin sets. The calcine composition information is needed for tasks such as performing facility safety analyses, ensuring regulatory compliance, and developing future waste-treatment and disposal processes. With respect to **waste retrieval**, the Calcine Retrieval Project was initiated in 2016 to develop and test a full-scale retrieval system to demonstrate DOE's ability to safely retrieve calcine from CSSF 1 and transfer it to CSSF 6. Construction and installation of the full-scale bin replica and transfer equipment were completed in early 2019 and testing is ongoing. This initiative is providing design-basis information that will be applicable, regardless of the eventual disposal decision.

Progress on the remaining components of the Calcine Disposition Project (i.e., treatment, packaging, loading, storage, and disposal) has been limited due to the lack of congressional funding, schedule delays associated with IWTU, and no designated long-term disposal site.[21] The current Calcine Disposition Project baseline is to repurpose the IWTU once the sodium bearing waste treatment mission is complete and install hot isostatic pressing units to treat calcine (the selected treatment for calcine per 75 FR 137).[22] It may be possible, if DOE issues a Record of Decision (ROD) amendment documenting a different treatment decision, to update or revise preliminary documents developed for calcine treatment using hot isostatic pressing or the IWTU waste acceptance documents to include vitrification or direct disposal processes. However, this assessment did not determine the scope of effort to do so, nor did this assessment identify the existing documents or established technical specifications that could be used to do so.

Direct disposal of calcine is another possibility with DOE's recent interpretation of the definition of the statutory term HLW as set forth in the Atomic Energy Act of 1954, as amended (42 USC 2011 et seq.),[23] and the Nuclear Waste Policy Act of 1982, as amended (42 USC 10101 et seq.).[24] As DOE stated in the October 2018 Federal Register Notice (83 FR 196)[25] and reiterated in the June 2019 Supplemental Federal Register Notice (84 FR 111),[26] DOE interprets the statutory term such that some reprocessing wastes may be classified as non-HLW and may be disposed of in accordance with its radiological characteristics.

The revised interpretation allows for waste resulting from spent nuclear fuel reprocessing to be characterized as non-HLW if it:

I) does not exceed concentration limits for Class C low-level radioactive waste as set out in section 61.55 of title 10, Code of Federal Regulations, and meets the performance objectives of a disposal facility; or

II) does not require disposal in a deep geologic repository and meets the performance objectives of a disposal facility as demonstrated through a performance assessment conducted in accordance with applicable requirements.

Since calcine is waste resulting from the reprocessing of SNF, if it can meet one of the two criteria above, it "may be classified and disposed in accordance with its radiological characteristics in an appropriate disposal facility provided all applicable requirements of the disposal facility are met" (86 FR 111).[27] DOE recognizes that development of the disposal path forward under either criterion will be dependent on executing a number of technical and regulatory steps including meeting the WASRD requirements for nonvitrified waste.

In summary, there are challenges with implementing the CCIM technology to treat calcine because Idaho will need to develop and implement a program that will ensure product acceptance per the WAPS requirements; however, these challenges are not insurmountable, and will be required regardless of disposition path. The Idaho Site has done some preliminary work to implement WASRD and WAPS requirements and other DOE sites have existing programs that Idaho could reference and then tailor as needed to meet their mission objectives and regulatory obligations. Additionally, it may be possible to identify and review historical program documents associated with hot isostatic pressing and IWTU to determine if they are valid and usable if they are updated to reflect a decision to treat calcine with the CCIM technology.

DOE also has the option to pursue direct disposal of calcine if it can be managed as non-HLW under the HLW definition interpretation that was issued in the 2018 Federal Register Notice and 2019 Federal Register Supplemental Notice. Though this is a viable path, it will require a significant coordinated effort by DOE to ensure all regulatory requirements are satisfied.

5.3 Product/System Mismatch

The utility of the CCIM derives from its versatility to process a variety of waste streams thru a single melter system. A distinct advantage of CCIM technology is the relatively simple design and resistance to degradation of the refractory furnace box. CCIMs utilize an electromagnet designed to internally heat the feed material through induced eddy currents. Since the feed material itself is heated, very high temperatures can be obtained without compromising the materials of construction and relatively pure melts can be achieved since the material itself acts as its own containment. Because CCIMs consist of a power supply with interchangeable work-heads, they can be designed with a high-level of versatility. CCIMs can be integrated into batch or continuous processing systems and can be fed directly with calcine or liquid feed. The CCIM at La Hague uses a two-step system to first calcine the liquid feed, and direct liquid feeding at rates as high as 60 L/hr have been demonstrated at the R&D vitrification facility (CEA Marcoule).[28] The CCIM at La Hague has been operating for more than 10 years of continuous feeding and has produced ~1000 canisters of HLW borosilicate glass. The CCIM at La Hague is qualified up to 45 kg/hr of calcine feed and up to 1 curie/g of glass. Inspections of the melter show glass with highly corrosive constituents, e.g. P and Mo, easily detach from the CCIM refractory and show corrosion-free material.[29]

Given the maturity and demonstration of CCIM technology for the vitrification of HLW, it can be expected to provide a vitrified product without special equipment. Maintenance will be required, but CCIMs can be developed modularly with components that can be removed remotely, and major demonstrations of maintainability have been performed.[28, 29] Lessons learned from CCIM technology deployed internationally establish a techno-economic justification for full-scale, mirrored facilities. These full-scale, non-radiological facilities are critical to attainment of the CCIM system as they allow troubleshooting operational issues, practice for maintenance activities, and continuous improvement without introducing layers of uncertainty and assumptions that accompany scaled systems. An initial investment in a full-scale support facility should be considered for long-duration and developing missions to guard against future risk and reduce the overall life-cycle costs. The return on investment (ROI) from a full-scale support facility may exceed the costs incurred using incremental scaled testing as the alternative.

5.4 Operational Constraints

A retrofit of existing infrastructure to integrate a CCIM at either DOE site would need to consider operational constraints and the potential to mitigate or surmount any limitations would need to be understood.

5.4.1 H-Canyon

It is assumed that the CCIM technology, if employed for H-Canyon effluent vitrification, would utilize the same processes and equipment at the DWPF, wherever practical. This assessment is primarily concerned with installing a CCIM within H-Canyon, but another option is a stand-alone modular facility. Because H-Canyon is an operating facility, many of the existing components, instruments, and capabilities are known and can be re-purposed for a CCIM system. Nevertheless, the following general constraints should be considered:

- All equipment designed or selected shall be modular in nature and able to be picked and placed with a 50-ton crane.
- All equipment shall be designed to be easily removable so that critical components can be replaced safely and easily.
- Equipment shall be selected to last at least 3 years in a radiologically hot environment to satisfy projected mission requirements.
- All equipment shall be designed to utilize existing standard Hanford connectors where possible.
- All equipment shall be designed to utilize the existing positioning trunnions and guides that exist in the H-Canyon.
- H-Canyon lacks sufficient installed power to operate a baseline CCIM.

5.4.2 ICP Core Calcine

It is assumed that the CCIM technology, if deployed for the Idaho cleanup project, would utilize a retrofitted IWTU facility. Further evaluation would be needed to determine if this assumption provides the best path forward to process the calcine to a point where it is ready by the 2035 milestone. Based on technical drawings and specifications,[30-40] the following IWTU facility operational constraints should be considered:

5.4.2.1 Cranes

- The IWTU Maintenance Crane, CRN-SRC-987, covers the entire length and width of the process room, and is equipped with a 20-ton main hoist, a 5-ton auxiliary hoist and a 1-ton auxiliary hoist.
- The Transfer Bell Crane, CRN-SRC-985, is dedicated to the transport of the Transfer Bell and its contents. The Shielded Transfer Bell has two hoists, the Canister hoist, with a capacity of 8000 lbs., and the Shield Plug/Cask Lid hoist, also with a capacity of 8000 lbs.

5.4.2.2 Utilities

5.4.2.2.1 Electrical

- Commercial power from two separate and independent sources is fed to Substation 2, then Substation 15, then to the IWTU Power Distribution Switch which provides redundancy. Only one source is required. Both feeds are in the same concrete duct banks in separate raceways. The duct banks are very robust and resistant to accidental breach. There is an existing available electrical supply of 1800 Amps @ 480 Volts, which should be adequate power for two CCIM units as described in the outline provided.

5.4.2.2.2 Compressed (Plant) Air

- The compressed air supply for a CCIM installation should be more than adequate. INTEC is currently installing two new Ingersoll Rand TA3000 500hp air compressors to provide air for INTEC and the IWTU. In addition, IWTU is installing a its own new compressor with a free air delivery capacity of 1175 cfm.

5.4.2.2.3 Process Water

- Production of the process water streams is characterized by redundant wells, storage vessels, pumps, and distribution headers. Failure of individual components and equipment is mitigated by redundancies such that alternate supply routing maintains reliability of supply, with the exception of the Utility Tunnel. All process water streams are routed through the Tunnel which poses a single-point failure for disrupting supplies.

- The IWTU has a small demand for process water. During operation usage is typically on the order of 30-35 GPM. If the demand increases to 100 gpm, or more, an upgrade to the INTEC treated water pumps should be considered.

5.4.2.2.4 Steam

- Steam to IWTU, and condensate return from IWTU, is provided from INTEC via the Utility Tunnel and buried piping. The INTEC steam production system is robust, comprised of redundant boilers, pumps, lines, and tanks except for the main distribution pipe in the Utility Tunnel. These redundancies provide for a reliable source of steam.

5.4.2.2.5 Process Gases

- Oxygen – (1) 11,000-gallon liquid oxygen storage tank
- Nitrogen - (1) 50,000 gallon and (2) 11,000-gallon liquid nitrogen storage tanks

5.5 Process Flowsheet and Physical Space Constraints

The CCIM can conceptually be installed in two basic configurations: (1) retrofitted into existing facilities or (2) positioned as a standalone system that is integrated into existing processes. The physical placement of the CCIM system will not fundamentally affect performance or product quality, however, the installation configuration would impact facility design and material handling operations. Significant regulatory or permitting considerations may also need to be considered. Therefore, one of the primary objectives of this task was to assess the physical placement of the CCIM system.

5.5.1 H-Canyon

One possible location for the CCIM process would be section 13 and 14 on the hot side of the H-Canyon facility. If this location was selected it would require the removal of three existing mixer-settler tanks, two decanter tanks, and associated piping. Figure 5-3 shows the possible building location and process envelope for the CCIM.

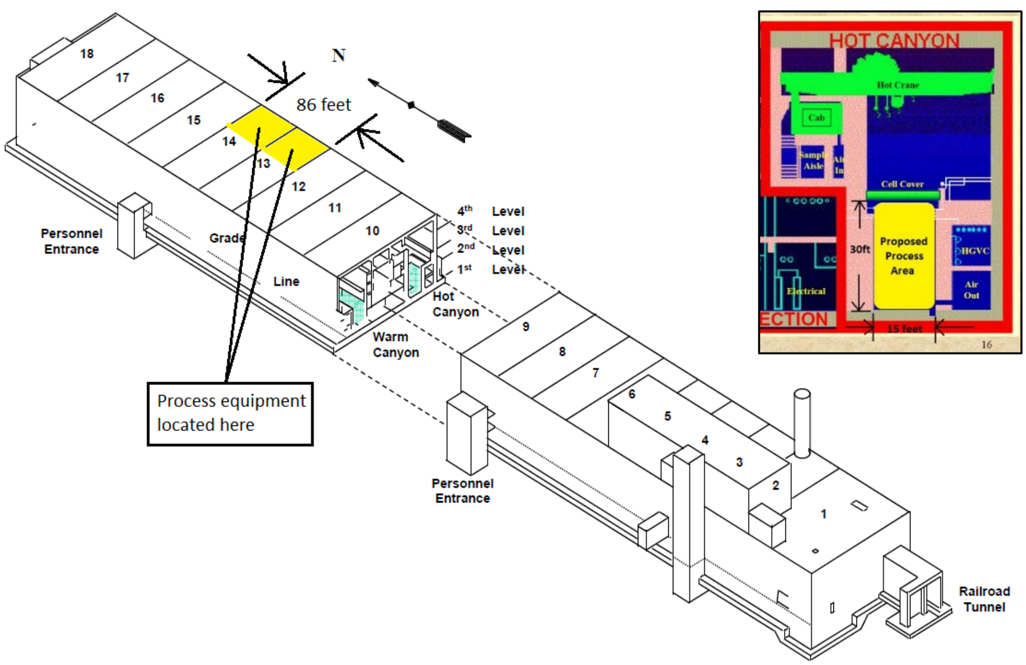

Figure 5-3. Isometric view of H-Canyon showing possible placement of CCIM system. Cross-section of hot canyon showing process and building equipment (inset).

The orientation direction of the CCIM process layout would need to be considered, but a conceptual process is shown schematically in Figure 5-4. Based on the DWPF process, the following major components and systems are assumed required for the proposed vitrification process using a CCIM. Each of these systems is discussed in more detail to consider the challenges required to install a CCIM in H-Canyon.

- CCIM system
- Canister conveyance system
- Off gas collection and treatment system
- Frit storage, conveyance, and introduction system
- Canister cooling system or space
- Plug install equipment
- Plug press and welding equipment
- Canister decontamination system(s)
- Associated electrical considerations
- Special tooling
- Special handling requirements/equipment for ingress and egress of canisters

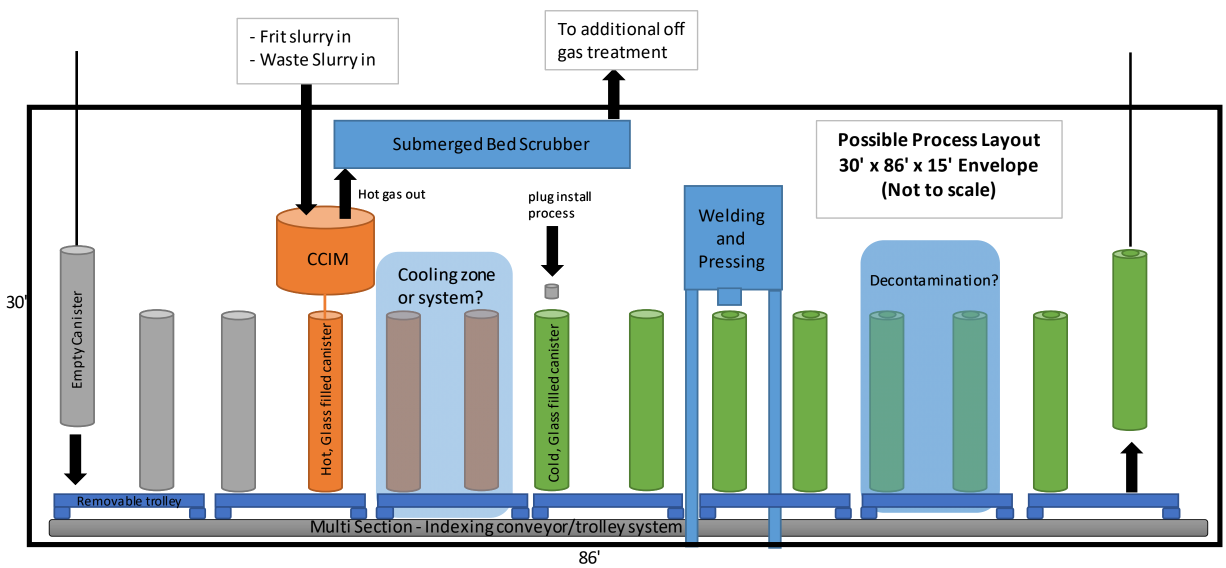

Figure 5-4. Conceptual process layout for H-Canyon CCIM.

5.5.1.1 CCIM System Considerations:

The CCIM vessel will require a structure to be designed to elevate it the necessary distance above the floor so a canister can be placed underneath. The CCIM Melter system requires approximately 600 gallons per minute of cooling water for the vessel shell and high frequency leads. According to the H-Area cooling water system engineer there is 4000 gallons per minute available, therefore this will not be an issue. The proposed 650mm CCIM vessel and system are small enough to fit into the space constraints of the hot side of the H-Canyon facility. The CCIM vessel will have at least one agitator motor and several monitoring instruments. The power and communication for these devices will come from level 1 and level 3 respectively. Refer to the electrical consideration section for more detail. The CCIM melter has high frequency and high power requirements as outlined in the common design and basis assumptions. It may be necessary to increase or install additional electrical utility infrastructure inside and outside the H-Canyon facility to support the electrical load required for this system. Refer to the electrical consideration section for more detail.

5.5.1.2 Canister Conveyance System

A custom canister conveyance system will need to be designed to accept empty canisters, index them into position under the melter and then continue indexing the filled canister through the remaining process steps. Ease of install and the reliability of this conveyor system are paramount to the success of this system. The system will need to use highly durable components that can withstand the highly radioactive environment. Conceptually a modular inductive rail system with mechanical limit switches could be used to accomplish this. Alternatively, multiple mechanical conveyors could be used with radiation hardened motors. Electrical power requirements for this canister conveyance system would likely be 480V 3 phase. This power already exists in the H canyon building and could easily be supplied via existing electrical penetrations and jumpers. If an inductive conveyance system is chosen it would require an additional wall penetration for high frequency leads.

5.5.1.3 Off-gas Collection and Treatment System

The off-gas collection and treatment system should be located inside the 30' x 86' envelope. The submerged bed scrubber and condensate collection will need to be placed near the CCIM due to the need for the process off gas to be at a high temperature when entering the scrubber. The exhaust from this collection and treatment system will then be directed towards the existing H-canyon exhaust system which will subsequently go through the existing sand filter and stack. The off-gas collection and treatment system is discussed further in Section 5.8.

5.5.1.4 Frit Storage, Conveyance, and Introduction System

The frit could be stored outside the H-Canyon facility in the tanks at the cold chemical storage area and cold feed prep. The frit slurry would then be pumped into the third level of H-Canyon and subsequently into the CCIM using existing piping and valves. The properties of the frit (e.g., gelation) would need to be evaluated and controlled if stored as a slurry.

5.5.1.5 Canister Cooling System or Space Considerations

It is not known if it would be necessary to cool the canisters prior to inserting a plug to seal the canisters. If required, the space requirement and cooling system will need to be designed.

5.5.1.6 Canister Plug Install Equipment

A temporary plug is used to seal canisters after they are filled at DWPF. Currently at DWPF this operation is done by a person using a hoist to lift and place the plug into the canister. To load and plug a canister in the H-Canyon, an automated system will need to be developed. Consideration will have to be given to how many plugs need to be queued at any given time as well as how the plugs are brought to the process. i.e., will there need to be a tray of plugs, or can they be collated.

5.5.1.7 Plug Press and Welding Equipment

If the same type of process as DWPF is selected to weld and press the plugs into the canisters there will be a need to core additional penetrations through the wall separating level 2 from the hot canyon due to the power requirements (250,000 amps @ 4-12 volts DC) and the large conductor sizing. If available, the plug welding and press machine that DWPF uses may be able to be re-purposed. This will have to be considered during the design process.

Alternate forms of securing the plug to the canister should be considered to see if it's possible to utilize the existing 480v power inside the facility (i.e., Tig welding the plug to the canister or changing the size and material of the plug/canister to reduce the power required for resistance welding). A hydraulic power unit will likely be needed and could be placed on level 2 to support the 80,000 pounds of force pressing operation.

5.5.1.8 Canister Decontamination System(s)

There may be a need for a decontamination step prior to exiting the 30’ x 86’ process envelope. The canisters could have final decontamination performed in the existing swimming pool inside the H-Canyon. Consideration will need to be given to the handling, disposal, and treatment of the solution(s) used to decontaminate the canisters.

5.5.1.9 Associated Electrical Considerations

The potential layout for the electrical utilities is shown in Figure 5-5. All 480v power could be obtained from the existing electrical rooms on level 1 adjacent to section 13 and 14 where the process equipment could be installed. Existing electrical penetrations and jumpers will be used as much as possible, but it is likely that new penetrations will need to be created between level 1 and level 2 to route power from existing switchgears to process electrical cabinets and electrical equipment. It is likely a new transformer and transformer pad will need to be sized and placed outside of the canyon building to support all process equipment that cannot be supported by the existing infrastructure. Process electrical cabinets and electrical equipment could be placed on level 2 adjacent to the process area. The following major components will be required:

- CCIM impedance adapter cabinet. (needs to be placed as close as possible to CCIM)
- CCIM high frequency generator.
- Inductive rail system high frequency generator.
- Inductive rail system controls and capacitors.
- Welding press hydraulic power unit and controls
- Welding press rectifier
- Local I/O cabinet(s).

Consideration will need to be given to the heat generated by this electrical equipment on level 2. There may be a need to place some of this equipment outside the H-Canyon building or to place walls around the equipment and to cool the space using existing chilled water and heat exchangers or other suitable means.

High frequency water cooled leads for the CCIM will need to be routed from the impedance adapter cabinet on level 2 into the hot canyon. Power supply leads for the canister welding process will need to be routed from the rectifier on level 2 into the hot canyon. These will require core drilling new penetrations in the process envelope as shown in Figure 5-5. The coring/excavation of H-Canyon’s interior wall for high frequency leads and large conductors is a very high risk and technically challenging activity. Further consideration and discussion are needed around this issue to determine if coring/excavation of the interior wall is feasible.

Motor, motor control, and process instrumentation wiring/conductors can likely be routed through existing electrical jumpers and penetrations into level 1’s MCC’s and control cabinets.

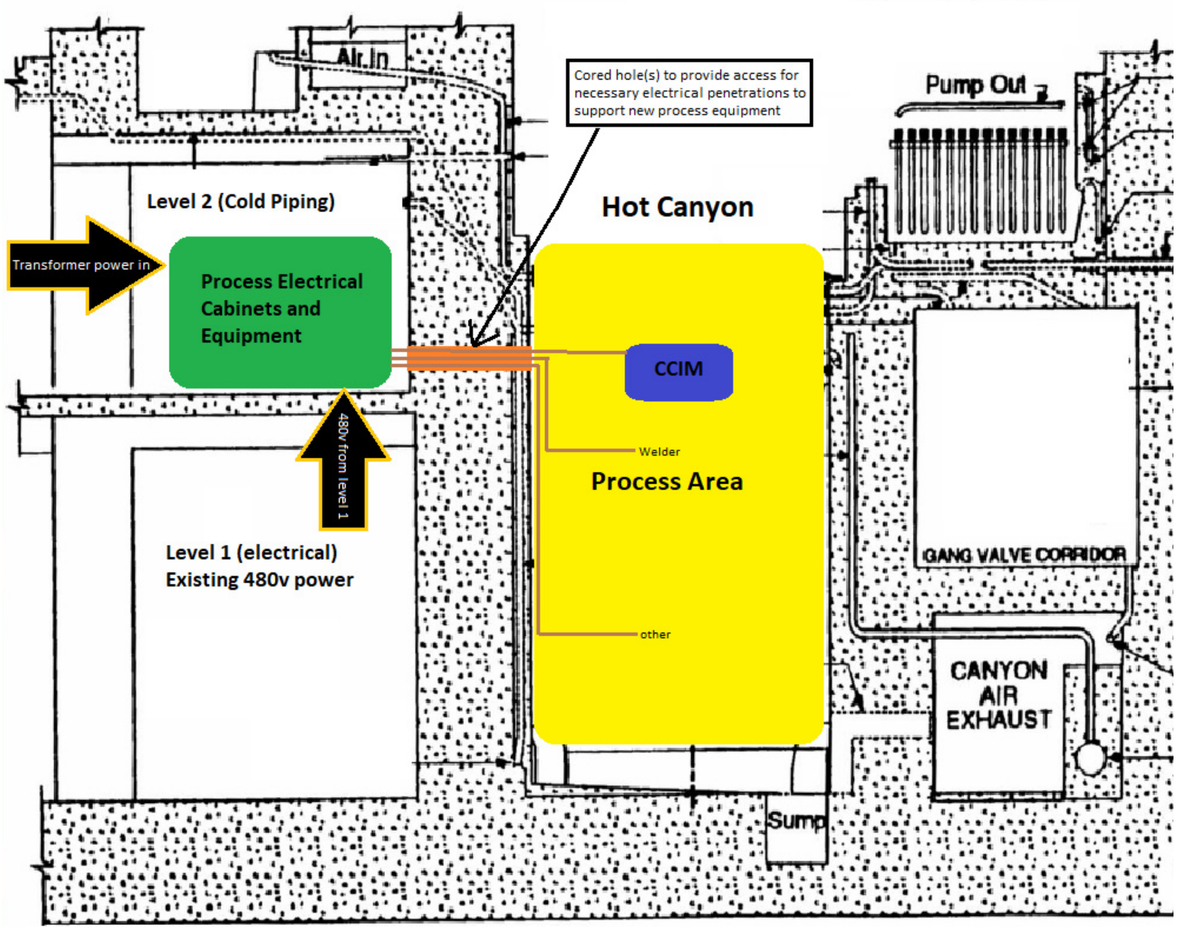

Figure 5-5. Potential layout of electrical supply for the CCIM system.

5.5.1.10 Special Tooling

It is likely that special tooling will need to be developed for the crane and other parts of the process to handle the canisters and plugs.

5.5.1.11 Special Handling Requirements/Equipment for Ingress and Egress of Canisters

Special handling procedures for the canisters will need to be developed. As these procedures are developed it most likely will create requirements for specialized equipment to be purchased. This will need to be considered.

5.5.2 ICP Core Calcine

This assessment assumes siting a CCIM process at the existing IWTU facility once Sodium Bearing Waste (SBW) processing has been completed. The Advanced Mixed Waste Treatment Project (AMWTP) is an alternative siting option, however, AMWTP does not possess the necessary shielded structures needed for processing HLW and is not in close enough proximity to the stored calcine to facilitate direct retrieval into a treatment/repackaging facility. To use AMWTP, the calcine would need to be retrieved, packaged, and transported by some vehicular means.

The original Technical and Functional Requirements (T&FR) for the IWTU included provisions for converting the SBW packaging facility to support possible treatment, packaging, and shipment of the existing HLW calcine. These provisions included improvement in process cell structural and seismic protection meeting safety significant, PC-3 design criteria. Appropriate space, shielding and penetrations were to be included in the design to facilitate adding the capability for packaging calcine in the future.

Based on a limited review of the tentative CCIM technical layout drawing for the DWPF retrofit proposal,[3] it is conceivable that a similar CCIM arrangement could, potentially, be made to fit within the confines of the existing IWTU Canister Fill and Decontamination Cells, Can Fill Cells 0 and 1. The original design of the IWTU included three Canister Fill and Decontamination Cells. Only two were completed and are fully functional. The third cell, Can Fill 2, remains essentially empty and is not currently equipped with the necessary shield plugs, shield windows or manipulators to support any kind of packaging activities.

The two functional cells are configured into an upper and lower cell. The upper cell houses a Product Receiver vessel from which RH-TRU 72-B canisters are filled, and a filter vessel. The lower cell houses the canister handling and filling equipment and a decontamination robot. The upper cell is separated from the lower cell by an 8” thick steel plate. The upper cell measures 17’6” in width, 10’3” in depth and 17’8” in height. The lower cell measures 17’6” in width and 23’8” in depth. The lower cell ceiling height is 18’8 at the canister load-in port and 15’4” at the canister fill port. See Figure 5-6 and Figure 5-7.

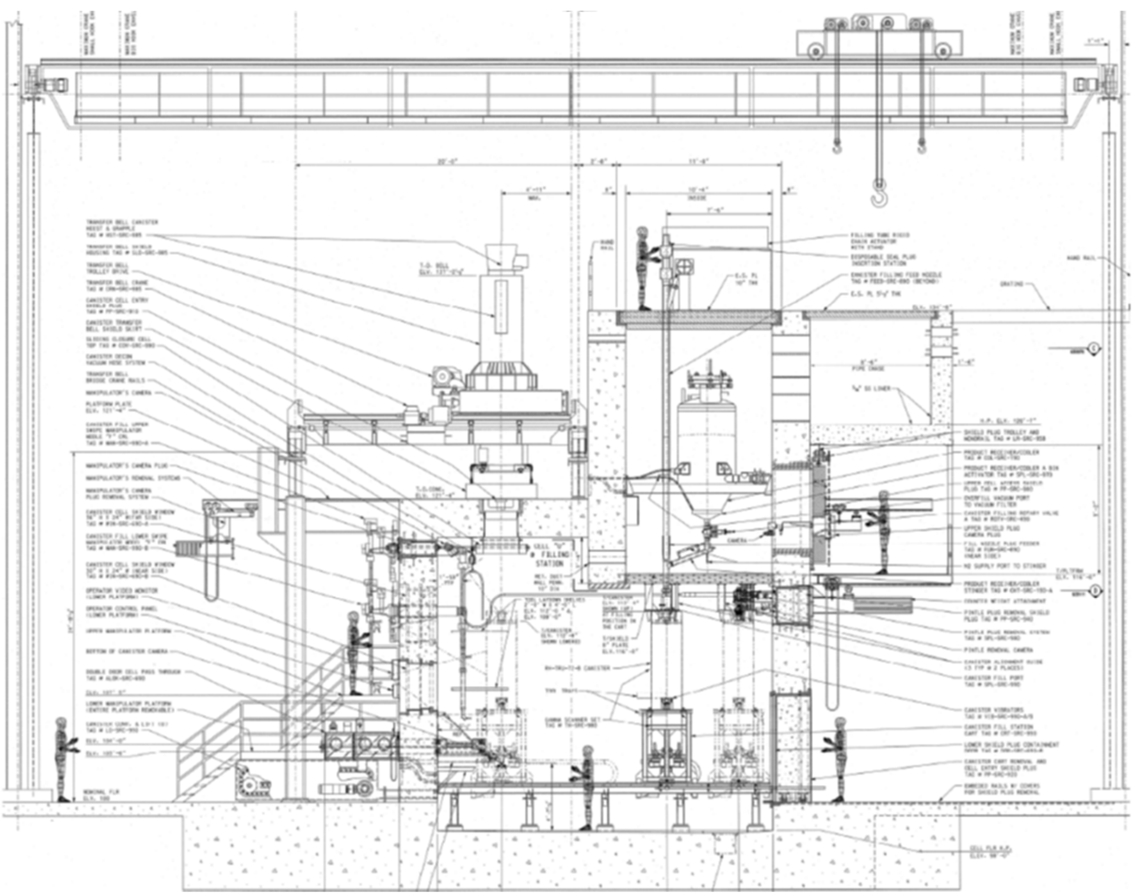

Figure 5-6. IWTU canister filling and decontamination cell, north elevation view.

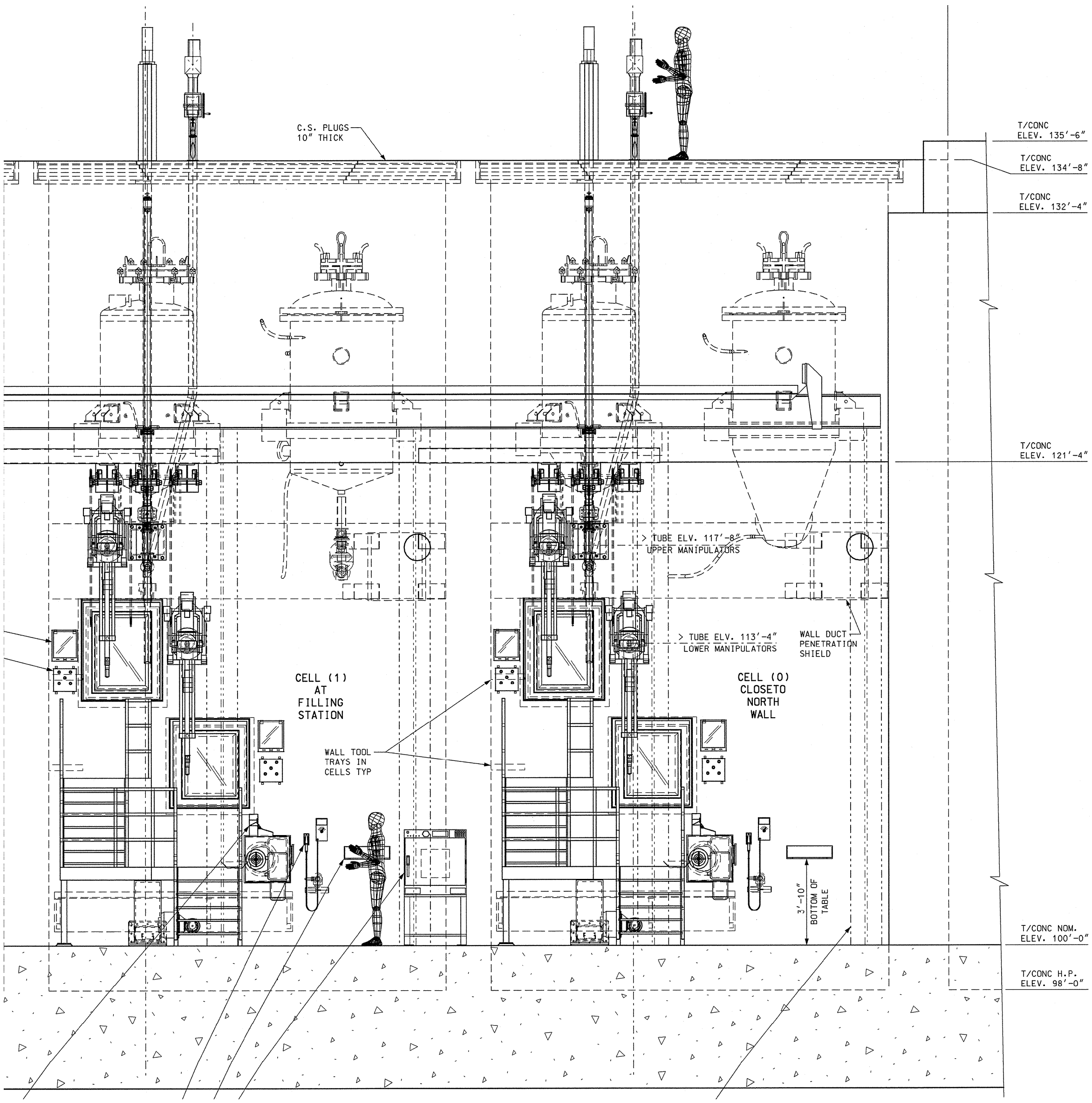

Figure 5-7. IWTU canister filling and decontamination cells, view looking south.

Upper cell access for maintenance is provided through shield plugs and removable roof plates. Process connections are made from the South pipechase through penetrations between the pipechase and cell walls. Access for maintenance to the lower cell is also made through a shield plug. For operations, the lower cell is equipped with two shielded windows, two manipulators, CCTV cameras, and a double-door pass-through glovebox. Canisters are introduced and removed from the lower cell through a circular port in the ceiling of the lower cell.

Both Can Fill cells are equipped with a decontamination spray down system. Installation of a robotic system for surveying and decontaminating canisters in each cell is currently undergoing commissioning and start-up. These systems will have the capability of taking smear samples from the filled canisters and passing them through the double-door pass through to be surveyed. The robot also has the capability of vacuuming the canister surfaces to remove contamination, as well as wiping them down, as necessary.

The third Canister Filling and Decontamination Cell, Can Fill 2, as mentioned previously, was not completed during construction. It does, however, have the same penetrations and openings through the shield walls as Canister Fill Cells 0 and 1. This cell could conceivably be retrofitted to provide a space for cooling, intermediate storage, canister sealing/welding, or other processing equipment and activities that may be required. The same opportunities for access exist as with Can Fill 0 and 1, with process connection routing between cells available through the existing pipechase.

The remaining processing areas within the IWTU include the 4-Pack, which currently houses the Waste Feed Tank, the Denitration Mineralization Reformer (DMR), the Process Gas Filter (PGF) and the Off-Gas Filter (OGF), the 2-Pack, which houses the Carbon Reduction Reformer (CRR) and the Off-Gas Cooler (OGC), the North Pipechase and the South Pipechase. See Figure 5-8.

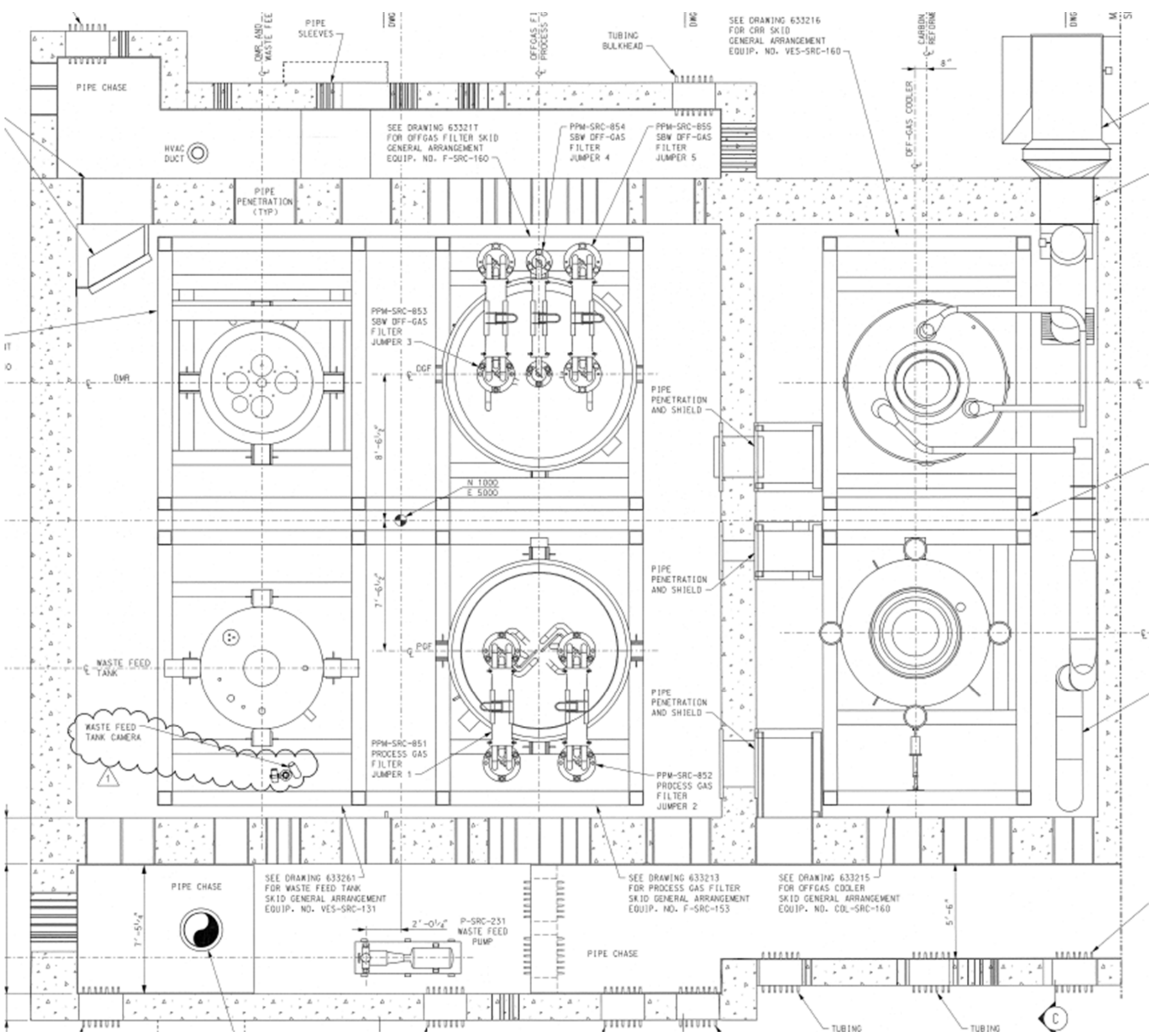

Figure 5-8. IWTU 4-pack, 2-pack, north and south pipechase plan view.

The 4-Pack is 37’2” wide, 34’5” deep with an inside ceiling height of 31’8”. Access to the 4-Pack is provided through three shield doors at the finished floor elevation, one each at the DMR, PGF and OGF, as well as removable roof plates above the DMR, PGF and OGF. There are a variety of penetrations through the shield walls for electrical conduit and piping. Process connections are made through the floor of the 4-Pack and the North and South Pipechases. Access to the North and South Pipechases is provided by removable roof plates.

The 2-Pack is 19’8” wide, 34’5” deep with an approximate ceiling height of 33’. This height does not include the penthouse structure, which is an additional 7’6” in height. Access to the 2-Pack is made through doors on the North and South sides of the 2-pack at the finished floor elevation. These are not shield doors. Access to the top of the 2-Pack is made through the penthouse roof, which is also not a shielded construction. There are a limited number of wall penetrations for electrical conduit and piping. Process connections are made through the South Pipechase and the shield wall between the 2-Pack and 4-Pack. See Figure 5-9.

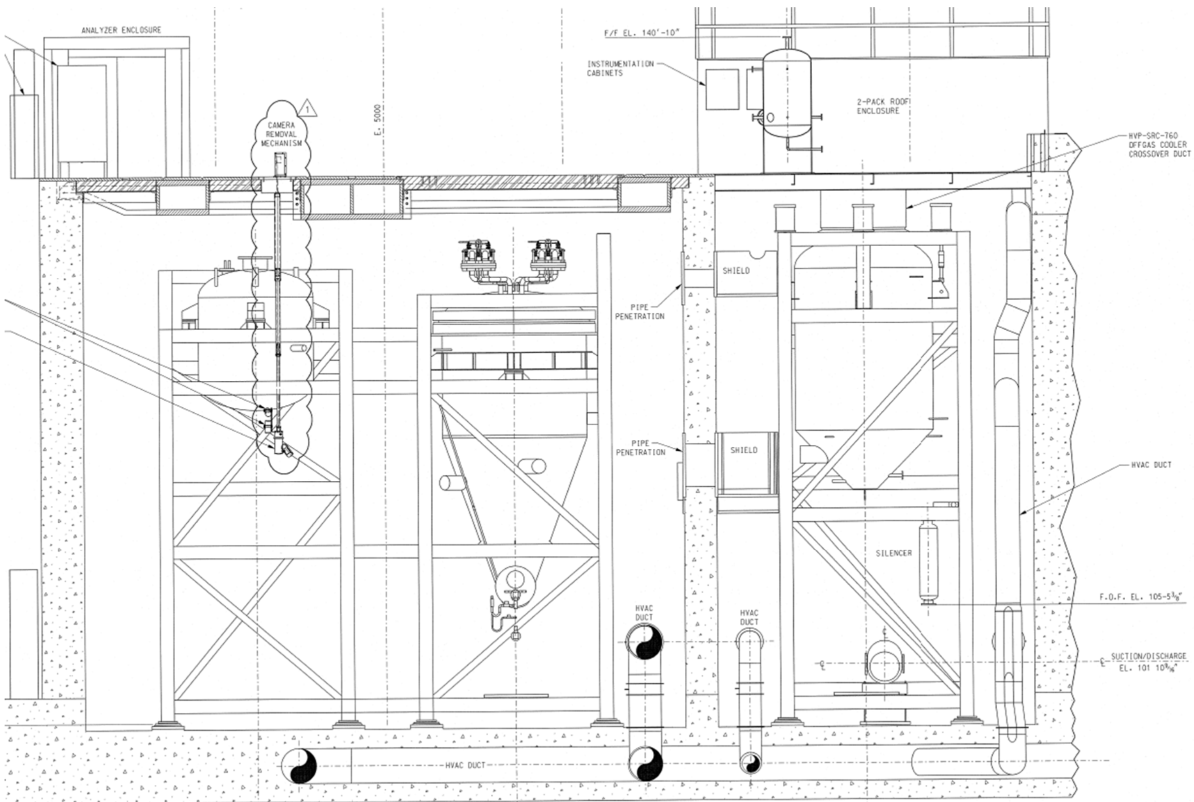

Figure 5-9. 4-pack and 2-pack, view looking north.

Based on the provided assumptions and what is known about the CCIM system that was considered for the DWPF retrofit, it is likely feasible that such a system could be retrofitted into the IWTU facility. However, a larger system, with greater throughput capacity, would be more difficult to integrate into the existing process cells. This preliminary evaluation can, and will need to be refined with additional information, and time to develop a higher degree of confidence in the outlook.

The current plan is to utilize the IWTU facility for calcine packaging. Therefore, an effort to utilize as many components from the IWTU facility would be pursued, i.e., canister handling equipment, off gas components, hot cells, remote handling equipment, etc. A conceptual flow diagram for the CCIM process that describes the general operations and equipment that would be required for packaging calcine is shown in Figure 5-10.

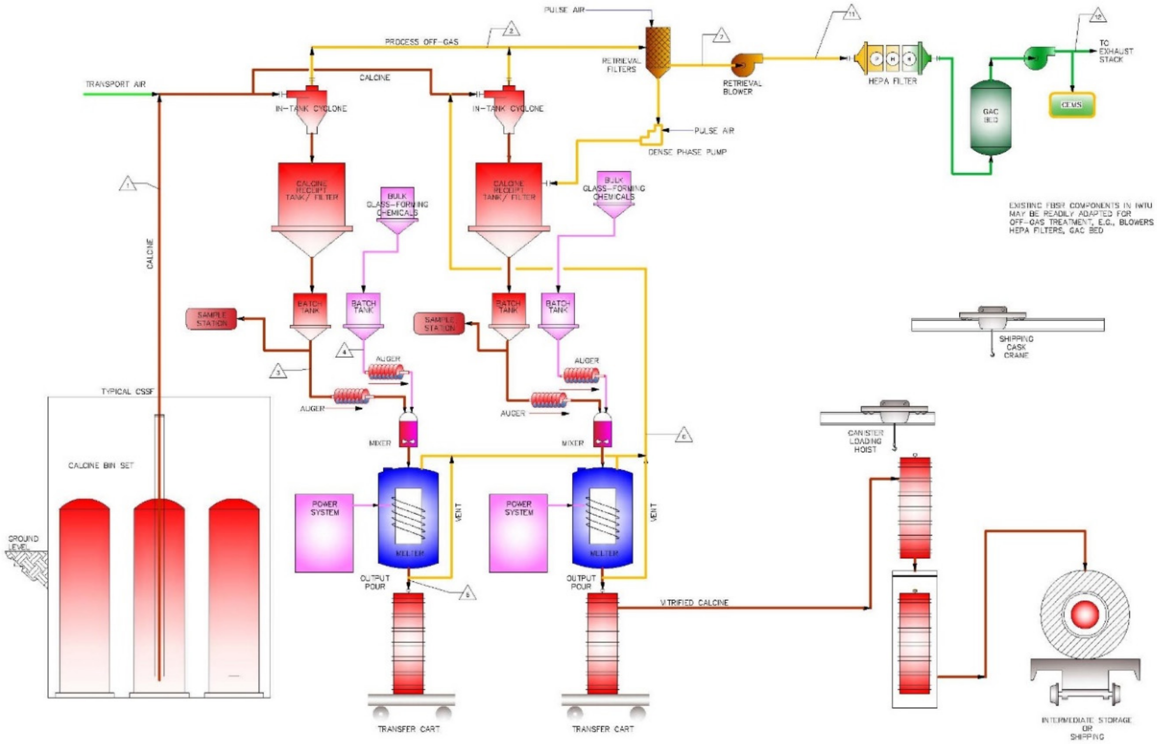

Figure 5-10. Conceptual flowsheet for HLW calcine processing using a CCIM.

In addition to the systems and concerns discussed for implementation at H-Canyon and stated in "High-Level Waste Vitrification Facility Feasibility Study,"[41] the following material handling/processes would need to be designed and employed:

- Calcine Retrieval, transport, and receiving
- Material receiving and handling
- Empty canister receipt and handling
- Blending and sampling of the calcine to determine waste/frit recipes
- Waste/frit mixing, sampling, and feeding
- Radionuclide contamination control

5.5.2.1 Calcine Retrieval, Transport, and Receiving

Calcine will need to be retrieved and transported through several hundred feet of piping to a receiving location. It is expected that calcine will be pneumatically retrieved and transported from each CSSF to a calcine processing facility. The Calcine Retrieval Project is developing and testing several components and systems that will be used to remove radioactive calcined waste from the Calcined Solids Storage Facility (CSSF) bin sets. Work performed by the Calcine Retrieval Project supports the DOE's mission to meet the 2035 milestone.

The function of the CSSFs is to safely store and manage radioactive calcine. The CSSFs are composed of seven discrete bin sets (CSSFs 1 through 7), schematically shown in Figure 5-11. The bin sets were designed by different architectural engineering firms and built at different times. Each bin set has a unique design, reflecting varying design criteria and lessons learned from historical CSSF operations. Individual bin sets contain from 3 to 12 stainless-steel bins. The bins range from 6.1 to 20.7 m (20 to 68 ft) in height, and each bin set is housed in its own concrete vault. The configuration of each of the bin sets and their respective calcine volumes and usable capacities are represented in Figure 5-11. About 4,400 m^3 (5,500 yd^3) of calcine is stored in CSSFs 1 through 6 and CSSF 7 has not been used and is empty.[42] The varying bin set designs will affect future calcine retrieval processes and equipment.

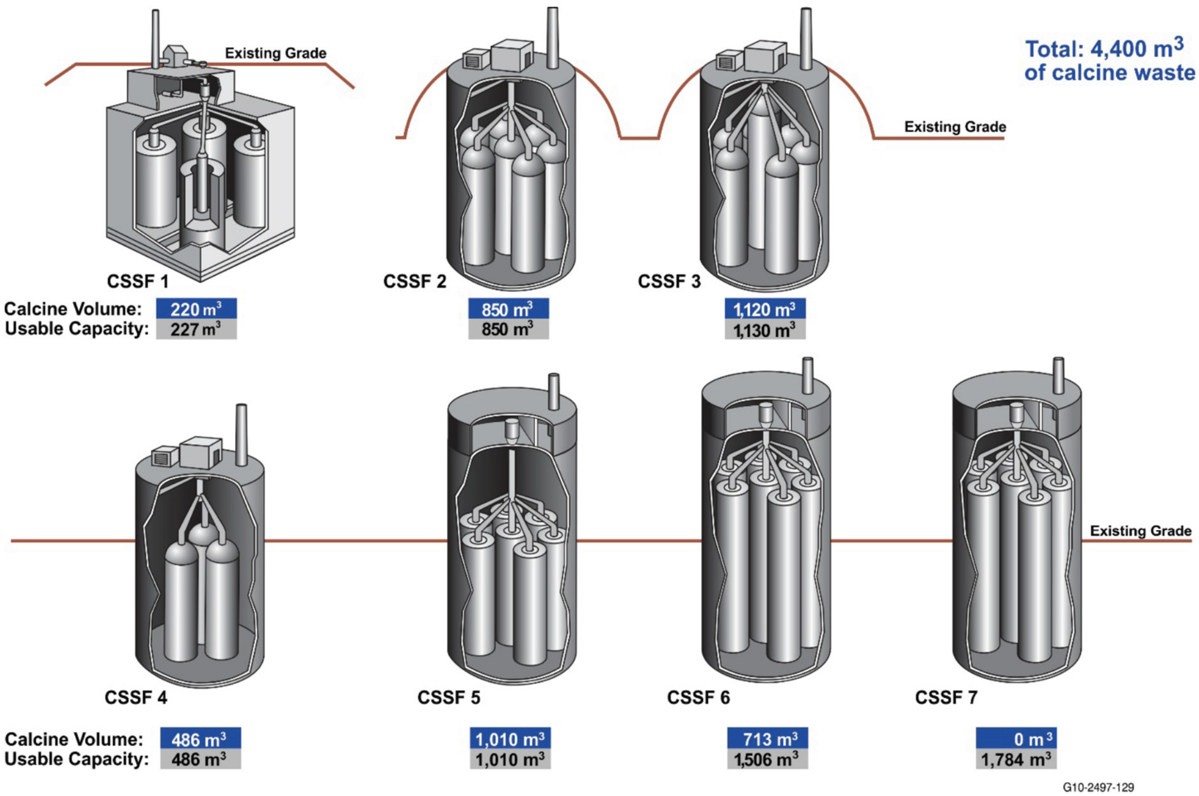

Figure 5-11. Illustration of the CSSF bin sets and their unique volumes and usable capacities.

The general strategy to remove calcine from the bin sets involves modifying the CSSF to install retrieval equipment and then removing calcine from the bin sets using bulk pneumatic retrieval and residual cleanout systems. The removal strategy requires uniquely designed and tested equipment, tools, and processes to ensure calcine is safely removed from the bin sets and the CSSF is closed in compliance with multiple regulatory standards. Testing objectives are to mitigate safety hazards, eliminate design risk, and optimize design configurations for retrieval and transfer of calcine. Overall, testing of various calcine retrieval equipment has demonstrated successful operation of the components and systems and has identified areas that will require further development.

The calcine retrieval project is currently testing retrieval techniques and pneumatically transporting the calcine simulant at CPP-691 at INTEC using the full-scale mockup. A receiving storage hopper has not been designed to date for this purpose, however, receiving storage hoppers are used extensively in industry and therefore there is little concern with the design of this component.

5.5.2.2 Material Receiving and Handling

The major concern with handling and receiving calcine will be the rad levels and how often maintenance will need to be completed on the various systems. This will need to be a major part of the considerations for designing the material receiving and handling equipment.

5.5.2.3 Empty Canister Receipt and Handling

Similar to IWTU, canisters for the CDP will need to have a receipt and handling procedure to ensure the canisters are clean and meet the specifications. It is expected this will be similar to what will be used for IWTU.

5.5.2.4 Blending and Sampling of the Calcine or Liquid to Determine Waste/Frit Recipes

Due to calcine stratification concerns within the bin sets, it is unknown how many various frit recipes will be needed to vitrify all the calcine. Blending/mixing may be necessary to ensure that a representative sample of the calcine can be taken to ensure the correct frit recipe is used for a quality vitrified end product. Although blending/mixing and taking samples of material is a common industrial practice, it is unknown at this time how long the calcine will need to be mixed and how long it will take to get an analysis of the constituents within the calcine ensuring the right frit is used.

5.5.2.5 Waste/Frit Mixing, Sampling, and Feeding

Once the calcine is mixed and sampled a corresponding frit recipe can then be determined and mixed with the calcine. This new mixture would then need to be sampled and fed to the melter. This process is not technically difficult to develop but this is another step that is needed to produce a quality vitrified end product.

5.5.2.6 Radionuclide Contamination Control

Contamination control will need to be considered as the radioactive waste will go through several processes and through several components each of which will have a risk to breaching containment. These processes will need to be robustly designed with a backup plan for how to clean up the contamination should a breach in containment occur.

5.6 <u>Regulatory Compliance and Permitting Changes</u>

5.6.1 H-Canyon

The H-Canyon facility currently transfers low-equity materials unsuitable for recovery to the tank farm where they are processed with other waste materials and vitrified at the DWPF. The H-Canyon facility does not treat or process any waste for disposal and does not have permitting to do so. The introduction of the CCIM for vitrification will effectively make H-Canyon, or an adjacent support facility, a HLW treatment facility. The H-Canyon facility will need to be modified to either install the CCIF vitrification system, or for transfer of the effluent to an adjacent new facility containing the vitrification system. Regulatory compliance for waste treatment within H-Canyon or the external HLW treatment facility will require appropriate permitting, and a supplemental NEPA evaluation of the environmental risks will need to be performed.

5.6.2 ICP Core Calcine

Calcine is currently stored in the CSSF and it is an Idaho Department of Environmental Quality (DEQ) permitted hazardous waste storage facility. Once calcine is retrieved from the CSSF bin sets it is proposed to be vitrified in the IWTU, which also is a RCRA-permitted facility for treatment of sodium bearing waste (PER-111).[43] Being a permitted facility, adding the treatment of calcine under the IWTU permit should be available through the submittal of permit modifications to the Idaho DEQ. It is noted that during the evaluation of alternatives for remediation of HLW at the INL Site, the Idaho DEQ preferred alternative for treatment of calcine was vitrification.

Regulatory compliance and permitting changes will include compliance with the *Partial Permit for HWMA Storage for the Calcined Solids Storage Facility at the INTEC on the INL* (CSSF HWMA/RCRA Permit) (PER-114) and either: modifying the *Partial Permit for HWMA Storage and Treatment for the Liquid Waste*

Management System at the Idaho Nuclear Technology and Engineering Center on the Idaho National Laboratory (PER-111)[43] or CSSF HWMA/RCRA Permit to add the vitrification treatment process, or a third option would be to prepare a separate HWMA/RCRA permit for calcine treatment.

The modifications will need to be in accordance with DOE requirements as a HLW facility and in accordance with HWMA/RCRA closure requirements for a tank system. Closure of the CSSFs are also subject to State of Idaho-approved closure plans under HWMA/RCRA and Section 3116 of the "Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005" (NDAA Section 3116) (Public Law 108-375).[44] In addition, the treatment process will need to address potential air emissions issues to determine if a new air quality permit is required or if the existing IWTU air permit is sufficient (IDAPA 58.01.01).[45]

5.7 Facility Safety Considerations

Facility and safety considerations were reviewed associated with implementing CCIM technology with the Idaho calcine and H-Canyon effluent. The following facility safety considerations will need to be reviewed for industrial safety and hygiene, fire protection, and radiological protection. Many of the facility safety considerations are applicable to both sites; those which are site-specific are noted. This list is not exhaustive, and reviews would need to be considered before implementing a specified design/system.

5.7.1.1 Industrial Safety and Hygiene:

- Potential for hazardous gases at the CCIM operating temperature will have to be addressed in the design of the process filtration system.
- Ambient air temperature around, or in the space that houses the CCIM unit will need to be evaluated

5.7.1.2 Fire Protection:

- New facility or existing facility will have to be reviewed for upgrades required by the heat generated during the CCIM process and storage of the vitrified waste containers.
- Process Off Gas Ventilation system will have to be reviewed to ensure material used in the construction and treatment of the exhaust are acceptable per NFPA.
- Fire suppression system will have to be designed for process conditions per NFPA.
- Need to evaluate the decay heat in filled waste containers in the fire protection plan.

5.7.1.3 Radiological Protection:

- The radionuclide inventory will need to be considered:
  [ICP Calcine] Over 95% of the HLW calcine material's radioactive source term is Cs-137/Ba-137m and Sr-90/Y-90.
  [H-Canyon] SNF will be processed at SRS. These fuels consist of various designs, enrichment, burnup, and physical state.
- At the CCIM process operating temperature, some constituents are volatile (e.g., Cs-137, Sr-90, Ru-106), which will require the process and off gas system to be designed to limit radioactivity carry over via volatilization.
- Radiological shielding requirements for personnel exposure, waste storage, and shipping will need to be determined on the final canister dimension.
- Any residual glass remaining in the CCIM (e.g., the protective layer on the crucible surface) after being drained needs to be better understood to estimate radiological conditions for maintenance activities and waste handling.
- Failed crucible removal, replacement, and disposal.
- Method to remove residual/solidified glass (decontaminate) in the crucible will be needed to reduce worker dose during maintenance activities occurring in the cell housing the CCIM.
- Product fill port needs to be considered a critical process detail.

- [H-Canyon] the addition of a penetration through the canyon wall to provide power will provide an additional radiological risk to personnel that will need to be assessed.

5.7.1.4 Criticality Safety

- A nuclear criticality safety evaluation (NCSE) will need to be completed for the CCIM crucible dimensions as part of design and implementation.
- [H-Canyon] H-Canyon uses concentration control for criticality safety. This will not be practical for CCIM operation. Size and geometry of the melter and waste container need to be finalized so alternate criticality controls like enrichment control and/or poisons can be analyzed.

5.7.1.5 Facility:

5.7.1.5.1 Modify H-Canyon

- Removal and disposal of legacy equipment will be required to make room for the installation of the CCIM process.
- A modular or scalable process design is required that can be installed and removed using the remote crane.
- Modifications for installing the CCIM process would have major impacts on concurrent dissolution schedules as a result of reduced crane time availability.
- Installation of the melter will require the installation of a stand-alone power supply that will require penetration through the wall of the hot canyon. This type of activity was performed many years ago to install the electrolytic dissolver, but current safety requirements will need to be evaluated.

5.7.1.5.2 Modify IWTU

- Current process estimate for IWTU is that it will take 3 to 5 years to process the 900,000 gallons of sodium bearing waste but does not include the time it will require to process the tank wash water generated during the tank RCRA cleaning.
- Decontamination and facility reconfiguration work to install the CCIM process will be conducted employing radiological controls.
- Maintenance inside the cell needs to accomplished using remote tooling and programmed systems.
- Modular or scalable process designs are required that can be installed and removed using remote tools.

5.7.1.5.3 Build New Facility

- Designed and sized for a predetermined production rate.
- Maintenance inside the cell needs to be accomplished using remote tooling and programmed systems.
- [ICP Calcine] A new facility removes the time waiting for IWTU to complete its intended mission.
- A modular or scalable process that can be installed and removed using remote tools will need to be created.
- [H-Canyon] Methods and processes will be required to transfer material from H-Canyon to stand-alone CCIM facility.

5.8 Off-gas Handling and System Components

5.8.1 Off-gas Requirements for CCIM Melters

The high temperatures of the CCIM process will result in volatilization of some portion of the feed as the vapor pressure of a number of species is significant at the expected operating temperature. The expected off-gas from the calcine solids represent a different operating regime for the off-gas system than a slurry feed from H-Canyon; thus the off-gas system for each will be described separately. Note that the assumptions in this document are made to show that an exhaust system can be developed using existing technology to decontaminate various constituents from the off-gas system. This review evaluated off-gas systems used for HLW melters at West Valley[46] and DWPF,[47] as well as the planned off-gas system for the Hanford HLW and LAW melters.[48]

5.8.2 H-Canyon

A hypothetical off-gas treatment system for an H-Canyon CCIM is shown in Figure 5-12 with the major components identified. The CCIM is expected to be slurry fed and contain significant amounts of mercury. The basic projected off-gas treatment needs are:

- Condense water and semi-volatiles
- Entrained solids removal
- Hg abatement
- NO_x abatement
- I-129 abatement

The assumed off-gas system components are:

- Film cooler with air and steam additions
- Submerged bed scrubber with NaOH addition (maintained at pH of 10)
- Steam atomized scrubber
- High efficiency mist eliminator (HEME)
- Carbon bed
- High Efficiency Particulate Air (HEPA) filter
- Blower
- Condensate collection with recirculation and cooling systems
- Transfer of collected condensate to a grouting facility

The projective off-gas treatment needs shown above are somewhat speculative at this point and could be reduced as more information is available on the CCIM system to be utilized, the expected operation of the system, and whether the off-gas system is tied into the existing H-Canyon exhaust or is a stand-alone unit. Optimization of the system components using newer or different technologies and operating approaches is likely possible. The system components are discussed subsequently.

5.8.2.1 Film Cooler

The primary function of the film cooler is to cool the off-gas prior to the scrubber and to prevent scale formation on the piping between the melter and the scrubber. In addition, the air flow into the film cooler can be controlled to maintain the melter at the desired vacuum. The hot exhaust from a melter is typically cooled at the exit of the melter through the use of air or steam injection along the walls of the off-gas pipe. This "film" of cool air cools the hot particulates in the off-gas stream and allows molten or volatile species to form solids in the center of the pipe versus forming scale on the walls. Some maintenance on these systems to remove any scale buildup not prevented by the "film" is needed. This maintenance could be as simple as water rinse or it could involve using a chimney sweep-type device to scour the walls clean. Film cooler systems have been used on the DWPF melter, the West Valley melters, and are planned for the WTP LAW and HLW melter systems. The technology readiness of these systems is high for HLW vitrification.

5.8.2.2 Scrubber Systems

Particulate removal is typically the first step in the off-gas treatment system for HLW melters. Two types of scrubbers have been used in DOE melters. The particulate removal often consists of two units, one for coarse particulate removal and a second system for fine particulate removal. The initial coarse scrubber typically also provides a cooling function and will condense the water and semi-volatiles from the off-gas stream.

5.8.2.3 Coarse Scrubbing

DWPF utilizes a venturi scrubber while West Valley and the Hanford melters utilize(d) Submerged Bed Scrubber (SBS) systems as the initial coarse scrubber. For this evaluation, a submerged bed scrubber with cooling is utilized. This system has a high Technology Readiness Level (TRL) for HLW melters since it has been used at West Valley and extensive testing of the systems was performed for the Hanford HLW melter.

The removal of particulate is primarily a physical process and scrubber pH is not a major factor in the solid's removal. However, the pH of the scrubber solution is a significant factor for the efficiency of removal of non-condensable species. Operation of the scrubber at a high pH by addition of NaOH would allow the SBS to remove any NOx or other acid gases from the off-gas system as well as removal of most iodine species. Operation of a caustic scrubber for the removal of acid gases and iodine is wide-spread throughout the chemical industry. The Hanford LAW system includes a caustic scrubber for NOx abatement, but utilizes a separate system from the SBS instead of maintaining the SBS as a caustic system. If addition of caustic to maintain the SBS at a pH > 10 is not feasible, a caustic scrubber can be added to the system between the Steam Atomized Scrubbers (SAS) and High Efficiency Mist Eliminator (HEME) systems.

5.8.2.4 Fine Scrubbing

Both the DWPF and Hanford HLW melter systems utilize a second stage system to remove fine particulate while the West Valley system did not. DWPF utilizes a SAS while Hanford will utilize a Wet Electro-Static Precipitator (WESP). The use of a SAS was selected for this exercise because of its use at DWPF versus the planned use at Hanford. This scrubber uses steam to generate a fine mist that removes very small particulate at high efficiency. This system is considered to be at a high TRL for HLW system due to the prior use at DWPF.

5.8.2.5 Mist Elimination

The wet scrubbing from the SBS and SAS units can entrain fine water droplets in the off-gas stream. A HEME is included in the off-gas systems at West Valley, DWPF, and Hanford. These systems are in common use throughout the chemical industry and the TRL is high.

5.8.2.6 Mercury Removal

Mercury removal may be required to meet emission limits. If required, a carbon bed system would be utilized. Carbon beds are frequently used to remove mercury in the exhaust of coal plants and will be utilized on the Hanford HLW and LAW melter systems. The carbon bed would also absorb other species remaining in the off-gas, such as any organics or iodine. It should be noted that any NOx still present could negatively impact the carbon bed. A heater would likely be used prior to the carbon bed to prevent condensation of any water still remaining in the off-gas system. Removal of mercury with a carbon bed is a mature technology.

5.8.2.7 Final Filtration

High Efficiency Particulate Air (HEPA) filters would be installed to mitigate any release of radioactive materials. These systems are ubiquitous throughout the nuclear industry and considered to be at a high TRL.

5.8.2.8 Blower

Blower fans would be installed to exhaust non-condensables and maintain the melter and off-gas systems under vacuum. These systems are ubiquitous throughout the nuclear industry and considered to be at a high TRL.

5.8.2.9 Condensate Handling

Collection of the condensate into a vessel and recirculating the material to provide scrubbing fluids for the initial coarse scrubbing is performed at West Valley, DWPF, and Hanford. This system is at a high TRL.

5.8.2.10 Condensate Grouting

It was assumed during this exercise that the condensate would be grouted. Grouting of low-level radioactive waste is performed at SRS, West Valley, and many other DOE sites. However, grouting of this stream would need to be evaluated to ensure that the criteria for handling the grouted waste as LLW are met.

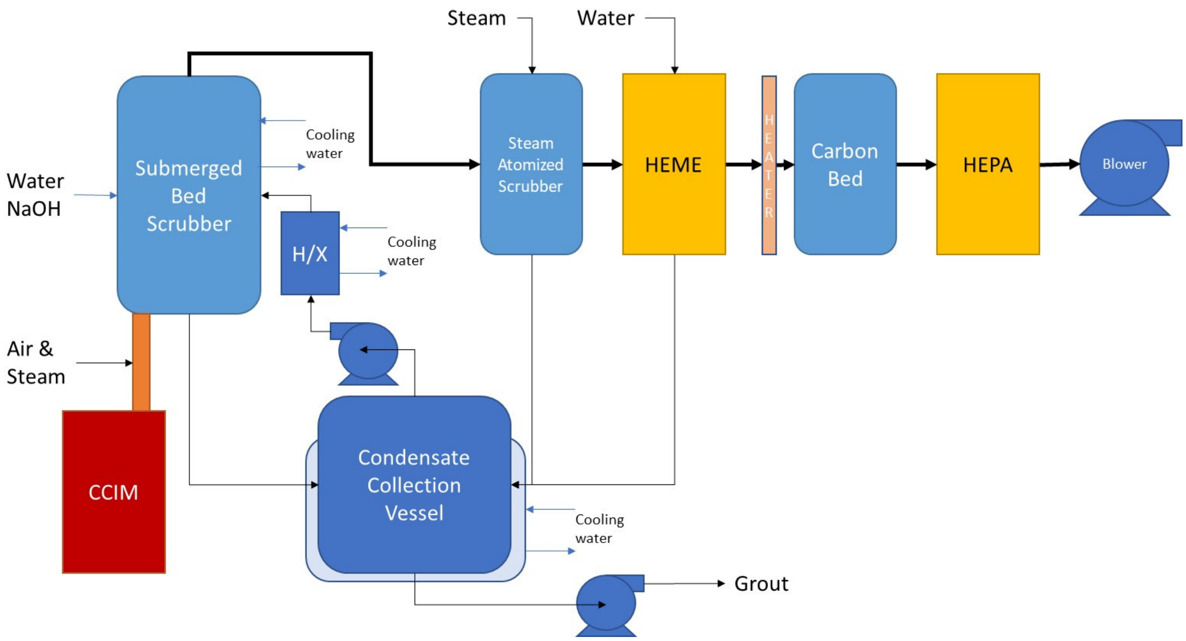

Figure 5-12. Hypothetical off-gas system for H-Canyon CCIM.

5.8.2.11 Overall Summary

Overall, the off-gas treatment needed for a CCIM can be performed using technologies that are generally at a high TRL. However, size constraints if the off-gas system must fit into a designated space inside H-Canyon could result in design decisions that reduce the TRL of one or more unit operations.

5.8.3 ICP Core Calcine

The CCIM for the vitrification of Idaho calcine waste would be expected to be a dry system, with little to no water in the melter feed and all to nearly all feed components present in an oxide form. This condition simplifies the off-gas requirements such that all components except an air cooled film cooler, HEPA, and blower could likely be removed from the off-gas system. A cyclone separator, candle filter, or other coarse particulate removal system could be installed to reduce the particulate load on the HEPA with the collected solids recycled to the melter. Overall, the TRL of an off-gas system for the calcine waste is high. As with the H-Canyon system, size constraints needed to fit the off-gas system into a designated space inside an existing facility could result in design decisions that reduce the TRL of one or more unit operations.

If there is no cold cap, then it is assumed that the off-gas system will be similar to the La Hague unit in France; however, the dry calcine will have a much lower off-gas flow than a slurry-fed CCIM. Expected off-gas constituents include dust particulates, NO_X, semi-volatile alkali metals, cadmium, mercury, and semi-volatile radionuclide elements cesium, ruthenium and technetium.

In the La Hauge unit, dust and semi-volatile metals are removed by a wet scrubber followed by HEPA filters. In the La Hague unit, off-gas scrubber solution could be fed back to a rotary kiln calciner connected to the melter.

The Idaho site unit does not require a rotary kiln calciner so a liquid spent scrubber stream would need to be processed, such as by feeding back to the melter. An alternative to the use of a scrubber for the Idaho Site would be to route the melter off-gas back to the calcine transport line upstream of the cyclone used to separate calcine from the transport air. There the cold transport air would cool the off-gas and the high surface area of the calcine particles would promote redeposition and capture of semi-volatile metals which could then be collected in the cyclone and retrieval filter.

The HLW calcine has only a few percent (1 to 9.6 wt%) nitrate, so NO_X emissions will be low. The IWTU is permitted for up to 32 lb/hour of NO_X (maximum 40 tons/yr); therefore, NO_X abatement is not expected to be required for the Idaho CCIM off-gas system.

Mercury in the off-gas will be removed by a sulfur-impregnated granular activated carbon (GAC) bed. The CCIM off-gas can be tied into the Integrated Waste Treatment Unit (IWTU) HEPA filters, GAC beds, blowers and stack. This IWTU off-gas system also has sample ports for mercury sampling and a continuous emission monitoring system for measuring NO_X and radioactive emissions.

Uncertainties include the amounts of semi-volatile metals in the off-gas and the treatment of secondary waste stream (spent scrubber solution). There is also uncertainty in effectiveness of “dry scrubbing” and the potential for plugging the calcine retrieval filters if the melter off-gas is to be routed to the calcine transport gas.

5.9 Flowsheet Adaptability

5.9.1 H-Canyon
There is uncertainty in the future flowsheets for processing the diverse inventory of SNF through H-Canyon. While this uncertainty may have a significant impact on H-Canyon operations, conceptually, vitrification of any effluent from H-Canyon can be expected to be processible with CCIM technology. In certain aspects, (e.g., modularity, size, operational temperatures, etc.) a CCIM may offer greater versatility than other melter designs (e.g., DWPF-type Joule heated melter) and could reduce risk associated with flowsheet uncertainty. A more detailed evaluation to the extent of flowsheet variation should be considered to understand the risk/benefit and life-cycle costs better.

5.9.2 Idaho Cleanup Project Calcine
The new calcine processing flowsheet would have similar components to the existing SBW product handling system and it is expected that calcine could be processed with CCIM technology; however, it is unknown which components at IWTU could be reused to implement CCIM technology at IWTU. It is expected that the IWTU off-gas system (blowers, HEPA filters, GAC beds, continuous emissions monitoring system, and stack) can be reused by the calcine CCIM system. Development of flowsheets for the wide variety of calcine compositions is needed.

6.0 Summary
This report summarizes the results from an assessment of the appropriateness and readiness of CCIM technology to vitrify HLW calcine solids at the Idaho Site and H-Canyon effluent at SRS. The assessment considered a number of system factors including feasibility of the technology for the specific site application, the potential extent of the regulatory and design challenges, and evaluation of the ability to deploy within the constraints specific to each site.

Although siting the CCIM in a standalone facility is an option, this assessment focused on retrofitting existing infrastructure for the CCIM. No insurmountable hurdles were identified to prevent deployment of the technology at either site, using existing infrastructure. The greatest challenge for SRS will be installation of electrical upgrades to power the CCIM. The greatest challenge for Idaho Site will likely be the development of a strategy and system for blending and transfer of the material prior to vitrification. The canister dimension was identified as critical to both sites as it will affect all aspects of the process including design, facility, operations, safety, regulatory compliance, and product acceptance.

CCIM vitrification technology is well established and is an appropriate technology for SOA (canistered borosilicate glass) treatment of HLW calcine solids at the Idaho Site and HLW process effluent from H-Canyon operations. In general, the appropriateness of the CCIM technology and the system components are demonstrated or can be reasonably expected. One critical aspect that may determine the appropriateness of the overall SOA to treat the HLW calcine solids is the blending strategy, transfer, and ability to characterize the material. While some aspects are technologically mature and deployable, in general, the readiness of the CCIM technology and the system components are not demonstrated for the entire flowsheet, and some aspects were identified that have challenges. The readiness of CCIM technology is dependent on the interface and implementation aspects for each site.

Table 6-1 summarizes a subjective ranking of the readiness for aspects evaluated and presented in this report. Those aspects that are shaded in green (Yes) are demonstrated or are expected to need the least development. Those aspects that are shaded in orange/yellow (U) have some known challenges, but are expected to be able to be demonstrated with further development. Those aspects that are shaded in gray (No) have known uncertainty and further development/evaluation is needed to evaluate their demonstration potential. No aspects were identified as show stoppers.

Table 6-1. Summary of readiness aspects.

Criteria	ICP		SRS	
Vitrification Potential of Wastes	U	-may require more than one composition envelope - Fluorine content and high viscosity will challenge existing glass models	Yes	-high waste loading challenges -development of flowsheet uncertainty needed
Product Acceptance	No	-Only a preliminary framework exists, development needed	U	-could leverage existing strategies (GPCP)
Product/System Mismatch	U	-ability to blend waste is needed -additional infrastructure needed to move calcine -canister movement/transfer strategy needed	U	-canister movement/transfer strategy needed
Operational Constraints	No	-IWTU availability and retrofit needed	No	-installed electrical power is insufficient
Process Flowsheet and Physical Space Constraints	U	-potential siting identified, buildout and design specifications needed	U	-potential siting identified, buildout and design specifications needed
Regulatory Compliance and Permitting Changes	U	-changes to baseline permitting required	No	-baseline permitting as HLW producer does not exist
Facility Safety Considerations	U	-canister dimension and system design specification needed	U	-canister dimension and system design specification needed -Initial buildout retrofit will introduce additional aspects
Off-gas Handling and System Components	Yes	-specification needed to design -halide content (e.g. F/I) will need to be considered	Yes	-specification needed to design -Hg removal will need to be considered
Flowsheet Adaptability	U	-development of flowsheets for the wide variety of calcine compositions is needed	Yes	-some unknown flowsheets

U = unknown or uncertain

7.0 Conclusions and Recommendations

The CCIM is an appropriate and proven technology to vitrify HLW into borosilicate glass. The deployment of the CCIM to treat the HLW calcine solids and H-Canyon effluent is conceptually feasible. However, the design of system flowsheets, to include the ancillary processes such as material handling, off gas treatment, canister movement and storage, as well as the regulatory and permitting aspects are needed to better understand the CCIM technology application potential.

The technology readiness level (TRL) for CCIM vitrification of the HLW calcine or H-Canyon is less dependent on the system aspects, and more dependent on the interface and installation constraints specific to each of the applications. Much of the physical system components (e.g., CCIM, off gas, etc.) are well established with proven functionality, while many of the evaluated criteria (e.g., vitrification potential, regulatory compliance, safety, etc.) are not expected to pose significant issues based on existing practice and experience. However, other required aspects such as retrofitting buildout, upgrading utilities, and permitting changes are technically feasible, but the path to their accomplishment is less clear and depends on several factors. Further evaluation and development of these critical aspects is needed to drive a TRL determination for the unit operations and integrated system in the near term.

Per previous discussions with the DOE-EM TD program, a preliminary technology maturation plan (TMP) is recommended to identify the development needs to realize system validation and adequacy for each application. Evaluation of the associated costs, risk, and rewards to DOE (current and future missions) from deploying CCIM technology should be considered as well. The preliminary TMP is intended to provide an overview of the critical path needs for development for each application.

8.0 References

1. *Office of Environmental Management-Technology Development, "Evaluation of Cold Crucible Induction-Heated Melter Technology," Task Change Request, 2021-36 FP 86 Rev. 0 (2021).*
2. *Topical Report (Volume I of the ART – CCIM Project Comprehensive Report), AREVA-C0122-DOC-009.*
3. *Areva, Technical Drawing PI-13542-30-0001 Revision A., Savannah River Plant 2005 Area Defense Waste Processing Facility Layout-Tentative-Cell Plan.*
4. *"Technical Reviews," Savannah River Site, Aiken, SC, Manual E7, Procedure 2.60, current revision.*
5. *"Savannah River National Laboratory Technical Report Design Check Guidelines," Westinghouse Savannah River Company, Aiken, SC, WSRC-IM-2002-00011, Rev. 2, 2004. .*
6. *Staiger, M. Daniel and Michael C. Swenson, 2021, Calcined Waste Storage at the Idaho Nuclear Technology and Engineering Center, INEEL/EXT-98-00455, Rev. 6, U.S. Department of Energy Idaho Operations Office, September 2021.*
7. *Crum, J. V., J. D. Vienna, D. K. Peeler and I. A. Reamer, "Formulation Efforts for Direct Vitrification of INEEL Blend Calcine Waste Simulate: Fiscal Year 2000," PNNL-13483, March 2001.*
8. *Matlack, Keith S., Gan, Hao, Pegg, Ian L., Bowan, II, Bradley W., Smith, Eric C., Diener, Glen A., and Joseph, Innocent. Vitrification Process for Idaho HLW Calcine – 18433, - WM2018 conference, March 18-22, 2018. United States: N. p., 2018. Web.*
9. *Didierlaurent, Régis, Eric Chauvin, Jacques Lacombe, Christian Mesnil, Catherine Veyer, "Cold crucible deployment in La Hague facility: the feedback from the first four years of operation – 15119," WM2015 conference, March 15 – 19, 2015, Phoenix, AZ, USA.*
10. *D.K. Peeler and T.B. Edwards, "Frit Development Effort for Sludge Batch 4 (SB4): Nominal and Variation Stage Assessments," Savannah River National Laboratory, Aiken, SC, WSRC-TR-2005-00372, Rev. 0, 2005.*
11. *T.B. Edwards, "SME Acceptability Determination for DWPF Process Control," Savannah River National Laboratory, Aiken, SC, WSRC-TR-95-00364, Rev. 6, 2017.*
12. *Office of Environmental Management, "Waste Acceptance Product Specifications for Vitrified High-Level Waste Forms WAPS," USDOE Document DOE/EM-0093, Revision 2, U.S. Department of Energy, Germantown, MD, 1996. .*
13. *Office of Environmental Management, "Waste Acceptance Product Specifications for Vitrified High-Level Waste Forms WAPS," USDOE Document DOE/EM-0093, Revision 3, U.S. Department of Energy, Germantown, MD, 2012. .*
14. *Kluk, Tony and Ken Picha, 2008, "EM Waste Acceptance Product Specification (WAPS) for Vitrified High-Level Waste Forms, Presentation to the HLW Corporate Board," U.S. Department of Energy Environmental Management, July 2008.*
15. *DOE-RW, 2007, Waste Acceptance System Requirements Document (WASRD), DOE/RW-0351P, Rev. 5, U.S. Department of Energy Office of Civilian Radioactive Waste Management, January 1993.*
16. *J. W. Ray, B. H. Culbertson, S. L. Marra and M. J. Plodinec, "DWPF Glass Product Control Program," Savannah River Site, Aiken, SC, WSRC-IM-91-116-6, Rev. 5, 2004.*
17. Jantzen, C.M., et al., *Characterization of the Defense Waste Processing Facility (DWPF) Environmental Assessment (EA) Glass Standard Reference Material*. 1993, Westinghouse Savannah River Company: Aiken, SC.
18. *C. L. Crawford, M. C. Hsieh, F. C. Johnson, D. P. Lambert, J. M. Pareizs and M. S. Williams, "Demonstration of Defense Waste Processing Facility (DWPF) Higher Fissile Content Glass," Savannah River National Laboratory, Aiken, SC, SRNL-STI-2021-00208, Rev. 0, 2021.*
19. *DOE M 435.1-1 Chg 3 (LtdChg), 2021, "Radioactive Waste Management Manual," U.S. Department of Energy, January 11, 2021.*

20. *DOE-ID, 2007, Mission Need Statement: Calcine Disposition Project, Major Systems Acquisition Project, DOE/ID-11251, Rev. 0, U.S. Department of Energy Idaho Operations Office, January 2007.*
21. *Hernandez, Nicole, U.S. Department of Energy Idaho Operations Office, letter to Natalie Creed, Idaho Department of Environmental Quality, September 29, 2020, "Department of Energy, Idaho Operations Office Request for an Extension of the Site Treatment Plan Calcine Disposition Project Milestones Identified in Table 5-1 (CLN201660)," CCN XXXXXX.*
22. *75 FR 137, 2010, "Amended Record of Decision: Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement Revised by State 12/21/09," Federal Register, U.S. Department of Energy, January 4, 2010.*
23. *Atomic Energy Act of 1954, 42 U.S.C. § 2011 et seq., (1954).*
24. *Nuclear Waste Policy Act of 1982, 42 U.S.C. § 10101 et seq. (1982).*
25. *83 FR 196, 2018, "Request for Public Comment on the U.S. Department of Energy Interpretation of High-Level Radioactive Waste," Federal Register, U.S. Department of Energy, pg 50909, October 10, 2018.*
26. *84 FR 111, 2019, "Supplemental Notice Concerning U.S. Department of Energy Interpretation of High-Level Radioactive Waste," Federal Register, U.S. Department of Energy, pg 26835, June 5, 2019.*
27. *86 FR 11, 2021, "High-Level Radioactive Waste Interpretation Limited Change to DOE Manual 435.1-1, Radioactive Waste Management Manual and Administrative Change to DOE Order 435.1, Radioactive Waste Management," Federal Register, U.S. Department of Energy, pg 5173, January 19, 2021.*
28. Delaunay, M., et al., *Vitrification of Savannah River Site HLW Sludge Simulants at CEA Marcoule Industrial ‐ scale Cold Crucible Induction Melter Demonstration Platform*, in *WM2009*. 2009: Phoenix, AZ.
29. *Correspondence between DOE/SRNL/Orano regarding Orano's vitrification technologies, 2021.*
30. *TFR-349, Technical and Functional Requirements for the Integrated Waste Treatment Unit, Revision 17, October 2011.*
31. *Scheunemann, Barton, RPT-1727, Integrated Waste Treatment Unit External Utilities Vulnerability Evaluation, May 2019.*
32. *IWTU Specification SPC-15584, Maintenance Bridge Crane.*
33. *IWTU Specification SPC-14632, Transfer Bell Crane.*
34. *IWTU Specification SPC-14621, Transfer Bell Shield Housing.*
35. *IWTU Drawing 633056, DMR-CRR Cell Plan Elevation 129'0" General Arrangement.*
36. *IWTU Drawing 633063, DMR-CRR Cell General Arrangement Section.*
37. *IWTU Drawing 633067, Canister Filling and Decon Cell.*
38. *IWTU Drawing 633068, Canister Filling and Decon Cell General Arrangement Section East Elevation.*
39. *IWTU Drawing 633069, Canister Filling and Decon Cell General Arrangement South Elevation.*
40. *SmartPlant/PDS Original IWTU Piping Design Model File: drv007.*
41. Lopez, D.A., *High-Level Waste Vitrification Facility Feasibility Study*. 1999, Idaho National Engineering and Environmental Laboratory: Idaho Falls, ID.
42. *DOE, 2002, Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement, DOE/EIS-0287, U.S. Department of Energy, September 2002.*
43. *PER-111, 2017, Partial Permit for HWMA Storage and Treatment for the Liquid Waste Management System at the Idaho Nuclear Technology and Engineering Center on the Idaho National Laboratory, Books 1, 2, 3, and 4, EPA ID NO. ID4890008952, Idaho Department of Environmental Quality, September 2017.*
44. *Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Public Law 108-375, 108th United States Congress, (2004).*
45. *IDAPA 58.01.01, 2020, "Rules for the Control of Air Pollution in Idaho," Idaho Administrative Procedures Act, Idaho Department of Environmental Quality, March 2020.*

46. *R.F.B. Vance, B.A.; Carl, D. E.; Dhingra, H. S.; Meigs, R.A.; Studd, M. G., "Design of Equipment Used for High-Level Waste Vitrification at the West Valley Demonstration Project," West Valley Nuclear Services, Inc., West Valley, New York, 1997.*
47. *M.R. Norton, H.B. Shah, M.E. Stone, L.E. Johnson, and R. O'Driscoll, "Overview – Defense Waste Processing Facility Operating Experience," Westinghouse Savannah River Company, Aiken, South Carolina, 2002.*
48. *Y. Deng, B. Slettene, R. Fundak, R.C. Chen, M.R. Gross, R. Gimpel, and K. Jun, "Flowsheets Bases, Assumptions, and Requirements," Bechtel National, Inc. River Protection Project Waste Treatment Plant, Richland, Washington, 24590-WTP-RPT-PT-02-005, Rev 8, 2016.*

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