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____ Date: ____ ____ Date: ____

____ Date: ____ ____ Date: ____

(c) Responsible Manager (Print/Sign): P.A. Cavanah Date: 2013.3.21

(13) Distribution:

(a) Name	(b) MSIN	(a) Name	(b) MSIN
T. H. May	H8-04		
R. A. Robbins	H8-04		
L. E. Thompson	H8-04		
R. M. Russell	H8-04		
K.R. Sydnor	H8-04		
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TECHNETIUM REMOVAL TECHNOLOGY DEVELOPMENT PLAN FOR ELUTABLE ION EXCHANGE

Author Name:
R. A. Robbins
Washington River Protection Solutions
Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-08RV14800

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TECHNETIUM REMOVAL TECHNOLOGY DEVELOPMENT PLAN FOR ELUTABLE ION EXCHANGE

Daniel J. McCabe

FEBRUARY 20, 2013

Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, SC 29808

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REVIEWS AND APPROVALS

Daniel J. McCabe, SRNL Advanced Characterization and Process Research — Date 2/21/13

William King — 2/21/13

William King, Peer Review, SRNL Advanced Characterization and Process Research — Date

2/21/13

Frank Pennebaker, SRNL Manager, Advanced Characterization and Process Research — Date

2/22/13

Rebecca Robbins, Washington River Protection Solutions — Date

2/21/13

Sharon Marra, SRNL Level 3 Manager, E&CPT Research Programs — Date

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LIST OF ACRONYMS

BV	Bed Volume (IX resin)
CTE	Critical Technology Element
DF	Decontamination Factor
DOE	Department of Energy
DSA	Documented Safety Analysis
ETF	Effluent Treatment Facility
GPM	Gallons per Minute
HLW	High Level Waste
IDF	Integrated Disposal Facility
IX	Ion Exchange
L	liter
LAW	Low Activity Waste
M	Molar
ORP	Office of River Protection (DOE)
PA	Performance Assessment
R&D	Research and Development
SRS	Savannah River Site
TD	Technology Development
TMP	Technology Maturation Plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TRU	Trans-Uranic
WRPS	Washington River Protection Solutions
WTP	Waste Treatment Plant

EXECUTIVE SUMMARY

The purpose of this Technology Development plan is to summarize the status of the maturity of elutable ion exchange for technetium removal from Hanford tank waste, and to outline the technology development activities needed to complete its maturation. The needed activities will be identified by following the guidance, format, and content of the *U.S. DOE Office of Environmental Management Technology Readiness Assessment (TRA) and Technology Maturation Plan (TMP) Process Guide*. This plan will assess whether prior testing adequately bounds the application for Hanford tank waste, and recommend what additional testing is required.

Technetium-99 (^{99}Tc) is a long-lived radionuclide with a half-life of 210,000 years and is a significant fission product from nuclear reactors. Over fifty years of nuclear materials production at the DOE Hanford facility has generated waste containing approximately 26,500 Curies of ^{99}Tc, which is predominantly soluble, and will be processed as Low Activity Waste (LAW). The primary chemical form of ^{99}Tc found in LAW is as pertechnetate anion (TcO_4^-) with a +7 technetium oxidation state. Pertechnetate will not be removed from the aqueous waste in the Hanford Waste Treatment and immobilization Plant (WTP), and will primarily end up immobilized in the LAW glass, which will be disposed in the Integrated Disposal Facility (IDF). Because ^{99}Tc has a very long half-life and is highly mobile, it is the largest dose contributor to the Performance Assessment (PA) of the IDF.

Removal of technetium from the LAW would eliminate a key risk contributor for the IDF PA for disposal of supplemental waste forms, and has potential to reduce treatment and disposal costs. Elutable ion exchange has been developed for removing ^{99}Tc from LAW at Hanford, but the technology is not fully matured. A formal Technology Readiness Assessment (per the *U.S. DOE Office of Environmental Management Technology Readiness Assessment (TRA) and Technology Maturation Plan (TMP) Process Guide)* has not been performed, but this document contains a self-assessment of the status of the elutable ion exchange with SuperLig® 639[1] resin and provides a plan and rough order of magnitude estimates for maturing it. This information will be used to evaluate options for deployment.

The Tc removal process is assumed to treat LAW that has already been decontaminated for Cs-137. The Cs and Tc-decontaminated LAW is assumed to then be processed for immobilization. The disposal route for the Tc stream is assumed to be HLW vitrification.

Elutable ion exchange with SuperLig® 639 was tested extensively in 1996-2003 for deployment in the original Hanford WTP flow-sheet, and is the most mature technology for this application. The requirement to remove Tc was deleted from the flow-sheet because the LAW glass waste form sufficiently retained it, not because of issues with the Tc removal process. The process involves pumping the LAW through the resin, which removes the Tc; followed by elution with warm water. Several actual waste tank samples were processed through each step in the entire original WTP flow-sheet, including Tc ion exchange. Completed testing includes

[1] SuperLig is a trademark of IBC Advanced Technologies, Inc., American Fork, UT

demonstrations with six actual waste tank samples, full-height pilot-scale simulant performance tests, full-scale resin sluicing, resin stability, resin cycling, and computer modeling. Most of the information can be directly used for the design of any new deployment, and ion exchange technology is generally very mature in both commercial and radioactive applications. Technically, the absence of new design and safety documentation requires assigning a low technology readiness level, and much work on those elements remains. But the extensive experience with the media gives confidence that the pertechnetate removal technology can work at full scale, and many design-related parameters are already documented. No significant technical issues are known that would prevent deployment of this technology for removal of pertechnetate from LAW. This evaluation only involves the technical maturation of pertechnetate removal by ion exchange with SuperLig® 639, and its applicability to treating DOE-Hanford tank waste. This document addresses removal of Tc from LAW feed to supplemental immobilization. Technical maturity is too low for an evaluation of the feasibility of removing Tc in other locations in the Hanford tank waste treatment flow sheet.

A varying amount of the Tc present in Hanford tanks is present as a soluble non-pertechnetate species, and its chemistry is not well understood and no technologies are known to remove it. If the non-pertechnetate must also be removed, then another separation process is needed, or a method is needed to convert it to pertechnetate prior to ion exchange. Non-pertechnetate to pertechnetate conversion methods have been tested, but the technology readiness levels are immature. Regardless of whether the non-pertechnetate is removed, it is still important to quantify the amount of non-pertechnetate present so that it can be accounted for in the LAW disposal facility. Technical maturity is too low at this time to evaluate non-pertechnetate removal technology.

Appendix A in this report contains a description of how the Tc removal technology is envisioned to be deployed and is the process description used for this assessment. The projections are estimates, based on the prior planned deployment in WTP, available test data, and comparisons with other similar deployments. The evaluation of the technology readiness is based on the original WTP deployment plan adapted for current needs, since future plans are not yet defined. As more detail of the future plans are defined, their impact on the technical maturity can be assessed, and a full Technology Readiness Assessment (TRA) can be performed at that time. The purpose of this document is to align past work with the projected application, identify known technology gaps related to resin technology maturity, and attempt to identify where some of the potential technology gaps (i.e. “risks”) may appear as the project proceeds.

Estimated Technology Development (TD) costs and durations are included as Relative Order of Magnitude (ROM) comparisons. The deployment of SuperLig® 639 as an elutable ion exchange system is estimated to require two years and approximately $4 million for the ion exchange technology development. These costs are for the developmental work to reach a Technology Readiness Level (TRL) of six for the Tc removal method, and do not include project, design, vendor, or engineering documentation costs, or any new waste form development.

Several TD tasks have been identified that are needed regardless of the final system design:

- Computer modeling update
- Resin manufacturing scale-up

- Non-pertechnetate quantification
- On-line Tc monitor maturation
- Integrated process demonstration with new flow-sheet

After a conceptual design is complete and a preliminary safety analysis is performed, additional TD tasks may be identified. Since this Tc removal technology has already been tested under multiple conditions and scales, it is likely that it can be matured and deployed without substantial technical barriers.

1.0 INTRODUCTION

The objective of the Hanford Tc Removal Project is to mature a Tc removal process that, if deployed in conjunction with supplemental immobilization, would enable options for disposal of Tc in the River Protection Project flow-sheet. Removal, followed by off-site disposal of technetium from the LAW, would eliminate a key risk contributor for the IDF PA for supplemental waste forms [Mann, 2003], and has potential to reduce treatment and disposal costs. This project will identify viability of the Tc removal process, lay out the path forward for deployment, and help to determine if it is viable for inclusion in the RPP flow-sheet. This overall project for Low Activity Waste supplemental immobilization is still in the pre-conceptual stage, so it is too early for a comprehensive Technology Maturation plan.

The purpose of this Technology Development (TD) plan is to describe the technical maturity of the selected Tc removal process and its readiness for insertion into the RPP design and execution schedule to enable decision-making. This TD plan will detail the steps necessary for developing the technology to the point where it is ready for project insertion. Because some interfaces have not been identified, aspects of the technology development cannot yet be detailed, but can be generally described. Similarly, many aspects of the design and engineering of the Tc removal process have not begun, and so a genuine assessment of the maturity of the technology cannot be done at this time. However, since this technology was selected for deployment in the original Waste Treatment Plant in 1997 and was largely matured for that design, many engineering parameters are already tested, substantially reducing technical risk. This TD plan will identify where residual technical gaps are known to still exist, as applied to the current project status and flow-sheet.

This TD plan examines the technical aspects of the maturation of this Tc-removal technology, and whether they have been demonstrated to meet the Technology Readiness Levels as described in the *U.S. DOE Office of Environmental Management Technology Readiness Assessment (TRA) and Technology Maturation Plan (TMP) Process Guide*[2]. The *guide* contains a description of Technology Maturation Plans, and this document parallels that description. The *guide* contains a systematic, metric-based system for assessing technology maturity known as "calculator tables". Those tables are used here to identify technology gaps that need to be addressed to reach maturation of technical elements of the ion exchange media usage. Where an expected need for TD is identified, or where an anticipated issue exists, these are pointed out in the discussion. However, at this time, a formal self-assessment cannot be performed for all of the Programmatic and Documentation related parameters and the Manufacturability/Quality aspects. To evaluate these aspects of the maturation, several other tasks need to be completed and documented. If a decision is made to proceed with Tc removal, then a more thorough assessment can be performed that will encompass engineering and interface items, such as safety, disposition of the Tc, and compatibility with the immobilized Low Activity Waste (LAW) form.

Technetium-99 (^{99}Tc) is a long-lived radionuclide with a half-life of 210,000 years and is a significant fission product from nuclear reactors. Over fifty years of nuclear materials production at the DOE Hanford site has generated 55 million gallons of waste contained in 177

[2] This TD Plan utilized the November, 2012 draft Revision 1 TRA/TMP Guide.

underground storage tanks. The waste contains approximately 26,500 Curies of Tc [[TWINS, 2012], which is predominantly soluble, and will be processed as LAW.

The primary chemical form of ^{99}Tc found in LAW is as pertechnetate anion (TcO_4^-) with a +7 technetium oxidation state, although some is also present in the tanks as a soluble "non-pertechnetate" species that is not fully characterized. Pertechnetate is highly soluble in water, and is mobile if released to the environment. Pertechnetate will not be removed from the aqueous waste in the Hanford waste treatment plant, and will primarily end up immobilized in the LAW glass waste form after several recycle passes. The LAW glass will be disposed in the IDF. Because ^{99}Tc has a very long half-life and is highly mobile [Icenhower, 2008, 2010], it is the major dose contributor to the PA of the IDF, even though it is largely retained by the glass. Some of the ^{99}Tc will be vaporized during vitrification of the waste, and partition to the off-gas system where it will be recycled back into the melter to improve Tc retention in the LAW glass [Abramowitz, 2012]. Due to the soluble properties of pertechnetate, the volatility during vitrification, and the potential for impact to the PA, effective management of ^{99}Tc is important to the overall success of the River Protection Project mission.

Washington River Protection Solutions (WRPS) is developing conceptual flow sheets for LAW treatment and disposal that could benefit from technetium removal. One of these flow-sheets will specifically address removing Tc from the LAW feed stream to supplemental immobilization. This activity will support a Tri-Party Agreement Milestone (M-062-40ZZ), which is a one-time report on supplemental immobilization technology alternatives that is scheduled for delivery by October 31, 2014. To enable an informed decision regarding the viability of technetium removal, an evaluation of available technologies was performed [McCabe, 2012]. The outcome of this activity is to pursue Tc removal using elutable ion-exchange with SuperLig® 639 as the primary media and a back-up development of an alternative elutable ion exchange technology. This TD plan summarizes the activities needed to mature technetium removal using the preferred technology, elutable ion exchange using SuperLig® 639, so that the LAW disposal project can evaluate the viability of its deployment. This is part of an overall Tc management plan that is currently being formulated. It should be noted that this document will only discuss the technology aspects, and does not consider the regulatory or waste form aspects for Tc removal.

The information contained in this document includes estimates of process parameters for technetium removal using elutable ion exchange implementation, based on the design originally developed for use in the WTP. SuperLig® 639 was extensively tested for deployment in the original Hanford WTP flow-sheet [McCabe, 2001]. This resin had very good selectivity for pertechnetate, and is eluted with warm water. Testing for application with Hanford tank waste included radioactive sample performance with six actual Hanford waste tank samples, radiation and chemical stability, pilot-scale simulant performance, full-scale sluicing, computer modeling, and spent resin characterization. It is this high level of technical maturation that led to the recent selection of this resin as the primary technology for deployment. Although there are differences with the current application, much of that work can be utilized directly or can help to mitigate the risk that technical issues will be found.

Since many of the required design, safety, and flow-sheet activities needed for levels 5-6 are not complete, other TD gaps may be identified as the other programmatic and manufacturability activities are matured, and these are identified where currently known. Although the TRA/TRL tables in Appendix B only address levels 5 and 6, there are unresolved elements in lower levels also. These are not evaluated because the gaps identified in levels 5 and 6 tables also cover those technical elements, and the non-technical elements will be covered if a Project is initiated. It should be recognized that a substantial amount of testing was performed for the prior design, and there is low risk that a new technology issue for Tc ion exchange will be identified that would prevent deployment. Most of the TD needs identified for SuperLig® 639 are aimed at providing confirmation of expected performance, improving the performance predictions to support a basis for design, or further maturation of already proven techniques.

1.1 PROCESS INTEGRATION

This evaluation focuses on the removal of Tc from LAW using elutable ion exchange. At this early stage in the development of the flow-sheets, parameters are estimated for the Tc removal process integration based on the prior WTP plan, extrapolated to current conditions. These parameters include process throughput, waste disposal paths, equipment location, and schedule for deployment. Where differences or uncertainties are known to exist, these are identified, and mitigation of any residual technical risk is discussed.

1.1.1 Enabling Assumptions

The process concept used for this TD plan is described in Appendix A, and is based on the Tc removal design concept for the WTP [Olson, 2002], adapted to the current projected application. Where changes have been identified, such as the larger Decontamination Factor (DF), these are included in the TRL tables in Appendix B. As the program matures, further changes need to be evaluated against the original plan and any new gaps must be identified and incorporated into a revised TDP.

The Tc removal process is assumed to treat LAW that has been retrieved, diluted to ~5 M [Na^+], filtered, and pretreated for Cs-137 removal using ion exchange at ambient temperature. If a higher density or higher temperature feed is desired, additional work would be needed to evaluate its impact. Performance decreases linearly at lower sodium concentrations [Rapko, 2003], yielding a lower overall system efficiency, but is not dramatic. The Tc-decontaminated LAW product is assumed to be sent to a separate storage tank where it will be staged prior to LAW immobilization. The assumed disposal path of the Tc-containing stream is HLW immobilization. The assumed simplified flow-sheet is shown in Figure 1, along with the Critical Technology Element (CTE) of the SuperLig® 639 ion exchange resin columns, including resin preconditioning, feed treatment, feed displacement, elution and column operation.

Although the elutable ion exchange media to be used for Tc removal is expected to be compatible with LAW that has not been decontaminated for Cs, for the purposes of this review it is assumed that Cs has already been removed. The target concentration of ^{137}Cs in the LAW is assumed to be class A, since using Cs-decontaminated LAW has the benefit of minimal radiation damage to the Tc-removing agents, simplifies equipment maintenance, reduces shielding

requirements, and meets the proposed LAW glass waste acceptance limits for IDF. Depending on the Tc disposition path and the spent resin path, it may also allow for media disposal as a lower classification waste because it will not be cross-contaminated with Cs.

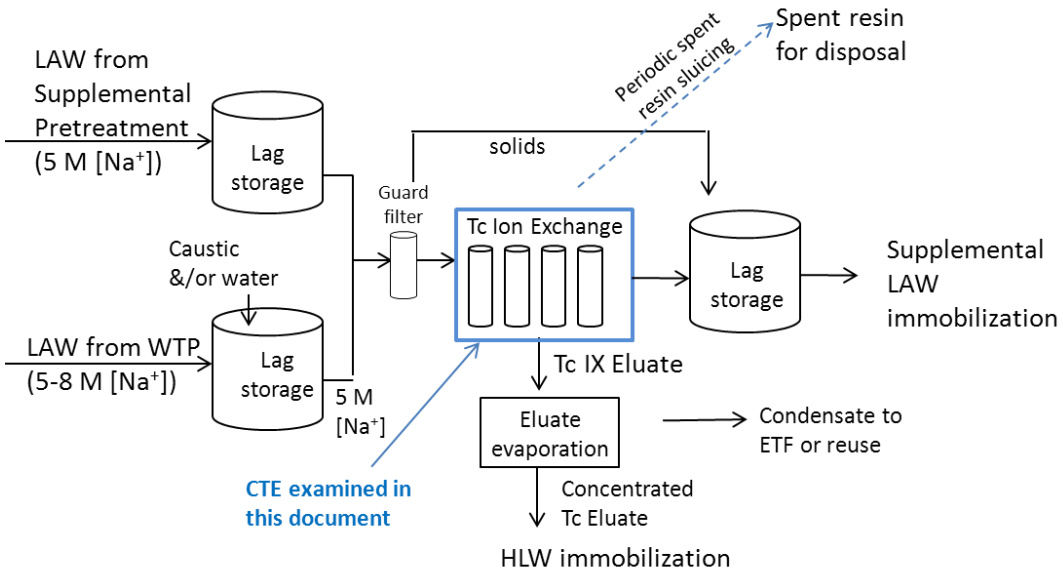

Figure 1. Assumed simplified flow-sheet

Table 1 shows the assumed conditions for the Tc-removal process. Although these conditions may be modified with further testing, they define a configuration that would be reasonable, based on the known and tested properties of elutable ion exchange technologies for Tc removal.

Table 1. Assumed Conditions for Tc Removal Using Elutable Ion Exchange

Parameter	Target	Basis
Conceptual Process Description & design	Appendix A	Previous WTP Tc IX description and conceptual design
$[Na^+]$	$\leq$ 5.5 M	Floating of IX resin, fluid viscosity
[Cs-137]	<1 Ci/m^3	Consistent with Class A limit for LAW, reduces dose rates and radiation damage
Temperature	< 30 °C	Performance and potential degradation of organic Tc-removal resin
Column flow rate	3.4 m^3/hr	Consistent with WTP throughput (15 GPM)
Pertechnetate Decontamination Factor	100 for TcO_4^-	Minimize impact on IDF PA
Non-pertechnetate Decontamination Factor	0 for non-TcO_4^-	No technology has been developed
Tc Disposal	HLW vitrification	Previous WTP Tc disposal path
Composition range	Bounded by current dataset	Undefined until flow-sheet and modeling work are complete
Spent resin disposal	Elute, dewater, and package	Current practice for DOE and commercial resins

In this evaluation, the target pertechnetate DF is assumed to be 100 (99% removal) to minimize the impact on the IDF PA, but this is purely an arbitrary target and is not based on any specific regulatory or PA driver. However it is anticipated that this target will be refined as data on the performance of the supplemental waste forms are assessed in the planned Risk Assessment.

The current process plans for WTP will involve a wider range of feed conditions than was required for the original WTP contract, which included only ten tanks. It was this original contract that set the limits for the original Tc removal test program, so the full range of possible compositions was not tested. The current plan for WTP feed includes more tanks, and leachates from periodic caustic leaching of aluminum and oxidative leaching of chromium. The current baseline assumption is that the LAW feed to the Tc Ion Exchange (IX) process is first treated in WTP, therefore, an evaluation is needed to determine if these feeds are substantially outside of the tested compositional range. If so, then testing may be needed to expand the range. The System Plan 6 feed vectors will be used to perform this evaluation and to identify the gaps. It is not expected that this would prevent deployment of the technology, only impact the process throughput and efficiency. The tank samples that were tested in the original program encompassed a good range, and the simulants were designed to maximize the ranges within the contract specifications, where possible, so the risk is low that a substantial issue would be discovered, so long as there is no residual chromium oxidizer remaining in the solution (which would not normally be expected).

Some of the Hanford tanks contain appreciable amounts of soluble technetium that is not pertechnetate [Schroeder, 2001, 2002, 2004, Hassan, 2000a, 2002], and technologies have not been identified for removing the soluble non-pertechnetate form of Tc without first converting it to pertechnetate. Some tanks have up to 70% of the Tc as non-pertechnetate, particularly the tanks that contain high concentrations of soluble organics (a.k.a. complex concentrate tanks or *Envelope C*[3]). The prior work did not require removal of non-pertechnetate, only that the overall average vitrified waste met the limits after pertechnetate removal. If it is determined that removal of non-pertechnetate is required in the future, an additional technology development program will need to be established to convert or remove it. This document does not address non-pertechnetate removal technologies. It will be assumed that if prior testing demonstrated 99% removal of pertechnetate, further technology maturation work on pertechnetate removal is not needed. It should be noted that since the majority of the overall inventory of Tc is present as pertechnetate, the majority of the total Tc can be removed using existing technology.

Elutable ion exchange generates an aqueous stream containing Tc that will be assumed to be concentrated by evaporation and then to the High Level Waste (HLW) melter. Although the evaporator is a separate Critical Technology Element (CTE), it will not be evaluated independently because evaporation of low ionic strength contaminated streams is common in the DOE complex and is assumed to be mature for similar applications (TRL >6). To confirm that this stream did not behave in an unexpected way, testing was previously performed on evaporation and characterization of the SuperLig® 639 resin eluate to ensure that the Tc did not

[3] Waste "Envelopes" were waste composition ranges defined in the early phase of Waste Treatment Plant Privatization contract. Envelope "A" referred to high nitrate/hydroxide dissolved salt solution; Envelope "B" referred to high sulfate dissolved salt solution; Envelope "C" referred to high soluble organic dissolved salt solution (a.k.a. "complex concentrate" waste); Envelope "D" referred to sludge.

vaporize [King, 2000c]. It will also be assumed that prior testing has established that disposal in HLW glass is a viable solution [Crawford, 1998; Smith, 2001; Hrma, 2004], and that no TD of the ion exchange process related to SuperLig® 639 viability is needed for verification (i.e., there are no unknowns in the products or performance of the ion exchange process that impact the vitrification process), but vitrification studies of the Tc eluate may be needed to examine the retention and performance of the vitrification process. Once the integrated flow-sheet is determined, there may be additional work identified related to the disposal paths. Pilot-scale vitrification testing of HLW simulant containing the Tc eluate is expected to be necessary to improve retention in the melter, but details of those tasks are outside the scope of this TD plan.

Periodically, the ion exchange resin must be replaced due to degradation. It is assumed that at that time, the resin would be eluted, sluiced to a container, and dewatered. Disposal of the drained resin is the assumed path, without further manipulation. Prior testing examined the residual components on eluted spent resin [Kurath, 2000], but this has not been evaluated against the current disposal criteria.

This document only addresses removal of Tc from LAW feed to supplemental immobilization. Removal of Tc in other locations in the Hanford tank waste treatment flow sheet is not considered here.

2.0 TECHNOLOGY ASSESSMENTS

No independent technology reviews or assessments have been performed for Tc removal from LAW. Testing to support the original plan to include Tc removal in the WTP design began in 1997 and ended in 2003, when Tc removal was de-scoped from the baseline. This technology development plan is to define what testing would still be needed to mature it for possible deployment. The TRA/TMP guide is used here to ensure that all elements are considered to the extent possible at this point.

2.1 CRITICAL TECHNOLOGY ELEMENT SELECTION

The CTE in this TD plan is focused on the SuperLig® 639 ion exchange resin columns, including resin preconditioning, feed treatment, feed displacement, elution and column operation, as described in Appendix A. Additional CTEs are expected to include the resin receipt and preparation equipment, spent resin sluicing and disposal equipment, and the eluate evaporator. Since none of these additional facilities are at the stage of conceptual design, it is not feasible to evaluate them. However, all of these processes are routinely used in other radioactive environments, and these are not expected to be significantly different for this application. Prior testing with resin was performed on sluicing the resin into and out of a full-scale column [Norato, 2000], although the resin was slightly smaller in particle size than other batches, but was within the specifications in place at the time. Between this data and commercial experience, it is expected that additional test data is not needed. Similarly, sluicing radioactive resin into disposal casks is routinely performed at spent fuel pools at commercial and DOE sites, and is not expected to require additional development. It is assumed here that the spent resin, after a final elution, can be disposed as is, and does not need to be converted into an immobile form. If the spent resin must be further decontaminated or converted into a monolith to meet disposal

requirements, testing would be needed to examine the integrity and characteristics of the material during and after treatment. Similarly, the eluate evaporator is assumed to be a routine operation and additional testing is unlikely to be needed. Prior testing showed that the Tc is not volatile during eluate evaporation [King, 2000c], as expected.

The upstream and downstream processing of the waste is not within the scope of this TD plan and is not reviewed, other than as an interface. The upstream filtration and cesium ion exchange processes and downstream immobilization are separate CTEs. The Tc IX process has not been demonstrated with feed that has been decontaminated with the current cesium ion exchange resin. The risk is low that there is an undiscovered technical incompatibility issue; nonetheless, this TD plan includes this as an open interface item in the TRL tables that requires testing. Similarly, the down-stream immobilization process for LAW that was previously tested was the LAW vitrification. If another immobilization method is selected, testing would be needed to demonstrate that that waste form is viable. To create samples for that demonstration, waste samples are assumed to be processed through filtration, Cs ion exchange, and Tc ion exchange. Performing this integrated test is assumed necessary in this TD plan, and is included in the TRL tables, but the upstream pretreatment and downstream immobilization CTEs are not evaluated and those TD plans are not described.

2.2 SUMMARY OF SUPERLIG® 639 TEST STATUS

SuperLig® 639 was extensively tested for deployment in the original Hanford WTP flow-sheet [McCabe, 2001]. This technology has been demonstrated to remove pertechnetate from several actual Hanford tank samples. This resin had very good selectivity for pertechnetate, and improved performance is observed with high potassium-containing feeds. The resin is eluted with warm water, generating a dilute Tc-containing aqueous stream. The aqueous stream is suitable for downstream immobilization with several technically feasible options, such as vitrification or grouting. Resin testing already completed for application with Hanford tank waste included radiation and chemical stability, radioactive sample performance, pilot-scale simulant performance, full-scale sluicing, computer modeling, and spent resin characterization. Generally, ion exchange with radioactive materials is mature, with many examples used over the years. Similarly, commercial ion exchange is commonly used, and this knowledge can be used to aid in design of a full-scale system. There was some variability in the SuperLig® 639 resin batches that were used, but all were within an acceptable range. The resin does not swell significantly. Ion exchange technology is generally robust, as long as the resins do not shrink and swell or degrade. Some batches of the resin did partially float in the high ionic strength LAW solutions but were still effective, as long as the feed remained around 5 M [Na^+]. Although ion exchange can concentrate the radionuclides to considerable levels, the ^{99}Tc emission is a low-energy beta. This is not expected to be a challenge for ion exchange, since the hydrogen generation and dose to personnel or the resin is readily managed.

Testing of SuperLig® 639 has recently been reviewed and summarized [Duncan, 2011], and will not be repeated here. A summary table is shown below that identifies samples tested and the scale or purpose of the test.

Table 2. Tank Waste Testing with SuperLig® 639

Tank/Simulant	Scale/purpose	Reference
AN-105 simulant	Small-scale column, Re Kd measurements	King 2000a
AN-105, AZ-102, AN-107 simulants	Small-scale column	King, 2003a
AN-105, AZ-102, AN-107 simulants	Small-scale kinetics column and batch Kd measurements	Duffey, 2003
AN-105, AZ-102, AN-107 simulants	Small-scale column	King, 2005
Simple + AN-105 simulant + variants	Kd measurements with varying NO_3/Tc and Re	Rapko, 2003
AN-103	Small-scale radioactive column, Kd measurements	Hassan, 2000b
AZ-102	Small-scale radioactive column	King, 2001a
AN-102	Small-scale radioactive column	Hassan, 2000a
AW-101	Small-scale radioactive column	Blanchard, 2000a
AN-107	Small-scale radioactive column	Blanchard, 2000b
AN-102 + C-104 sludge	Small-scale radioactive column	Burgeson 2004a
AP-101	Small-scale radioactive column	Burgeson, 2002
AZ-102	Small-scale radioactive column	Burgeson, 2004b
AW-101	Multi-cycle small-scale radioactive column	Hassan, 2004
NA	Spent resin analysis from radioactive tests (used with AW-101, AN-107)	Kurath, 2000
AZ-102	Radioactive Tc eluate evaporation	King, 2000c

Table 2 (continued) Tank Waste Testing with SuperLig® 63

Tank/Simulant	Scale/purpose	Reference
C-106C-104/AZ-102 AZ-101	Radioactive Tc eluate immobilization	Crawford, 1998 Smith, 2001 Hrma, 2004
AN-102	Intermediate-scale radioactive column	King, 2001b
SRS Tank 44	Intermediate scale radioactive column	King, 2000b
AN-105 simulant (Envelope A)	Pilot-scale column (full height)	Steimke, 2000
NA	Resin radiation stability	Arm, 2003b
AN-105 simulant	Resin chemical stability	Arm, 2003
water	Resin thermal shock stability	King, 2003c
AZ-101	Resin compatibility with TBP & NPH	Adu-Wusu, 2002
NA	Preliminary thermodynamic and column performance computer modeling	Hamm, 2000
NA	Full-scale resin sluicing and hydraulic flow demo with SuperLig® 659	Norato, 2000

2.3 CURRENT PROJECT ACTIVITIES WITH SUPERLIG® 639

Three activities are currently being pursued to further the maturation of SuperLig® 639: (a) preliminary flow-sheet development by WRPS and subcontractors, (b) preparation for scaled-up resin manufacturing by the resin vendor and Savannah River National Laboratory, and (c) updating the computer model by Savannah River National Laboratory. All of this work is expected to be complete by September 30, 2013. Some Hanford waste tank samples are also being analyzed to quantify the amount of non-pertechnetate present.

2.3.1 Preliminary Flow-sheet Development

To quantify the cost and benefit of removing technetium, WRPS is developing a conceptual technetium-removal flow-sheet. This flow-sheet information will be used to prepare a technetium-removal life cycle cost estimate to allow a cost-benefit decision. Supporting the flow-sheet will be technology development activities that will determine the overall technetium removal efficiency and column change-out/elution frequency for the chosen ion-exchange media. The flow-sheet effort will consist of compilation of underpinning assumptions, preparation of process flow diagrams and mass balance, identification of required equipment and associated sizing calculations, and preparation of a list of process consumables.

The flow-sheet will be for an ion exchange system that removes the technetium from the Low Active Waste (LAW) feed prior to the supplemental immobilization treatment process. This flow-sheet is applicable to each of the four immobilization technologies being considered.

2.3.2 Resin Manufacturing Maturation

To reach technology maturation, manufacturing of critical materials and equipment at appropriate scale is needed. The prior program to scale up the manufacturing of the SuperLig® 639 was terminated before completion. Work is now underway with the SuperLig® 639 vendor to establish acceptance criteria and then perform bench-scale testing in preparation for an appropriate demonstration of scale-up for manufacture of the primary resin. This will include calculating allowable batch-to-batch variability, developing resin acceptance criteria, and providing status on resin floating. Activities include providing specifications and test instructions for ensuring that the resin meets the needs of the technetium removal process, and demonstrating consistency of confirmatory analyses between labs. Bench-scale samples of resin will be produced and tested in preparation for production of a pilot-scale batch.

2.3.3 Computer Performance Model Updating

The preliminary Ion-Exchange performance model for SuperLig® 639 was completed in 2001 [Hamm, 2001], and therefore does not contain data generated between 2001 and 2003. Data generated during that period includes composition and temperature variability studies, and additional tests with actual waste tank samples. Work is underway at the Savannah River National Laboratory to update the model with the newer data to improve the model predictions. The model is actually two models; one is for calculating the thermodynamic equilibrium of the Tc absorbing onto the resin, and the other is of the kinetics of the flowing process to enable predicting column performance. Once complete, this tool will be available to assist in evaluating the achievable Decontamination Factor, process flow rate, resin cycle time, and the impact of waste composition and temperature.

2.4 MANAGEMENT OF TECHNOLOGY MATURITY

WRPS, on behalf of DOE-ORP, is responsible for managing the activities described in this technology development plan. This work will be used to supplement the decisions and recommendations for the Tri-Party Agreement Milestone (M-062-40ZZ), but is not specifically identified as required for that milestone.

3.0 TECHNOLOGY DEVELOPMENT PLAN

This TD plan will assume the original process configuration and approach [Olson, 2002] but applied to the current conditions and requirements. Changes are invoked only when necessary. For example, the original columns were sized for WTP throughput, with a selected geometry, resin retention screens, and pumping flow rate. The new design is assumed to utilize the same parameters, and any deviation from that would require engineering justification or testing. Because of current conditions and requirements, there are several changes related to the technical aspects of the ion exchange technology, primarily:

(1) waste stream composition

(2) equipment location
(3) required decontamination factor (assumed target)
(4) upstream Cs removal process
(5) down-stream LAW immobilization

Waste stream composition: this evaluation assumes operation at ~5 M [Na^+] and ambient temperature (~25 °C), consistent with the prior design. Since pretreated LAW from WTP is included, this stream is assumed to be diluted as needed and cooled prior to Tc IX. The original waste stream composition for technetium removal targeted treatment of the first ten tanks for WTP processing at ambient temperature and ~5 M [Na^+]. As the preliminary flow-sheet is developed and the System Plan 6 feed vectors are generated, these compositions and conditions will be compared against previously tested ranges. Assuming Tc removal on all LAW compositions, additional testing may be necessary for feeds or conditions not previously examined.

Equipment location: the equipment will no longer be within WTP, although this is expected to have minimal impact on the technical maturity other than a different resin sluicing configuration. Once the design is underway, the original sluicing test results and current engineering experience will be utilized to determine if additional TD work is needed.

Decontamination factor:, the original required Tc decontamination factor was five (80% removal) overall, including non-pertechnetate. The other change from the prior work is the assumed Tc decontamination factor is 100 (99% removal) specifically for pertechnetate, which was also a working assumption originally, but not a requirement. Prior work on Tc removal for the Hanford WTP targeted the contract requirement of 0.1 Ci/m^3 in the final vitrified waste form and 80% Tc removal overall [WTP Contract No. DE-AC27-01RV14136, Mod. 016, Section C, specification 2.2.2.8]. This requirement was removed in 2003, and there is no requirement for removing Tc in the current revision to the contract.

Upstream Cs removal process: the upstream WTP Cs-removal ion exchange resin has changed (current baseline technology is elutable ion-exchange using spherical resorcinol formaldehyde resin). Since the Cs-removal process does not significantly change the waste stream bulk chemical composition, minimal impact on Tc IX is anticipated. However, this needs to be verified by demonstration with actual waste as part of an integrated test.

Downstream LAW immobilization: the downstream waste form may change. Since the Tc IX process also does not significantly change the bulk LAW chemical composition, little impact on the immobilization process is expected. This also needs to be verified by demonstration with actual waste as part of an integrated test.

Table 3 describes the similarities and differences between the original WTP design and the current plan. Although this list is not comprehensive, it addresses the key technical elements that impact the TD program.

Table 3. Comparison of WTP and Current Plans for Tc Ion Exchange

WTP	Current plan	Resolution
Waste feed composition		
10 tanks	177 tanks	Examine System Plan 6 feed vectors and compare to prior testing to evaluate potential impacts
Equipment location		
WTP pretreatment	To be determined	Configuration of equipment may change (e.g. height of resin preparation tank vs. column); evaluate differences as design is initiated
Decontamination Factor		
0.1 Ci/m^3 in LAW glass and 80% overall total Tc – 99% removal of pertechnetate assumed to achieve overall Tc DF	99% of pertechnetate assumed	99% removal of pertechnetate demonstrated in prior testing; confirm with integrated test
Upstream processing		
LAW feed adjusted to 5M [Na^+], filtered, Cs IX by SuperLig® 644	LAW feed adjusted to 5 M [Na^+], filtered, Cs IX by spherical Resorcinol-Formaldehyde resin	Confirm no impact of using different Cs IX media in integrated test
Downstream immobilization		
LAW vitrification	To be determined	Confirm compatibility of LAW with immobilized waste form
Tc Eluate handling		
Evaporation and HLW vitrification	Evaporation and HLW vitrification	No change
Spent Resin disposal		
Tentatively packaged and disposed in IDF	Tentatively packaged and disposed in IDF	No change

3.1 IDENTIFYING TECHNOLOGY DEVELOPMENT REQUIREMENTS

The technology development activities are defined here based on the Technology Readiness Level Calculator (Appendix B). Although a formal TRA has not been performed, this TD plan will be used instead to help identify the technology development activities required to bring the Tc removal technology to TRL ~6 for technical elements. Not all of the TRL questions can be answered at this time, because many of the activities defined as "programmatic", including the process safety evaluations, have not begun. However, since many of the programmatic activities were matured in the prior effort and addressed in the development program, major unaddressed technical gaps are not expected to be uncovered.

3.2 LIFE-CYCLE BENEFIT

Completion of the technology development activities will help to identify the viability of deploying Tc removal in support of the M-062-40ZZ Tri-Party Agreement Milestone project. Tc removal may open an opportunity to dispose of LAW in a different waste form with minimal environmental impact, or may be used to avoid Tc volatility issues in LAW vitrification.

3.3 SPECIFIC TECHNOLOGY DEVELOPMENT PLANS

The critical technology element being evaluated is the Tc ion exchange process using SuperLig® 639 columns, including preconditioning, loading, and elution. Sluicing and eluate evaporation are also discussed where applicable, but since the configuration of the addition and removal systems will change, this cannot be fully evaluated at this time. The objective of this process is to selectively remove pertechnetate from the bulk of the waste, and isolate it in a separate stream for disposition.

The scope of the technology development described here is limited to "technical" and resin-related "manufacturing" activities. Although these activities cannot be completely severed from the programmatic elements, the basis for identifying the outstanding TD activities is the incomplete maturation in the prior program to deploy it in WTP. Most of the parameters envisioned for this application are similar enough to the prior program that the TD activities are applicable.

Table 4 contains a summary of the outstanding technical gaps, and the known potentially outstanding technical gaps. The gaps are based on the items identified in the TRL calculator tables in Appendix B. In some cases, the gaps are known to exist regardless of the final system design, and are included in this TD plan. Other gaps could appear, depending on the final design and implementation, and are identified as potential gaps (risks).

Table 4. Summary of Outstanding Technical Gaps

Technical Gaps currently included in TD Plan		
Technical Gap	**Impact**	**Resolution**
Resin density	Resin may float, causing poor DF	TD plan to examine manufacturing scale-up*; control with Procurement Specification; plan to adjust feed density by dilution.
Resin manufacturing scale-up	May be unable to obtain large-scale amounts of resin with all desired properties	TD plan to develop specification and demonstrate manufacturing scale-up*
Column performance computer modeling	Prior model had poor prediction of performance on some wastes	TD plan to incorporate newer data*; second phase to optimize design and operating conditions

Table 4 (continued) Summary of Outstanding Technical Gaps

Technical Gaps currently included in TD Plan		
Technical Gap	**Impact**	**Resolution**
Non-pertechnetate quantification	Non-pertechnetate will pass IX treatment, ending up in LAW waste form, potentially impacting IDF PA	Measure non-pertechnetate content in tank samples*; calculate impact on IDF PA; potentially initiate R&D program to convert/remove non-pertechnetate
On-line Tc monitoring	Unable to actively monitor Tc breakthrough in columns, causing generation of LAW that cannot be disposed without reprocessing	TD plan to complete development of On-line monitoring system; develop process and control logic to accommodate off-line lab analysis turn-around-time
Composition range not fully tested, either for some tank wastes or some WTP process effluents (e.g. aluminum leaching, Cr leaching)	Column performance may be poorer than expected, resulting in less efficient processing	Examine composition ranges from System Plan 6 modeling versus test data when flow-sheet activity is complete*; utilize updated computer model to evaluate impact; develop TD plan to examine wider range, if necessary
Current integrated process has not been demonstrated and Tc IX may not be compatible with new Cs removal resin or alternate LAW waste form	Unexpected incompatibilities between processes may occur, such as formation of solids or chemical reactivity	TD plan to demonstrate integrated process with simulated and actual waste samples
Required DF for TcO_4^- cannot be achieved	Impact to IDF PA	Demonstrate performance in integrated process demonstration; include 3rd column in conceptual design; evaluate achievable DF using updated computer model
Tc disposal in HLW is not planned in WTP and retention is not fully examined in large-scale WTP melter	Tc disposal is not integrated into current WTP planning or glass formulations	Perform large-scale HLW vitrification tests and integrate into plans and glass formulations (not in scope of this TD plan). Alternatively use a dedicated smaller melter (e.g., induction melter)
*indicates TD work is currently underway		

Table 4 (continued) Summary of Outstanding Technical Gaps

Potential Technical Gaps not included in TD Plan		
Technical Gap	**Impact**	**Resolution**
Waste properties may differ from tested range (e.g. temperature, density)	Resin performance or compatibility may be lower than projected	Assume waste is adjusted or blended to acceptable range; develop TD plan to address condition if this cannot be done
Process safety issues could arise as design advances	Safety evaluation and Process Hazard Review have not been performed against current requirements, and unexpected items could arise	If unexpected safety related issues are identified, develop TD plan to address
HLW glass is not selected for Tc disposal path	Waste form has not been developed	Develop TD plan to test new waste form, and include into planned integrated demonstration tests
Spent resin cannot be disposed as dewatered solid without further manipulation	Resin treatment &/or stabilization process would be needed	Develop TD plan to test new waste form
IDF cannot accept quantity &/or chemical behavior of non-pertechnetate	Non-pertechnetate must be removed or converted in another process	Develop TD plan to create new process; test integration with Tc IX process; develop new process
Equipment location and/or design and arrangement is inconsistent with previous design and conditions	Hydraulic properties, such as sluicing behavior and arrangement of resin addition and removal tanks, may lead to operational difficulties	Utilize prior testing and design where practical; evaluate impact of changes; utilize commercial and DOE expertise; develop TD plan if necessary
Prior sluicing demonstration does not bound current resin properties	Resin with different properties may not mobilize as readily during bed fluidization and sluicing	Measure fluidization velocity of new resin and compare to equipment capabilities during design phase; develop TD plan if substantially different and cannot be accommodated with available experience
Further definition of interfaces (e.g. LAW waste form) may reveal unexpected TD issues	Additional TD needed to resolve issues	Develop TD plan to address emergent items

3.3.1 Technology Development Scope

The technical elements of the technology development scope that are needed to mature the Tc-removal process CTE to TRL=6 for technical elements are shown below. This is based on a projection of the implementation plan, which is not yet developed, but it is clear that at least these items are needed for maturation. Once the programmatic (P) and manufacturing (M) activities are matured, the TD scope may need to be adjusted. Some tasks cannot be performed until some of the Programmatic documents are produced and other programs mature. For example, performing the integrated process demonstration cannot be performed until the supplemental immobilized waste form is finalized and formulated for the available samples. Similarly, the need to remove non-pertechnetate has not been determined, but it must be at least quantified to determine its impact.

Table 5 describes the scope of the identified TD scope, and the estimated level of technology readiness achievable when the work is complete.

Table 5. Technology Development Scope

Milestones	Performance Targets	TRL Achieved at Milestone*
Update computer modeling	Incorporate 2001-2003 data and improve predictions**	5
Non-pertechnetate quantification	Non-pertechnetate content in tanks must be quantified to determine if it must be removed.**	5
Update computer modeling (phase 2)	Additional modeling required after performance requirements, equipment size, DF, and waste composition ranges are established	6
On-line Tc monitor	Design, build, and demonstrate continuously operating system	6
Prepare IX resin batch at bench-scale	Define IX resin specifications to meet process requirements and prepare batch(es) at bench-scale**	5
Manufacture large-scale batch of resin	Define resin requirements and demonstrate manufacturing of sufficient resin to meet projected production schedule needs	6
Integrated process demonstrations	Tests with simulated and actual wastes to demonstrate integrated process viability with Cs-decontamination, Tc-removal, and supplemental LAW immobilization	6

*tentative TRL assignment for technical elements, based on anticipated design
**TD work included in current program

Assumptions:

- Pertechnetate removal target is 99%
- Prior IX testing with SuperLig® 639 demonstrated >99% removal of pertechnetate in several tank samples - further confirmation is not necessary
- If non-pertechnetate removal/conversion is required, a separate program for non-pertechnetate identification/removal/conversion/compatibility is initiated
- Composition of tanks that will be selected for treatment will be sufficiently predicted by the computer modeling using the current test data (note that this will be examined once the flow-sheet and modeling tasks are complete)
- Prior analysis of spent resin is sufficient for meeting current disposal criteria
- No additional immobilization or treatment of spent resin is needed
- Prior sluicing and hydraulic testing is sufficient for the new design (this cannot be assessed at this time, as the new design effort has not begun)
- Tc eluate disposal is by HLW vitrification, and additional pilot-scale testing is expected to be required, but cost and schedule are not included in this program
- The program to examine alternative immobilized LAW waste forms will perform integrated tests using tank samples; Tc IX tasks related to that task are included below, but tank sampling, characterization, filtration, and Cs removal are not.
- Additional TD may be identified as the interfaces and design become more defined
- Updating the computer modeling of prior testing does not identify inconsistencies
- LAW treatment for Tc removal involves processing the supernate through at least two SuperLig® 639 columns in series (lead/lag configuration)

Updated computer modeling

Computer modeling is needed to incorporate data that was generated after the preliminary report [Hamm, 2000] was published. This is expected to improve predictions, and expand the range of waste compositions included in the model database. This will enable a prediction of performance of the process across the wider range of projected feeds to WTP and to demonstrate consistency of scaled tests. The first phase of this will be done to get a projection of the column performance and aid in design. Subsequent modeling will be needed to finalize performance projections once the composition, conditions, targets, and parameters are more definitively quantified. This will aid in selecting an achievable DF target, estimating process cycle time (load-elute frequency), equipment sizes, and estimated impacts of changes to waste feed compositions and conditions.

On-line Tc monitor

An on-line Tc analysis monitor was developed during the previous program, but not completely matured for deployment. Completion of testing and demonstration of an on-line Tc monitor is included as an assumed need, although it has not been determined if other off-line options may be sufficient. The online monitor would allow for real-time process information during operation of the Tc removal processing. The risk of not using an on-line monitor is that LAW could be produced that does not meet the immobilization process criteria, and would need to be re-processed. Alternatively, if a third (polishing) ion exchange column is used, performing off-line analysis of the effluent from the second (lag) column is likely sufficient, although this would need to be determined during the preliminary design phase. Testing involved in maturing this

technology would encompass completion of the method maturation to improve the detection limit, manufacturing a prototype device using automated switching equipment, and performing endurance testing. The earlier work achieved a detection limit of 6.36E-7 Ci/L [Egorov, 2003], which was sufficient for the performance requirement at the time, but would not be sufficient for the current assumed target of 99% removal. Ideally, this work would be coupled with the integrated process demonstration described below. Because of the uncertainty in need, this development work could likely be pushed out to later in the project phases, after the need is clearly established.

Ion Exchange Manufacturing maturation

Prior testing of SuperLig® 639 used small scale batches of resin (1-4 L),, versus an estimated 1000 L each in as many as four columns in the final facility. To work toward demonstrating manufacturing a larger batch of resin that can consistently meet the needs for this process, acceptance criteria will be developed to establish the resin performance requirements. This will include determining acceptable batch-to-batch variability, developing resin acceptance criteria, and resolving outstanding technical issues (for example, resin floating). Parameters such as resin particle size, manufacturing residue content, and Re (surrogate for Tc) absorption capacity and kinetics need to be defined. Manufacture of a large batch of resin that is demonstrated to meet the acceptance criteria and production requirements is needed. The quantity of the batch has not been determined, but is estimated at a minimum of 100 L of resin manufactured in a single batch within 1 week. Depending on the ease of further scale up, this may be repeated 2-3 times to ensure consistency and reliability.

Integrated process demonstration

A different ion exchange resin was used for cesium removal in all the prior testing, so it needs to be confirmed that the new resin (spherical Resorcinol-Formaldehyde)[4] does not impact the Tc-removal performance. Similarly, the previous specific flow-sheet involved sending the decontaminated LAW to vitrification, and the Tc eluate to HLW vitrification. The fate of these streams is not yet finalized (i.e., the supplemental immobilization technology has not been selected), but the TD activities identified in this TDP assume that the decontaminated LAW is sent for supplemental immobilization, with the eluate stream being sent to HLW. Because of these differences, samples of the decontaminated LAW product would need to be generated using Cs removal and Tc removal so that it could be tested with the new waste form, if selected. Likewise, the disposal method and waste form of the Tc stream would need to be tested, if it is not HLW. An integrated flow-sheet test is needed to demonstrate the processes perform together as expected. This flow-sheet integration testing would also demonstrate the 99% removal of pertechnetate, and that all the waste streams can be disposed as planned. This testing would presumably be performed on simulants and a range of samples, assumed to be three different tank samples, at a scale sufficient to generate enough LAW for the supplemental waste form testing. Simulant testing could likely be done at bench-scale with comparable equipment, such as resin column screens and guard filters, and could be closely coupled to ensure unexpected incompatibilities do not occur, such as formation of precipitates or plugging of column screens.

[4] sRF is the baseline Cs IX resin that will be used for WTP Pretreatment Cs removal. It is an acid-elutable resin.

4.0 PLAN TO MATURE SYSTEM INTEGRATION

This plan will identify TD activities that are considered necessary to mature the Tc IX system, although this is subject to modification once the flow-sheet integration decisions are finalized. These activities are applicable, regardless of whether the Tc IX process will be fed from an auxiliary pretreatment process or WTP, or both. If the waste originates from WTP, it is assumed to be adjusted to density and temperature to meet the criteria for Tc removal. Similarly, these activities are applicable to any alternative immobilization process selected for LAW, with minimal work needed if glass is chosen. If non-pertechnetate Tc removal or conversion is determined to be necessary, additional scope to evaluate its integration would be needed.

It is assumed that HLW immobilization of the Tc eluate is selected as the disposal path. Prior testing of actual waste is expected to be sufficient and actual Tc eluate does not need to be generated for HLW vitrification studies. Prior crucible-scale testing was completed with HLW crucible-scale vitrification of three actual waste samples containing Tc eluate [Crawford, 1998; Smith, 2001; Hrma, 2004]. Minimal additional information is expected to be gleaned from more testing at this scale, unless the formulation changes significantly. It is expected that additional scaled melter simulant testing is needed to examine Tc retention and HLW glass melter process impacts, but that schedule and cost are not included here, since it is not part of the Tc removal process. Testing would be needed to evaluate methods to optimize retention of the Tc in the HLW glass, similar to what was done for LAW glass [Abramowitz, 2012]. If this involves significantly different glass formulations than previously tested in radioactive samples, then additional radioactive eluate would need to be generated for crucible-scale integrated testing. Intermediate-sized tank waste samples (several liters) are expected to be needed for this demonstration in order to generate enough concentrated eluate for the testing. The amount of concentrated eluate generated from this Tc IX process is about 0.2% of the volume of waste processed, so larger scale tests would be needed to generate enough material.

If HLW immobilization of the Tc eluate is not selected as the disposal path, an eluent stabilization development task is needed. As part of the program to stabilize the Tc stream, several additional tasks would be needed as part of that program. The immobilization method would need to be selected and tested with simulants. Actual waste samples would need to be used in the Tc-removal process to generate multiple actual Tc eluates from multiple (~3) intermediate-sized actual waste samples for immobilized form testing. Subsequent evaporation and stabilization of the eluates, and testing of the new immobilized/stabilized Tc stream would then be performed. (It is estimated that three samples would be needed to span a range of tank waste compositions to demonstrate the maturity of the process to achieve TRL 6.)

Depending on the location of the Tc IX process, and the disposal path selected for some waste streams, additional testing may be needed. If it is necessary that the non-pertechnetate fraction must also be removed from the LAW waste stream, it is assumed that a process to oxidize the non-pertechnetate to a form that can be removed by ion exchange will be developed. Interface tests would be needed then to demonstrate that the IX resin is compatible with the oxidation process. These tests would include confirmation that residual oxidizer (or secondary oxidizers generated during the oxidation) is destroyed prior to ion exchange treatment and quantify the impact of any byproducts, such as an increased nitrate concentration due to the oxidation of

nitrite. Integrated small-scale oxidation and IX testing with multiple simulant samples and 3 tank waste samples would be needed to demonstrate that there are no adverse impacts on resin lifetime.

Periodically, the Tc IX resin must be discarded and replaced due to chemical and radiolytic degradation. It is assumed that the spent Tc IX resin can be dewatered and disposed. If it must be converted to a monolith or encapsulated, testing would be needed to demonstrate the process and show that there are no adverse impacts. Simulant testing at a range of scales would be needed. Spent resin from the integrated test described above could be used for the radioactive demonstration of this process, if needed.

5.0 TECHNOLOGY MATURITY SCHEDULE

Table 6 describes the Relative Order of Magnitude estimate of the duration of TD activities needed to mature the Tc IX technology. The durations are based on prior experience, where available.

Table 6. Technology Maturation Estimated Durations

Scope	Duration (months)	Predecessors
Updated computer modeling		
Phase 1: incorporate newer data, preliminary processing estimates*	6	LAW composition estimates
Phase 2: finalize processing estimates	8	LAW composition ranges; process conditions; target DF; preliminary design
Non-pertechnetate quantification		
Archive sample non-pertechnetate quantification*	6	Analytical procedures
Ongoing sample non-pertechnetate quantification*	Ongoing	Analytical procedures; tank sampling
On-line Tc monitor		
Complete maturation of method	6	Establish processing need
Manufacture device and perform endurance tests	18	Integrate with actual waste tests
Ion Exchange Resin Manufacturing maturation		
Establish resin acceptance testing protocol*	6	Identify parameters of concern
Confirmation of resin consistency with historical testing*	6	Manufacture of resin batches within limits
Scaled-up manufacturing	12	Demonstration of pilot-scale manufacturing within acceptance limits

Table 6 (continued) Technology Maturation Estimated Durations

Integrated process demonstration		
Perform integrated simulant test to demonstrate compatibility of filtration, Cs and Tc IX, and supplemental waste form. Perform actual waste column tests to generate LAW for supplemental immobilization testing; assume 3 laboratory-scale samples (1-2 L each)	18	Select supplemental waste form; establish Tc-removal performance criteria; select simulants and sample 3 waste tanks; adjust and characterize waste samples; perform filtration and Cs IX pretreatment (and Sr/TRU removal, if needed); develop online Tc monitor, if needed; select Tc eluate disposition pathway.

*TD work included in current program

Estimates above are based on a comparison to prior work with expected flow-sheet and design needs, which may change as the flow-sheet and design are matured. Very limited information on the regulatory requirements is known, and this may impact the duration. (For example, if the spent resin must be manipulated or consolidated in some way, this process would need to be developed and tested, potentially at larger scale than typical ion exchange testing.)

The estimates above are based on examples of the prior work, so they should be reasonable, although unforeseen circumstances can always occur. The scheduled durations do not include precursor tasks. For example, the integrated process demonstration would require sample collection, adjustment, characterization, and Cs decontamination, which are not included in the duration estimate above. The duration shown for the integrated demonstration only includes the time to set up, process, and characterize 3 samples through Tc IX, assuming that they are available. If the scope of the test changes, such as the DF required, sample size required, or number of samples, the duration and costs may change. Similarly, it is envisioned that 2-3 batches of resin would need to be manufactured at pilot ($1/10^{th}$) scale, and increased scope would increase schedule and costs.

6.0 SUMMARY TECHNOLOGY MATURITY BUDGET

Table 7 describes the Relative Order of Magnitude estimate of the cost of TD activities needed to mature the Tc IX technology. The costs are based on prior experience, where available. Note that these costs are of the TD activities for Tc IX only, and do not include items such as waste tank sample collection and preconditioning, vendor contracts, and waste form testing.

Table 7. Technology Maturation Estimated Costs

Scope	Cost ($K)	Comments
Updated computer modeling		
Phase 1: incorporate newer data, preliminary processing estimates*	150	
Evaluate current feed vector vs. prior test compositions	150	Additional $400K needed if additional simulant testing is needed
Phase 2: finalize processing estimates	300	
Non-pertechnetate quantification		
Archive sample non-pertechnetate quantification*	-	Not included in current cost analysis
Ongoing sample non-pertechnetate quantification*	-	Not included in current cost analysis
Data summary and evaluation	150	
On-line Tc monitor		
Complete maturation of method	250	
Manufacture device and perform endurance tests	600	
Ion Exchange Resin Manufacturing maturation		
Establish resin acceptance testing protocol*	200	Does not include vendor costs
Confirmation of resin consistency with historical testing*	500	Does not include vendor costs
Scaled-up manufacturing	650	Does not include vendor costs
Integrated process demonstration		
Perform integrated testing with up to 3 simulants	750	Tc IX related costs only
Perform actual waste column tests to generate LAW for supplemental immobilization testing; assume 3 laboratory-scale samples (1-2 L each)	2000	Tc IX related costs only, not including tank sampling, characterization, filtration, Cs IX, or LAW immobilization

*TD work included in current program

Similar to the duration estimates, cost estimates above are based on a comparison to prior work with expected flow-sheet and design needs, which may change as the flow-sheet and design are matured. Very limited information on the regulatory requirements is known, and this may impact the budget (such as testing for the final disposition of spent resin).

The scheduled costs do not include precursor tasks. For example, the integrated process demonstration would require sample collection, adjustment, characterization, and Cs decontamination, which are not included in the estimate above because they would be part of an overall project to demonstrate the LAW waste form. The cost shown for the integrated demonstration only includes the time to set up, process, and characterize 3 samples through Tc IX, assuming that they are available. If the scope of the test changes, such as the DF required, sample size required, or number of samples, the costs may change. Similarly, it is envisioned that 2-3 batches of resin would need to be manufactured at pilot ($1/10^{th}$) scale, and increased scope would increase schedule and costs. Vendor costs for this activity are not known.

HLW vitrification formulation and pilot-scale melter simulant testing are not included in the cost estimates, since this is not within the Tc IX CTE. Similarly, costs are not included for testing of the ion exchange system to support development of a new waste form in the event of selection of a Tc eluate disposal option other than HLW vitrification.

Some of the tasks in Table 7 have been performed in very similar conditions, giving confidence that these activities can be successfully executed. Comparable tasks include:

- The Tc Ion Exchange preliminary modeling has been completed, and similar models have been developed for Cs removal with Ionsiv IE-911 (a.k.a. CST) [Hamm, 2002] and spherical Resorcinol Formaldehyde [Hardy, 2004]. Although the technical details of the media and ion are different, the concepts and functions are comparable.
- An on-line monitor for Tc has not been used, but alternative solutions exist if this method fails to be reliable or accurate, such as sampling and off-line analysis coupled with process control.
- Development and scale-up of spherical Resorcinol-Formaldehyde resin for cesium removal.
- Integrated Tc IX testing was performed with this resin on several actual Hanford waste tank samples in 1997-2003 at two national laboratories [McCabe, 2012].

7.0 CONCLUSIONS

Removal of technetium from the Hanford LAW would eliminate a key risk contributor for the IDF for potential acceptance of supplemental waste forms. Coupling technetium removal with supplemental waste forms has potential to reduce treatment and disposal costs. Elutable ion exchange using SuperLig® 639 has been developed for removing ^{99}Tc from LAW at Hanford, but the technology is not fully matured. This document contains a description of Technology Development activities needed to advance the technology readiness, based on the *U.S. DOE Office of Environmental Management Technology Readiness Assessment (TRA) and Technology Maturation Plan (TMP) Process Guide.* After a conceptual design of the elutable ion exchange process is complete and a preliminary safety analysis is performed, additional TD tasks may be identified. Since this Tc removal technology has already been tested under multiple conditions using several Hanford samples, and at multiple scales, it is likely that it can be matured and deployed without substantial technical barriers.

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9.0 ATTACHMENTS

Appendix A contains a description of the assumed configuration of deploying the elutable ion exchange technology at Hanford for treatment of LAW. This should be considered as a projection suitable for evaluating technology maturation, not final design input.

The description contains:

- Process Summary – overall description of the process
- Conceptual Process Diagram – schematic of assumed process steps/equipment
- Process Description – detailed steps in process operation
- Compatibility – identification of interface issues and chemical reactivity issues
- Schedule for Development – estimated schedule to develop to TRL = 6

Attachments:
Appendix A. Description - Elutable Ion Exchange
Appendix B. TRL Calculator Tables for SuperLig® 639

APPENDIX A. DESCRIPTION – Elutable Ion Exchange

Process Summary

This option requires the following to be installed in a facility:
3-4 ion exchange columns
Eluate addition system
Resin addition system
Resin removal system
Eluate storage and evaporation system
Spent resin handling system

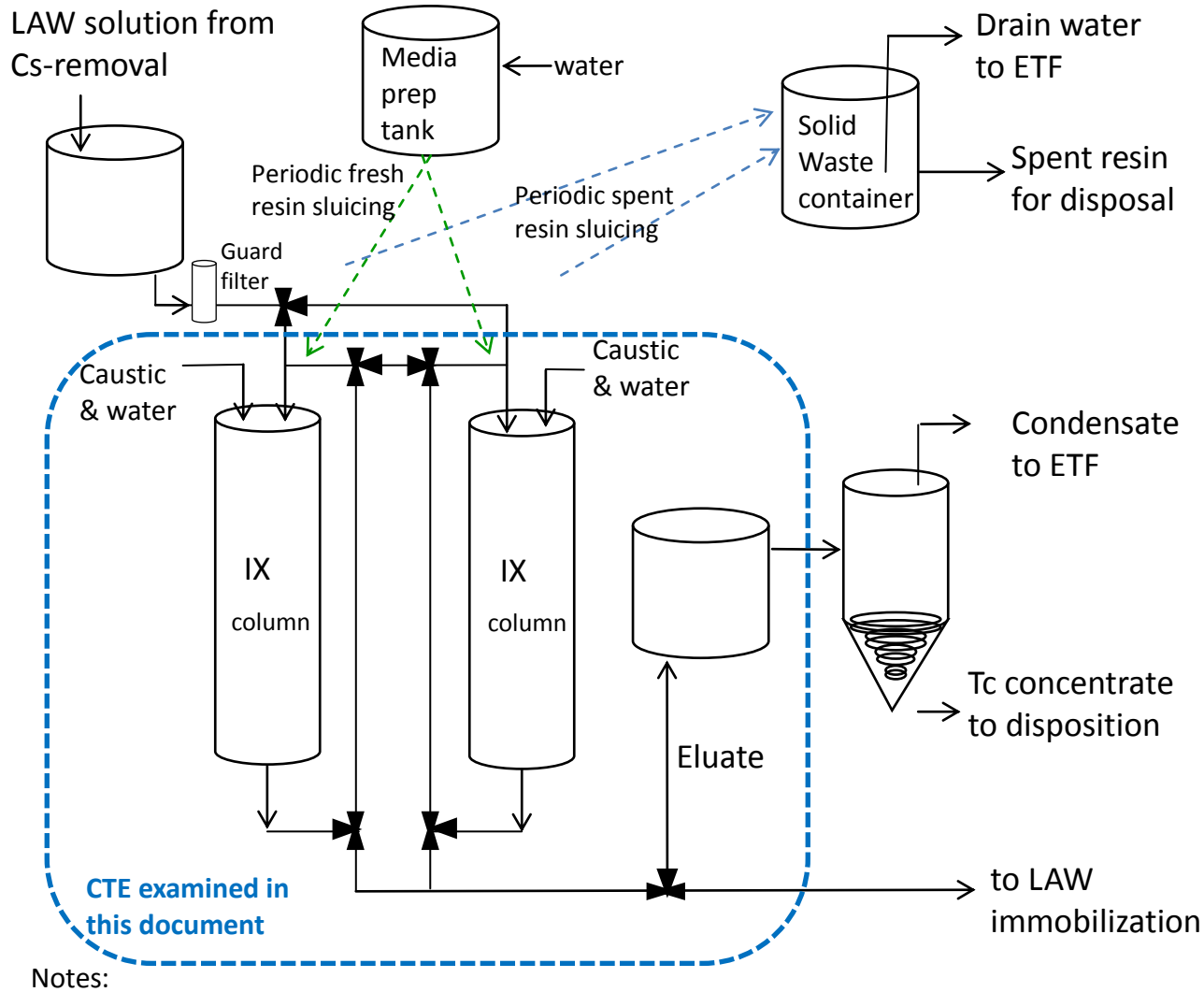
This process utilizes ion exchange columns containing specialized ion exchange media to remove pertechnetate from the tank supernate. The media in the columns is pretreated with caustic prior to each LAW processing cycle. The process consists of 2-3 ion exchange columns operating continuously in series, processing the waste until the cumulative effluent concentration limit is reached (i.e., the point where the summed average Tc concentration of a batch of processed LAW reaches the effluent limit), then the process is stopped. The media in the lead column is then rinsed with dilute caustic to displace the waste, and eluted from the column with warm water. The number of columns in series (two or three) will depend upon the desired process throughput and decontamination factor, and will be determined by process modeling and testing. The columns will operate in a carousel configuration, where the lead column is loaded with technetium, eluted, and then returned to service in the lag (or polish) position by re-aligning valves. It is desirable to utilize a fourth "spare" column in the carousel configuration so that the lead column can be taken out of service and eluted while continuing to operate the process by valving-in the spare column. After elution of the lead column, it is returned to service in the last position or held as the spare, and the partially loaded column(s) is valved to rotate it to the lead position(s).

The system is assumed to be controlled by on-line Tc monitors, yet to be fully developed. One on-line monitor would be utilized for monitoring the decontamination factor of the LAW solution exiting the columns, and another would monitor the Tc concentration during elution. It is possible that both functions may be performed by a single monitor, but two will be assumed for this evaluation.

The elution system will prepare the eluate and control its flow into the column. For this evaluation, the eluate is assumed to be warm water. The spent eluate will be transferred to a storage tank. Depending on the fate of this stream, the eluate is assumed to be evaporated to reduce the volume for storage or subsequent disposal.

Due to radiological and chemical degradation, the resin must be replaced periodically. For this evaluation, it is assumed that the spent, drained resin can be disposed in a suitable solid waste container without further manipulation.

Conceptual Process Diagram



Notes:
IX column reagent prep tanks/piping, water heater, and Tc monitors not shown
Valves and piping shown allow lead-lag carousel of columns
Additional columns may be needed – see text

Process Description

Media Preparation

The resin is received wetted with water in drums. One bed volume (BV = assume 1 m^3) of resin is added to the resin media preparation tank. The resin is washed up-flow with ~5BV of water to remove fines and excess chemicals. The wash-water is filtered and then disposed as industrial waste.

Feed Preparation

The LAW feed batch (5 M [Na^+]) is assumed to be received into a feed tank via a pretreatment facility that removes the entrained solids and ^{137}Cs. The batch is assumed to be previously analyzed to ensure compositional limits are satisfied, and tested at laboratory scale to ensure compatibility with the Cs and Tc removal processes. It is assumed that the LAW feed solution is adjusted to 5 M [Na^+] prior to Tc removal.

Ion Exchange System Preparation

The resin is sluiced into the empty column by pressurizing the media preparation tank with air and opening the drain valve. After sluicing, the prep tank and addition system is rinsed with 0.25 BV of water which is also transferred into the column. The column is backwashed (up-flow) with 1 BV of water to remove air bubbles and to level the bed. The resin is then preconditioned with down-flow of dilute caustic solution (assume 3 BV of 1 M NaOH). Water and caustic is disposed to LAW immobilization.

Feed Processing

Filtered, Cs-decontaminated LAW feed solution is pumped down-flow through the resin column at a flowrate of 3.4 BV/hour.

Technetium Capture

The LAW feed is processed through the ion exchange columns until the accumulated average Tc effluent concentration exiting the lag column approaches the disposal limit; the feed is then stopped. Monitoring of the Tc concentration in the decontaminated LAW solution is assumed to be performed with an online monitor (to be developed).

Disposition of Tc-decontaminated LAW

The Tc-decontaminated LAW solution is transferred to a staging tank in the LAW immobilization facility.

Feed Displacement

After feed to the column is stopped, the residual feed in the lead column is displaced with dilute caustic (down-flow); assume 2 BV of 1 M NaOH solution, which is sent forward with decontaminated LAW solution for immobilization.

Resin elution

For this evaluation, the eluate is assumed to be warm (60 °C) water. The volume of eluate is assumed to be 20 BV, and will be sent to a storage tank. Monitoring of the Tc concentration in the eluate solution is assumed to be performed with an online monitor (to be developed). After

down-flow elution of the column, the bed is regenerated in down-flow with up to 3 BV of 1 M NaOH. The column is then returned to service in the last position, and the partially loaded column(s) is rotated to the lead position(s).

Eluate Evaporation
Depending on the fate of this stream, the eluate is assumed to require evaporation to reduce the volume. The evaporator would need to be sized for evaporating the eluate volume in the same time as a resin loading cycle, assumed to be ~80 hours, equivalent to ~1 GPM. The solution would be concentrated ~10X, consistent with the prior testing and measured composition of the concentrated eluate [King, 2000c].

Dispose of Tc
The disposition path for the concentrated eluate is assumed to be HLW vitrification. The concentrated Tc stream will be campaigned periodically to the HLW melter as a Tc/water only stream.
Dispose of other waste streams
Caustic and water used to sluice or precondition the resin in the column prior to and after loading are sent forward to be mixed with the Tc-decontaminated LAW solution for immobilization. Testing indicated that this is estimated to add <12% to the LAW volume overall [Olson, 2002, section 6.2.4].

Due to radiological and chemical degradation, periodically, the resin must be replaced. After final elution, the resin is sluiced from the column into a spent resin solid waste container, where it is dewatered and disposed, similar to current practice at spent fuel pools. For this evaluation, it is assumed that the spent, drained resin can be disposed in a solid waste container without further manipulation. (This is consistent with prior work; analyses were performed during the R&D program to confirm that the residual components remaining on the used resin were at acceptable levels at the time [Kurath, 2000].) The empty column is then refilled by sluicing in a fresh batch of resin using a resin addition system. Any necessary preconditioning of the resin is then performed, and the column is then returned to service. The sluice water and preconditioning fluid (assumed to be dilute caustic) are discarded by addition to the Tc-decontaminated LAW solution tank. The frequency of resin disposal has not been definitively determined, but the resin is expected to be re-usable for at least twenty load-elute cycles, since 26 cycles have been shown to exhibit no loss in performance [Arm, 2003].

Process Resumption
Restart of feed processing requires re-valving to reverse the lead-lag configuration, placing the freshly eluted and preconditioned column into the last position in the series.

Compatibility with LAW and Downstream Processes

LAW
Chemical compatibility of process with different LAW solutions:
There are no known degradation or competition issues, and the primary competitor is nitrate ion. Low potassium in feed causes lower absorption of Tc, but the impact has not been quantified.

The resin can become buoyant with high density LAW solutions, causing poor decontamination. This can be mitigated by diluting the feed, although all expected compositions are acceptable at 5 M [Na^+]. To examine compatibility with high organic feeds, the resin has been tested with samples from two complex concentrate tanks (AN-102 and AN-107) with no observed adverse effects.

If a chemical oxidation is performed to convert non-pertechnetate to pertechnetate, it must be confirmed that the oxidant or secondary oxidants are destroyed or do not degrade the IX resin. Also, the conversion of nitrite to nitrate in oxidation process will cause reduced performance of Tc IX because competition between nitrate and pertechnetate is greater than nitrite and pertechnetate.

Total dilution of the Tc-decontaminated LAW stream by addition of sluice water and caustic is estimated at <12% [Olson, 2002, section 6.2.4]. All added streams are neutral pH or alkaline.

Scale up issues:
No known process issues. Establishing resin acceptance criteria and demonstration of resin production within those criteria at full scale has not been performed.

Tc Stream
Changes required in the flow-sheet to accommodate the Tc stream:
If Tc is added to HLW for vitrification, a route to send the eluate to WTP is needed, such as the dedicated Cs/Sr capsule line. If eluate is added continuously to the melter, the change will impact facility operations (to add this waste stream and account for the compositional and volume changes), and glass chemistry (to make it more reducing to improve Tc retention in the melter).

If eluate is added in campaigns, then interim storage of the eluate would be needed, as well as the above mentioned changes to facility operations and glass chemistry.

Number of additional HLW canisters will be produced:
Expected to be minimal, based on assumed continuous addition of Tc eluate to HLW vitrification. The HLW glass chemistry is assumed to be adjustable to accommodate this dilute stream. If the Tc stream is disposed in separate HLW vitrification campaigns, an unknown number of additional canisters could be created. This may be minimal, assuming that sludge is concurrently processed in the melter and the batching strategy can accommodate the change.

Impact to HLW melter throughput:
Small amount of additional evaporation of water from the concentrated Tc eluate may impact the throughput.

Impact to sludge batch preparation:
The concentrated Tc eluate contains small amounts of LAW components, such as sodium hydroxide and sodium nitrate. These are very low, but may need to be accounted for in the glass formulation.

Additional legacy waste streams
Spent resin is assumed disposed in the IDF or comparable facility after sluicing into an appropriate solid waste container and draining.

Controls

DSA
Expected DSA controls for this process (number and complexity of interlocks and administrative controls):
Unknown – maximum source term is estimated to be <0.1 Ci/L beta

Process
Expected process controls (non-safety) (number of interlocks and administrative controls)
Unknown – expect minimal due to low source term and minimal chemical incompatibilities. Expect interlock with on-line Tc monitor (which is yet to be developed) to prevent production of LAW that exceeds the LAW immobilization specification.

Processing Schedule
Expected duration to process the material from one waste tank:
It is assumed that this system will retain the original WTP configuration, which included the "spare" column to allow near continuous operation. Assuming 1 m^3 of resin per column, at 3.4 BV/hr and 70% availability, 1E6 gallons could be processed in 66 days.

APPENDIX B – TECHNOLOGY READINESS LEVEL CALCULATOR TABLES SELF ASSESSMENT

As much as practical, the new design and operating plans will be based on the prior system, maximizing leverage of the TD activities that have been completed, and minimizing risk. The yes/no responses recorded below are based on those prior designs and plans, but including projected changes described in Appendix A and assumptions in Section 1.1.1. As design activities are initiated, any deviations from the original design and conditions will be evaluated against the available test data, and any gaps will be identified and filled by the TD program.

Top Level Questions for Determining Anticipated TRL

Top-Level Question		Yes/No	If Yes, Then Basis and Supporting Documentation
TRL 9	Has the actual equipment/process successfully operated in the full operational environment (hot operations)?	N	
TRL 8	Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?	N	
TRL 7	Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?	N	
TRL 6	Has engineering scale equipment/process testing been demonstrated in a relevant environment?	Y	Full-height column testing performed with a simulant [Steimke, 2000] Full-scale hydraulics [Norato, 2000b]
TRL 5	Has laboratory/bench scale equipment/process testing been demonstrated in a relevant environment?	Y	Radioactive waste bench-scale columns: AN-102, [King, 2001b] SRS Tank 44, [King, 2000b] Radioactive waste small scale columns: AN-103, [Hassan, 2000b] AZ-102, [Hassan, 2001]

			AN-102, [Hassan, 2000a] AW-101, [Blanchard, 2000a] AN-107, [Blanchard, 2000b] AN-102/C-104, [Burgeson 2004a] AP-101, [Burgeson, 2002] AZ-102, [Burgeson, 2004b] AW-101 (multicycle), [Hassan, 2004] Actual waste Kd tests: AN-102, AN-103, AZ-102 [Hassan, 2002] AW-101, AN-107 [Kurath, 1999]
TRL 4	Has laboratory/bench scale testing, at a minimum, of similar equipment systems been completed in a simulated environment? For some systems, such as mechanical systems, this may require full-scale prototype testing.	Y	Small-scale simulant columns: AN-105, AZ-102, AN-107, [King, 2003] [Duffey, 2003]
TRL 3	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?	Y	Simulant Kd testing: AN-105, [King, 2000a] Composition ranges, [Rapko, 2003]
TRL 2	Has an equipment and process concept been formulated?	Y	Small-scale simulant columns: AN-105 [King, 2000a], AN-105, AZ-102, AN-107 [King, 2003] [Duffey, 2003]
TRL 1	Have the basic process technology process principles been observed and reported?	Y	Simulant Kd testing: AN-105, [King, 2000a] Composition ranges, [Rapko, 2003]

TRL 5 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		1. The relationships between major system and sub-system parameters are understood on a laboratory/bench scale.	System parameters tested, including superficial velocity, resin batch variability, bed dimensions, elution conditions [King, 2000a, 2003] resin particle size, feed composition, and temperature [Duffey, 2003]. On-line Tc monitor developed and tested [Egorov, 2003]. Resin addition/removal system tested [Norato, 2000b]. Computer modeling of Tc IX process examined relationships between test conditions and calculated results predicted for full-scale operating conditions [Hamm, 2000]. Updated Computer Model Results needed to incorporate 2001-2003 data and improve predictions.
T		2. Plant size components available for testing.	Full-height column (WTP design) testing performed with simulants [Steimke, 2000]; full-scale hydraulics demonstrated [Norato, 2000b] (equipment has been dismantled). IX columns are common industrial equipment. No TD activities anticipated at this time.
T		3. System interface requirements known. (How would system be integrated into the plant?)	Prior design integrated Tc IX into WTP pretreatment utilizing 2-3 sequential 1 m^3 columns with spare. Process required that elution/preconditioning cycle was shorter than loading cycle to allow continuous carousel column operation. Eluate evaporator sized to elution cycle duration. Concentrated eluate was disposed in HLW glass. Evaporator condensate disposed or re-used. Interface requirements are needed for proposed new process.
P		4. Preliminary design engineering has begun	

TRL 5 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		5. Requirements for technology verification established, to include testing and validation of safety functions.	Prior requirements defined in WTP contract, specifying demonstration of processing with actual waste samples [Contract No. DE-AC27-01RV14136, Mod. 016]. No specific safety issues identified. Requirements and Safety Assessment needed for new system; no TD activities anticipated at this time.
T		6. Interfaces between components/subsystems in testing are realistic (bench top with realistic interfaces).	Components include IX columns, elution system, and resin addition/removal system, which were tested at pilot or full-scale [Steimke, 2000] [Norato, 2000b]. Scaled eluate evaporation system was not tested; but is mature technology. On-line Tc monitor was tested with a full-scale prototype [Egorov, 2003]. Performance Specification needed; no TD activities anticipated at this time.
M		7. Prototypes of equipment system components have been created (know how to make equipment).	IX columns and evaporators are common industrial equipment, and various column designs have been used by DOE previously. A version of the online Tc monitor has been prototyped.
M		8. Manufacturing techniques have been defined to the point where largest problems defined.	IX resin manufactured at bench scale, larger scale manufacturing demo needed.
M		9. Availability and reliability (RAMI) target levels identified.	RAMI target levels needed; No TD activities anticipated at this time.
T		10. Laboratory environment for testing modified to approximate operational environment; to include testing and validation of safety functions.	Operational environment defined in Task Technical and QA specifications for intermediate-scale radioactive waste tests [McCabe, 1999]; no specific safety functions identified. Need safety analysis.
T		11. Component integration issues and requirements identified.	Full-scale hydraulics and sluicing test demonstrated resin loading and removal [Norato, 2000b]
P		12. Detailed 3D design drawings and P&IDs have been completed to support specification of a engineering-scale testing system.	Detailed 3D design drawings and P&IDs needed.
T		13. Requirements definition with performance thresholds and objectives established for final plant design.	Performance Specification needed for new system. (Including for non-pertechnetate removal)

TRL 5 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
P		14. Preliminary technology feasibility engineering report completed; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process*.	Engineering report needed.
T		15. Integration of modules/functions demonstrated in a laboratory/bench-scale environment.	Prior system interfaced with Cs IX, LAW glass, eluate evaporation, and HLW glass. Interface compatibility demonstrated by processing all LAW actual waste samples through Cs IX prior to Tc IX, then generating LAW glass, and evaporating eluate and generating HLW glass. Performance Specifications needed for new system interfaces.
T		16. Formal control of all components to be used in final prototypical test system.	Task and QA plan for pilot-scale full-height column tests [Steimke, 1998] Task and QA plan for full-scale column sluicing and hydraulics tests [Norato, 2000a]
P		17. Configuration management plan in place.	Configuration management plan needed
T		18. The range of all relevant physical and chemical properties has been determined (to the extent possible).	Resin properties measured [Hassan, 1999]; [Norato, 2000b], radioactive samples were analyzed (included in Tc IX reports). Range of waste compositions and properties in proposed future process is needed from Process Flow-sheet Report.
T		19. Simulants have been developed that cover the full range of waste properties.	Simulants for Re (sub for Tc) IX testing with AN-105, AZ-102, AN-107, [King, 2003] [Duffey, 2003] (3 envelopes developed). Range of waste compositions and properties in proposed future process is needed from Process Flow-sheet Report.
T		20. Testing has verified that the properties/performance of the simulants match the properties/ performance of the actual wastes.	Correlation between perrhenate and pertechnetate examined for limited composition range [Hamm, 2000]. Updated Computer Model Results needed to incorporate 2001-2003 data and improve predictions. Simulant of non-pertechnetate has not been produced.

TRL 5 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		21. Laboratory/bench scale tests, at a minimum, on the full range of simulants using a prototypical system have been completed – results validate design.	Distribution coefficient (Kd) tests with AN-105 simulant [King, 2000a], and range of compositions [Rapko, 2003] Column tests with simulants of each envelope based on AN-105, AZ-102, AN-107, [King, 2003] [Duffey, 2003] Updated Computer Model Results needed to incorporate data generated in 2001-2003.
T		22. Laboratory/bench scale tests, at a minimum, on a limited range of real wastes using a prototypical system have been completed – results validate design.	Laboratory scale actual waste column tests: AN-103, [Hassan, 2000b] AZ-102, [Hassan, 2001] AN-102, [Hassan, 2000a] AW-101, [Blanchard, 2000a] AN-107, [Blanchard, 2000b] AN-102/C-104, [Burgeson 2004a] AP-101, [Burgeson, 2002] AZ-102, [Burgeson, 2004b] AW-101 (multicycle), [Hassan, 2004] Bench-scale actual waste column tests: AN-102 [King, 2001b] SRS Tank 44, [King, 2000b] Actual waste Kd tests: AN-102, AN-103, AZ-102 [Hassan, 2002] AW-101, AN-107 [Kurath, 1999] Online Tc monitor device [Egerov, 2003]

TRL 5 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		23. Test results for simulants and real waste are consistent.	Perrhenate used for simulants. Correlation between Re and Tc examined [Hamm, 2000]. Tc absorption ~40% better than Re. Updated Computer Model Results needed to incorporate 2001-2003 data and improve predictions. No simulant for the non-pertechnetate form of Tc has been tested. This form passes through the IX columns. The overall amount of non-pertechnetate was beneath the 0.1 Ci/m^3 limit in WTP LAW glass. No additional TD activities anticipated at this time. A simulant would be needed if non-pertechnetate must be removed.
T		24. Laboratory/bench to engineering scale scale-up issues are understood, if applicable, and resolved; to include testing and validation of safety functions.	Scale-up parameters examined [McCabe, 2001]; no specific safety functions identified. Process Hazard Analysis for proposed new system is needed. No TD activities anticipated at this time.
T		25. Limits for all process variables/parameters and safety controls are being refined.	Process parameters examined for limited range of compositions [Hamm, 2000]. Updated Computer Model Results needed to incorporate 2001-2003 data and improve predictions. Process Hazard Analysis evaluation and process variables for proposed new system are needed.
P		26. Test plan documents for engineering-scale tests completed.	[Steimke, 1998]. No TD activities anticipated at this time.
P		27. Risk management plan documented; to include compliance with DOE STD 1189-2008.	Prior program preceded DOE STD 1189-2008, Safety Design Strategy document needed. No TD activities anticipated at this time.
P		28. Test plan for laboratory/bench scale, at minimum, tests executed – results validate design; to include testing and validation of safety functions.	Test plan for bench-scale testing issued [McCabe, 1999], and testing completed [King, 2000b, King 2001b]. Process Hazard Analysis evaluation for proposed new system is needed. No TD activities anticipated at this time.
P		29. Finalization of hazardous material forms and inventories, completion of process hazard analysis, and identification of system/components level safety controls at the appropriate preliminary design phase.	Spent resin that was used in testing with actual waste was characterized [Kurath, 2000]. Process Hazards Analysis for proposed new system is needed.

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

TRL 6 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		1. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	System parameters tested with simulants, including superficial velocity, resin batch variability, bed dimensions, elution conditions [King, 2000a, 2003] resin particle size, feed composition, and temperature [Duffey, 2003]. On-line Tc monitor developed and tested [Egorov, 2003]. Resin addition/removal system tested [Norato, 2000b]. Resin sluicing and dewatering in disposal container assumed to be nuclear industry standard design and procedure. Computer modeling of Tc IX process examined relationships between test conditions and calculated results predicted for full-scale operating conditions [Hamm, 2000]. Updated Computer Model Results needed to incorporate 2001-2003 data and improve predictions.
M		2. Availability and reliability (RAMI) levels established.	RAMI analysis needed.
P		3. Preliminary design drawings for final plant system are complete; to include compliance with DOE STD 1189-2008, *Integration of Safety into the Design Process.*	Preliminary design drawings needed.
T		4. Operating environment for final system known.	Prior environment defined in WTP contract, including Tc removal requirement (overall average of 0.1 Ci/m^3 in glass and 80% removal) [Contract No. DE-AC27-01RV14136, Section C, specification 2.2.2.8]. Basis of Design (for TWRS Privatization) [Page, 1999] Process Flow-sheet Report needed for new system

TRL 6 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
P		5. Collection of actual maintainability, reliability, and supportability data has been started.	Resin chemical [Arm, 2003] and radiation [Arm, 2003b] stability has been tested; Resin compatibility with organics in waste has been tested [Adu-Wusu, 2002]. Equipment RAMI analysis needed.
P		6. Performance Baseline (including total project cost, schedule, and scope) has been completed.	Performance Baseline needed.
T		7. Operating limits for components determined (from design, safety and environmental compliance).	Preliminary computer modeling complete [Hamm, 2000]; pilot-scale simulant testing complete [Steimke, 2000]; radiation stability of resin tested [Arm, 2003b], chemical stability of resin tested [Arm, 2003]; Updated Computer Model Results needed to incorporate 2001-2003 data and improve predictions. Performance Specification document needed for new system. Target DF for Tc needed, including if non-pertechnetate must be removed.
P		8. Operational requirements document available; to include compliance with DOE STD 1189-2008.	Basis of Design (for TWRS Privatization) [Page, 1999] (Preceded DOE STD 1189-2008); Safety Design Strategy needed.
P		9. Off-normal operating responses determined for engineering scale system.	Operating procedure for pilot-scale system [Norato, 1999]

TRL 6 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		10. System technical interfaces defined.	Prior system interfaced with Cs IX, LAW glass, eluate evaporation, and HLW glass. Interface compatibility demonstrated by processing all LAW actual waste samples through Cs IX prior to Tc IX, then generating LAW glass, and evaporating eluate and generating HLW glass. Lab scale actual waste column tests: AN-103, [Hassan, 2000b] AZ-102, [Hassan, 2001] AN-102, [Hassan, 2000a] AW-101, [Blanchard, 2000a] AN-107, [Blanchard, 2000b] AN-102/C-104, [Burgeson 2004a] AP-101, [Burgeson, 2002] AZ-102, [Burgeson, 2004b] AW-101 (multicycle), [Hassan, 2004] Bench-scale actual waste column tests: AN-102 [King, 2001b] Radioactive Tc eluate evaporation for AZ-102 [King, 2000c] Radioactive Tc eluate immobilization in HLW glass: C-106, [Crawford, 1998] C-104/AZ-102, [Smith, 2001] AZ-101, [Hrma, 2004] Performance Specification document needed for new system interfaces. Once interfaces are established for the proposed system, an evaluation is needed to determine if previous testing is sufficient. SL639 has not been tested with samples that were Cs-decontaminated with sRF, and only once with CST (SRS Tank 44). Preparation of immobilized supplemental LAW samples with (Cs and) Tc-decontaminated simulant and actual waste samples is needed.

TRL 6 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
T		11. Component integration demonstrated at an engineering scale, at a minimum. May include full-scale prototype for some technologies, such as mechanical systems.	Full-height column testing with AN-105 simulant: [Steimke, 2000] [McCabe, 2000] Full-size column for hydraulics and sluicing [Norato, 2000b]. Once preliminary design specification is complete for the proposed new system, an evaluation is needed to determine if additional testing is needed.
P		12. Analysis of project timing ensures technology will be available when required	Project schedule not established.
P		13. Have established an interface control process.	Interface control process not established.
P		14. Acquisition program milestones established for start of final design (CD-2).	Project schedule not established.
M		15. Critical manufacturing processes prototyped.	Resin manufactured at bench scale (1-gallon) [Serkiz, 2004]. Maturation of resin manufacturing is needed.
M		16. Most pre-production hardware is available to support fabrication of the system.	IX columns and evaporators are common industrial equipment.
T		17. Engineering feasibility fully demonstrated.	Full-height column testing with AN-105 simulant: [Steimke, 2000] Full-scale sluicing and hydraulics: [Norato, 2000b] Once a preliminary design specification is complete for the proposed new system, an evaluation is needed to determine if additional testing is needed.
M		18. Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	IX columns and evaporators are common industrial equipment. Maturation of resin manufacturing is needed.
P		19. Technology “system” design specification complete and ready for detailed design.	Performance Specification for new proposed system is needed.
T		20. Engineering-scale system is high-fidelity functional prototype of operational system.	Full-height column testing with AN-105 simulant: [Steimke, 2000] Scale-up effects examined: [McCabe, 2000]
P		21. Formal configuration management program defined to control change process.	Project is not yet established.

TRL 6 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
P		22. Final technical report on technology completed; to include compliance with DOE STD 1189-2008. Report is a summary of technology development activities.	Final technical report on technology is needed.
M		23. Process and tooling are mature to support fabrication of components/system.	IX columns and evaporators are common industrial equipment.
T		24. Engineering-scale tests, at a minimum, on the full range of simulants using a prototypical system have been completed – results validate design.	Full-height column testing with one simulant (AN-105): [Steimke, 2000] Bench-scale simulants of AN-105, AZ-102, AN-107: [King, 2000] [King, 2003] [Duffey, 2003] Preliminary computer modeling to show consistency between multiple radioactive samples through full-height simulant: [Hamm, 2000]
T		25. Engineering to full-scale scale-up issues are understood and resolved.	Scale-up parameters examined [McCabe, 2000]; preliminary computer modeling [Hamm, 2000] Updated Computer Model Results are needed to incorporate data from testing in 2001-2003 and improve predictions.
T		26. Test results are consistent for laboratory/bench and engineering-scale experiments, and/or prototype testing as applicable.	[McCabe, 2000] [Hamm, 2000] Updated Computer Model Results are needed to incorporate data from testing in 2001-2003 and improve predictions
M		27. Production demonstrations are complete (at least one time).	Resin manufacturing demonstrated at bench scale. Maturation of resin manufacturing needed.
P		28. Integration demonstrations have been completed (e.g. construction of testing system); to include testing and validation of safety functions.	Full-height column testing completed with one simulant (AN-105): [Steimke, 2000] Full-size column for hydraulics and sluicing [Norato, 2000b]. No specific safety functions identified. Process Hazard Analysis of proposed new system is needed.

TRL 6 Questions for Critical Technology Elements			
T/P/M	**Y/N**	**Criteria**	**Basis and Supporting Documentation**
P		29. Finalization of hazardous material forms and inventories; completion of process hazard analysis, identification of system/components level safety controls at the appropriate preliminary/final design phase.	Spent resin that was used in testing with actual waste was characterized [Kurath, 2000]. Process Hazards Analysis for proposed new system is needed.

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

TRL 6 Questions for the Waste Processing System (WPS)			
CTE:			
	Y/N	**Questions**	**Basis and Supporting Documents**
Processing		1. Have all TEs that require an increase or change in capability been identified as CTEs?	Performance Specification report is needed to quantify required capabilities. No additional TD for Tc removal is anticipated at this time.
		2. Can the WPS accept the full range of wastes to be processed?	Process Flow-sheet Report needed to establish expected range. TD for Tc removal may be needed to extend composition range.
		3. Is the WPS capable of meeting targets for startup and completion of waste processing?	Performance Specification report is needed to quantify targets. Prior design was comparable to WTP throughput rate. No TD for Tc removal is anticipated at this time.
		4. Have the target operational and performance requirements for the WPS been determined?	Performance Specification report is needed to quantify targets. No TD for Tc removal is anticipated at this time (assumes non-pertechnetate does not need to be removed).
		5. Have major sections of the WPS and their interfaces been modeled and/or tested?	Preliminary computer modeling complete [Hamm, 2000] Updated Computer Model Results are needed to incorporate data from testing in 2001-2003 and improve predictions. Models and testing are needed for other sections and interfaces.
		6. Has WPS data collection and data flow been modeled/tested?	Interface Control documents needed to identify requirements. On-line Tc monitor development may require TD on data collection & management.

TRL 6 Questions for the Waste Processing System (WPS)			
CTE:			
	Y/N	**Questions**	**Basis and Supporting Documents**
		7. Has WPS process flow and process control been modeled/tested?	Interface Control documents needed to identify requirements. No TD activities for Tc removal anticipated at this time.
		8. Have WPS single point failures been identified?	Interface Control documents needed to identify failure points. No TD activities for Tc removal anticipated at this time.
		9. Can TEs be sized to meet WPS throughput requirements?	Comparable equipment has been deployed; no TD activities for Tc removal anticipated at this time.
		10. Have all new or novel operating modes of the WPS been modeled and/or tested?	Tc removal has been modeled and tested; Performance Specification report is needed to determine additional TD activities.
		11. Are all recycle streams fully characterized?	No recycle streams generated in Tc IX. Feed displacement fluid characterized [Hassan, 2004]; Resin conditioning fluid is dispositioned with LAW. No TD for Tc removal is anticipated at this time.
		12. Are all WPS recycle streams included in process models?	Process models are needed. No recycle streams generated in Tc IX. No TD for Tc removal is anticipated at this time.
		13. Have the key safety aspects of the WPS related to processing been identified?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.
		14. Are appropriate measures in place to ensure safe operation of the processing activities?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.

TRL 6 Questions for the Waste Processing System (WPS)			
CTE:			
	Y/N	**Questions**	**Basis and Supporting Documents**
		15. Is the appropriate documentation in place that adequately describes the safety features related to processing, and their functions in the overall integrated WPS?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.
Disposal		16. Will the WPS produce a product or products that can be dispositioned?	Tc removal waste streams are identified and disposition paths are described in Appendix A. For demonstration of disposition of LAW as supplemental waste form, simulated and actual Cs and Tc-decontaminated LAW will need to be generated. (Outside the scope of this CTE, an evaluation is needed to determine the scope of testing needed to mature incorporation of Tc eluate simulant into HLW vitrification.)
		17. Are all WPS waste streams identified?	Tc removal waste streams identified and expected disposition paths described in Appendix A.
		18. Have the waste streams produced by the WPS been fully characterized?	Tc IX eluate and evaporator concentrate have been characterized [King, 2000c]; spent resin has been characterized [Kurath, 2000, Hassan, 2004]; No TD for Tc removal is anticipated at this time.
		19. Has a disposition path been determined for each waste stream, including, process liquids, off gases, and solids?	Tc removal waste streams identified and expected disposition paths described in Appendix A.

TRL 6 Questions for the Waste Processing System (WPS)			
CTE:			
	Y/N	**Questions**	**Basis and Supporting Documents**
		20. Will the waste forms meet the waste acceptance criteria of the proposed disposition facilities?	Tc removal waste streams identified and expected disposition paths described in Appendix A. Performance Specification document needed for new system interfaces and disposal facilities. SL639 has not been tested with samples that were Cs-decontaminated with sRF, and only once with CST (SRS Tank 44). Preparation of immobilized supplemental LAW samples with (Cs and) Tc-decontaminated simulated and actual waste samples is needed. HLW glass made with Tc IX eluate has been shown acceptable [Crawford, 1998, Smith, 2001, Hrma, 2004].
		21. Have the disposition facilities/sites been contacted to ensure that the waste streams are compatible with disposal facility/site **operations, procedures, and regulations**?	Interface Control Documents needed to establish interfaces. Spent resin disposal may require stabilization.
		22. Have the key safety aspects of the WPS related to disposal been identified?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.
		23. Are appropriate measures in place to ensure safe operation of the disposal activities?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.
		24. Is the appropriate documentation in place that adequately describes the safety features related to disposal, and their functions in the overall integrated WPS?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.
Interfaces		25. Are all WPS technology interfaces and dependencies determined and understood?	Performance Specification document needed for new system interfaces. No TD for Tc removal is anticipated at this time.

TRL 6 Questions for the Waste Processing System (WPS)			
CTE:			
	Y/N	**Questions**	**Basis and Supporting Documents**
		26. New or novel interfaces among WPS systems have been identified as CTEs?	Performance Specification document needed for new system interfaces. No TD for Tc removal is anticipated at this time.
		27. Have all WPS TE interfaces been modeled or tested?	Performance Specification document needed for new system interfaces. SL639 has not been tested with samples that were Cs-decontaminated with sRF, and only once with CST (SRS Tank 44). Preparation of immobilized supplemental LAW samples with (Cs and) Tc-decontaminated simulated and actual waste samples is needed.
		28. Are the processing modes of the TEs (e.g., batch, continuous) compatible?	Tc IX will operate in a semi-continuous batch mode. Tankage will be required at interfaces (see Appendix A)
		29. Have the key safety aspects of the WPS related to disposal been identified?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.
		30. Are appropriate measures in place to ensure safe operation of the disposal activities?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.
		31. Is the appropriate documentation in place that adequately describes the safety features related to disposal, and their functions in the overall integrated WPS?	Process Hazards Analysis needed. No TD for Tc removal is anticipated at this time.

INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

Part I: Background Information

Title: Technetium Removal Technology Development Plan for Elutable Ion Exchange	Information Category: ☐ Abstract ☐ Journal Article ☐ Summary ☐ Internet ☐ Visual Aid ☐ Software ☐ Full Paper ☑ Report ☐ Other
Publish to OSTI? ☐ Yes ☑ No	

	Yes	NA
Trademark/Copyright "Right to Use" Information or Permission Documentation	☐	☑

Document Number: RPP-PLAN-54676 Revision 0	Date: March 2013
Author: Prindiville, Kerry A	

Part II: External/Public Presentation Information

Conference Name: NOT APPLICABLE			
Sponsoring Organization(s): DOE ORP			
Date of Conference: NOT APPLICABLE	Conference Location: NOT APPLICABLE		
Will Material be Handed Out? ☐ Yes ☑ No	Will Information be Published? ☐ Yes ☑ No	*(If Yes, attach copy of Conference format instructions/guidance.)*	

Part III: WRPS Document Originator Checklist

Description	*Yes*	*N/A*	*Print/Sign/Date*
Information Product meets requirements in TFC-BSM-AD-C-01?	☑	☐	Prindiville, Kerry A Approved - IDMS data file att.
Document Release Criteria in TFC-ENG-DESIGN-C-25 completed? (Attach checklist)	☑	☐	Prindiville, Kerry A Approved - IDMS data file att.
If product contains pictures, safety review completed?	☐	☑	

Part IV: WRPS Internal Review

Function	*Organization*	*Date*	*Print Name/Signature/Date*
Subject Matter Expert	WRPS	07/15/2020	Prindiville, Kerry A Approved - IDMS data file att.
Responsible Manager	WRPS	07/09/2020	Swanberg, David J Approved - IDMS data file att.
Other: Subject Matter Expert	WRPS	08/10/2020	Darling, David B Approved - IDMS data file att.

Part V: IRM Clearance Services Review

Description	*Yes*	*No*	*Print Name/Signature*
Document Contains Classified Information?	☐	☒	If Answer is "Yes," ADC Approval Required Print Name/Signature/Date
Document Contains Information Restricted by DOE Operational Security Guidelines?	☐	☒	Reviewer Signature: Print Name/Signature/Date
Document is Subject to Release Restrictions? *If the answer is "Yes," please mark category at right and describe limitation or responsible organization below:*	☐	☒	Document contains: ☐ Applied Technology ☐ Protected CRADA ☐ Personal/Private ☐ Export Controlled ☐ Proprietary ☐ Procurement – Sensitive ☐ Patentable Info. ☐ OUO ☐ Predecisional Info. ☐ UCNI ☐ Restricted by Operational Security Guidelines ☐ Other (Specify)
Additional Comments from Information Clearance Specialist Review?	☐	☒	Information Clearance Specialist Approval APPROVED By Sarah Harrison at 2:05 pm, Aug 11, 2020 Print Name/Signature/Date

When IRM Clearance Review is Complete – Return to WRPS Originator for Final Signature Routing (Part VI)

INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

Part VI: Final Review and Approvals

Description	Approved for Release		Print Name/Signature	
	Yes	N/A		
WRPS External Affairs	☒	☐	Mc Cune, Hal C	Approved - IDMS data file att.
WRPS Office of Chief Counsel	☒	☐	Peters, Amber D	Approved - IDMS data file att.
DOE – ORP Public Affairs/Communications	☒	☐	Levardi, Yvonne M / Tyree, Geoff T	Approved - IDMS data file att.
Other: ORP OCC	☒	☐	King, Grace J	Approved - IDMS data file att.
Other: ORP SME	☒	☐	Papp, Ivan G	Approved - IDMS data file att.

Comments Required for WRPS-Indicate Purpose of Document:

The subject document is a reference to the draft VLAW WIR.

As such it is being requested by the NRC as part of their consultation review and must be publicly cleared to support that review.

APPROVED
By Sarah Harrison at 2:05 pm, Aug 11, 2020

Approved for Public Release; Further Dissemination Unlimited

Information Release Station

Was/Is Information Product Approved for Release? ☒ Yes ☐ No

If Yes, what is the Level of Releaser? ☑ Public/Unrestricted ☐ Other (Specify) _____

Date Information Product Stamped/Marked for Release: 08/11/2020

Was/Is Information Product Transferred to OSTI? ☐ Yes ☒ No

Forward Copies of Completed Form to WRPS Originator

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        Exchange, Revision 0, submitted by Kerry Prindiville for external public
        release. Thank you, Sarah Harrison Information Clearance</comments>
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