Development, Qualification, and Disposal of an Alternative Immobilized Low-Activity Waste Form at the Hanford Site - 11031

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ABSTRACT

Demonstrating that a waste form produced by a given immobilization process is chemically and physically durable as well as compliant with disposal facility acceptance criteria is critical to the success of a waste treatment program, and must be pursued in conjunction with the maturation of the waste processing technology. Testing of waste forms produced using differing scales of processing units and classes of feeds (simulants versus actual waste) is the crux of the waste form qualification process. Testing is typically focused on leachability of constituents of concern (COCs), as well as chemical and physical durability of the waste form. A principal challenge regarding testing immobilized low-activity waste (ILAW) forms is the absence of a standard test suite or set of mandatory parameters against which waste forms may be tested, compared, and qualified for acceptance in existing and proposed nuclear waste disposal sites at Hanford and across the Department of Energy (DOE) complex. A coherent and widely applicable compliance strategy to support characterization and disposal of new waste forms is essential to enhance and accelerate the remediation of DOE tank waste. This paper provides a background summary of important entities, regulations, and considerations for nuclear waste form qualification and disposal. Against this backdrop, this paper describes a strategy for meeting and demonstrating compliance with disposal requirements emphasizing the River Protection Project (RPP) Integrated Disposal Facility (IDF) at the Hanford Site and the fluidized bed steam reforming (FBSR) mineralized low-activity waste (LAW) product stream.

INTRODUCTION

Historically, DOE nuclear waste treatment and immobilization strategies have differed by site and era. Typically, waste has been treated according to its level of radioactivity and chemical hazard. The tank waste, both liquid and solid, at Hanford, the Savannah River Site (SRS), and the Idaho National Laboratory (INL) is composed of the process effluents from reprocessing nuclear fuels, decontamination operations, and other Cold War activities. To facilitate immobilization processing, tank waste is separated into two or more fractions, usually a small fraction of high-level waste[1] (HLW) and a generally much larger fraction of LAW [2]. These processes primarily employ ultra- or micro-filtration and ion exchange to separate and concentrate highly radioactive species, forming the HLW stream. Reasons for classifying waste as described include repository selection (near-surface versus deep geologic disposal), repository Performance Assessment (PA) techniques, and immobilization technology selection and use.

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[1] *Highly radioactive waste material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that is determined, consistent with existing law, to require permanent isolation [18].*

[2] *Waste that remains following the process of separating as much of the radioactivity as is practicable from HLW. When solidified, LAW may be disposed of as low-level waste in a near-surface facility [1].*

For example, it is practical to separate HLW and LAW because the LAW stream processing components require less shielding and are therefore easier to operate, monitor, and maintain. Table 1 summarizes immobilization technologies and proposed final destinations of DOE radioactive tank wastes [1-5].

Table 1. DOE Sites, Wastes, and Disposal Strategies.

DOE Site	Waste Type	Immobilization Technology	Disposal Facility
Hanford	HLW	Vitrification	Federal Repository To Be Determined (TBD)
	LAW	Vitrification + TBD[a]	RPP IDF
Idaho	HLW	Calcination + Hot Isostatic Pressing	Federal Repository TBD
	Sodium-Bearing Waste (Remote-Handled Transuranic Waste)	FBSR[b]	Waste Isolation Pilot Plant
Savannah River	HLW	Vitrification	Federal Repository TBD
	Low-Level Waste (LLW)	Grout/Saltstone	On-Site Disposal Units (Vaults)
West Valley	HLW	Vitrification	Federal Repository TBD
	LLW, MLLW	Grout	Commercial and/or DOE Facilities TBD

[a] Supplemental immobilization technology decision has not yet been rendered. Candidates are a 2nd LAW Vitrification facility, FBSR, Bulk Vitrification, and Cast Stone.
[b] The FBSR unit at the Idaho site will produce a carbonate product.

LAW Immobilization Technology Background

Vitrification is the currently planned immobilization technique for both HLW and LAW for the 56 million gallons of radioactive tank waste at the Hanford Site [1]. The Waste Treatment and Immobilization Plant (WTP) is designed to vitrify about one third of all LAW originating from tank farms and resulting from WTP pretreatment. The WTP is currently under construction, and the LAW facility is nearly 70% complete. A supplemental LAW processing facility will be required to treat all Hanford LAW within the mission schedule mandated in Hanford's Federal Facility Agreement and Consent Order (Tri-Party Agreement or TPA) [6]. The current baseline[3] assumption for supplemental LAW immobilization capacity is that a second LAW vitrification facility will be designed, constructed and operated [1]. In the WTP, the LAW to be vitrified will be separated from the HLW fraction of Hanford tank waste by removing radioactive solids via filtration and radioactive cesium through ion exchange. The resultant clarified LAW feed will be mixed with glass forming chemicals and vitrified in joule-heated ceramic melters (JHCMs) designed by Energy*Solutions*. Each melter will produce borosilicate glass at an average melt temperature of 1150^{o}C [7]. The glass will be poured into stainless steel containers, cooled and is assumed to be disposed at the RPP IDF [1]. A considerable amount of testing on simulated and

[3] The current assumption for the baseline immobilization method is used for planning purposes. A supplemental immobilization technology selection decision will be made as part of DOE/ORP's ongoing Critical Decision process.

radioactive Hanford ILAW glass specimens produced in bench-scale crucible melts from multiple tank samples demonstrates that the ILAW glass is chemically durable with respect to federal land disposal restrictions and RPP-WTP contractual specifications [8]. Additionally, a full PA for ILAW glass has been issued. Results of this study indicate that long term performance objectives will be met for ILAW glass disposal at the RPP IDF near surface disposal facility [9]. While vitrification has been a preferred option for immobilization of HLW throughout the DOE complex, Hanford is the only site that has selected vitrification as the primary immobilization technology for LAW. As shown in Table 1, LAW/LLW immobilization technologies vary, but those producing cementitious waste forms are most common.

The U.S. DOE, along with contractor Washington River Protection Solutions, LLC (WRPS), is currently conducting the Hanford LAW supplemental immobilization technology Critical Decision (CD) process, the next step being CD-1. This decision will determine the alternative technology option for supplemental LAW immobilization capacity. The technologies under consideration are a second LAW vitrification facility (functioning much like the first system in the WTP but with greater capacity), direct solidification resulting in a cast stone product, bulk vitrification, and FBSR to produce a mineral product.

Direct solidification and production of a cast stone waste form is under consideration at the Hanford Site. This process chemically converts the hazardous and radioactive constituents in the LAW to less soluble, mobile, or toxic forms. During solidification, COCs are chemically incorporated into a high strength, stable monolithic form. The dry reagents include Portland cement (binding material), fly ash (aggregate), blast furnace slag (promotes reducing environment), and ferrous sulfate monohydrate, a reducing agent used in small quantities relative to the other reagents [10]. The LAW feed is mixed with the solid reagents and gravity-fed into containers for curing and disposal. Study of the waste form has focused on the WTP Effluent Treatment Facility (ETF) secondary waste with encouraging but mixed results in preliminary Toxicity Characteristic Leaching Procedure (TCLP) testing [11]. However, studies relating to the retention of technetium-99 (Tc-99) and chromium have shown that the product can demonstrate a high level of chemical durability regarding diffusive release when a reducing, cementitious monolith is formed [12]. The relative simplicity of the process and DOE complex-wide application of similar immobilization technologies make it appealing for supplemental LAW immobilization at Hanford. Further investigation of waste form durability focused on LAW instead of secondary waste will be necessary.

Bulk vitrification (BV) is a technology for in-container vitrification of Hanford LAW. The BV process would receive waste from a supplemental pretreatment system and combine the LAW feed with a metered amount of soil (the BV glass former) and graphite, which increases electrical conductivity of the mixture to initiate melting [10]. The assumed soil composition is 88.7% silica (SiO_2), 1.3% soda (Na_2O), and 10% moisture. Refractory sand is used as a liner in the bottom and sides of the container to protect the container from overheating and provide radiation shielding [10]. This technology also commands a high level of technical maturity [10]. The glass waste form has met all performance objectives related to release of COCs through TCLP, Product Consistency, and Vapor Hydration testing [13]. However, it has been observed that migration of rhenium (Re - cold Tc surrogate) into the refractory and sand layers can occur. LAW turns to molten ionic salt (MIS) at 300°C and decomposes by 750°C, well below the melt temperature of 1300°C. However, the transition time allows the low viscosity MIS, carrying Tc, to penetrate into the refractory and sand layers. Furthermore, Tc has been shown to preferentially reside in salt layers which form above the glass product. In these layers, the Tc remains in a soluble state. Improved melt formulations and cold-cap control could potentially mitigate Tc migration [13].

Fluidized bed steam reforming is a relatively low temperature (700-750^{o}C) process that utilizes a solid particle bed fluidized by low pressure, superheated steam. The waste feed is a solids-free liquid with clays added as co-reactants to produce the mineral forms. With a carbon additive for fuel, the process destroys organics, converts nitrates and nitrites into nitrogen gas, and captures radionuclides and heavy metals within a stable, crystalline mineral product [14]. The three primary phases that form are nepheline, nosean, and sodalite. The FBSR process for nuclear waste forms the sodium aluminosilicate (NAS) minerals with waste nuclides and metals bound within the crystalline network [14]. These crystalline products have been shown to be very effective for immobilizing and retaining radioactive tank waste species, displaying leach resistance comparable to borosilicate glass in preliminary durability testing. However, in order to meet RPP IDF Waste Acceptance Criteria (WAC), the granular NAS product would be further immobilized by macro-encapsulation in a monolithic product using a durable, chemically benign binder material [15]. The driving criteria for the secondary process are centered on ensuring physical compressive strength and preventing product dispersal in a disposal site intruder scenario [16].

The remainder of this paper will focus on the steam reforming product from a waste form qualification standpoint. Sufficient information and data exist for the BV and direct solidification technologies to enter the CD-1 process. The steam reforming technology lacks maturity in the waste form qualification arena. A strategy for maturing this technology based on qualification of the product for RPP IDF disposal is presented.

DOE Technology Maturation using the Technology Readiness Assessment Technique

The DOE Guide 413.3-4, *"Technology Readiness Assessment Guide,"* provides guidance for conducting technology readiness assessments or developing technology maturation plans. The Forward to DOE G 413.3-4 [17] states:

> *"This Guide presents a tailored version of a proven National Aeronautics and Space Administration (NASA) and Department of Defense (DoD) technology readiness assessment model that assists in identifying those elements and processes of technology development required to ensure that a project satisfies its intended purpose in a safe and cost-effective manner that will reduce life cycle costs and produce results that are defensible to expert reviewers."*

The DOE has provided this guide for use by government agencies and contractors. The technique is invaluable to normalization of technology development processes and, more specifically, to the development of new, innovative waste treatment and immobilization methods and the subsequent waste forms. The Guide is built on the need to demonstrate the technology at increasing scales and in increasingly relevant operating environments, e.g. transitioning from cold simulant testing to radioactive testing in a hot cell or a scaled facility. The following figure is adapted from DOE G 413.3-4 and provides a summary of the scales, feed types, and schedule allotments required to achieve a given Technology Readiness Level (TRL) along with a guide to the DOE CD process.

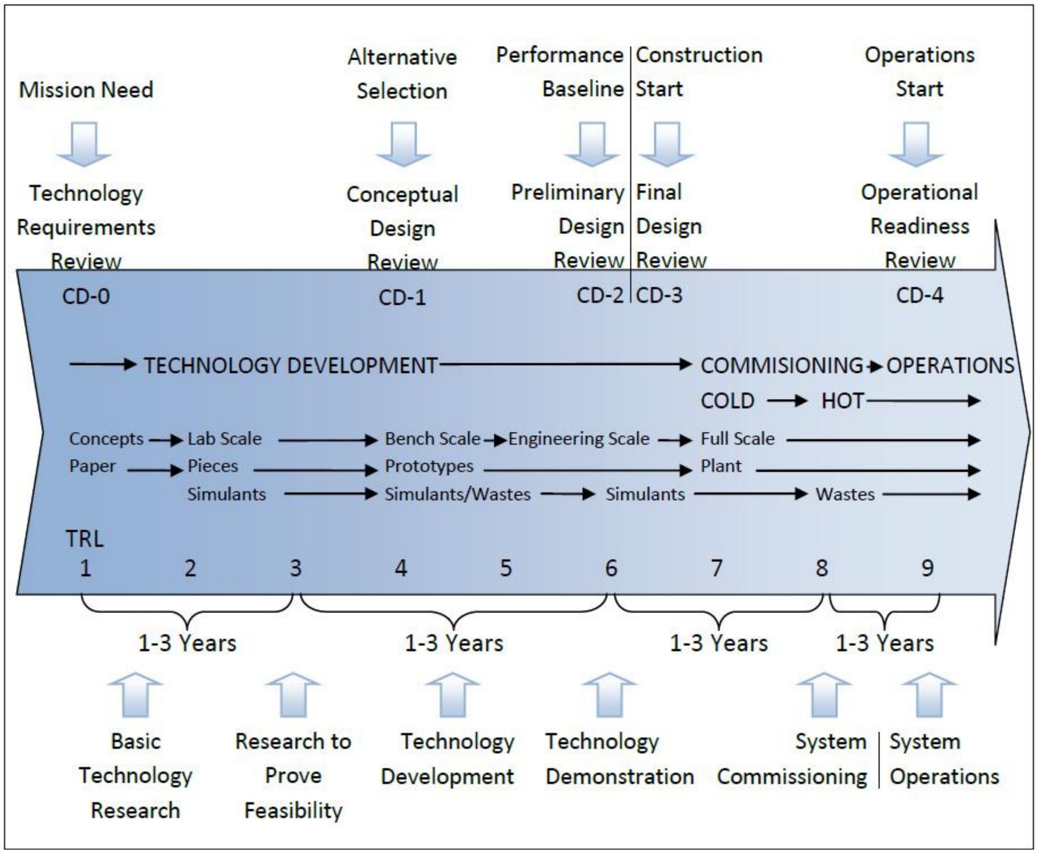

Figure 1. Technology Readiness Level Progression, as adapted from DOE G 413.3-4.

The TRL/TRA (Technology Readiness Assessment) technique provides a standardized method that can be applied to maturation of waste treatment and immobilization technologies. Demonstration that a compliant waste form can be produced by a given technology drives the need and precedence of associated technology development activities. Therefore, by following this process and ensuring product performance is assessed at appropriate stages, a logical, data-driven justification to continue or to conclude maturation work on a given immobilization process can be obtained.

WPRS is using the TRA process to establish the TRLs for each candidate supplemental immobilization technology to support the CD-1 down-selection process. Once the supplemental immobilization technology has been selected, the TRA/TRL process will establish, in a technology maturation plan, the requirements for going forward and guide the development and deployment of the chosen technology at the Hanford Site.

Regulatory Entities and Roles in Waste Disposal at Hanford

The regulatory environment for disposal of immobilized nuclear waste at Hanford is particularly complex. Due to the nature of the waste, immobilization and disposal are governed by the DOE, Washington State Department of Ecology (Ecology), and the United States Environmental Protection Agency (EPA). The DOE provides the Radioactive Waste Management Manual, DOE M 435.1-1, and the associated regulations to describe the obligation to complete PAs and Composite Assessments (CAs) [18]. The Resource Conservation and Recovery Act (RCRA), promulgated by the EPA and applicable chapters from the Code of Federal Regulations (CFR), describes the Universal Treatment Standards (UTSs) and the Land Disposal Restrictions (LDRs) [19, 20]. The RCRA requirements have since been adopted by the State of Washington into their Dangerous Waste Regulations that are codified at WAC 173-303. These statutes and regulations mandate the standards for permissible waste form composition and define certain aspects of waste form performance. Finally, Ecology regulates the RPP IDF by issuing the permit for land disposal of radioactive mixed waste. Mixed waste is waste that contains or exhibits both radioactive and hazardous constituents or characteristics. Hanford tank waste is regulated as mixed waste as stipulated in the Tri-Party Agreement [21].

Furthermore, there is significant interest from several groups of stakeholders regarding the performance and longevity of any radioactive waste disposed in Washington State. These include but are not limited to the DOE Office of River Protection (ORP), Ecology, the Hanford Advisory Board, local and displaced Native American tribes, and concerned members of the public. While all of these organizations typically cannot control the actions of the Tank Operations Contractor (TOC), DOE ORP, as the WRPS TOC client, and Washington State Ecology do significantly influence the path forward and long term site remediation agenda.

The following figure illustrates how each of the regulatory bodies control land disposal of immobilized Hanford tank waste. The figure shows the relevant regulations, codes, and obligations that the TOC must satisfy.

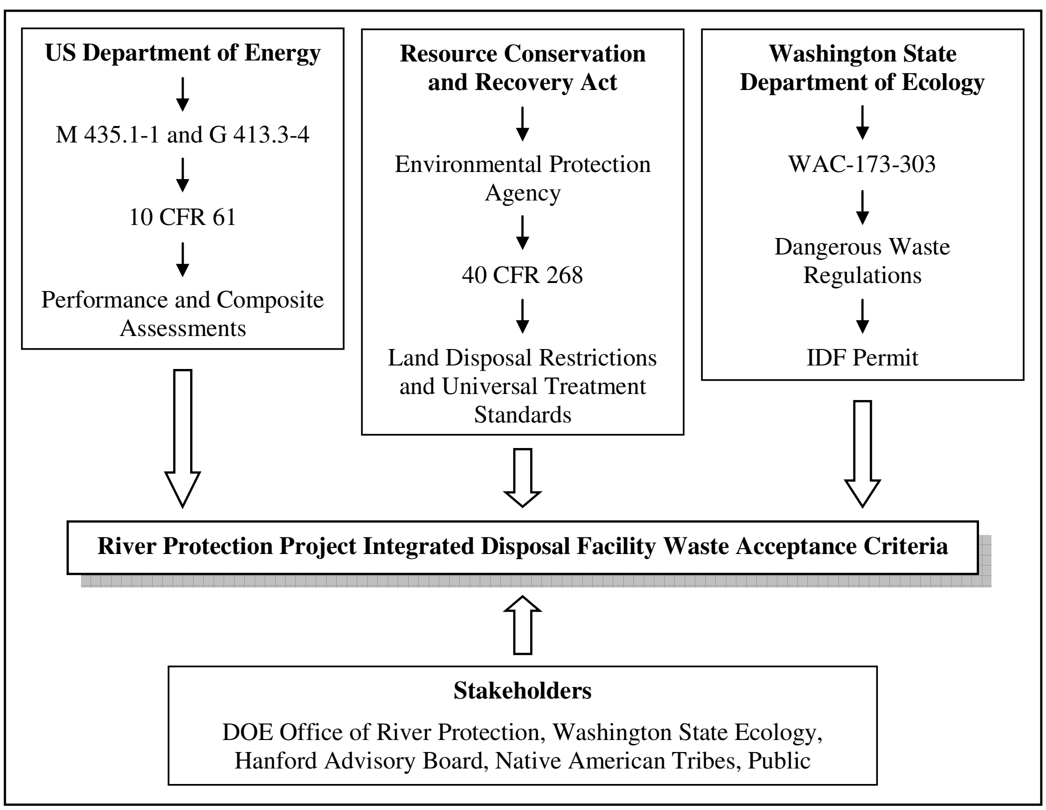

Figure 2. Regulators, Regulations, and Stakeholders Relevant to IDF Waste Disposal.

QUALIFICATION GUIDELINES

The purpose of this section is to provide the framework of a program for expedient and financially efficient qualification of a proposed waste form for immobilizing LAW. It is not intended to address every concern with waste form qualification and disposal.

With a candidate waste form and production process, there are a few key questions that must be asked, and answered, before waste processing or land disposal can occur. The following questions are critical for waste form development, qualification, and disposal.

Is the process effective, well understood and controlled, and legally compliant?

Processing technique selection is dependent on many technical and non-technical criteria. One principal criterion is effectiveness in immobilizing COCs. When developing a durable, robust waste form, the processing technique (and the control and understanding thereof) is of utmost importance. For LAW, Tc-99 and iodine-129 (I-129) are of particular significance and interest to governing bodies, stakeholders, and engineers due to their long half-lives and mobility in the environment. If the process cannot sufficiently immobilize the Tc-99, then perhaps it is not the best waste processing choice. Furthermore, waste loading into the product is important (i.e., the ratio of non-volatile waste mass to total waste form mass). A processing technology that will yield a greater number of waste packages with very little radioactive material in each is also likely not an optimum technology because it would consume more processing time and yield large disposal volumes and costs.

New, innovative waste forms such as the steam reforming product and the final monolithic waste form may require additional characterization to fully understand the material and provide a more comprehensive basis for selection as an immobilization technology. In the case of the steam reforming product, operational testing and initial mineralogy studies and experiments have been conducted [22] and additional mineralogy and durability studies are currently underway. Additional testing to verify speciation of COCs and the effects of COCs on the crystalline mineral structure will also be conducted.

The process also must be shown to be legally compliant during routine operations, startup, and shutdown. Demonstrated off-gas control is of particular importance. Total processing facility radionuclide inventory must also be evaluated and regulated for the purpose of DOE facility hazard classification [23].

Path Forward/Strategy

A process must be demonstrated at small scale, and then at increasing scales and in more realistic environments, to demonstrate that it can be controlled, is well understood, and performs well throughout a range of testing conditions that are characteristic of actual operating conditions. The process must be shown to immobilize the COCs at various scales, starting with bench-top process demonstrations to minimize technical and financial risk. Increasing scales and testing with both cold simulants and real wastes are key strategies to increase the TRL of the process [17].

For steam reforming, the Savannah River National Laboratory (SRNL) has both radioactive and non-radioactive bench-scale reformer (BSR) units available to characterize the process and produce mineralized product for waste form performance testing. The Hazen Facility in Golden, Colorado[4] has an engineering-scale technology demonstration platform, providing a non-radioactive unit for testing simulants from Hanford and other sites and producing the mineralized product [22]. Processes can be tested, modified, and assessed at these smaller scales to verify functionality and product scalability, and provide input to process design and testing at full scale. Additionally, non-radioactive COC surrogates, such as Re for Tc, can be used to provide initial assessment of the ability of the FBSR product to effectively immobilize the actual COCs, and reduce risk in further testing.

Full-scale verification testing will be conducted during facility cold and hot commissioning. This final testing will demonstrate aspects of the technology such as process control, product composition control, off-gas control, and compliance with nuclear safety requirements. The demonstration would also provide final validation and verification regarding the range of operating parameters over which a consistent, acceptable product is formed. In summary, technology maturation is achieved by scaling up processes to provide understanding of process characteristics as well as technological effectiveness. This sequence of testing should be conducted in accordance with DOE G 413.3-4.

Does the final product meet federal and state land disposal criteria?

Hanford LAW is classified as mixed waste and thus the ILAW waste form must meet both RCRA and DOE disposal requirements. The DOE disposal requirements are found in DOE Manual 435.1-1 which invokes requirements for near-surface disposal of LAW found in 10 CFR 61 [24]. These requirements limit the radionuclide content of the waste and dictate that the waste must be structurally stable, maintaining physical dimensions under loading and other circumstances. DOE 435.1-1 further requires that a PA of the disposal facility must be conducted as well as a CA to demonstrate less than 25 mrem/yr dose to the maximally exposed individual. The 10 CFR 61 standards also mandate that the waste form must maintain structural stability after being exposed to biological, radiological, and liquid contact (leaching) effects [24]. These tests are conducted according to procedures in American Society for Testing and Materials (ASTM) G21 and G22, radiation dose of 10^6 rads, and American National Standards Institute (ANSI) 16.1 or ASTM 1308, respectively. These standards and procedures are addressed specifically in the RPP IDF WAC [16] and will be discussed in the following section.

RCRA requirements are based on federal and state LDRs found in 40 CFR Part 268 [20]. The waste form must be shown to immobilize underlying hazardous constituents to meet UTSs. In general, Hanford ILAW will need to meet UTS limits for toxic metals when tested via the TCLP. Finally, since vitrification is currently the specified treatment standard for RCRA metals found within the Hanford tank waste, the FBSR waste form must satisfy a determination of equivalent treatment (DET) [20].

Path Forward/Strategy

Demonstrating that the waste form complies with UTS limits via EPA Method 1311, *Toxicity Characteristic Leaching Procedure,* is relatively straightforward [25]. Testing should be conducted at several scales. For steam reforming, TCLP data regarding product obtained from

[4] *The Hazen Facility is owned by Carbon Fuels, LLC of Denver, Colorado.*

processing simulants in an engineering-scale facility are available and show encouraging results [22]. TCLP testing is currently underway on samples of steam reformer product made from actual Hanford LAW using the BSR process at the SRNL. The following table describes TCLP testing, as is required by state and federal law.

Table 2. Description of Federal and Washington State Required Testing [20, 21, and 25].

Test Name	Standard Number	Test Output	Relevant Regulation and Source	Glass Specific?
Toxicity Characteristic Leaching Procedure (TCLP)	EPA Method 1311	Concentrations of Hazardous Materials in Groundwater (Specifically RCRA Metals)	Federal UTS and LDR; Washington State Land Disposal Restrictions: See WAC-173-303-090 or 40 CFR 264.94 for list of RCRA Metals' Concentration Limits	No

The more rigorous DET and treatability variance testing would first involve a formal data quality objectives (DQO) process to define the study questions, determine the scope and scale of testing required, and establish requirements for data quality. The testing program would be similar to that conducted for LAW vitrification, with the addition of TCLP testing for COCs that were already covered by the vitrification treatment standard [HLVIT] and therefore not addressed during ILAW glass testing.

A petition for determination of equivalent treatment along with information and testing data that demonstrate the capability of the FBSR waste form to meet the RCRA metals' treatment standards would be filed if FBSR technology is selected and matured. Furthermore, because the sampling, analysis, and testing of treated wastes required to demonstrate compliance with the treatment standards regarding underlying hazardous constituents is inconsistent with the principles of "As Low as Reasonably Achievable (ALARA)," a treatability variance would be pursued.

Does the final product meet disposal criteria for the specific disposal site[5]?

Beyond government disposal restrictions and regulations, there are facility-specific WAC that vary greatly from site to site. The facility WAC include both qualitative and quantitative objectives. The following list provides a selection of quantitative restrictions for the RPP IDF [16]:

- Radionuclide concentrations are limited to Class C;
- Dose rates at package surface and at 30 centimeters from package surface are limited to 200 and 100 mRem/hr, respectively;
- A minimum leachability index[6] of 6 is stipulated;

[5] Each disposal site for DOE radioactive wastes specifies an individual and unique set of acceptance criteria. This section will focus on the RPP IDF.
[6] An index value related to the leaching characteristics of solidified waste materials as measured by the leach test defined in ANSI 16.1 [27].

- Category 3 wastes (such as steam reforming product) must exhibit 500 pounds per square inch (PSI) or greater compressive strength;
- Total heat content of a waste package cannot exceed 3000 BTU/lb;
- After processing, acceptable waste must contain less than 0.5 vol.% free liquids.

Qualitative restrictions include procedures for labeling, closing and sealing; documentation of waste compositions; waste handling provisions; and quality assurance considerations [16].

Path Forward/Strategy

Demonstration of compliance for each criterion is to be documented and presented according to the RPP IDF Waste Certification Program, explained in RPP-8402 [16]. This document outlines the necessary documentation and quality assurance certifications that must be presented to the IDF acceptance group [16].

Compliance with each requirement should be demonstrated through testing of the waste form and any significant interim products. Historically, a compliance strategy for each acceptance criterion is developed and published in a planning document, as was done for the BV program [26]. Multiple processing unit scales and classes of feeds (e.g., cold simulant versus real waste, or simulant spiked with radioactive species) will be specified in the compliance strategy depending on the specific objectives and testing involved. Due to the complex nature of the Hanford tank waste, several carefully selected waste samples will be processed and tested during the FBSR waste form qualification campaign. In some cases, criteria are based on the results of established, standardized testing. An example of this practice is that the IDF requires a leachability index of at least six [16]. The demonstration and compliance plan for this particular requirement would entail ANSI 16.1 [27] or ASTM C1308 [28] testing because these standardized tests can be used for determining leachability index.

Testing should focus on demonstrating that WAC are met according to the defined compliance strategy. The following chart provides information on two important tests specified as mandatory for satisfying the IDF WAC.

Table 3. Description of Testing Specified by the River Protection Project Integrated Disposal Facility Waste Acceptance Criteria [16, 27, 29].

Test Name	Standard Number	Test Output	Relevant Regulation and Source	Glass Specific?
Measurement of the Leachability of Solidified Low Level Radioactive Wastes by a Short Term Test Procedure	ANSI 16.1	Leachability Index	IDF Requirement: Leachability Index must be greater than 6	No
Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens	ASTM C 39/C 39M-99	Compressive Strength of a Waste Monolith	IDF Requirement: Category 3 wastes must have S > 500 PSI	No

An additional requirement for IDF disposal is characterization and modeling of long term performance of the waste form and disposal site, accomplished by conducting a Performance Assessment [16, 18]. The PA employs an iterative calculation process along with advanced computer simulations to quantify long term COC migration into surrounding areas and exposure to human populations. Contaminant migration in soil and groundwater is derived from laboratory data regarding leachability, physical and chemical alteration rates, and release rates of particular species (primarily sodium, uranium, Tc, I, neptunium, and other actinides) [9]. Results of the PA are used primarily to confirm long term protection of public health and the environment. A PA for the RPP IDF was conducted in 2001 assuming all Hanford LAW would be vitrified. The following were presented as the preferred suite of laboratory tests for source term development [9]. The PA and the laboratory tests use comparison and feedback logic to provide increased confidence in resultant data sets.

Table 4. Principle Testing Requirements for Provision of Performance Assessment Source Term [9, 30-33].

Test Name	Standard Number	Test Output	Relevant Regulation and Source	Glass Specific?
Standard Test Methods for Determining Chemical Durability of Nuclear, Hazardous, and Mixed Waste Glasses and Multiphase Glass Ceramics: The Product Consistency Test (PCT)	ASTM C 1285-02	Normalized Mass Loss of Key Constituents	WTP Contract Specification: Na, B, Si normalized mass loss < 2 g/m^2	No
Standard Practice for Measurement of the Glass Dissolution Rate Using the Single-Pass Flow-Through (SPFT) Test Method	ASTM C 1662-07	Kinetic Rate Information (Forward Dissolution Rate under Steady State Flow Conditions)	No specified requirement; used to define rate-limiting release element(s) and characteristics. Important input parameter for PA.	No
Pressurized Unsaturated Flow (PUF) Test	N/A	Vadose Zone Diffusion and Alteration/Reaction Behavior, Secondary Phase Formation Characterization	No Requirement; used to characterize behavior of waste forms in unsaturated flow land burial conditions (representative of the IDF, vadose zone); provides release/alteration rate information inputs for PA	No
Standard Method for Measuring Waste Glass or Glass Ceramic Durability by Vapor Hydration Test (VHT)	ASTM C 1663-09	Glass Phase Alteration Rate	WTP Contract Specification: glass alteration rate < 50 $g/(m^2*day)$	Yes

Is the proposed waste form comparable to borosilicate glass?

A difficult yet important question to answer for stakeholders, regulators, scientists, and engineers is: *"Is this waste form as good as glass?"* The question is difficult to answer primarily because it is unclear. It could be argued that if the waste form durability is equivalent to glass, all other factors being equal, the new waste form should demonstrate equivalent performance under disposal site conditions and yield an equivalent PA result, and therefore be considered "as good as glass."

Numerous tests have been developed for characterization and assessment of vitreous waste form durability such as the Product Consistency Test (PCT). The PCT is also a qualified test method for glass-ceramic waste forms and DOE is currently gathering data that can be used to qualify this method for use with the FBSR mineral waste form. There is particular value in using this test as the PCT is historically a well accepted test for determining and comparing the durability of radioactive waste forms. The SPFT and PUF tests were designed to yield data on a variety of waste forms. Due to the nature of these tests, data is rendered that can be directly related to disposal site conditions and can be reliably used to predict alterations to waste forms that would occur over long periods of time. These tests were used to predict the long term ILAW glass performance (impact to human health and the environment) for the 2001 PA calculations [9]. Similar tests were used to predict steam reforming product waste form performance for risk assessment calculations performed in 2003 [34].

Path Forward/Strategy

A series of product durability tests will be conducted on the FBSR products and the results compared to those of ILAW glass. These tests should and will include tests to determine long term waste form alteration phases and mass losses such as the PUF test and long-term PCT tests. A statistically significant amount of FBSR product testing using the PCT will take place at multiple laboratories during the ongoing waste form qualification campaign. These data may be submitted to ASTM for qualification of the PCT for mineral waste forms and would alleviate any concern of test applicability. Short-term PCT testing should also be conducted to provide a quick comparison of performance and potential correlation to SPFT and PUF results. This testing should and will be supplemented with tests that are designed for a wide range of waste forms (amorphous and crystalline) to include the ASTM C1308 leach test and the TCLP. All of these test results will be assessed alongside those of glass allowing a definitive, quantitative comparison of waste form performance to be made.

Demonstration of high leach resistance and product durability (particularly relevant to Tc and I retention) is a critical aspect of steam reforming product testing and qualification. If the product can be shown to perform comparably to ILAW glass in these areas, then there should be a very strong case for further development and implementation of this technology at the Hanford Site.

PROGRAM OVERVIEW AND STATUS

Steam reforming has been indentified for development at the Hanford Site due to the robust nature of the process and promising performance of the mineralized waste form. The stable mineral product has been shown to be durable and effective in immobilizing COCs. The monolithic waste form that will result from binder material addition and curing provides compliance with remaining IDF WAC.

DOE has contracted the SRNL to process three actual Hanford waste samples, chosen to represent the balance of mission waste needing supplemental treatment and immobilization, in its radioactive BSR unit to further understand product chemistry and durability. These tests will also include the monolithing portion of the FBSR immobilization process. Durability and qualification testing of the material produced in the SRNL bench-scale unit, conducted by the Pacific Northwest National Laboratory (PNNL) and the SRNL, commenced in late 2010 and will continue into fiscal year (FY) 2012. Resultant data will be cross-walked with that of previous pilot- and engineering-scale tests with simulants and additional scaled-up simulant testing to be conducted in the future. The intent is to demonstrate that the large scale non-radioactive product is directly comparable to the bench-scale actual waste product, minimizing the need for large-scale radioactive testing. Finally, tests will feed a preliminary PA and will provide a basis for the final supplemental treatment decision by October 2014.

CONCLUSIONS

Qualification of a non-vitreous waste form for disposal at the Hanford IDF is an important activity. The RPP IDF WAC were tailored toward disposal of ILAW glass at that facility. WRPS has focused on the issue of qualification of a new technology application and waste form, reviewed historically relevant activities, and developed and enacted a program that will provide data for an objective supplemental immobilization technology selection and resolve the question of whether the steam reforming product is “as good as glass.” Waste form qualification efforts should center on demonstrating compliance with regulations and disposal facility acceptance criteria through established, appropriate testing methods based on technical criteria, and not on historic preference.

Product and process design are driven by the required and exhibited characteristics of a waste form, and vice versa, making facility design and flowsheet development more difficult and interrelated. These considerations drive the strategy for waste form qualification and technology development. Following the methods described in the previous section and the guidance of DOE G 413.3-4, new waste form qualification and technology development campaigns can be more successful and expedient, providing efficient and fiscally tenable radioactive waste treatment and immobilization solutions.

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