Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

12-AMRC-0113

MAR 28 2012

Mr. D. A. Faulk, Program Manager
Office of Environmental Cleanup
Hanford Project Office
U.S. Environmental Protection Agency
309 Bradley Blvd, Suite 115
Richland, Washington 99352

Dear Mr. Faulk:

COMPLETION OF HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER (TRI-PARTY AGREEMENT) MILESTONE M-016-171, COMPLETE K BASIN SLUDGE TREATMENT AND PACKAGING TECHNOLOGY EVALUATION REPORT AND SUBMIT A SCHEDULE INCLUDING PROPOSED NEW INTERIM MILESTONES FOR BENCH SCALE OR IDENTIFIED TESTING IN ORDER TO MEET M-016-173

The purpose of this letter is to notify the U.S. Environmental Protection Agency that Tri-Party Agreement Milestone M-016-171, "Complete K Basin sludge treatment and packaging technology evaluation report and submit a schedule including proposed new interim milestones for bench scale or identified testing in order to meet M-016-173," has been completed.

The U.S. Department of Energy Richland Operations Office (RL) completed the attached sludge treatment and packaging technology evaluation report (PRC-STP-00465) as required by M-16-171. The report recommends that warm water oxidation (WWO) be identified as the technical baseline for the Sludge Treatment Project (STP) Phase 2 Treatment and Packaging Project, and that the WWO process be further developed along with the Size Reduction and Fenton's Reagent processes as potential enhancements to the technical baseline. The final selection of the treatment and packaging system will be a part of the M-16-173 Milestone.

RL has also developed the attached technology development schedule and a draft change notice that establishes two interim milestones during FY 2013 and FY 2014 for consideration as required by M-16-171.

If you have questions, please contact me or your staff may contact Tom Teynor, of my staff, on (509) 376-6363.

Sincerely,

Jonathan A. Dowell, Assistant Manager
for the Central Plateau

AMRC:SCS

Attachments:
1. PRC-STP-00465
2. Technology testing schedule
3. Draft TPA Change Notice

cc/attachs:
G. Bohnee, NPT
L. Buck, Wanapum
S. Harris, CTUIR
J. A. Hedges, Ecology
R. Jim, YN
S. L. Leckband, HAB
R. A. Lobos, EPA
N. M. Menard, Ecology
K. Niles, ODOE
D. Rowland, YN (4) plus 2 CDs
Administrative Record, H6-08
Environmental Portal, A3-01

cc w/o attachs:
J. W. Crocker, PAC
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T. W. Noland, MSA
R. E. Piippo, MSA
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D. Watson, CHPRC

Change Number	Federal Facility Agreement and Consent Order Change Control Form	Date
M-16-12-02	Do not use blue ink. Type or print using black ink.	March 19, 2012

Originator DRAFT **Phone**

J. A. Dowell (509) 373-9971

Class of Change

[ ] I - Signatories [**X**] II - Executive Manager [ ] III - Project Manager

Change Title

Establish two Interim Milestones for Testing of K-Basin Sludge Treatment and Packaging Technology to complete Interim Milestone M-016-171.

Description/Justification of Change

This change package establishes two interim milestones to document progress on testing of the K-Basin sludge treatment and packaging technologies that were evaluated under interim milestone M-016-171. Bench-scale testing will be conducted to refine the identified treatment and support the design of the treatment and packaging process.

continued on page 2

Impact of Change

The two new interim milestones will provide definitive testing of the warm water oxidation treatment technology. The results of this testing will support completion of TPA Interim Milestone M-016-173, "Select K Basin sludge treatment and packaging technology and propose new interim sludge treatment and packaging milestones" due March 31, 2015.

Affected Documents

The Hanford Federal Facility Agreement and Consent Order, as amended, and Hanford Site internal planning, management, and budget documents (e. g., USDOE and USDOE contractor Baseline Change Control documents; Project Management Plans).

Approvals

J. A. Dowell ____________ ______Approved______Disapproved
DOE Date

D. A. Faulk ____________ ______Approved______Disapproved
EPA Date

N/A ____________ ______Approved______Disapproved
Ecology Date

Description/Justification of change, continued

The initial proof-of-concept testing and engineering analysis identified warm-water oxidation (WWO) as the technical baseline for sludge treatment and packaging, with the potential for process enhancements that could shorten the treatment schedule. The following major functional areas will be evaluated and tested:

- Sludge Transport and Storage Container (STSC) Retrieval
- WWO process
- Uranium Metal Size Reduction
- Fenton's Reagent Oxidation
- Slurry Agitation and Transfer
- Oxidation Monitoring and Drum Assay
- Simulant formulation and qualification
- Remote Sludge Immobilization and Drumming

Laboratory testing of the WWO process and enhancements will be conducted to support selection of the treatment and completion of the K-Basin sludge treatment process and packaging design, as identified in new interim TPA milestones.

Modifications are denoted by the use of ~~strikeout~~ to indicate text to be deleted and double underline to indicate text to be added.

M-016-179 Lead Agency: EPA	Initiate Laboratory Testing Necessary to Design the Warm Water Oxidation Process for K-Basin Sludge Treatment.	08/30/2013
M-016-180 Lead Agency: EPA	Complete Warm Water Oxidation Process Testing	10/31/2014

PRC-STP-00465
Revision 0
Volume 1

K-BASIN SLUDGE TREATMENT PROJECT - PHASE 2 TECHNOLOGY EVALUATION AND ALTERNATIVES ANALYSIS

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

PRC-STP-00465
Revision 0
Volume 1
EDC #: ECR-11-001397

K-BASIN SLUDGE TREATMENT PROJECT - PHASE 2 TECHNOLOGY EVALUATION AND ALTERNATIVES ANALYSIS

Document Type: TR Program/Project: STP

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Date Published
July 2011

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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Nancy A Fouad 7/28/2011
Release Approval Date

JUL 28 2011
DATE:
STA: 15
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Total Pages: 74

Executive Summary

Background: Highly radioactive sludge (containing up to 120,000 curies of actinides and fission products), resulting from the storage of degraded spent nuclear fuel, has been consolidated in Engineered Containers (ECs) in the 105-K West Storage Basin located on the Hanford site near the Columbia River in Washington State. CH2M Hill Plateau Remediation Company (CHPRC) is proceeding with a subproject (Engineered Container Retrieval, Transfer, and Storage Project, or ECRTS) to retrieve the sludge, place it in Sludge Transport and Storage Containers (STSCs) and store those filled containers within the T Plant Canyon facility on the Hanford Site Central Plateau. This retrieval and transfer of the sludge material enables the removal of the 105-K West Basin and allows remediation of the subsurface contamination plumes under the basin.

Recommendation

- Select Warm Water Oxidation as the Technical Baseline for Phase 2 Treatment and Packaging of K Basin Sludge
- In parallel develop and demonstrate Size Reduction and Fenton's Reagent Processes to TRL 4
  - Reduce technical risk
  - Potential treatment schedule improvement
- Resolve Outstanding Issues
  - Regulatory questions regarding Nitrate Chemical Inhibitor Process (NCIP)
  - Technical feasibility of sludge drying only

The US Department of Energy (DOE) plans to treat and dispose of the K Basin sludge as remote handled transuranic waste (RH-TRU) at the Waste Isolation Pilot Plant (WIPP) located in New Mexico. The established transportation and disposal requirements require the transformation of the existing K Basin sludge stored slurry to a chemically stable, liquid-free waste form within a certifiable waste package. The K Basin sludge currently contains uranium metal which reacts with water present in the stored slurry, generating hydrogen and other byproducts.

The purpose of this Report is to document the evaluation of technologies and processes for treating and packaging K Basin sludge and recommend further development of those that have a high certainty of successful deployment.

A previous K Basin sludge alternatives analysis was conducted in 2008-2009 [1] that evaluated hundreds of technical alternatives and implementation strategies for retrieval, packaging, and treatment and for their ability to support DOE's expressed desire to complete waste removal and remediation activities for waste sites along the Columbia River by 2015. This previous study included a recommendation to break the project into two phases. In Phase 1 (also referred to as ECRTS) the sludge would be retrieved and transferred for interim storage on the central plateau. In parallel, characterization of the sludge would be completed. In Phase 2 DOE would evaluate and develop treatment and packaging technologies to enable final disposal of the material as RH-TRU at the WIPP facility.

Purpose and Scope: The purpose of this Report is to document the evaluation of technologies and processes for treating and packaging K Basin sludge and recommend further development of those that have a high certainty of successful deployment.

This report is organized into two volumes. Volume 1 contains the summary of the analyses and the CHPRC recommendations. Volume 2 contains the details of the analysis, which provides the bases for the summary and the recommendations.

Process: Section 2 of this report describes the process used to identify the viable technology approaches, to perform bench top feasibility testing on the selected technology approaches, to generate data, and to evaluate the selected technology approaches to form the basis of the recommendations.

In summary, CHPRC conducted a formal evaluation process to identify and evaluate alternative technology approach for the treatment and packaging of K Basin Sludge which is discussed in Section 3. A Request for Technology Information (RFI) was issued and potentially applicable technologies were identified through a commercial procurement, technical workshops, and review of the numerous previous sludge treatment technology studies.

Evaluation Criteria

- Safety
- Regulatory/stakeholder acceptance
- Technical Maturity
- Operability and Maintainability
- Life-cycle cost and Schedule
- Potential for Beneficial Integration with STP-Phase 1 Activities
- Integration with Site-wide RH-TRU Processing/Packaging planning, schedule and approach

The identified technology approaches were screened using the criteria established in the Decision Plan [3], and focused bench top feasibility testing was conducted.

Finally, engineering evaluation of the costs, schedules, technical maturity were developed and evaluated by the technical team. CHPRC empanelled a Decision Support Board (DSB) to review the collected information and formulate recommendations to the project as discussed in Section 4. The CHPRC recommendations presented in this report (Section 5) were developed based on input from the DSB and the CHPRC technical team.

The criteria used in the evaluation process were as follows:

1. Safety
2. Regulatory/stakeholder acceptance
3. Technical maturity
4. Operability and maintainability
5. Life-cycle cost and schedule
6. Potential for beneficial integration with ongoing STP-Phase 1 activities
7. Integration with Site-wide RH-TRU processing/packaging, planning, schedule, and approach

The criteria used for this evaluation are discussed in Section 2.1 and the data developed in support of this evaluation are documented in Volume 2 of this report.

Recommendation: CHPRC recommends that Warm Water Oxidation be identified as the technical baseline for the Phase 2 Treatment and Packaging project. In parallel, CHPRC recommends that DOE develop the Size Reduction and Fenton's Reagent Processes to a Technology Readiness Level of 4 (TRL-4) to further reduce risk, and potentially shorten the sludge treatment time by 2-3 years. As an adjunct to the recommendations to continue development of these three technologies, resolution of outstanding regulatory issues associated with the Nitrate Chemical Inhibitor Process and evaluation of the feasibility of direct sludge drying should be considered.

Basis for Recommendation: Selection of Warm Water Oxidation provides the following benefits to DOE:

- Most technically mature
- No significant chemical additions, simplifying the process design and eliminating operational requirements of chemical management facilities, training and qualification programs, and the necessity for workers to use chemical personal protective equipment (PPE) during the chemical receipt, handling, and transfer operations
- Operation at less than atmospheric pressure improves safety by simplifying safety controls including confinement features
- A reasonable processing schedule, with opportunity for further optimization
- Proposed processing equipment can potentially be designed to provide process flexibility by allowing operation of a range of other processes, depending on the degree of demonstrated effectiveness, thus further reducing technical risk while providing opportunities for optimization

Parallel development of the Size Reduction process could reduce the treatment duration by 2 to 3 years, as well as greatly reduce the difficulty in transfer, agitation, and the preparation of a homogeneous immobilized waste form.

Parallel development of the Fenton's Reagent Process could also reduce the treatment schedule by 2-3 years and would result in an immobilized product that oxidizes uranium to the maximum extent, which in turn may reduce the potential for any swelling of the immobilized product post treatment.

Nitrate Chemical Inhibitor Process and sludge drying are technologies that might meet the requirements for shipment to WIPP without the oxidation of the uranium metal in the sludge. These approaches require resolution of outstanding technical issues and require discussions with WIPP representatives to determine if there are sufficient advantages to justify further evaluation.

Path Forward Actions to Implement the Recommendation: CHPRC has developed a list of risks and uncertainties and the recommended actions to mitigate these risks. These risk mitigation actions, plus other activities needed to implement the recommendation are included in Section 6. These, along with other programmatic and project risks, will be incorporated into the Phase 2 STP risk mitigation plan when the conceptual design effort is initiated. Section 6 includes recommended immediate actions, near term and intermediate term actions DOE should consider to move forward with the implementation of this recommendation.

The recommended Immediate Actions to be initiated by DOE-RL include:

- Schedule a series of Requirements Workshops with WIPP officials to identify, refine, and address outstanding issues with regard to the applicability and interpretation of requirements established in the RH-TRAMPAC and WAC for WIPP. Clarification of requirements is also needed to evaluate the potential for continued development of the Nitrate Chemical Inhibitor Process or direct drying and packaging of sludge as identified by the DSB. It is important that a common, agreed upon set of interpretations be established prior to finalizing the Functions and Requirements/FDC for the Phase 2 project.

- Conduct a formal siting study to determine the preferred location of the Phase 2 Treatment capability. Required seismic and structural evaluations should be identified, including needed updates to seismic source terms and soils data to meet current requirements and expectations. For existing facilities, the current conditions and seismic/safety qualifications should be reviewed, and potential updates, upgrades, and expansions due to increased sludge treatment source terms and proposed operations should be identified. Ongoing operational plans should be evaluated to identify any space and/or resource conflicts. Costs and schedules for upgrades and modifications should be developed and compared to costs and schedules for new construction alternatives.

- Develop and maintain a flexible conceptual design for space considerations in the functions and requirements to facilitate potential packaging of other site RH-TRU waste. As shown in Appendix M of Volume 2, the primary shared functions of these identified streams and the K-Basin sludge material is the need for a qualified, category 2 structure with a robust nuclear ventilation systems, and the immobilization, packaging, and assay of the product waste drums.

- Authorize uranium metal size reduction testing to establish that the previous simulant work is representative of the potential for size reduction. This work can be done in the near term and would serve to focus subsequent near term testing and technical development work.

- Develop a project lifecycle plan to support out-year budget planning, as well as the necessary change requests and other contract direction requirements for CHPRC. Once the necessary change requests and contract direction are approved, CHPRC will update the STP Project Execution Plan (or create a standalone PEP) to reflect the DOE-RL approved contract direction.

Contents

Appendices (located in Volume 2)

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Figures

Tables

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Terms

ALARA	As Low As Reasonably Achievable
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CD	Critical Decision
CHPRC	CH2M Hill Plateau Remediation Company
CMT	Concentration Mix Tank
DOE	Department of Energy
DOE-CBFO	Department of Energy – Carlsbad Field Office
DOE-RL	Department of Energy - Richland Operations Office
DSB	Decision Support Board
EC	Engineered Container
ECRTS	Engineered Container Retrieval and Transfer System
EPA	Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
ERP	External Review Panel
ETF	200 Area Effluent Treatment Facility
ETR	External Technical Review
FDC	Functional Design Criteria
FGE	^{239}Pu Fissile Gram Equivalents
FMEA	Failure Modes and Effects Analysis
FROP	Fenton's Reagent Oxidation Process
FY	Fiscal Year
GPM	Gallons per Minute
ICV™	In-Container Vitrification™
IVS	Induction-Heated In-Container Vitrification System
IWTS	Integrated Water Treatment System
KE	K East
KW	K West
KOP	Knock-Out Pots
LAW	Low-Activity Waste
LST	Lag Storage Tank
MAR	Material at Risk

MAU	Multi-Attribute Utility Analysis
mR	milirem (10^{-5} sievert)
MT	Milling Tank
NCIP	Nitrate Chemical Inhibitor Process
NLOP	K Basin North Loadout Pit
OMB	Office of Management and Budget
PCIP	Phosphate Ceramic Hydrogen Inhibitor Process
PCOP	Peroxide Carbonate Oxidation Process
PNNL	Pacific Northwest National Laboratory
PPE	Personnel Protective Equipment
RFI	Request for Technology Information
RH-TRAMPAC	Remote Handled Transuranic Waste Authorized Methods for Payload Control
RH-TRU	Remote Handled Transuranic
RRT	Receipt and Reaction Tank
SME	Subject Matter Expert
SNF	Spent Nuclear Fuel
SOW	Statement of Work
SRWOP	Size Reduction Water Oxidation Process
STP	Sludge Treatment Project
STSC	Sludge Transport and Storage Container
TEAA	Technology Evaluation and Alternatives Analysis
TME	Technical Maturity Evaluation
TOE	Total Operating Efficiency
TPA	Tri-Party Agreement
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TRL	Technical Readiness Level
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant
WWO	Warm Water Oxidation
µm	micrometer (10^{-6} meter)
® and ™	Registered trademarks in the United States and other countries. All logos and trademarks are the property of their respective trademark owners, and all rights are reserved.

1 Introduction

1.1 K Basin Background

The K West Basin, where sludge materials are stored, is one of the last facilities in the Columbia River corridor containing stored nuclear material. Once these sludge materials are removed, the remaining structures will be demolished and removed by the 100K Project. Completion of K Basins sludge material removal will enable demolition of the K West Basin, 100 K Area remediation, and, ultimately, conversion of the K West (KW) reactor to interim safe storage – the last of the eight reactors to be placed in interim safe storage.

Highly radioactive sludge (containing up to 120,000 curies of actinides and fission products) resulting from the storage of degraded Spent Nuclear Fuel (SNF) has been consolidated in Engineered Containers (ECs) located in the 105-K West Storage basin near the Columbia River. This K Basin sludge material resulted from extended storage of excess N-Reactor fuel in both the KE and KW Basins. A significant fraction of the N Reactor SNF degraded during the lengthy underwater storage period due to damage to the Zircaloy cladding sustained during reactor discharge and the subsequent corrosion of the metallic uranium, along with basin water chemistry issues in the KE Basin. The SNF corrosion products, together with other debris, accumulated in the K Basins over the years. That portion which passed through a screen with a 0.64 cm (0.25 inch) opening is collectively referred to as sludge [10]. Most of the sludge on the KE Basin floor and in its adjacent pits has been transferred to KW Basin and consolidated into large (~5 ft. x ~12 ft. x 13 ft. tall) ECs for underwater storage. Most of the sludge on the KW Basin floor and in its adjacent pits has also been consolidated into ECs for underwater storage on the floor of the KW Basin. A small amount of sludge remains on the floor of the KW Basin which will be disposed as part of the decontamination and decommissioning of the basin.

Spent fuel cleaning and packaging operations were conducted in the KW Basin. SNF canisters from KE Basin were transferred to KW for cleaning and repackaging. The Integrated Water Treatment System (IWTS) was installed in the KW Basin to maintain water clarity during the fuel cleaning operations. Much of the material smaller than 0.25 inch that had been in the KE and KW canisters was captured either in IWTS Knock-Out Pots (KOP)/Strainers (particles larger than 600 microns), or in settler tanks or on garnet filters (particles smaller than 600 microns). Sludge previously contained in the settler tanks has been transferred to EC-230 and will remain segregated from the other EC sludge. The EC and settler tank sludge inventory are to be disposed as remote-handled transuranic (RH-TRU) waste in the Waste Isolation Pilot Plant (WIPP) disposal facility. The KOP material is specifically excluded as a waste stream in this treatment process and has another route for its disposal and is outside the scope of this report.

1.2 Previous Alternatives Analyses

The US Department of Energy's (DOE's) efforts to identify and implement an effective treatment and packaging system for the K Basin sludge have a long and difficult history. A number of disposition approaches have been initiated, but were abandoned for a variety of technical and programmatic reasons. Some 39 different alternatives analyses of varying depth and rigor have been documented over the last 10-15 years. In 2007, DOE reset the Sludge Treatment Project (STP) back to "between Critical Decision (CD)-0 and CD-1" [20]. DOE also directed that an updated alternative analysis be conducted, including compliance with DOE Order 413.3 (now DOE Order 413.3b) and utilization of DOE Standard 1189 and the Technology Readiness Assessment (TRA) process defined in the DOE TRA guide (now DOE Guide 413.3-4). DOE's primary objective was to reduce the technical and programmatic risk of the STP by utilizing the formal project management tools that DOE has established to assure successful project delivery.

In January 2009, CH2M Hill Plateau Remediation Company (CHPRC) issued an alternatives analysis report for the removal and treatment of the sludge contained in the K West Basin ECs and settler tanks [1]. The report documented the screening of hundreds of technology and implementation options and documented the detailed evaluation of seven retrieval and treatment strategy options. A key finding of the report was that DOE's expressed objective to meet a 2015 date to remove all waste materials from the Columbia River corridor with a high certainty resulted in a recommendation to divide the mission into two phases. Phase 1 was defined as the efforts to retrieve, transfer and interim store the K Basin sludge material on the 200 Area Plateau. The report concluded that "Commitment to final treatment technology is not required until Phase 2; this allows adequate time to develop and establish robust treatment and immobilization technologies and resolve any outstanding disposal pathway issues."

1.3 Phase 1 and Phase 2 Project Scope

CHPRC is proceeding with a subproject to develop and demonstrate the retrieval process, install retrieval equipment in the KW Basin, and modify an existing annex to support loading of the sludge into Sludge Transport and Storage Containers (STSCs). The loaded STSCs will be shipped to the 200 Area plateau for interim storage in the T Plant Canyon facility. This subproject is defined as the Engineered Container Retrieval and Transfer System (ECRTS), and is also referred to as Phase 1 of the STP.

Phase 2 of the STP is defined as the treatment (stabilization) and packaging of the sludge such that it can be transported to and disposed at WIPP as RH-TRU waste [1]. Phase 2 is assumed to begin after the successful completion of Phase 1 sludge retrieval, transfer and placement in interim storage; commencing operations after an indefinite interim storage period. Phase 2 work performed to date is limited to development of a Phase 2 Technology Evaluation and Alternatives Analysis (TEAA), which is summarized in this report. The primary purpose of the TEAA is to recommend to DOE a technical approach for Phase 2 treatment and packaging that represents a high certainty of successful deployment and completion of the STP treatment and packaging mission. A Request for Technology Information (RFI) was issued in October 2009 to solicit candidate technologies for use in Phase 2. The RFI also include a preliminary definition of Phase 2 functions and requirements [4].

The *Preliminary STP Container and Settler Sludge Process System Description and Material Balance* (i.e. flowsheet) [2] defines the Phase 1 project flowsheet and estimated radionuclide and chemical compositions for the EC and settler tank sludge that will be loaded into the STSCs. The loaded STSCs represent both the product of the Phase 1 project and the starting material for the Phase 2 project. Flowsheet estimates for ^{239}Pu fissile gram equivalent (FGE) concentrations and volumes of primary sludge types to be packaged are found in Table 1-1. In addition to the sludges listed in Table 1-1, three STSCs are estimated to be filled with sludge and garnet filter media from the KW Basin IWTS and one STSC filled with material from the ECRTS subproject sand filter media. The STP Phase 1 baseline assumes a total of 30 STSCs will be used to package sludge, garnet and sand filter materials for interim storage at T Plant, which provides allowance for uncertainties relative to flowsheet estimated quantities.

Sludge compositions assumed for this Phase 2 TEAA can be found in Appendix J, along with other requirements, bases, and assumptions used for base case Phase 2 flowsheet analysis. Sludge characterization is continuing, and additional characterization data has become available since the start of the Phase 2 TEAA (see Appendix I). A sensitivity analysis that addresses this emerging data and refinement of the anticipated sludge stream properties can be found in Appendix I.

Table 1-1. Quantities and composition of K Basin sludge (circa 2009)

	KE Engineered Containers	KW Engineered Containers	Settler	Total
Total Volume of Sludge (m^3)	18.4	5.1	5.4	28.9
FGE (g/m^3) [sludge concentration]	702	1,560	7,340	-

1.4 Purpose of Report

The purpose of this STP Phase 2 TEAA report is to document the evaluation of technologies and processes for treating and packaging K Basin sludge and recommend further development of those that have a high certainty of successful deployment. Volume 1 of this report contains the results of the technology evaluation and includes the recommended technical approach. Volume 2 of the report includes a summary of the technical information that was developed during the evaluation process, which included a series of feasibility demonstration tests for most of the candidate technologies.

These tests were designed to provide clear proof-of-principle results to demonstrate the fundamental feasibility of the proposed approach. Technology approaches which could not demonstrate the fundamental feasibility at the bench top scale were eliminated from further consideration. Based on the results of the technical evaluation and alternatives analysis, CHPRC developed the recommended strategy for a treatment technology approach which could be developed and deployed to meet the mission requirements with the necessary investment in development, design, construction, and operations.

2 Technology Alternatives Analysis Process

The primary purpose of the TEAA evaluation is to recommend to DOE a technical approach for Phase 2 treatment and packaging that represents a high certainty of successful deployment and completion of the STP treatment and packaging mission. This Phase 2 TEAA is a structured technology evaluation that began in October 2009. The evaluation process included initial identification of candidate technologies through a formal solicitation process, evaluation and selection of the most promising candidates for further testing and evaluation, testing and other data gathering for the selected candidates, and formal evaluation of the assembled information leading to a path forward recommendation. This is considered a pre-conceptual alternatives analysis that will provide input to a formal conceptual design and technology demonstration activity. Further activities will be required to bring the most promising candidate (or candidates) to a sufficient state of maturity so that a conceptual design of the process can be completed and a project baseline established.

An RFI was issued in October 2009 to solicit candidate technologies for evaluation [4]. The RFI specified that the sludge would be hydraulically removed from the STSCs and transferred to the treatment facility. As a result of this transfer process, it is assumed that the slurry would be diluted to 5% by volume solids and delivered for treatment and packaging at 70 gallons per minute (GPM) through a 1-1/2" diameter hose. The proposed treatment process is required to remove the excess water, treat the sludge to eliminate or reduce hydrogen gas production to acceptable levels, and eliminate free liquids in order to be in compliance with the requirements of the Remote Handled Transuranic Waste Authorized Methods for Payload Control (RH-TRAMPAC) [7] and the WIPP waste acceptance criteria (WAC) [8]. The treated sludge would then be packaged for transportation to WIPP for disposal as RH-TRU. It is anticipated that lag storage on the Central Plateau will be required before shipment to WIPP is completed, since the rate of packaging is likely to exceed WIPP's ability to transport the certified packages to the repository in any given timeframe.

Details of the fundamental assumptions provided to the potential vendors and used in the evaluation process are discussed in Appendix J and summarized below in Section 2.3.1.

2.1 Decision Plan

The Phase 2 TEAA Decision Plan [3] describes the process by which the various alternative technologies would be identified and evaluated in the selection of the recommended technical approach (or approaches). To successfully perform this alternatives analysis, the following major actions were included in the process:

- Define the decision strategy.
- Document the information required to support the decision process.
- Identify the decision maker and other responsible parties supporting the decision process.
- Define the decision criteria to be used for each stage of the selection process.
- Describe information that will be used to reach the decision.
- Define when information will be available to the decision maker.

The Decision Plan anticipated a sequential down-select from many proposals to a handful to be tested, and one or two options to be evaluated for potential implementation. However, evaluation of the initial RFI response and initial test results showed there were more viable alternatives than expected. In addition, several of the alternatives had no prior testing or engineering evaluation work for the K Basin sludge application. This resulted in a wider feasibility testing phase than originally contemplated in the Decision Plan and a larger number (6) of alternatives being carried forward into the formal evaluation.

This adjustment was necessary to assure that the recommended approach was the result of evaluation of a range of potential approaches, rather than limited to those which had previously been tested with K Basin simulants. A schematic of the decision process is given in Figure 2-1.

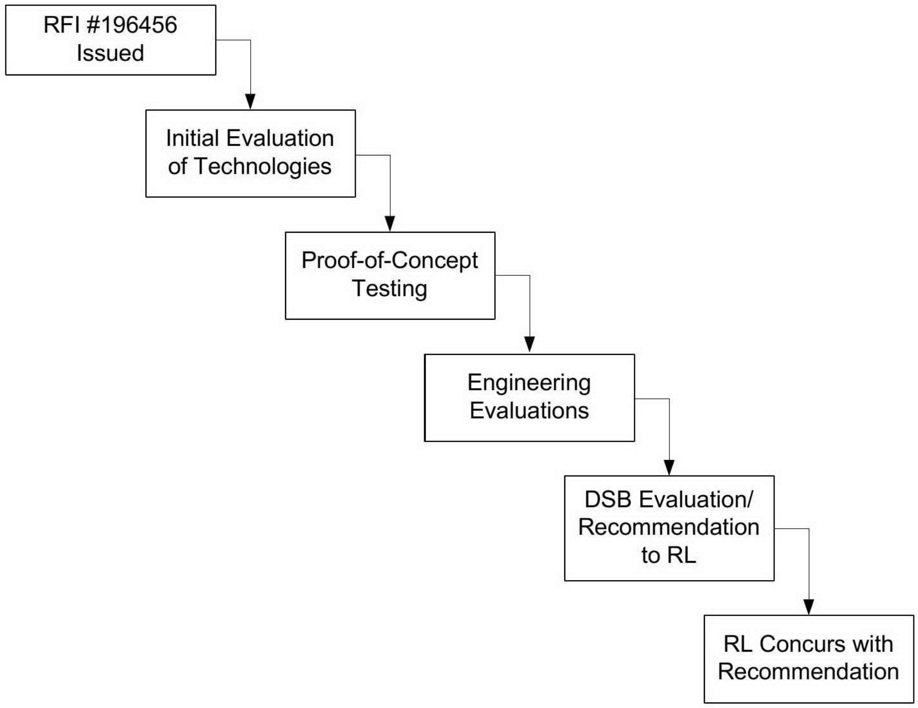

Figure 2-1. Evaluation and Alternatives Analysis Logic for Down-Selection of K Basin Sludge Treatment and Packaging Technologies

The decision criteria, goals, and measures were retained from the Decision Plan and are shown in Table 2-1.

Table 2-1. STP - Phase 2 Decision Criteria, Goals, and Measures [3]

Criterion	Goals	Measure
Safety	• Ensure worker safety • Ensure protection of the general public	• Relative ease/difficulty in implementing adequate safety features as measured by the number of passive (inherently safe) vs. active engineered safety features
Regulatory/stakeholder acceptance	• Ensure compliance with environmental laws and regulations and DOE orders. • Address sludge management concerns in *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* record of decision.	• Achieve acceptance of regulators and other stakeholders

Criterion	Goals	Measure
Technical maturity	• Maximize confidence in process implementation	• Technical Readiness Level (TRL) of the proposed technology (exclusive of project considerations) • Estimated volume of waste going to WIPP
Operability and Maintainability	• Maximize operability • Maximize maintainability	• Ability for process to be remotized • Ability for process to treat and/or package K Basin sludge inventory in 5 – 7 years • Acceptability of secondary waste streams for disposal at ERDF (solids) and ETF (liquids)
Life-cycle Cost and Schedule	• Optimize life-cycle costs for sludge treatment and packaging facility • Provide acceptable schedule to stakeholders	**Cost** • Cost of maturing technology to TRL-6 • Capital cost • Operating and maintenance cost • Deactivation and decommissioning cost **Schedule** • Facility startup • Complete treatment and packaging
Potential for beneficial integration with ongoing STP – Phase 1 activities	• Optimize cost or schedule for STP – Phase 2 • Consider co-location of needed facilities provided by STP – Phase 1	• Potential for integration of treatment and/or packaging with interim storage in T Plant • Potential for shared functions with those being provided by STP Phase 1 • Optimization of location to reduce/eliminate intermediate shipping or repackaging of the sludge material
Integration with Site-wide RH-TRU processing/packaging planning, schedule, and approach	• Optimize processes, equipment, and facilities for K Basin sludge treatment and packaging with other Hanford Site RH-TRU waste streams	• Number of other Hanford Site RH-TRU waste streams that can be treated with candidate process • Number of other Hanford site RH-TRU waste streams that can be packaged with candidate packaging process

2.2 Selection of Alternatives and Initial Evaluation

CHPRC reviewed vendor responses to the RFI, the results of previous alternatives analyses, and information on additional technology options identified by the project; and conducted a technical workshop with knowledgeable staff from the project and PNNL. On the basis of this review CHPRC selected 8 candidate treatment processes for feasibility evaluation:

- Warm Water Oxidation (WWO)
- Fenton's Reagent Oxidation Process (FROP)
- Size Reduction Water Oxidation Process (SRWOP)

- Phosphate Ceramic Hydrogen Inhibitor Process (PCIP) using Borobond™[1]
- Peroxide Carbonate Oxidation Process (PCOP)
- In-Container Vitrification (ICV™)[2]
- Inductively Heated In-Container Vitrification System (IVS)
- Nitrate Chemical Inhibitor Process (NCIP)

Proof-of-concept testing was completed for key elements of all candidate technology approaches except IVS. IVS was at an early stage of development and was not advanced sufficiently to complete a feasibility demonstration in the time frame of this study, so an engineering report was prepared to provide additional descriptive information for the evaluation process. Testing was carried out by five vendors and PNNL.

The purpose of the testing was to clearly demonstrate whether a specific technology approach was feasible at a bench scale for the process steps not previously demonstrated at a bench scale. Testing data was supplemented with pre-conceptual engineering studies to allow the comparison of the technology approaches on a sufficiently even basis. This basis allowed for the selection of the most suitable technologies for further development consideration.

CHPRC assigned a technology advocate for each of the selected technologies. The technology advocates served as the liaison or interface between the vendor participants and CHPRC. The technology advocates continued to work with their respective participants throughout the performance of respondents' activities. The technology advocates provided support to the decision-making process. The advocates served as Subject Matter Experts (SMEs) for each technical approach and provided information and support to the Decision Support Board (DSB), as well as supported development of the CHPRC recommendations.

2.3 Engineering Information to Support Alternatives Analysis

The evaluation activities were based on the testing and engineering study results. Using Warm Water Oxidation (WWO) as a reference baseline, detailed technology maturity evaluations and facility deployment concepts were developed. For the other technologies, material balances and process equipment sizing were developed and compared to the more detailed information developed to support definition of the WWO process. It was concluded that all the technologies except the vitrification technologies were sufficiently similar to the WWO process (the base case) that WWO could be used as a basis for an integrated flowsheet that contained most of the required elements of the other technologies. Summaries of testing and engineering studies are provided in Appendices A-H, which are the primary inputs to the CHPRC recommendations.

2.3.1 Development of Standardized Flowsheets

To provide a uniform basis for evaluation of technologies, a process basis document was prepared to summarize key process functions, requirements, and enabling assumptions to be used as the basis for the engineering evaluation phase of the STP Phase 2 TEAA (see Appendix J). The process basis document was provided to each testing contractor as an attachment to their Statement of Work (SOW). With the exception of NCIP, the contractors developed summary process descriptions and preliminary sizing and

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[1] Borobond is the registered trademark of Ceradyne, Inc., Boron Products LLC, 3250 South 614 Road, Quapaw, OK 74363; all rights reserved.

[2] In Container Vitrification and ICV are registered trademarks of the Geosafe Corporation, a wholly-owned subsidiary of Battelle Memorial Institute of Columbus, Ohio, whose ICV technology is exclusively licensed to Impact Services, Inc., 103 Palladium Way, Oak Ridge, TN 37830; all rights reserved.

processing rate estimates for the technology alternatives based the process basis document. The CHPRC technical team laid out similar information for the NCIP.

The contractor reports showed some variation in approach and level of detail. To get to an "apples to apples" comparison, it was necessary for the CHPRC technical team to develop a set of standardized flowsheets. These flowsheets were developed by starting with the contractor input and making adjustments to allow comparison of the alternative flowsheets on a reasonably consistent basis.

The TEAA base case standardized flowsheet analysis for each process was developed using bases and assumptions defined in Appendix J. The following list summarizes key bases and assumptions from Appendix J:

- The process capacity must provide for complete processing of the sludge into WIPP compliant drums within 5 years or less based on an assumed 70 % total operating efficiency (TOE).
- The calculations assume receipt of up to 13.2 m^3 (3,500 gallons) of dilute sludge and flush water per STSC. The treatment system must be designed to accept the entire batch in one transfer at up to 70 gallons per minute (265 liters per minute). For the TEAA, utilization of the STSCs as part of slurry receipt and treatment system is not allowed (may be considered in later project optimization work).
- A total of 24 STSCs containing K-Basin Sludge material are to be processed (current estimate is 30 STSC's; see Section 1.3)
- The assumed sludge volume breakdown is 18.4, 5.1, and 5.4 m^3 of as-settled sludge (SS) volume each for KE EC, KW EC, and settler sludge. These values agree with the Phase 1 baseline at the time the TEAA was initiated in October, 2009.
- For the base case calculation of the number of product drums required, an average loading of 40 ^{239}Pu FGE per drum is assumed unless waste loading is limited by physical volume of the sludge.
- The maximum size of uranium (U) metal particles in the KE and KW sludge is 6,350 μm (0.25 inch). Maximum size of U metal particles in the settler sludge is 600 μm.
- Water oxidation calculations assume uranium particles are oxidized to extinction using water at temperatures near the boiling point. Reaction time is calculated per the equation provided in the Sludge Project Technical Databook [10] assuming anoxic water. The base case assumes an oxidation rate "enhancement factor" of 1.0. Sensitivity cases may consider oxidation rate enhancement factors between 3.0 and 1/3 per Sludge Project Technical Databook requirements.
- Sludge processing time cycle analyses do not consider ramp up at the start of hot operations or clean out after sludge processing is completed.

See Appendix J for additional information on base case requirements, bases, and assumptions. Note that available data has continued to evolve since the TEAA was initiated, and in some cases base case assumptions used for the TEAA normalized flowsheets differ from current STP Phase 1 project baseline values due to evolution of the Phase 1 project technical basis. Appendix I provides a discussion of emerging data and sensitivity case evaluations wherein selected bases and assumptions are varied.

2.3.2 Simulants Used for Testing

For the STP Phase 2 TEAA, testing using actual K Basin sludge was not practical since limited amounts of K Basin sludge is available and most of the vendors and their supporting laboratories could not process radioactive materials. Therefore, simulants were required. The STP has established a formal definition of simulants to be used for various aspects of K Basin sludge testing [18]. A KW Origin Container Sludge simulant recipe was selected as the primary basis for the Phase 2 proof-of-concept testing. There are two versions of the base recipe:

- Physical Simulant. The simulant referred to as "physical simulant" contains no uranium. Cerium oxide and steel grit are substituted for uranium oxides. The physical simulant components are given in Appendix J. In addition to the "base simulant" as defined in the STP Sludge Simulant Strategy and Design Basis [18], supplemental components that were identified as important were added to the base simulant for certain tests (e.g. graphoil, organic ion exchange resin, zeolite/mordenite, and flocculent). In some cases the base recipe was modified on a case by case basis to meet needs of specific tests.
- Uranium Containing KW Container Simulant. The Uranium Containing KW Container Simulant was prepared by PNNL per reference [11] and supplied as needed for all tests that utilized uranium containing simulant. The simulant components are given in Appendix J.

The simulants used for testing of the various technical approaches are summarized in Table 2-2.

Table 2-2. Simulants Used for Specific Tests for the Current Technology Evaluation Activity

Technology and Scope	Simulant Used
Joule Heated In-Container Vitrification (ICV™) Process (Dryer tests only)	Used physical simulant; base simulant plus all supplemental components.
Peroxide Carbonate Oxidation Process (PCOP) Laboratory Testing	Tests used Uranium Containing KW Container Simulant plus ¼ inch U metal coupons
Fenton's Reagent Oxidation Process (FROP) Testing	Two tests used the Uranium Containing KW Container Simulant plus ¼ inch U metal coupons, balance of the tests used only the FeO(OH) and $Al(OH)_3$ simulant components plus U metal coupons.
Borobond™ Hydrogen Inhibition Tests	Some tests used 1.85 mm x 1.94 mm cylindrical U metal pellets either alone or with the FeO(OH) and $Al(OH)_3$ components of the physical simulant.
Borobond™ Waste Loading Tests	Tests used physical simulant with all supplemental components except flocculent and tungsten alloy
Size Reduction Water Oxidation Process (SRWOP) Immersion Mill Size Reduction Tests	Test 1 used only the <100 µm components of the physical simulant, plus a tungsten alloy as a stand in for U metal. Test 2 used the physical simulant; including all base and supplemental simulant components with the exception of flocculent. The tungsten alloy was used also in Test 2 as a stand in for U metal.
Warm Water Oxidation (WWO) Tests	Testing under the current effort used the Uranium Containing KW Container Simulant with U metal beads. In addition, parallel testing was conducted with a 50/50 U(IV)/U(VI) oxide mixture with U metal beads to represent KW Settler sludge. Earlier testing used a variety of simulants, actual K Basins sludge, and irradiated metallic uranium fuel.
Nitrate Chemical Inhibitor Process (NCIP) Tests	Testing under the current effort used the Uranium Containing KW Container Simulant with U metal beads and the KW Simulant with U metal beads in immobilization media (clays). Prior tests used water, simulant sludge components, KW simulant, and actual sludge, all with U metal beads.

2.4 Evaluation of Alternatives by Decision Support Board

To provide an independent evaluation of the alternative technology approaches, CHPRC commissioned a Decision Support Board (DSB) to review the technical alternative data and provide recommendations to CHPRC. The DSB was empanelled from onsite and offsite experts in areas of importance to the evaluation of these technologies. The multidisciplinary DSB members included representatives from STP operations, engineering, regulatory, nuclear safety, and radiological protection, and technical SMEs. The organizations they were drawn from included CHPRC, WIPP, and the STP External Review Panel (ERP). A facilitated STP Phase 2 DSB alternatives workshop was conducted May 9-12, 2011.

Since there were several criteria required for a given process to be deemed successful, a structured approach was taken for the analysis and evaluation. The structure was derived by processes commonly used in multi-attribute utility (MAU) analysis, which has been used by DOE in various decisions regarding disposal of nuclear waste [13]. Technology evaluations based on MAU analysis provide a sound foundation for measuring the value of proposed processes, making comparisons, and aiding in the final selection of how to proceed with the development of the appropriate technology. The multi-attributes, for example, are given in the Decision Plan (see Section 2.1 above) as the criteria that must be met for success. Analyses were conducted to evaluate performance of each technology with respect to these criteria. The DSB used a weighting system in comparing the various technologies against these attributes. A sensitivity analysis was conducted for the weighting system to evaluate the sensitivity of the process to the assigned weights. The DSB final report has been issued as PRC-STP-00460 [16] and is found in Volume 2, Appendix P.

3 Discussion of Processes Evaluated

In Phase 1 of the STP, sludge will be removed from the 105 KW Basin, placed in STSCs, and transported to T Plant for interim storage. The Phase 2 process starts with a sludge batch in an STSC in storage at T Plant and proceeds through the following overall process sequence:

- Retrieval. This first step includes removal of an STSC from storage in T Plant, transport of the STSC to the treatment facility, retrieval of the sludge from the STSC, and transfer to the Treatment System. The current assumption is that some type of hydraulic approach (e.g. sluicing) will be used for sludge retrieval, resulting in a diluted sludge slurry delivered as a relatively large batch (up to 13.2 m^3 or 3,500 gallons including assumed line flush water) to Treatment. The retrieval process is being developed and demonstrated as part of the Phase 1 system design and is outside the scope of the current sludge treatment technology evaluation. For purposes of the TEAA, CHPRC did not consider utilization of the STSCs themselves as part of slurry receipt and treatment system (this may be considered as a potential optimization alternative in future design phases)

- Receipt, Treatment, and Preparation for Immobilization. These systems act as a buffer to prepare each batch for transfer to the immobilization system. Process details vary depending on the specific alternative. However, all systems receive and interim store the STSC batch, concentrate the dilute sludge slurry by removing water, treat the sludge in some way, and deliver smaller batches of concentrated and treated sludge to the Immobilization and Packaging System.

- Immobilization and Packaging. The immobilization and packaging system accepts batches of concentrated sludge and packages it in drums that are sealed, decontaminated if needed, assayed to determine content of WIPP reportable isotopes, and transferred to on-site storage or shipping facilities. Details of the immobilization process vary by alternative. Key functions are to eliminate any free liquids, reduce hydrogen generation to acceptable rates, and determine content of WIPP reportable isotopes in each drum.

- Storage and Shipping. Finished drums will be stored on-site and eventually shipped to WIPP for disposal. The storage and shipping functions are outside the scope of the STP Phase 2 – TEAA.

The retrieval, receipt, and storage functions are common to all the technology options. While not expressly discussed in the technology evaluation, cost allowances for retrieval are included in the cost estimates.

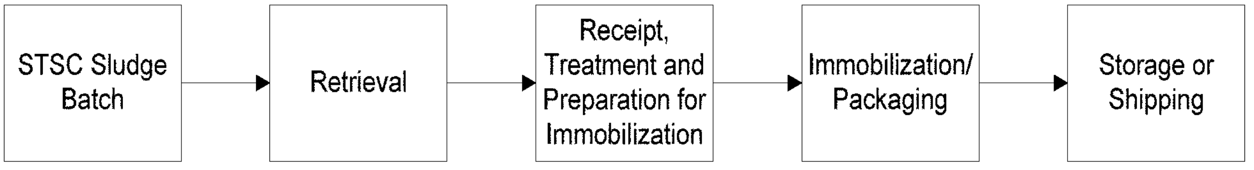

Figure 3-1. STP Phase 2 Overall Process Steps

All of the water-based processes (Warm Water Oxidation, Fenton's Reagent Oxidation Process, Peroxide Carbonate Oxidation Process, Phosphate Ceramic Hydrogen Inhibitor Process, and Nitrate Chemical Inhibitor Process) follow the same general process flow diagram with minor differences. Figure 3-2 illustrates the general process for these technologies.

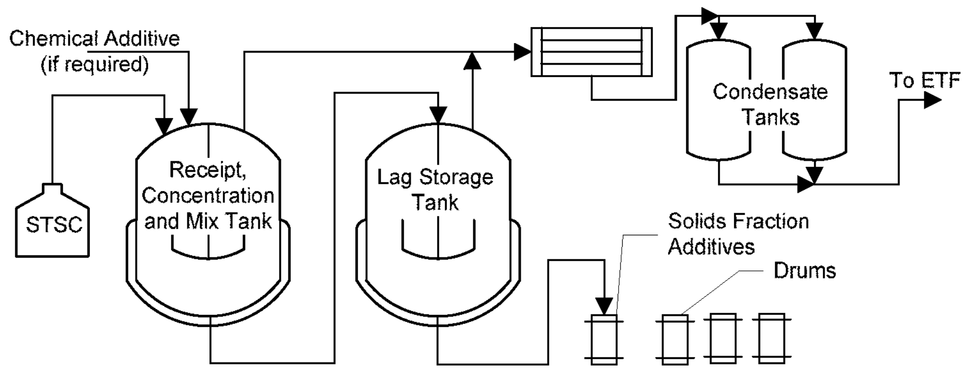

Figure 3-2. Simplified Flow Diagram for Water-Based Processes

The process flow diagrams for the other technologies are given in the following sections. Further details for all technologies can be found in Appendices A through H.

3.1 Warm Water Oxidation

3.1.1 Process Descriptions and Flowsheets

The Warm Water Oxidation (WWO) process is summarized in the general process flow diagram given above (Figure 3-2), noting that it does not require chemical additives. This flow diagram outlines the pathway of the K Basin sludge and condensate through the system. Sludge from an STSC is delivered directly to the Receipt and Reaction Tank (RRT). In the RRT, the sludge is agitated and heated to boiling (95° C to 98° C) at slightly below atmospheric pressure to remove dissolved oxygen, reduce the water content, and oxidize the uranium metal to uranium oxide. The uranium metal particles are oxidized to extinction to sufficiently reduce hydrogen generation so that the sludge will be safe during transportation and interim storage. The oxidized sludge is then concentrated by evaporation of water to meet the requirements of the downstream drumming process, and is transferred to a Lag Storage Tank (LST). From the LST, the sludge is transferred to the drumming portion of the process, where it is mixed with a cement-mix or other absorbent for immobilization and then packaged in drums for final disposal.

The major process equipment for the WWO are the RRT, LST, the off-gas treatment system, and the assay and drumming equipment. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be placed within a 50 foot by 60 foot building footprint. Supporting processes such as nitrogen purge air, vent gas treatment, cooling water, and process stream supply are also included in the WWO process. A more detailed flowsheet and process description can be found in Appendix A.

3.1.2 Test Results and Uncertainties

The proposed Warm Water Oxidation process appears to be an attractive option for sludge treatment based on the preliminary tests completed as part of the TEAA. These proof-of-concept tests were completed to validate basic functionality of the process chemistry and obtain preliminary information on process rates and reagent requirements needed to develop a preliminary flowsheet. The results showed slightly higher reaction rates (average of approximately 1.5 μm/hr) than the central value of the range of reaction rates predicted in the Technical Databook (1.05 μm/hr) [10] for the test conditions. The testing done on simulated sludges has produced mixed results relative to the issue of agglomeration. Earlier testing performed prior to this TEAA (see References 22 and 23 of Appendix A) had indicated that smaller particles could agglomerate to larger particles at these temperatures for some specific sludge samples. All small-scale tests performed for the TEAA indicated that there would be minimal concern about agglomeration of the sludge under normal operating conditions as long as the sludge was maintained in a wet condition. The last stirred test performed for the TEAA was at a larger scale and used uranium beads in a simulated sludge slurry. That test showed that using KW simulant, in regions of poor agitation, under relatively large temperature gradient, there was the possibility of the slurry to form a cohesive mass that was difficult to dislodge and re-combine with the rest of the slurry. The degree of agitation required to prevent that agglomeration has yet to be determined, which means that there is currently insufficient information on which to base a full scale agitation system design.

Overall the small scale and larger scale tests demonstrated the fundamental feasibility of the WWO process with oxidation rates that are consistent with the proposed process flowsheets.

Based on the success of the proof-of-concept tests and the use of commercially proven equipment, the primary WWO process steps are judged to be approximately TRL-3 as defined in DOE G 413.3-4 [6]. There are technical risks associated with the process facility and equipment. In particular, the drumming system and the assay system used to determine isotope concentrations in the drummed waste are not currently well-defined and require additional work. More details on the WWO technology development and readiness can be found in Appendix A.

If this technology is selected for implementation, additional testing needs to be completed to cover the complete range of feeds required, broadened range of reaction temperatures, and testing with actual sludge samples for the full length of time anticipated per sludge batch. Testing would also include more complete material balances, including off-gas generation and identification of the chemical species formed during the reaction, evaluation of the possible role of ferrihydrite and actual sludge matrices on uranium oxidation, and investigation of the conditions associated with potential agglomerate formation. A specific immobilization agent must be selected and demonstrated. It is expected that needed information on process chemistry and physical properties could be obtained with a modest amount of additional laboratory testing.

Principal engineering development activities center around agitation of the RRT and LST, instrumentation and monitoring of the extent of reaction, slurry transfer, control of the reacted sludge charged to the disposal drum, and the remote packaging and assay systems which are common to all aqueous treatment options.

3.2 Fenton's Reagent Oxidation Process

3.2.1 Process Descriptions and Flowsheets

The proposed Fenton's Reagent Oxidation Process (FROP) is summarized in Figure 3-2 above (Section 3.0), which outlines the pathway of the K Basin sludge and condensate through the system. Settled sludge from an STSC is delivered directly to the RRT. The sludge slurry is then concentrated by evaporation at low or near boil (90 ºC to 95 ºC) at slightly below atmospheric pressure to the desired concentration. The slurry is then cooled to 35 ºC before adding reagents.

Fenton's reagent, comprised of hydrogen peroxide and $Fe^{II/III}$ catalyst, is used to oxidize uranium metal without generation of hydrogen gas. A small amount of chloride, and ferrous iron if needed, are added to the RRT, and the pH is adjusted to between 1 and 4 using HCl or H_2SO_4. Hydrogen peroxide solution (30%) is then continuously added at a controlled rate throughout the oxidation time. When the uranium metal oxidation reaction is complete (or nearly complete), peroxide addition is stopped. The batch is then heated to near the boiling point and is concentrated to the desired solids concentration by evaporation. The post-reaction evaporation step also destroys any residual peroxide. The oxidized and concentrated sludge batch is then transferred to the LST. From the LST, the sludge is transferred to the drumming portion of the process where it is mixed with a cement-mix or other absorbent for immobilization and then packaged in drums for final disposal.

Supporting processes such as sweep air, vent gas treatment, cooling water, and process stream supply are also included in the FROP process. A more detailed flowsheet and process description can be found in Appendix B.

3.2.2 Test Results and Uncertainties

As a part of the current TEAA, proof-of-concept tests were completed to validate basic functionality of the process chemistry and obtain preliminary information on process rates and reagent requirements needed to develop a preliminary flowsheet. The results showed a U metal oxidation rate of approximately 40 µm/hr compared to the nominal 1.5 µm/hr for WWO. These results suggest a much shorter oxidation cycle as compared to WWO, with treatment times measured in days rather than months.

The aspects of FROP that were found to be less mature were related to the knowledge of chemical and physical behavior of the actual sludge in the treatment process. The remote process equipment for the FROP is expected to be nearly identical to that for WWO, with possible materials of construction upgrades due to the chemical additives. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO. The technology readiness of these items is discussed in the WWO context in Appendix A.

Based on the success of the proof-of-concept tests and use of commercially proven equipment the primary FROP process steps are judged to be approximately TRL-3 as defined in DOE G 413.3-4 [6]. More details on the FROP technology development and readiness can be found in Appendix B.

If this technology is selected for implementation, additional testing needs to be completed to cover the complete range of feeds required, broadened range of reaction temperatures, testing with actual sludge samples, more complete material balances including off-gas generation and identification of the chemical species formed during the reaction. Physical property testing of the slurry during reaction and chemical treatment steps has not been addressed at this point. It is expected that needed information on process chemistry and physical properties could be obtained with a modest amount of additional laboratory testing.

Principal engineering development activities center around agitation of the RRT and LST, instrumentation and monitoring of the extent of reaction, slurry transfer, control of the reacted sludge charged to the disposal drum, and the selection of a specific immobilization agent and the remote packaging and assay systems which are common to all aqueous treatment options.

An additional concern related to the FROP is the industrial safety risk of handling concentrated (30%) hydrogen peroxide used in the process. Because it is a relatively common industrial chemical, safe handling practices are well known it is expected that this will not present a major safety concern, but will add requirements for additional training and PPE for personnel protection during chemical handling and maintenance activities.

3.3 Peroxide and Carbonate Oxidation Process

3.3.1 Process Descriptions and Flowsheets

The proposed Peroxide and Carbonate Oxidation Process (PCOP) is summarized in Figure 3-2 above (Section 3.0), which outlines the pathways of the K Basin sludge and condensate through the system. Dilute sludge slurry from an STSC is delivered directly to the RRT. The sludge slurry is then concentrated by evaporation at low or near boil (90º C to 95º C) at slightly below atmospheric pressure to the desired concentration. The concentrated slurry is then cooled to near ambient temperature.

An ammonium bicarbonate solution is added to the concentrated slurry until a 1M carbonate/ bicarbonate concentration has been achieved in the RRT, and concentrated (50%) hydrogen peroxide solution is added until a 2M concentration is reached. Following the initial additions, 50% hydrogen peroxide and ammonium bicarbonate are then continuously fed into the RRT throughout the uranium metal oxidation process to maintain a 1M total concentration of carbonate/ bicarbonate. Oxidation of uranium metal using the PCOP does not generate hydrogen gas.

Depending on the volumes of peroxide and ammonium carbonate solutions added, intermediate evaporation steps may also be needed due to tank space constraints. Once uranium oxidation is complete, the sludge is concentrated by evaporation to the final concentration required by the drumming process. The oxidized and concentrated sludge batch is then transferred to the LST. From the LST, the sludge is transferred to the drumming portion of the process where it is mixed with a cement-mix or other absorbent for immobilization and then packaged in drums for final disposal.

Supporting processes such as sweep air, vent gas treatment, cooling water, and process stream supply are also included in the PCOP process. A more detailed flowsheet and process description can be found in Appendix C.

3.3.2 Test Results and Uncertainties

The aspects of PCOP that were found to be less mature were related to the knowledge of chemical and physical behavior of the actual sludge in the treatment process. As a part of the current TEAA, proof-of-concept tests were completed to validate basic functionality of the process chemistry and obtain preliminary information on process rates and reagent requirements needed to develop a preliminary flowsheet.

The results showed a U metal oxidation rate of 5.2 μm/hr compared to the 1.5 μm/hr for WWO. While these tests provided preliminary data, there are remaining uncertainties in the overall understanding of the process chemistry. There has been no testing with actual K Basin sludge and no testing regarding the effect of the process on physical properties (slurry rheology, yield strength, shear strength) of the treated sludge.

The process equipment for the PCOP is expected to be similar to that for WWO, but with slightly smaller RRT and LST. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO. The technology readiness of these items is discussed in the WWO context in Appendix A.

Based on the success of the proof-of-concept tests and use of commercially proven equipment the primary PCOP process steps are judged to be approximately TRL-3 as defined in DOE G 413.3-4 [6]. More details on the PCOP technology development and readiness can be found in Appendix C.

If this technology is selected for implementation, additional testing needs to be completed to cover the complete range of feeds required, broadened range of reaction temperatures, testing with actual sludge samples, more complete material balances including off-gas generation and identification of the chemical species formed during the reaction. Physical property testing of the slurry during reaction and chemical treatment steps have not been addressed at this point. It is expected that needed information on process chemistry and physical properties could be obtained with a modest amount of additional laboratory testing.

Principal engineering development activities center around agitation of the RRT and LST, instrumentation and monitoring of the extent of reaction, slurry transfer, control of the reacted sludge charged to the disposal drum, and the selection of a specific immobilization agent and the remote packaging and assay systems which are common to all aqueous treatment options.

An additional concern related to the PCOP is the industrial safety risk of handling concentrated (50%) hydrogen peroxide used in the process and treatment of ammonia in the process offgas. These are relatively common industrial issues. Safe handling practices are well known for concentrated hydrogen peroxide and it is expected that this will not present a major safety concern, but will add requirements for additional training and PPE for personnel protection during chemical handling and maintenance activities.

3.4 Size Reduction and Water Oxidation

3.4.1 Process Descriptions and Flowsheets

The proposed Size Reduction and Water Oxidation Process (SRWOP) is summarized in Figures 3-3 and 3-4, which outlines the pathways of the K Basin sludge and condensate through the system. Dilute sludge slurry from an STSC is transferred to a Milling Tank (MT) contained within the top of the RRT. The sludge is fed directly to a modified hydrocyclone separator within the MT. The hydrocyclone directs particles with slow settling rates, including the uranium metal particles less than 100 μm in diameter, into the RRT. Most of the remaining sludge slurry is directed into the grinding chamber of an immersion mill, where uranium metal particles are reduced to less than 100 μm in diameter. The MT is designed to allow slow settling particles to be carried upward and overflow into the RRT while recirculating larger uranium and other sludge particles (>100 μm) through the grinder until they have been reduced to the required size. A portion of the larger or fast settling particles are expected to settle to the bottom of the MT. An eductor is used to pick up settled material and direct it to the top inlet of the mill. Pressurized water is used to provide the motive power for the eductor.

In the RRT, the sludge is agitated and heated to the boiling point (95° C to 98° C) at slightly below atmospheric pressure. Uranium metal is oxidized to uranium oxide by reaction with water generating hydrogen gas, and the sludge is concentrated by evaporation to the final concentration required by the drumming process. The oxidized and concentrated sludge batch is then transferred to the LST. From the LST, the sludge is transferred to the drumming portion of the process where it is mixed with a cement-mix or other absorbent for immobilization and then packaged in drums for final disposal.

Supporting processes such as sweep nitrogen, vent gas treatment, cooling water, and process stream supply are also included in the SRWOP process. A more detailed flowsheet and process description can be found in Appendix D.

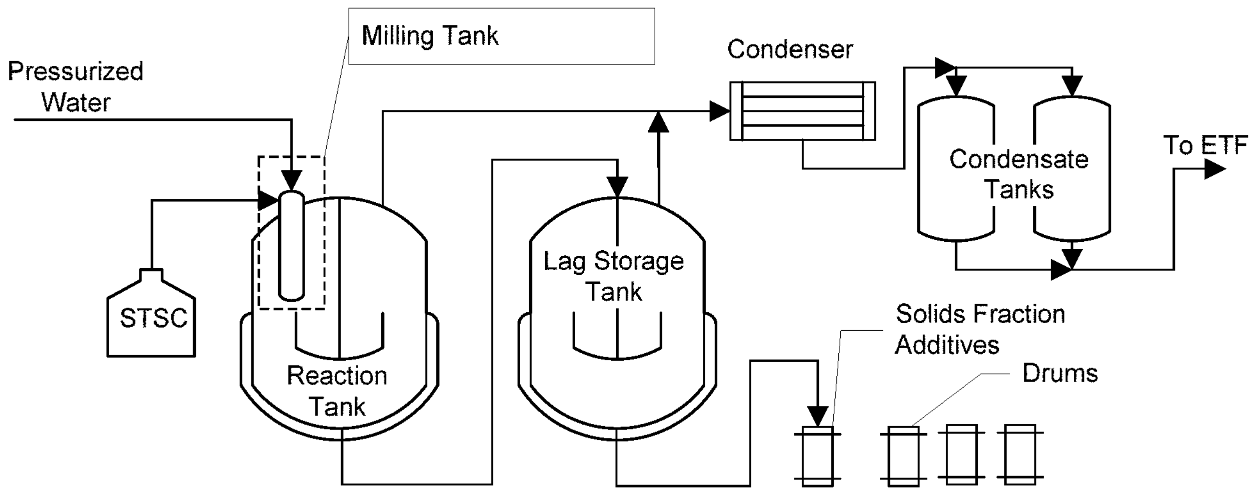

Figure 3-3. Simplified Process Flow Diagram for the SRWOP

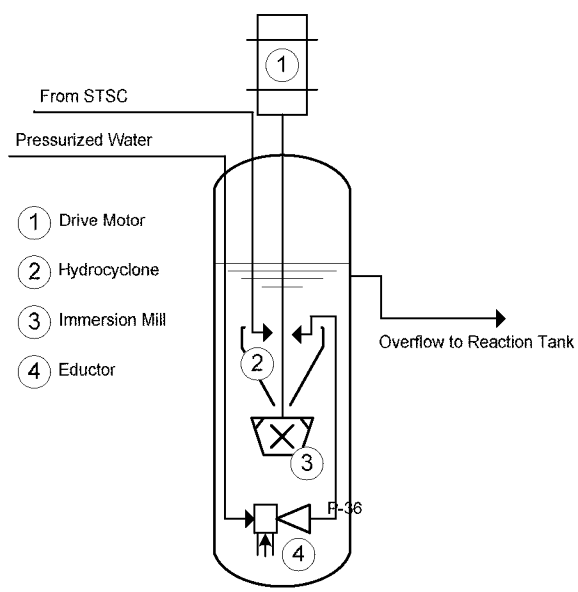

Figure 3-4. Expanded View of Milling Tank

3.4.2 Test Results and Uncertainties

The aspects of SRWOP that were found to be less mature were related to the knowledge of the physical behavior of the actual sludge in the treatment process and how the mill would wear. As a part of the TEAA, proof-of-concept tests were completed to validate basic functionality of the mill's capacity for grinding a uranium metal surrogate and obtain information on processing capabilities needed to develop a preliminary flowsheet. While these tests provided preliminary data, uncertainties remain in the overall understanding of the process design basis.

Densalloy™[3] SD170 was used in testing as a surrogate in place of irradiated uranium metal. Densalloy™ SD170 was identified by PNNL as having similar hardness and mechanical properties as irradiated uranium [19]. Additionally, no subsequent uranium metal reaction tests on size reduced sludge simulants were conducted other than those done for the reference WWO process, and there is insufficient data to perform a complete overall material balance and finalize the overall process design. No testing has been performed regarding the effect of the process on physical properties (slurry rheology, yield strength, shear strength) of the sludge.

A more complete definition of the MT system concept is needed, including both the internal configuration and the remote operating and maintenance features. The MT system requires further engineering evaluation and testing to better understand process performance and wear rate/life expectancy of the mill and other MT components.

The process equipment for the SRWOP is expected to be nearly identical to that for WWO, with the addition of the MT to the RRT. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO. The technology readiness of these items is discussed in the context of WWO in Appendix A.

Based on the success of the proof-of-concept tests and use of commercially proven equipment the primary SRWOP process steps are judged to be approximately TRL-3 as defined in DOE G 413.3-4 [6]. More details on the SRWOP technology development and readiness can be found in Appendix D.

If this technology is selected for implementation, additional testing needs to be completed to cover the complete range of feeds required, testing with actual sludge samples, and more complete material balances including off-gas generation. Physical property testing of the slurry during size reduction and during the reaction and treatment steps will be required. It is expected that needed information could be obtained with a modest amount of testing.

Principal engineering development activities center around agitation of the RRT and LST, MT design and performance, instrumentation and monitoring of the extent of reaction, slurry transfer, control of the reacted sludge charged to the disposal drum, and the selection of a specific immobilization agent and the remote packaging and assay systems which are common to all aqueous treatment options.

3.5 Nitrate Chemical Inhibitor Process

3.5.1 Process Descriptions and Flowsheets

The Nitrate Chemical Inhibitor Process (NCIP) is summarized in Figure 3-2 above (Section 3.0). Dilute sludge from an STSC is delivered batch wise, up to 13.2 m^3 (3,500 gallons) per batch to the Concentration/Mix Tank (CMT). The CMT is purged with sweep air to limit hydrogen buildup, is normally maintained at slightly below atmospheric pressure, and is agitated continuously when it contains a batch of sludge. The CMT contents are heated to near the atmospheric pressure boiling point of water using a steam jacket, and water is driven off by evaporation, concentrating the batch to the desired end point solids concentration. Sodium nitrate solution, in excess of that needed to react with hydrogen radicals generated during uranium metal reaction with water, is added either during or after the evaporation step. The nitrate reacts with hydrogen radicals in order to significantly reduce the evolution of hydrogen gas from the oxidation reaction of uranium with water. The mixed and concentrated batch is then cooled and transferred to the LST. From the LST, the sludge is transferred to the drumming portion

[3] Densalloy is a registered trademark of ATI Tungsten Materials, 1 Teledyne Place, La Vergne, Tennessee 37086, a business unit of Allegheny Technologies Incorporated (ATI); all rights reserved.

of the process where it is mixed with a cement-mix or other absorbent for immobilization and then packaged in drums for final disposal.

Supporting processes such as sweep air, vent gas treatment, cooling water, and process stream supply are also included in the NCIP. A more detailed flowsheet and process description can be found in Appendix E.

3.5.2 Test Results and Uncertainties

The aspects of the NCIP found to be less mature are related to the knowledge of chemical behavior of the actual sludge in the treatment process. A literature review and previous STP project testing, including testing with actual sludge, showed that nitrate addition will decrease hydrogen gas evolution from U metal reaction with water. Therefore, additional testing was initiated to provide proof-of-concept testing for nitrate addition and incorporation into candidate immobilized waste forms. The limited short term testing (discussed in Appendix E) demonstrated large reductions in hydrogen gas generation. For NCIP to be successful, it will need to effectively reduce hydrogen gas production for significantly longer time periods than those tested to this point. These longer periods could result from an extended interim storage period before shipping to WIPP (potentially 10+ years) and the 60 day window typically required for transportation to WIPP. Additional data regarding gas generation and nitrate depletion under more prototypic temperature cycles and longer interim storage conditions is needed.

An additional concern regarding NCIP is that it appears to be outside the range of technical approaches typically used for compliance with WIPP/TRAMPAC flammable gas generation requirements. The concern expressed by representatives of WIPP is that while hydrogen generation is reduced the underlying uranium reactions continue and may not be deemed to be "chemically stable" as part of the compliance with the WIPP waste compatibility requirement. Therefore, early agreement with WIPP on the acceptability and associated requirements are essential for continuing the NCIP alternative.

The remote process equipment for the NCIP is expected to be similar to that for WWO. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO. The technology readiness of these items is discussed in the context of WWO in Appendix A.

Based on the success of the proof-of-concept tests and use of commercially proven equipment the primary NCIP steps are judged to be approximately TRL-3 as defined in DOE G 413.3-4 [6]. More details on the NCIP technology development and readiness can be found in Appendix E.

3.6 Joule Heated In-Container Vitrification™

3.6.1 Process Descriptions and Flowsheets

The proposed In-Container Vitrification (ICV™) process is based on a Joule heated vitrification unit used to stabilize and solidify the K Basin sludge. The process is summarized in Figure 3-5. Dilute sludge from an STSC is delivered batch wise to the Receiver Vessel and then transferred into a smaller Batch/Assay Tank. The slurry is fed incrementally from the Batch/Assay tank into the Dryer/Mixer using gravity. The slurry is mixed with the required amount of glass former materials in the Dryer/Mixer and heated under vacuum to achieve low moisture content (2-5% water). The blended, dried product is then discharged into an empty ICV™ melter vessel that contains graphite electrodes for electrical heating and a ceramic insulating system. The dried sludge mixture is then heated to about 1,300°C in order to drive off residual volatile components and to melt the remaining waste and glass formers. When a batch is complete, the melt is allowed to cool and solidify. The drum is then sealed, surveyed, and loaded out.

Supporting processes such as vent gas treatment, cooling water, and process stream supply are also included in the ICV™ process. A more detailed flowsheet and process description can be found in Appendix F.

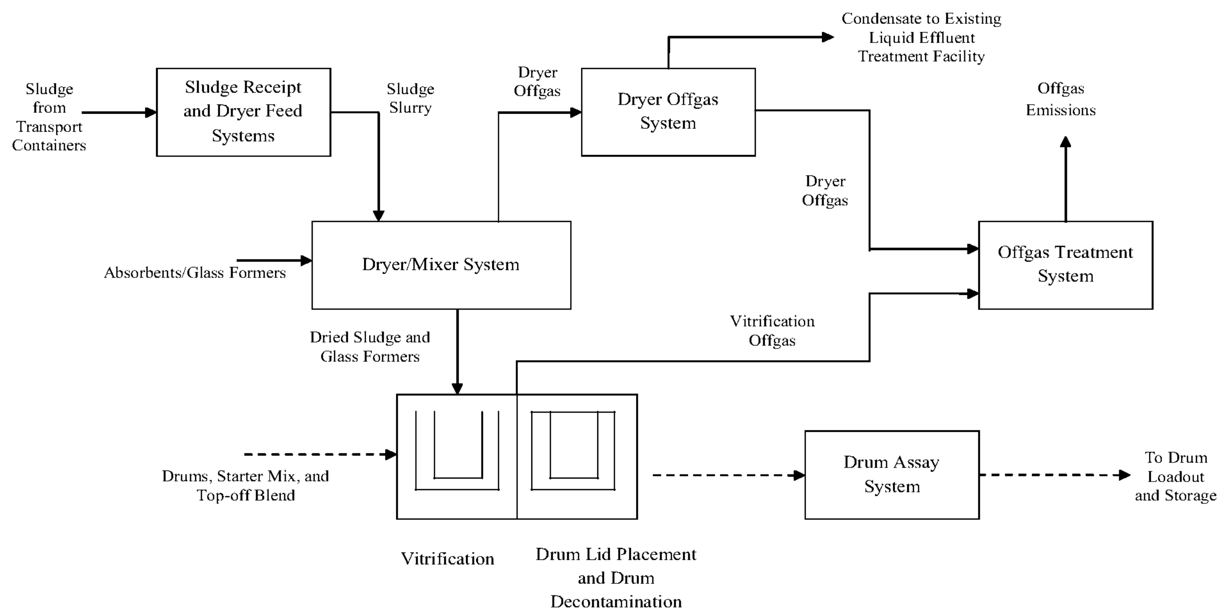

Figure 3-5. In-Container Vitrification™ System Simplified Block Diagram

3.6.2 Test Results and Uncertainties

Since the vitrification step was previously tested at full-scale using K Basin sludge simulants in 2003 [14], the outstanding feasibility questions centered on the feed preparation step where a dilute slurry is dried and mixed with glass formers. Testing of bench scale and full-scale drying systems was completed. The testing demonstrated that the mixer/dryer can produce simulant materials with the appropriate residual moisture and mix the simulant materials with the necessary glass forming additives, and that the simulant/glass forming mixture can flow by gravity into the ICV™ container for vitrification. When combined with vitrification tests previously performed outside of the Phase 2 TEAA effort [14], the major individual ICV™ unit operations have been tested with simulant on a production scale.

The ICV™ test program completed for this evaluation was intended to be proof-of-concept testing and did not aim to resolve all potential technical issues that may be associated with its implementation. Several remaining uncertainties require resolution during the conceptual design phase of the project. While the dryer operates under reduced pressure (less than 120 torr) and moderate temperature (~55 °C), the dryer unit operation conditions may accelerate uranium metal oxidation rates, generating hydrogen gas. Optimization of trade-off between vacuum and temperature of drying, and overall throughput remains to be completed. Operation of the dryer and vitrification system have the potential to release volatile and semi-volatile radionuclides to the vapor phase. Finally, while both the dryer and vitrification unit have been tested at near-production scale, they were tested with a single simulant composition. Consequences of variability in the sludge compositions could be addressed by future testing. More details on the ICV™ technology development and readiness can be found in Appendix F.

3.7 Induction-Heated In-Container Vitrification System

3.7.1 Process Descriptions and Flowsheets

Kurion, Incorporated offered its Modular Vitrification System®[4], an inductively heated In-Container Vitrification (IVS) approach to waste treatment, in response to the request for technology information. The system is summarized in Figure 3-6. Dilute sludge slurry from an STSC is transferred to the feed receipt and preparation tank. In the feed receipt and preparation tank, the slurry is mixed with glass forming materials to create 40 wt% solids slurry.

The melter unit is an induction-heated unit that vitrifies waste in the disposal drum by activating a sequence of induction coils (and therefore melt zone) from lower to higher elevations. Prior to the addition of the waste slurry, pure glass former is added to the drum and melted to create an end cap. The waste slurry is then slowly added to the drum using a metering pump and vitrified. Once the desired amount of waste slurry has been added to the drum, a second end cap of pure glass is added to the top. After an IVS container has been filled, it is moved to a cool-down area. Once cool, final compliance verification is performed and the container is placed in a removable lid canister and moved to temporary storage.

Supporting processes such as vent gas treatment and process stream supply are also included in the IVS process. A more detailed flowsheet and process description can be found in Appendix G.

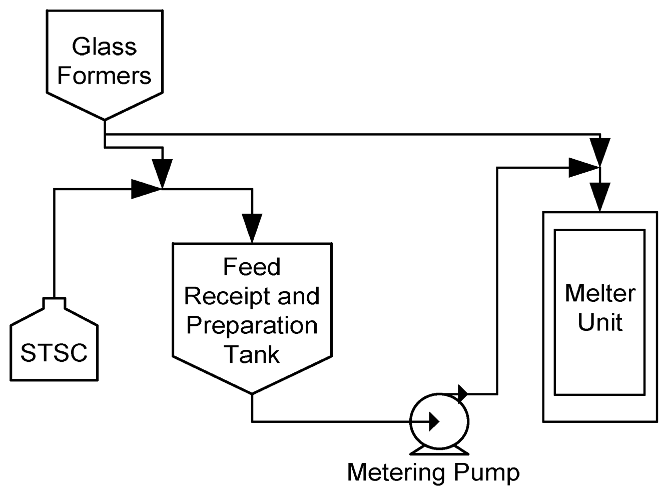

Figure 3-6. Simplified Process Flow Diagram for the Induction-Heated IVS Process

3.7.2 Test Results and Uncertainties

No tests were performed as part of the TEAA. At the current time, a privately-funded technology development and demonstration program is being conducted for the application of the IVS technology to the Low-Activity Waste (LAW) fraction of Hanford tank waste. Appendix G discusses this ongoing development program and identifies the incremental test and development activities needed to demonstrate this technology for treatment and packaging of K Basin wastes.

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4 Modular Vitrification System is the registered trademark of Kurion, 2040 Main St., Irvine, CA 92614-7216; all rights reserved.

While this technology has not yet been demonstrated at a size and scale needed for treatment of K Basin sludge, the currently planned engineering scale demonstration for LAW waste is equivalent to full-scale operations for a K Basin application.

If the privately-funded development and demonstration program is successful, it is possible that an application of the inductively-heated vitrification might be shown to be feasible, especially if the decision to move forward into conceptual design of the Phase 2 treatment and packaging system is delayed for a number of years.

At this time, CHPRC does not recommend that DOE-RL directly fund testing and development of potential application to K Basin sludge treatment.

3.8 Phosphate Ceramic Hydrogen Inhibitor (Borobond™)

3.8.1 Process Descriptions and Flowsheets

The concept for using chemically bonded phosphate ceramic (Borobond™) was to bind the metallic uranium in the ceramic matrix to sufficiently reduce the generation of hydrogen gas. The Phosphate Ceramic Hydrogen Inhibitor Process (PCIP) using Borobond™ is summarized in Figure 3-2 given above (Section 3.0) and follows the general aqueous process template previously discussed. Dilute sludge slurry from an STSC is delivered batch wise to the CMT. The CMT contents are heated to near the atmospheric pressure boiling point of water using a steam jacket and water is driven off by evaporation, concentrating the batch to the desired end point solids concentration. The mixed and concentrated batch is then cooled and transferred to the LST. The LST is continuously agitated when a sludge batch is present, and is cooled with a water cooling jacket. Concentrated sludge is transferred to the drumming system in smaller batches as needed, where it is mixed with the Ceradyne Borobond™ for immobilization and packaged into drums for final disposal.

Supporting processes such as sweep air, vent gas treatment, cooling water, and process steam supply are also included in the Borobond™ process. A more detailed flowsheet and process description can be found in Appendix H.

3.8.2 Test Results and Uncertainties

The limited short term testing of the PCIP using BoroBond™ demonstrated inadequate performance during the proof-of-concept testing. Because of this, the technical development status is considered to be insufficient for further consideration at this time. Process and/or product changes required to achieve acceptable performance are currently unknown. Hydrogen gas generation of the immobilized sludge simulant was essentially equivalent to previous PNNL tests evaluating grout and No-Char immobilization systems with gas generation reduction by a factor of 2-3 [17]. No further work utilizing BoroBond™ as a method to reduce/eliminate hydrogen gas generation is recommended.

However, BoroBond™ was demonstrated as an effective waste immobilization form with formulations that showed no bleed water formation or release during the testing period and should be considered in future Phase 2 project activities to evaluate and select an immobilization agent for K Basin Sludge material.

3.9 Immobilization of Treated Sludge

The immobilization and packaging steps are important parts of Phase 2 sludge processing. In the current TEAA, however, the primary emphasis was focused on the process steps associated with preparation for immobilization. There is substantial nuclear industry experience with vitrification and with Portland cement-based immobilization, including an earlier project that solidified K Basin North Loadout Pit

(NLOP) sludge using Portland cement. As part of the TEAA, limited testing was performed on immobilization using chemically bonded phosphate ceramics (Appendix H) and commercially available sorbents [17]. Test results, available literature, and vendor contacts indicate that achievable waste loadings for chemically bonded phosphate ceramics and commercially available sorbents are expected to be roughly comparable to Portland cement-based solidification. However, it is likely that more detailed testing will show that there are modest differences in waste loading between these options for specific overall scenarios. A perceived advantage of the sorbent-based approach is that the product is not a hard monolith, making removal of product from the drum easier if needed. A potential advantage of chemically bonded phosphate ceramic and glass from vitrification is that these are higher integrity product waste forms. However, the increased integrity is not needed to meet current WIPP requirements.

The TEAA also did not perform significant evaluation of Immobilization and Packaging System design, or operating and maintenance alternatives. The technology evaluations assumed that the immobilization and packaging system designs are the same for all water-based, or non-thermal alternatives.

Future project activities are needed to perform more detailed evaluations followed by selection of solidification agents and the overall immobilization and packaging approach to be implemented in the Phase 2 design.

4 Evaluation of Alternatives against Decision Plan Criteria

This section provides the evaluation of technology alternatives against the evaluation criteria discussed in Section 2.1. The initial evaluation began with eight candidate technologies, but two were not carried forward into the final evaluation based on performance against the initial RFI screening criteria (the screening criteria were a subset of the Decision Plan Criteria). The PCIP was not successful in producing a viable flowsheet and therefore could not be evaluated. The IVS system was not included in the final evaluation because of a lack of sufficient maturity of the technology.

Each of the decision criteria is discussed separately, and the technologies are compared against each criterion in turn. Section 4.1 gives a compilation of the evaluation considerations developed by the technical team. Section 4.2 provides an overall evaluation of the technology alternatives by the CHPRC technical team. Section 4.3 provides evaluations and numerical rankings developed by the DSB.

4.1 Evaluation Considerations

This section provides a compilation of the evaluation considerations used in performing the evaluations.

4.1.1 Safety

4.1.1.1 Summary

Overall safety considerations are dominated by the requirement to handle (agitate, pump, heat, mix, etc.) the highly radioactive sludge slurry (See Table 4-1). The remote processing equipment is similar in design, operation, remote maintenance features, and complexity for all alternatives, with a few exceptions. The SRWOP process includes an immersion mill and milling tank, and the ICV™ process includes a rotary mixer-dryer. The FROP, PCOP, and NCIP alternatives also require addition of hazardous chemical reactants and the WWO and SRWOP alternatives require use of inert gas atmospheres. These are relatively common chemicals that have been routinely used industrially and at the Hanford site. The ICV™ immobilization approach is somewhat more complex than the others and may be more prone to spread contamination due to volatilization and entrainment of contaminants into the off-gas and the associated need to make and break waste feed and off-gas connections for each drum produced. These differences are expected to be of relatively low importance compared to the overall hazards of all alternatives.

4.1.1.2 Discussion

Even though these technology approaches are at a very early stage, a hazards consideration review was completed for the technology alternatives in order to provide input to the cost, schedule, and risk considerations for the continued alternatives selection process. This hazards consideration evaluation was completed by a team of representatives from Engineering, Industrial Safety, Fire Protection, Radiological Control, and Operations within CHPRC [9]. Each alternative was considered individually, and then resolved into nodes, or specific activities that were considered for "what if" events.

The main considerations in the analysis included:

- Nuclear/process safety
- Criticality safety
- Industrial safety and hygiene
- Fire protection

The primary identified hazards associated with nuclear and process safety were transfer issues, hydrogen production rates, and chemical energy. All of these hazards were determined to be controllable for all alternatives; no nuclear safety discriminators were identified. All alternatives will require use of a hazard category 2 facility with shielded process cells, remote operation and maintenance capabilities, and ventilation systems that assure confinement of radioactive materials.

Potential issues due to criticality were determined avoidable through the use of controls, and no criticality safety discriminators were found.

The distinguishing industrial hygiene characteristics are related to hazards associated with chemical feed materials and off-gas, but all hazards were considered manageable.

In terms of fire protection, WWO and NCIP were determined to have less complex flammability issues. FROP, PCOP, NCIP and possibly ICV™ will all require chemical management areas. However, there are no significant fire protection challenges that would eliminate any of the alternatives.

A more detailed description of the hazards consideration review including a list of all hazards considered can be found in Reference 9. Table 4-1 summarizes the safety considerations for each alternative.

Table 4-1. Safety Considerations of Technology Alternatives

Technology Alternative	Safety Considerations
Warm Water Oxidation (WWO)	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries. • No chemical additives required. **Disadvantages** • Relatively long processing time results in longer risk period.
Fenton's Reagent Oxidation Process (FROP)	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries. • Relatively short operating period. • Inert gas blanketing not required. • Minimum material at risk (MAR)/inventory of sludge. **Disadvantages** • Use of reactive/hazardous chemical additives (30 % hydrogen peroxide) is required. Required chemicals are in use elsewhere at Hanford and for general industrial use.

Technology Alternative	Safety Considerations
Peroxide and Carbonate Oxidation Process (PCOP)	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries. • Moderate operating period. • Inert gas blanketing not required. • Minimum material at risk (MAR)/inventory of sludge. **Disadvantages** • Use of reactive/hazardous chemical additives (50 % hydrogen peroxide) is required. Required chemicals are in use elsewhere at Hanford and for general industrial use.
Size Reduction and Water Oxidation Process (SRWOP)	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries. • Relatively short operating period. • Minimum material at risk (MAR)/inventory of sludge. **Disadvantages** • Use of high speed rotating equipment (immersion mill). • Use of pressurized water for eductor.

Technology Alternative	Safety Considerations
Nitrate Chemical Inhibitor Process (NCIP)	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries. • Relatively short operating period. • Inert gas blanketing not required. • Minimum material at risk (MAR)/inventory of sludge. **Disadvantages** • Use of potentially hazardous oxidizer (sodium nitrate). Required chemicals are in use elsewhere at Hanford and for general industrial use.
In-Container Vitrification (ICV™)	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries. • Small radionuclide inventory in process equipment other than the primary receipt vessel. **Disadvantages** • High temperature (~1300 °C) process at near atmospheric pressure. • Relatively long processing time results in longer risk period.

4.1.2 Regulatory/Stakeholder Acceptance

4.1.2.1 Summary

All identified options appear to meet the requirements of the K-Basin amended record of decision (see Appendix N). The FROP, SRWOP, and NCIP alternatives may be viewed favorably by stakeholders because of the expected shorter operating duration to complete the mission. The WIPP representative on the Decision Support Board identified an open issue concerning the acceptability of retaining metallic uranium in the waste form, with the potential of an ongoing metal-water reaction, which could result in a chemical incompatibility concern. With the possible exception of the NCIP, all alternatives are expected to be able to meet WIPP acceptance requirements and RH-TRAMPAC transportation requirements.

4.1.2.2 Discussion

Analysis by CHPRC showed no significant regulatory or stakeholder concerns for any of the six alternatives. Potential discriminators identified were the time to treat and package the sludge, cost effectiveness, and the potential need to eliminate PCBs from the final waste form. All technology approaches were determined to be consistent with the existing K-Area CERCLA Record of Decision (see Appendix N).

Input from the WIPP representative during the DSB workshop discussions highlighted the principal issues with the alternative technical approaches from the WIPP waste acceptance criteria perspective[5]. Demonstrating compliance with WIPP's "non-reactive/chemically stable" criterion for the NCIP was also identified as a potential issue. While the generation of hydrogen gas is effectively inhibited, the underlying uranium metal oxidation continues as long as water is present. WIPP representatives expressed a willingness to work with the STP to achieve compliance for waste forms, and the requirements to demonstrate compliance are negotiable. The number of drums produced is not a discriminator among the alternatives considered, but WIPP may prefer a shielded 30 gallon drum to the base case 55 gallon drum since the contact-handled shielded drum provides more flexibility in the transportation and waste disposal operations at WIPP. It is not clear how much, if any of the K-Basin sludge material can be efficiently packaged in the contact-handled shielded drum and still meet the surface dose rates required (200 mR/hour at all surfaces).

4.1.3 Technical Maturity

4.1.3.1 Summary

All of the six retained alternatives have successfully completed proof-of-principle testing and are expected to be capable of successful development and implementation to meet mission needs. The overall process systems contain a large number of systems, subsystems and components, some of which are not well defined at the current stage of process design. As such, the overall technical maturity is not very advanced. Due to past project activities more testing and engineering work has been performed on the WWO process than the other alternatives.

4.1.3.2 Discussion

The technical maturity of each of the six candidate technologies was assessed to provide assurance that each technology can be successfully implemented in a reasonable time at a reasonable cost. Each technology was first broken down into its main process functions. The technology readiness level (TRL) of each of these functions was then estimated. Based on their main process functions, each technology was classified as either a non-thermal system or a thermal system (ICV™). The summary findings related to the technical maturity of each type of system are given in Tables 4-2 and 4-3.

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[5] Eric D'Amico, personal communication, May 11 2011.

The non-thermal technology alternatives are WWO, FROP, PCOP, SRWOP, and NCIP. The generic functions of each of these non-thermal systems are: sludge receipt, preparation for immobilization, lag storage of prepared sludge, sludge immobilization, drum handling and storage, and process support. Table 4-2 summarizes the estimated technical maturity of these various functions for the non-thermal technologies. Table 4-3 summarizes the estimated technical maturity of the various ICV™ functions.

Table 4-2. Estimated Technical Readiness of Generic Non-Thermal Process Functions

Function	TRL	TRL Basis	Uncertainties
Sludge Receipt	4	• Basic slurry transport similar to Phase 1 activities	• Slurry transfer control
Preparation for Immobilization	3	• Proof of principle testing demonstrated key step: oxidation of U metal with water (WWO, SRWOP), oxidation of U metal (FROP), oxidation of U metal (PCOP), size reduction of U metal simulant (SRWOP), hydrogen suppression by nitrate addition (NCIP) • Prior STP testing of sludge slurry transfers. • Limited evaluation of available off-gas measurement instruments for determining the reaction end point. • Balance of functions are common industrial processes (agitation, evaporation, etc.)	• Technology-specific • Design optimization • Impact of sludge variability
Lag storage of prepared sludge	3-4	• Gamma radiation measurement to estimated curie content has been used industrially. • Prior STP testing of metering pumps for sludge slurry transfers. • Balance of functions are common industrial processes (agitation, evaporation, etc.)	• Accuracy of determining actinide content based on gamma dose measurements is uncertain.
Immobilize Sludge	4-5	• Portland cement based immobilization is a common industrial process. • Performed successfully at full scale for K Basin NLOP sludge • Substantial past testing on grout formulation has demonstrated that liquid can be reliably eliminated.	• Routine system integration and design issues: remote maintenance including recovery from failures, contamination control.
Container Handling and Storage	Probably 2-4	• Gamma radiation measurement to estimated curie content of drummed waste has been used industrially.	• Accuracy of determining actinide content based on gamma dose measurements is uncertain.

Function	TRL	TRL Basis	Uncertainties
	2-3	• Remote drum closure methods -- Remote drum closure has been demonstrated at non-integrated scale only, for similar application [Alpha-Caissons]	• Remote equipment design/testing
Process Support	5	• Vessel vent system is standard industry practice (nothing novel)	• Development of inputs defining treatment scope deferred
	2-3	• Standard industry proven remote maintenance methods are expected to be used.	• Remote equipment design/testing

Table 4-3. Estimated Technical Readiness of ICV™ Primary Functions

Function	TRL	TRL Basis	Uncertainties
Sludge Receipt	2-3	• Basic slurry transport similar to Phase 1 activities • Assay methods not investigated	• Slurry transfer control from large storage vessel to small batch vessel • Assay control of transfer to dryer
Preparation for Immobilization	4	• Dryer performance tested at full scale using simulant	• Performed with physical simulant • Dryer design optimization • Impact of sludge variability
Immobilize Sludge	4	• ICV™ tested at full scale using simulant • Laboratory scale crucible tests	• Test may not represent actual glass former selected • Full scale test performed with physical simulant • Thermal analysis may change crucible size
Container Handling and Storage	2-3	• Assay methods not investigated	• Potential non-uniform distribution of radionuclides
Process Support	2-3	• Analogous off-gas treatment systems designed/tested • Remote system maintenance systems undefined	• Development of inputs defining treatment scope deferred • Remote equipment design/testing

4.1.4 Operability and Maintainability

4.1.4.1 Summary

All alternatives have similar issues with regard to operability and maintainability. There are not large differences in O&M for the alternatives under consideration. The shorter processing duration largely offsets the additional operational complexity of chemical additions or size reduction for FROP, SRWOP, and NCIP alternatives. The ICV™ process has a little more complexity and increased potential for spread of contamination without the offsetting benefit of a shorter processing duration. Similarly, the PCOP has more complexity and requires hazardous chemical addition with only a small reduction in operating duration.

4.1.4.2 Discussion

The factors relevant to a technology's inherent operability and maintainability include, but are not limited to: ease of implementation; ease of operations and process control; incremental personnel safety programs (chemical process safety training and qualification, PPE, etc.); process stability, flexibility, and robustness; ease and frequency of maintenance; generation of primary and secondary waste streams compliant with Hanford Site waste acceptance criteria; and as-low-as-reasonably-achievable (ALARA) considerations. Table 4-4 lists key evaluation considerations related to the O&M criterion for each of the candidate technologies.

The remote process equipment associated with preparation for immobilization is similar in design, operation, remote maintenance features, and complexity for all alternatives, with two exceptions:

1. The SRWOP process includes an immersion mill and milling tank.
2. The ICV™ process includes a rotary evaporator and a more complex offgas system than other alternatives.

The FROP, PCOP, and NCIP alternatives also require addition of hazardous chemical reactants and the WWO and SRWOP alternatives require addition of nitrogen to provide an of inert gas atmosphere in the reaction tank. Three alternatives (SRWOP, FROP, and NCIP) have relatively short process operating durations, which is expected to reduce the amount of maintenance needed for the contaminated equipment over the life of the project.

With the exception of ICV™, all the alternatives use conventional solidification typified by use of dry additives and a lost paddle in-drum mixing approach. The ICV™ approach uses high temperature to drive off water, oxidize uranium, and solidify the waste as a glass. Operationally, the ICV™ immobilization approach is expected to be more difficult due to volatilization and entrainment of contaminants into the off-gas and the associated need to make and break waste feed and off-gas connections for each drum produced.

Table 4-4. O&M Considerations of Technology Alternatives

Technology Alternative	O&M Considerations
Warm Water Oxidation (WWO)	• The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. • No additional chemical handling is required. • The total processing time is very close to the 5 year criterion, leaving little room for adjustment in retrieval schedule or unexpected downtime.
Fenton's Reagent Oxidation Process (FROP)	• Short process operating time (<2 years) results in low operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction Tank related components. • Short estimated processing time provides more allowance for downtime or process performance problems and still meet the 5 year window. • The FROP product is expected to be in a high oxidation state, eliminating pyrophoric material and reduced potential for post drumming expansion due to oxidation of UO_2. • The treatment system will use proven, familiar, remote equipment design concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. • The FROP equipment is very flexible and can also be used for several other process options with minimal modifications. • Expected to require upgraded corrosion resistant materials of construction due to potential corrosion problems with Cl present.

Technology Alternative	O&M Considerations
Peroxide and Carbonate Oxidation Process (PCOP)	• Reduced process operating time (<4 years) results in less operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction Tank related components. • The PCOP product is expected to be in a high oxidation state, eliminating pyrophoric material and reduced potential for post drumming expansion due to oxidation of UO_2. • The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. • The PCOP equipment is very flexible and can also be used for several other process options with minimal modifications. • More evaporation steps and more condensate produced due to the relatively large amount of peroxide added.
Size Reduction and Water Oxidation Process (SRWOP)	• The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. • Short process operating time (<2 years) results in low operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction Tank related components. • The short estimated processing time provides more allowance for downtime or process performance problems and still meets the 5 year window. • Elimination of large/heavy particles is expected to reduce erosion of agitators, pumps, tanks, and piping, and is expected to allow more uniform mixing. Could improve assay accuracy. • The SRWOP equipment can also be used for the WWO process without modification. • More complex equipment and operations. • Milling Tank equipment may need increased maintenance.

Technology Alternative	O&M Considerations
Nitrate Chemical Inhibitor Process (NCIP)	• The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. • Short process operating time (<2 years) results in low operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction Tank related components. • The short estimated processing time provides more allowance for downtime or process performance problems and still meet the 5 year window. • The NCIP equipment can also be used for the WWO process with minimal modification to add nitrogen blanketing. • Requires handing of a chemical oxidizer (sodium nitrate).
In-Container Vitrification (ICV™)	• The systems to prepare the waste for immobilization will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. • Production scale equipment is relatively small. • Designs for remote operation/remote maintenance of the immobilization step are not currently available. • High temperatures require additional precautions and operations considerations. • Contaminants volatilized at the higher temperatures require additional handling capabilities. • The production of powders and other friable and dispersible materials in the process makes the physical handling of this material more difficult than flowing slurries, and may increase problems with contamination control.

4.1.5 Life-cycle Cost and Schedule

4.1.5.1 Summary

The FROP, SRWOP, and NCIP alternatives are expected to offer moderately lower life cycle costs and moderately shorter schedule than the other alternatives. The other three alternatives (WWO, PCOP, and ICV™) are essentially equal relative to the life cycle cost and schedule. The capital project costs and schedules are expected to be essentially equal for all alternatives, while the differences in life cycle cost and schedule are primarily associated with differences in operating duration.

4.1.5.2 Discussion

Comparative cost estimates were developed for each alternative, including costs for technology development, design, construction, operation, and deactivation of the treatment and packaging facility (see Appendix O). The cost estimates also include recovery and movement of the loaded STSCs from T Plant to the Phase 2 Treatment facility, receipt of the STSCs at the Phase 2 facilities, and preparation for the sludge retrieval operations. After the STSCs are emptied they are decontaminated as necessary, and grouted for disposal at ERDF. The cost estimates exclude on-site transportation and storage of filled drums, final packaging and shipment to WIPP, and final decontamination and demolition of the processing facilities. The cost estimates range from $485 million to $710 million. The estimate is AACEI Class 5 which gives a -50% / +100% range as shown in Figure 4-1.

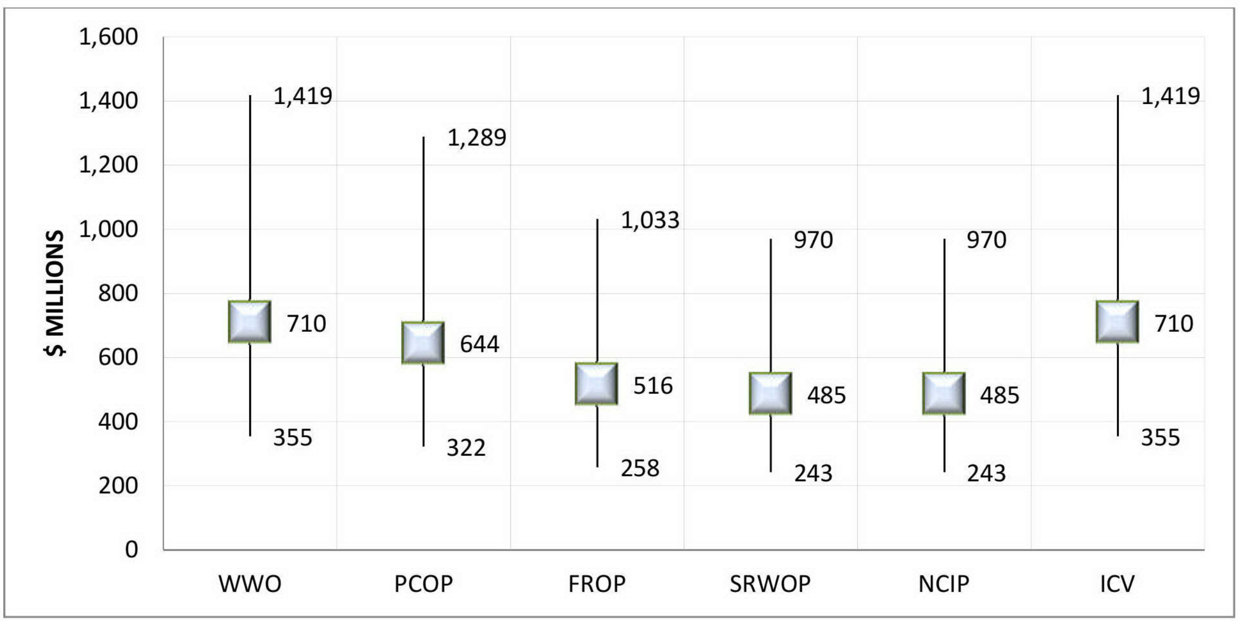

Figure 4-1. Comparative Life-Cycle Cost Estimates for Proposed Technologies

The schedules of activities for all the technologies are similar up to the beginning of operations. These activities are the conceptual design, preliminary design, final design, and construction. The total duration of these activities is estimated at 11 years. The total lifecycle duration includes engineering (conceptual through final), testing, procurements, construction, readiness, operations, and deactivation. The estimated total duration for each technology is given in the following Figure 4-2.

Present Net Worth evaluations consistent with EPA OSWER 9355.0-75 and OMB circular A-94 were completed, but due to the early nature of the design, costs estimates, schedule estimates and the resultant uncertainties in the key parameters, only minor differences in present net worth was identified between the alternatives.

The Present-Net-Worth comparison is shown in Figure 4-3. As shown SRWOP and NCIP had the lowest Present-Net-Worth of $364M, followed by FROP and PCOP at $383M and $461M. WWO and ICV™ were both evaluated at $500M Present-Net-Worth. At the early state of project definition for these alternatives, these evaluated deltas were not felt to be significant.

Details of the cost and schedule evaluations are discussed in Appendix O.

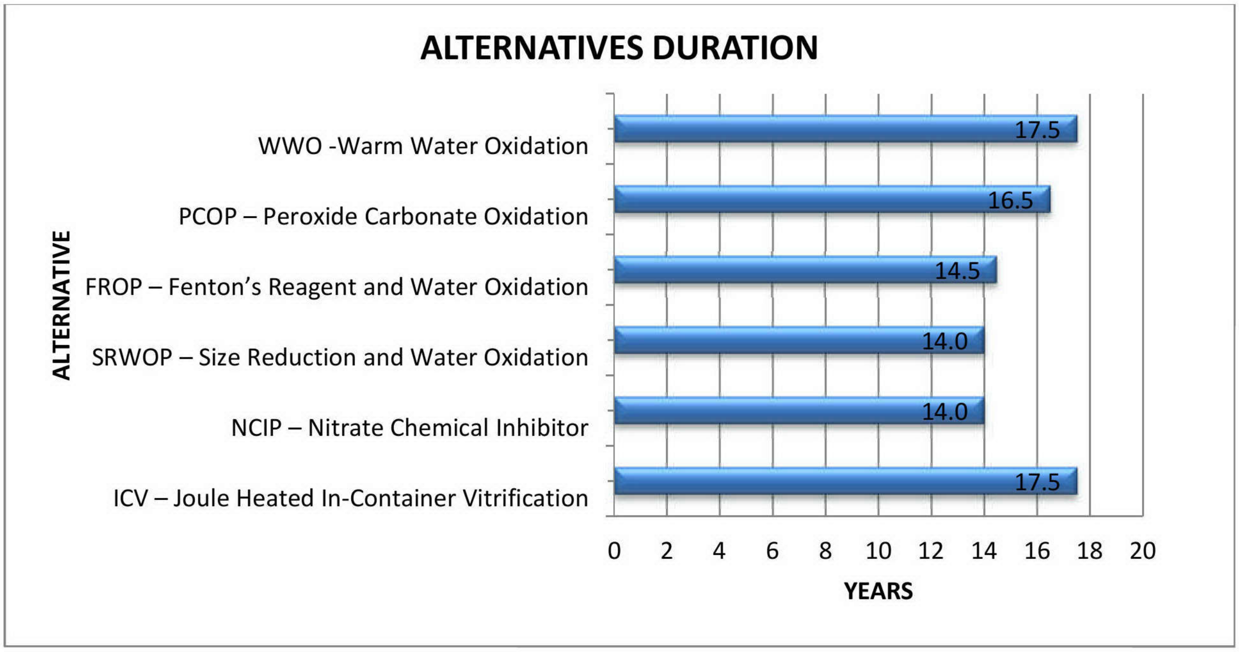

Figure 4-2. Total Duration for Each Proposed Alternative

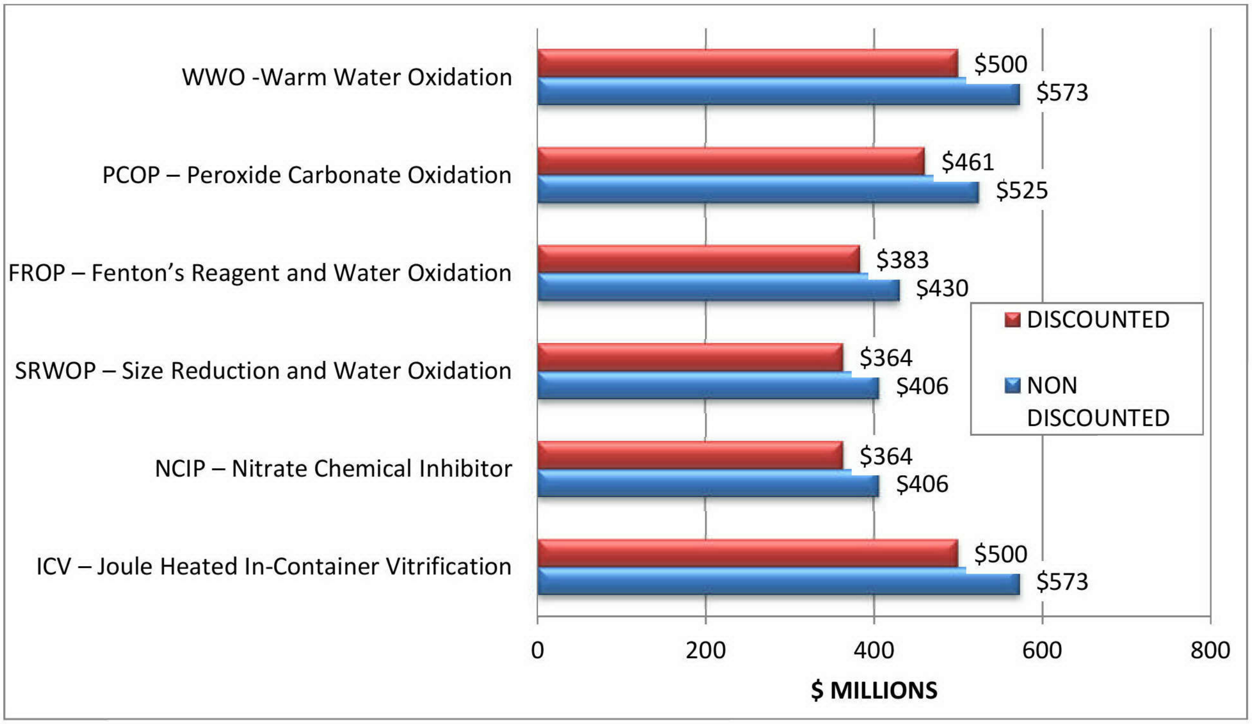

Figure 4-3. Present-Net-Worth for Each Proposed Alternative

4.1.6 Potential Integration with STP – Phase 1 Activities

4.1.6.1 Summary

All of the processes were found to be compatible with the Phase 1 design concept, and no discriminators across the alternatives were identified.

4.1.6.2 Discussion

The six technology alternatives were evaluated based on their potential for beneficial integration with the ECRTS in the ongoing STP – Phase 1 work. It was found that ECRTS has design features and technology to support integration with Phase 2. All of the processes were found to be compatible with the Phase 1 design concept, and no discriminators across the alternatives were identified.

As the Phase 2 conceptual design efforts begin, continued close integration with the Phase 1 project needs to continue. In particular the Phase 2 project needs to integrate with the Phase 1 project with respect STSC design, actual results from the Phase 1 retrieval and STSC loading operations, achieved sludge loading and inventories in each STSC, updated sludge characterization data from both laboratory and waste transfer operations, quantification of the use of flocculating agents to facilitate settling time cycles within the STSC, and operational experience with the XAGO EC sludge retrieval tool and testing of STSC sludge removal tools.

4.1.7 Potential for Integration with Site-wide RH-TRU Processing

4.1.7.1 Summary

A variety of RH-TRU waste container types are present at the Site, including large, heavy containers, small (1 gallon) containers, and drums. The wastes contained in these containers range from debris such as process equipment, PPE, piping, and HVAC ductwork to sludge from process tank heels and settling tanks (see Appendix M). In order to dispose of these wastes, processes are needed to repackage and size-reduce debris, sort remote-handled waste from other debris, radiography and assay TRU containers, sluice tank contents, solidify sludge, and load into shipping containers.

It is anticipated that solidification and containerization of other waste streams will be the only treatment needed for other Hanford Site RH-TRU wastes. Depending on the final design of the Phase 2 sludge treatment system, there is potential for integration of the facility and support systems, and specific elements such as solidification of RH-TRU sludges and decontamination solutions from processing RH-TRU solid waste , radiography/assay of containers, and shipping. An assessment of additional K Basin RH-TRU wastes (See Appendix I) indicates that all alternatives are capable of processing these specific identified wastes. The technical team identified small potential or hypothetical differences in flexibility of individual alternatives to process additional waste types (Table 4-5 below). However, within the uncertainty of available information, it is not clear that there are significant differences between the alternatives.

4.1.7.2 Discussion

At least 12 additional potential RH-TRU or transuranic mixed waste streams (see Appendix M) at the Hanford Site have been identified. Depending on the pre-conceptual facility concept, some or all of these streams might be considered for processing in the same facility that is used for processing and packaging K Basins Sludge. Two of those streams, KW Basin garnet filter material that will be retrieved and stored in STSCs in T Plant and KE NLOP stored in large diameter containers in T Plant, are discussed in more detail in Appendices K and L. Appendix M gives an overview of such streams and their potential for treatment in the same facility as that used for K Basins Sludge. The primary K Basin sludge processing requirements include the following capabilities:

- Operate in a nuclear facility with confinement, ventilation, and hazard category 2 rating
- Receive waste in storage and transportation containers from interim storage
- Transfer waste from the container to the process
- Process waste
- Characterize treated waste
- Package processed waste
- Certify waste package
- Load WIPP acceptable waste package into shipping container

These functional requirements were then compared with the requirements for treatment and packaging for the other twelve identified RH-TRU waste streams. The main functions in common were found to be the need for a qualified category 2 nuclear facility, the need to package the waste, and the need to certify the waste for shipment. There was little need for expanded treatment functions for most of the other waste streams. Exceptions include the KW garnet filter media and the KE NLOP and sand filter media, which will require the type of processing required for K Basins Sludge. As a result, the ability to process other identified RH-TRU was not a distinguishing feature for the processing part of the various technologies under consideration.

It was also noted that the schedule for processing these other streams were either slightly ahead of or concurrent with the projected schedule for K Basins Sludge. These scheduling considerations gives rise to the need to develop a facility design strategy that would provide a facility that could process both the K Basins Sludge material and the other RH-TRU streams. Four such strategies were discussed:

- Design a category 2 nuclear facility with the necessary remote handling capabilities, processing equipment, and packaging methods to handle the other RH-TRU streams. Use removable or modular equipment that can be removed so that K Basins Sludge processing equipment could be installed and the other RH-TRU processed next. The order could be reversed, i.e. other RH-TRU first, followed by K Basins Sludge.
- Design a facility for K Basins Sludge so that annex(es) could be added to support packaging of other RH-TRU.
- Design a facility large enough to simultaneously process both K Basins Sludge and the other RH-TRU.
- Requalify and upgrade an existing facility to process K Basins Sludge, as well as other RH-TRU.

The specific facility strategy needs to be clearly defined in order to complete the facility conceptual design, demonstrate adequate TRL of performance, and establish an achievable Phase 2 baseline schedule, if the same facility is to be used for other RH-TRU.

Table 4-5. Integration of Technology Alternatives with Site Wide RH-TRU Processing

Technology Alternative	Evaluation Considerations for Integration with Site-wide RH-TRU Processing
Warm Water Oxidation (WWO)	**Advantages** • The process is capable of processing additional K Basins TRU waste streams that have been identified. Other than the additional K Basins wastes, no specific RH-TRU streams have been identified for integration at this time. **Disadvantages** • None noted
Fenton's Reagent Oxidation Process (FROP)	**Advantages** • Upgraded material requirements to allow for moderate chloride levels provide added flexibility for chemical treatment and processing other waste streams (sludge, decontamination solutions, etc.). • The process is capable of processing additional K Basins TRU waste streams that have been identified. Other than the additional K Basins wastes, no specific RH-TRU streams have been identified for integration at this time. • The chemical oxidation system will destroy many organics, which could be useful in processing other waste streams. **Disadvantages** • None noted
Peroxide and Carbonate Oxidation Process (PCOP)	**Advantages** • The chemical oxidation system will destroy many organics, which could be useful in processing other waste streams. • The process is capable of processing additional K Basins TRU waste streams that have been identified. Other than the additional K Basins wastes, no specific RH-TRU streams have been identified for integration at this time. **Disadvantages** • None noted

Technology Alternative	Evaluation Considerations for Integration with Site-wide RH-TRU Processing
Size Reduction and Water Oxidation Process (SRWOP)	**Advantages** • Availability of size reduction equipment may increase flexibility for processing other waste streams (granular materials, sludge, decontamination solutions, etc.)The process is capable of processing additional K Basins TRU waste streams that have been identified. Other than the additional K Basins wastes, no specific RH-TRU streams have been identified for integration at this time. **Disadvantages** • None noted
Nitrate Chemical Inhibitor Process (NCIP)	**Advantages** • The process is capable of processing additional K Basins TRU waste streams that have been identified. Other than the additional K Basins wastes, no specific RH-TRU streams have been identified for integration at this time. • Could be applicable to other (unidentified) wastes with high radiolytic hydrogen gas generations to reduce hydrogen generation rate during shipment. **Disadvantages** None noted
In-Container Vitrification (ICV™)	**Advantages** • Thermal processes established as BACT for a wide variety of waste constituents, which may have broader application beyond K Basin sludge. **Disadvantages** • None noted

4.2 CHPRC Technical Team Conclusions

Based on the CHPRC technical team evaluation conducted over the last 18 months, the WWO, FROP, SRWOP, and NCIP were found to be superior to the other alternatives. In the case of WWO this is primarily because of more advanced technical maturity. For the other three this is primarily because of significantly shorter operating duration with associated improvement relative to the cost, schedule, and O&M evaluation criteria. The FROP, SRWOP, and NCIP alternatives each currently have uncertainties or risks that would preclude their selection as the sole option to be carried forward; however, resolution of these risks is expected to be feasible in within a moderate period of time. There are at most minor differences between alternatives relative to the evaluation criteria for safety, regulatory/stakeholder acceptance (except for NCIP), integration with STP – Phase 1 Activities, and integration with Site wide RH-TRU processing.

The similarity between process equipment for the four favored alternatives was noted by the technical team. If relatively minor flexibility features are included, the same process equipment is expected to be capable of running any of these processes.

The approach suggested by the CHPRC technical team is to continue to pursue all of these four alternatives, at least on an interim basis. The WWO is considered to be the baseline case with the most confidence. The SRWOP is basically an enhancement of the WWO process that adds a front end size reduction step that is expected to significantly improve performance (reduce operating time) and reduce technical difficulties related to transfer and mixing of coarse and fast settling particles in the sludge. If development of the size reduction step fails or is found to be far more difficult or expensive than expected, the process could revert to the basic WWO process. The FROP is expected to substantially reduce the reaction time and overall processing schedule compared to WWO, however, the risks and uncertainties associated with its chemistry and potential effects on materials of construction remain to be evaluated. If development of the FROP fails or is found to be far more difficult or expensive than expected, the process could revert to the basic WWO process using the same equipment. The NCIP is expected to reduce time required to prepare each sludge batch for immobilization and therefore the overall processing schedule compared to WWO, however, there are uncertainties concerning its regulatory acceptance and its long term performance if the drummed waste is subject to extended storage prior to shipping. If development of the NCIP fails or is found to be far more difficult or expensive than expected, the process could revert to the basic WWO process using the same equipment.

4.3 DSB Evaluations and Recommendations

To provide an independent evaluation of the alternative technology approaches, CHPRC commissioned a DSB to review the technical alternative data and provide recommendations to CHPRC regarding the preferred technology approach, as well as the identification of significant risks and mitigation actions for those risks.

4.3.1 Decision Support Board Evaluations

The DSB was convened as described in Section 2.4 and used a facilitated decision process based on a MAU methodology. Several STP SMEs delivered 14 presentations that ranged from sludge characterization, Phase 2 technology evaluations and alternative analysis, primary treatment and packaging requirements, to the baseline project assumptions, six technology alternatives, other technologies considered but not evaluated, and the project sensitivity analysis.

Following the SME presentations, the seven evaluation criterion presentations were delivered. After each criterion presentation and respective observations and inputs, the facilitator led the DSB to evaluate and rate each alternative against each criterion. The total ranking values for each of the technologies are given in the Figure 4-4.

After completion of the initial criteria evaluation matrix, the DSB reviewed the results, which were based on the pre-workshop draft criteria weighting factors and conducted a sensitivity analysis by adjusting weighting factors for the various criteria. Based on review of the second evaluation matrix, the DSB concluded the weight changes did not change the ranking.

The results show WWO and SRWOP with the highest scores, while PCOP and ICV™ received the lowest scores. The NCIP and FROP ranked in the middle.

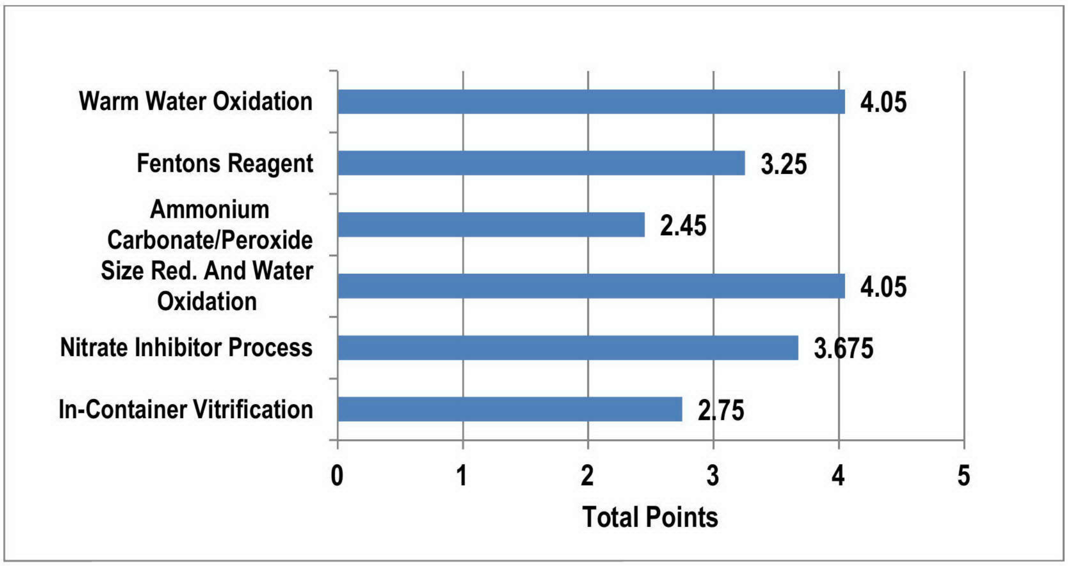

Figure 4-4. Total Ranking Values for Each Technology

4.3.2 DSB Recommendations

The technology approach recommended by the DSB team is to use Warm Water Oxidation (WWO) as a technical baseline and continue work to develop SRWOP and FROP processes as alternatives to potentially enhance the baseline. If implemented, these recommendations would result in development and demonstration of these three technologies during conceptual design for STP Phase 2 to achieve TRL-4 in support of Critical Decision 1 (CD-1). As an adjunct to the continued work to develop these technologies, the DSB recommended resolution of the outstanding regulatory issue identified during the DSB deliberations with NCIP. The DSB also identified direct sludge drying as a potential method of meeting requirements to ship the waste to WIPP without the necessity of oxidizing the uranium metal in the sludge. While there were technical uncertainties with this approach, the DSB recommended evaluation of the feasibility of this approach, along with discussions with WIPP regarding previous experience with drying as a stabilization method.

In addition, the DSB recommended maintaining a flexible conceptual design approach, including definition of functions and requirements to facilitate other site RH-TRU waste, which was specifically called out in the overall path forward.

The DSB risk mitigation recommendations centered on technology development, maintaining remote operating systems, and aggressive RH-TRU drum production. Technology development risk mitigation recommendations included:

- Focus on in-process sludge assay instrument testing to confirm the ability to accurately assay sludge.
- Consider the potential to remove part of the final waste form from a drum and/or mix and match drums in order to meet fissile gram equivalent limits.
- Evaluation/development of methods for determining completion of the uranium metal oxidation reaction.
- Evaluation/development of methods for sludge mixing/suspension.

In summary, the overall path forward recommended by the DSB calls for proceeding into conceptual design with the recommended technology approach while implementing the risk/vulnerability mitigation actions. This would include a schedule for implementation decisions. Specific activities include priority technology bench scale demonstrations, a siting study, evaluation of advanced assay methodologies, and evaluation of the potential to mix waste streams. The path forward also called for a joint DOE (Richland and Carlsbad offices), CHPRC, and WIPP workshop to determine requirements and potential options regarding transport and disposal of RH-TRU in the WIPP.

4.3.3 Implementation Risks and Uncertainties

The DSB identified three main areas of risks and vulnerabilities. They consist of the following:

- Level of process technology development
- Maintaining remotely operated systems
- Aggressive RH-TRU drum production rate of 3 drums/day of the final waste form

The DSB also suggested methods for mitigating the identified risks and vulnerabilities.

The technology development risks and vulnerabilities consisted of in-process sludge assay, determination of when the uranium metal oxidation is complete, and sludge mixing and suspension. In order to mitigate the risks associated with the development of an adequate in-process sludge assay system, the DSB recommended that a survey of potential vendors be completed and several candidate instruments be selected. Testing of candidate instruments would be conducted to determine the best performance for this application. Also to mitigate the sludge assay risk, the DSB recommended the development of the ability to remove part of the final waste form from the drum and to be able to mix and match drums. In order to mitigate the risks associated with the determination of when the uranium oxidation is complete, the DSB recommended also qualifying the process on the operational time and temperature controls so that the reliance solely on process instrumentation could be bypassed if required. In order to mitigate the risks associated with sludge mixing and suspension, the DSB recommended developing appropriate simulants and to conduct full-scale testing of the mixing and transfer systems prior to incorporation into the final design.

In order to mitigate the risks associated with maintaining remotely operated systems, the DSB recommended applying the design lessons learned from other DOE sites, as well as foreign sites where remote handling was used in similar processes (e.g., Sellafield, LaHague). They also recommended that the project acquire expertise in remote handled equipment maintenance. They further recommended maintaining adequate spare parts in order to minimize downtime during maintenance and equipment change-outs.

In order to mitigate the risks associated with an aggressive RH-TRU drum production rate, the DSB recommended applying lessons learned in design from other DOE sites, as well as foreign sites where remote handling was used in similar processes (e.g., Sellafield, LaHague). They also recommended making improvements in process sludge assay accuracy to reduce the drum count (through a lower total measurement uncertainty). This would result in a lower number of total drums required, which would translate into a lower production rate or acceptable TOE in order to process the same amount in a given period of time. They further recommended that consideration be given to running parallel lines to increase throughput.

Taken together, the mitigation steps described above would lower the overall level of risks associated with developing a final design, constructing the facility, and operating it successfully to complete the mission.

5 CHPRC Recommendation

The CHPRC recommendation has been built utilizing technical and programmatic inputs from the DSB and the CHPRC technical team. WWO, FROP, and SRWOP are identified as an attractive suite of technologies to be further developed as a basis for conceptual design. Most of the required process equipment, associated technology, and technology development needs are essentially identical for these alternatives. If limited flexibility features are included in the process system design, this would allow any of these processes to be operated. Therefore, considering the potential for large benefits from SRWOP and/or the FROP, continued parallel development of all three is a desirable approach. NCIP remains a simple and attractive option if the uncertainties concerning regulatory acceptance can be resolved. The DSB also suggested that the feasibility of direct drying be evaluated further. Additional information on both the technical feasibility and the regulatory acceptance of NCIP and sludge drying are needed for evaluation of these approaches as viable alternatives.

The DSB team provided path forward recommendations to deal with technical and programmatic risk that have been incorporated into the CHPRC recommendation.

5.1 Recommended Technical Approach

This section discusses the CHPRC recommendation to DOE-RL for the Technical Approach for Phase 2 Treatment and Packaging of the K Basin Sludge Material. Based on the results of this TEAA evaluation, CHPRC believes that the Technical Approach that has the best chance of successful implementation with a predictable cost and schedule is the development, design, and implementation of Warm Water Oxidation as the technical baseline to oxidize the uranium metal remaining in the K Basin Sludge material prior to immobilization and certification as RH-TRU waste for disposal in WIPP.

Recommendation 1: Develop, Design, and Implement the Warm Water Oxidation Process as the technical baseline for the Phase 2 Treatment and Packaging Project.

Proceeding into conceptual design utilizing WWO as the baseline technology provides DOE with the following key benefits:

- Most mature technical basis, with available water oxidation testing data with real K-Basin sludge
- No significant chemical additions, simplifying the process design and eliminating operational requirements for chemical management facilities, training and qualification programs, and providing PPE to workers for those chemical receipt, handling, and transfer operations.
- Operation at less than atmospheric pressure simplifies safety controls and confinement features
- A reasonable processing schedule, with opportunity for further optimization
- Proposed processing equipment can be designed to implement a range of other processes, further reducing risk

To further reduce the residual implementation risk, and to enable potential significant reductions in the projected operations schedule, CHPRC recommends that a parallel development and demonstration of the SRWOP and FROP be carried out with an objective to achieve demonstration of TRL-4 in the same timeframe as the WWO baseline conceptual design. This recommendation is consistent with the DSB recommendation discussed in Section 4.3.

Recommendation 2: Conduct Parallel development and demonstration of the Size Reduction Process through TRL-4 Demonstration.

SRWOP has a number of positive impacts on the overall WWO process. The reduction in the maximum uranium metal particle from 0.25" to less than 100 microns results in a substantial reduction in the time required to complete oxidation and could reduce the sludge treatment schedule by 2-3 years. The size reduced slurry will be much easier to transfer, agitate, assay, and incorporate into a homogeneous final product form.

Recommendation 3: Conduct Parallel development and demonstration of the Fenton's Reagent Process through TRL-4 Demonstration.

The FROP also has a significant impact on the uranium metal oxidation rate, and could reduce the sludge treatment schedule by 2-3 years. While a complete understanding of the detailed process chemistry remains to be developed, it appears that FROP will oxidize both the uranium metal and the uranium oxide compounds present to the highest oxidation state. This would place all the uranium present into the lowest density chemical form and eliminate any concerns regarding swelling that might occur post packaging due to ongoing oxidation of uranium oxides.

If either one of the enhancement pathways is successfully demonstrated, it would be incorporated into the project baseline to realize the 2-3 year operations schedule reduction and the significant operational cost reduction resulting from these improvements.

Recommendation 4: Resolve outstanding regulatory issues regarding NCIP and determine the technical feasibility of Direct Sludge Drying.

As an adjunct to the above recommendations, further evaluations should be conducted of the NCIP and sludge drying as potential technologies that might meet the requirements for shipment to WIPP without the oxidation of the uranium metal in the sludge. The potential waste acceptance compliance issues and technical feasibility with the NCIP and direct sludge drying should be discussed with WIPP to determine if there is any advantage to continue development and demonstration of these processes.

5.2 Mitigation of Residual Risk and Vulnerabilities

While CHPRC has high confidence in the recommended path forward, normal development and demonstration activities to support the Phase 2 Conceptual Design are required, along with the development and demonstration of SRWOP and FROP.

Uncertainties in the interpretation and application of requirements contained within the WIPP RH-TRAMPAC and the WIPP WAC need to be resolved prior to the start of or early in the conceptual design process. This will assure that the functions and requirements for the Phase 2 project will include a clear definition of all the necessary performance requirements.

Once the RH-TRAMPAC and WAC requirements are clarified, the Phase 2 project should proceed with a demonstration and selection of the desired waste immobilization approach. Currently, CHPRC has identified that selected grout formulations, Aquaset II®[6] clay absorption, and BoroBond™ (magnesium phosphate low temperature ceramics) can successfully immobilize the oxidized sludge material without the formation of unacceptable bleed water during storage and transportation of the immobilized sludge. Selected No-Char agents have been used at other sites to achieve a similar immobilization of stable waste materials.

The primary outstanding technical risk for the Phase 2 STP is the successful development, demonstration, and design of the remote handling and remote maintenance systems necessary to complete the packaging, immobilization, and assay of the immobilized RH-TRU waste package. While there are examples of remotely operated and contact-maintained systems for immobilization and packaging of radioactive wastes, there are few examples of waste packaging systems that are both remotely operated and remotely maintained. Primary examples identified are the massive high level fuel and waste processing facilities in the US and elsewhere in the world. These remotely operated and maintained systems have been deployed in large shielded facilities, with significant remote maintenance capabilities to remove and replace modular components.

CHPRC recommends a robust development and design process for the Phase 2 conceptual design effort similar to that used to develop and finalize the design of the Phase 1 sludge retrieval, packaging, and transport systems. This approach is characterized by the early involvement of engineering and operational staff in the development of concepts, testing of those concepts as part of developing and finalizing the design, followed by qualification of the designed system at the component and integrated system level. Use of a robust range of simulants, validated by testing with real sludge, is a necessary element of this development approach. It is likely that the integrated system testing will be done at essentially full scale, eliminating potential scale up issues from the design process.

An important schedule and cost driver will be the determination of whether the Phase 2 RH-TRU treatment and packaging capability is located in an upgraded existing facility, or deployed in a new category 2 structure (and whether integrated in some way with the balance of the Hanford site waste treatment plans, or as a facility dedicated to Phase 2 sludge processing).

A lifecycle Phase 2 Project Plan should be developed that identifies the major technical information needed to support the conceptual design baseline, as well as the parallel risk reduction activities. The primary technical and programmatic decisions need to be identified and scheduled so that the project can move forward. The functions and requirements for the Phase 2 project should include specific features that would enable the adoption of SRWOP, NCIP, or FROP, if these development programs are successful. As discussed earlier, it appears that all three processes share significant commonalities and could be implemented in similar equipment systems, with the noted differences in materials of construction.

During the deliberation of the DSB, a number of risks/uncertainties were identified. CHPRC has evaluated those risks and has identified mitigating actions for the risks identified. The DSB identified risks and uncertainties, and CHPRC's identified mitigation strategies are provided in Table 5-1.

[6] Aquaset II is a registered trademark of Fluid Tech - A Division of IMPACT Services, Inc., 2865 S. Jones Blvd., Suite 200, Las Vegas, NV 89146.

Table 5-1. Phase 2 Project Risk and Proposed Mitigation Approaches

	DSB Identified Risks/Uncertainties	Identified Risk	CHPRC Risk Mitigation Action
1.0	Technology		
1.1	In-process sludge assay	May overload sludge in the immobilized waste product; or underutilize available drum capacity	• Full scale development and demonstration with bounding simulants • Evaluate final product waste forms which may allow removal of loaded waste material along with mix/match of drums (powdered immobilizing agents vs. monoliths)
1.2	Monitoring completion of U-metal oxidation	Uranium metal may exceed limits in the immobilized waste form	• Parallel development and demonstration of off-gas fission product/and or hydrogen monitoring approach. • Assess process qualification approach using limiting compositional parameters
1.3	Sludge mixing/suspension	Inadequate mixing coupled with inadequate design features could result in accumulation of U-metal and large sludge particles in reaction vessels; and/or could result in non-uniformity in the immobilized product	• Develop and demonstrate vessel agitation systems with engineering and full scale mixing equipment with bounding simulants validated with testing with actual sludge materials • Immersion mill to eliminate fast-settling particles • Incorporate design features to allow remote flushing and cleanout of vessels and lines as required. • Demonstrate lost-paddle mixing of sludge and immobilization agent in waste drum at full scale with bounding simulants validated with testing with actual sludge materials
2.0	Maintaining remote operating systems	Unable to sustain production of remote-handled drums meeting requirements	• Evaluate existing industrial experience (US, Sellafield, LaHague) with remote packaging of similar materials • Full scale development, design, and demonstration of prototypical equipment at the component and integrated system level; including mockup of required maintenance capability and facility constraints. • Develop a suite of bounding simulants validated with actual sludge samples.
3.0	Aggressive RH-TRU drum production rate of 3 drums/day of final waste form	Complex operational steps and/or required maintenance results in excessive downtime and extends the production schedule with attendant increase in costs	• Develop and demonstrate remote mechanical equipment at full scale with bounding simulants. • Establish achievable production rates for major component systems based on testing and FMEA studies. • Incorporate installed redundancy and/or parallel lines as required • Incorporate quick change modules to reduce maintenance downtimes • Define and establish required spare parts and modules to support ongoing operations

6 CHPRC Implementation Plan

At this time no funded path forward has been established for the Phase 2 project, so it is not clear when the conceptual design of the treatment and packaging facility could begin. DOE has recently negotiated revised TPA milestones which established M-16-171 to complete the Phase 2 Treatment Technology Evaluation Report (due March 31, 2012), and M-16-173 to formally select the Sludge Treatment and Packaging Technology (due March 31, 2015).

While an integrated life-cycle project plan will address all of the key elements required over the project's lifecycle, CHPRC has identified several technical and programmatic activities that could be addressed in the immediate future (between now and September, 2011), the near term (FY12), and mid-term actions (FY13 and beyond) to obtain necessary design data, conduct engineering analyses, and focus the project deployment strategy prior to the start of conceptual design.

Performance of the activities proposed below would be contingent on the availability of funding and contract direction and concurrence from DOE-RL.

6.1 Immediate Actions

- Schedule a series of Requirements Workshops with WIPP officials to identify, refine, and address outstanding issues with regard to the applicability and interpretation of requirements established in the RH-TRAMPAC and WAC for WIPP. Clarification of requirements is also needed to evaluate the potential for continued development of the nitrate chemical inhibitor process or direct drying and packaging of sludge as identified by the DSB. It is important that a common, agreed upon set of interpretations be established prior to finalizing the Functions and Requirements/FDC for the Phase 2 project.

- Conduct a formal siting study to determine the preferred location of the Phase 2 Treatment capability. Required seismic and structural evaluations should be identified, including needed updates to seismic source terms and soils data to meet current requirements and expectations. For existing facilities, the current conditions and seismic/safety qualifications should be reviewed, and potential updates, upgrades, and expansions due to increased sludge treatment source terms and proposed operations should be identified. Ongoing operational plans should be evaluated to identify any space and/or resource conflicts. Costs and schedules for upgrades and modifications should be developed and compared to costs and schedules for new construction alternatives.

- Develop and maintain a flexible conceptual design for space considerations in the functions and requirements to facilitate potential packaging of other site RH-TRU waste. As shown in Appendix M of Volume 2, the primary shared functions of these identified streams and the K-Basin sludge material is the need for a qualified, category 2 structure with a robust nuclear ventilation systems, and the immobilization, packaging, and assay of the product waste drums.

- Authorize uranium metal size reduction testing to establish that the previous simulant work is representative of the potential for size reduction. This work can be done in the near term and would serve to focus subsequent near term testing and technical development work.

- Develop a project lifecycle plan to support out-year budget planning, as well as the necessary change requests and other contract direction requirements for CHPRC. Once the necessary change requests and contract direction are approved, CHPRC will update the STP Project Execution Plan (or create a standalone PEP) to reflect the DOE-RL approved contract direction.

6.2 Near-Term Actions

- Develop a project technology maturation plan to support conceptual design activities and assure that demonstration of TRL- 4 for the baseline WWO can be achieved to support a future CD-1 determination by DOE. In parallel the plan should advance the SRWOP and FROP to the same level so that a decision to incorporate one of the alternatives into the baseline project can be made prior to start of preliminary design. The following activities would be expected to start if funding is available:
  - Initiate expanded WWO process chemistry and physical property evaluations that address a wider range of sludge materials, a range of operating conditions, and establish a technical basis for an integrated material balance flowsheet including off-gas generations and secondary waste treatment requirements (if any).
  - Initiate the demonstration and selection process for the immobilization agent to be used for immobilization of the oxidized K Basin Sludge material. Consider Portland cement-based formulations, clay materials, BoroBond™, and commercially-available sorbent agents.
  - Initiate bench and engineering scale testing to demonstrate and design the uranium SRWOP. If testing is successful, continue to full scale demonstration of an integrated SRWOP system.
  - Initiate expanded FROP process chemistry evaluations to provide an improved understanding of the species being formed during the reactions, the off-gas being generated, and the physical characteristics of the oxidized sludge slurry. Evaluate a wider range of sludge materials, a range of operating conditions, and optimize the use of chloride ion and ferric ion for these sludge materials. Establish a technical basis for an integrated material balance flowsheet including off-gas generation and secondary waste treatment requirements.
- Evaluate the remote operations and remote operational experience for other similar waste streams in the US, at Sellafield, and LaHague, and identify remote design concepts that can be adapted to the sludge immobilization and packaging mission. Begin the development of components that can be tested with a range of simulant material to refine the design at the component level. Ultimately the demonstrated components would be integrated into a full scale operational system to determine the achievable productivity of the packaging system and finalize the immobilization and packaging system design.

6.3 Mid-Term Actions

- Develop a detailed material balance and flowsheet as the technical basis for the STP Phase 2 Treatment and Packaging Project.
- Prepare for the start of conceptual design by updating the Functions and Requirements or Functional Design Criteria documents based on results of previous activities, updating/preparing the Project Execution Plan, update/revise the STP Justification and Mission Need for the project (if required).
- Establish the acquisition strategy for the performance of the conceptual design (in house supported by staff augmentation vs. subcontract for conceptual design).
- Complete any outstanding tradeoff studies previously identified to firm up the basis for the conceptual design.

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K-BASIN SLUDGE TREATMENT PROJECT - PHASE 2 TECHNOLOGY EVALUATION AND ALTERNATIVES ANALYSIS

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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Contents

Appendices

Acronym List

AACE	Association for the Advancement of Cost Engineering
AD	Advancement Degree of Difficulty
ALARA	As Low As Reasonably Achievable
CD	Critical Decision
CDR	Conceptual Design Report
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHPRC	CH2M Hill Plateau Remediation Company
CH-TRU	Contact Handled Transuranic
CT	Condensate Tank
CTE	Critical Technology Element
CWC	Hanford Central Waste Complex
DNFSB	Defense Nuclear Facility Safety Board
DOE	Department of Energy
DOE-CBFO	Department of Energy – Carlsbad Field Office
DOE-HQ	Department of Energy - Richland Headquarters
DOE-RL	Department of Energy - Richland Operations Office
DOT	Department of Transportation
DSB	Decision Support Board
EC	Engineered Container
ECRTS	Engineered Container Retrieval and Transfer System
EF	Enhancement Factor
EPA	Environmental Protection Agency
EPC	Engineering, Procurement, and Construction
ERDF	Environmental Restoration Disposal Facility
ETF	200 Area Effluent Treatment Facility
FDC	Functional Design Criteria
FGE	^{239}Pu Fissile Gram Equivalents
FROP	Fenton's Reagent Oxidation Process
FRPT	Feed Receipt and Preparation Tank
FY	Fiscal Year
GFM	Garnet Filter Media or Glass Forming Materials

HEPA	High-Efficiency Particulate Air
HPT	Health Physics Technician
HVAC	Heating, Ventilation and Air-Conditioning
ICV™	In-Container Vitrification™
ISC	Interim Storage Container
IVS	Induction-Heated In-Container Vitrification System
IWTS	Integrated Water Treatment System
IXM	Ion Exhange Module
KE	K East
KOP	Knock-Out Pots
KW	K West
LAW	Low-Activity Waste
LCC	Life-Cycle Costs
LDC	Large Diameter Container
LLNL	Lawrence Livermore National Laboratory
LST	Lag Storage Tank
mR	milirem (=10^{-5} sieverts [Sv])
MT	Milling Tank
NCIP	Nitrate Chemical Inhibitor Process
NLOP	K Basin North Loadout Pit
NRC	U.S. Nuclear Regulatory Commission
O&M	Operations and Maintenance
OIER	Organic Ion Exchange Resin
PCB	Polychlorinated Biphenyl
PCIP	Phosphate Ceramic Hydrogen Inhibitor Process
PCOP	Peroxide Carbonate Oxidation Process
PFD	Process Flow Diagram
PNNL	Pacific Northwest National Laboratory
PSD	Particle Size Distribution
RCMT	Receipt, Concentration and Mix Tank
RCRA	Resource Conservation and Recovery Act
RH-TRAMPAC	Remote Handled Transuranic Waste Authorized Methods for Payload Control
RH-TRU	Remote Handled Transuranic

RH-WAC	Remote Handled Waste Acceptance Criteria
RLC	Removable Lid Canister
ROD	Record of Decision
ROM	Rough Order-of-Magnitude
RRT	Receipt and Reaction Tank
SBS	Submerged Bed Scrubber
SDF	Slurry Dilution Factor
SEM	Scanning Electron Microscope
SME	Subject Matter Expert
SRS	Savannah River Site
SRWOP	Size Reduction Water Oxidation Process
STP	Sludge Treatment Project
STS	Sludge Transport System
STSC	Sludge Transport and Storage Container
TEAA	Technology Evaluation and Alternatives Analysis
TBD	To Be Determined
TEC	Total Estimated Cost
TME	Technical Maturity Evaluation
TMP	Technical Maturation Plan
TMU	Total Measurement Uncertainty
TOE	Total Operating Efficiency
TPA	Tri-Party Agreement
TRL	Technical Readiness Level
VSS	Volume Fraction Settled Solids
WIPP	Waste Isolation Pilot Plant
WM	Waste Management
WWO	Warm Water Oxidation
µm	micrometer (10^{-6} meter)
® and ™	Denote registered trademarks in the United States and other countries. All logos and trademarks are the property of their respective trademark owners, and all rights are reserved.

Description of Volume II

As part of the retrieval and processing of the Container and Settler Tank sludge contained in the K West Basin, it is first removed from K West Basin and placed in STSCs for interim storage at T Plant on the Central Plateau. This retrieval and storage process is called Phase 1. Phase 2 consists of the treatment and packaging of the sludge for eventual shipment to WIPP as RH-TRU for permanent emplacement in that repository. This report, in two volumes, conveys the results of the Technology Evaluation and Alternatives Analysis (TEAA) conducted as the first part of Phase 2.

Volume 1 of this report contains the CH2M HILL Plateau Remediation Company (CHPRC) summary report on the results from the TEAA for treatment and packaging of Container and Settler Tank sludge contained in the K West Basin.

Volume 2 – this volume – consists of the appendices that provide the details that support Volume 1 evaluations and recommendations. Of particular note is Appendix J, which provides the bases and assumptions that were used in the development of the base case flowsheets and subsequent analyses of all of the technologies evaluated. Appendix P is the final report of the Decision Support Board (DSB).

Appendices A through P provide supporting documentation for the information contained in Volume 1 and serve as the basis for the evaluations and recommendations made. They summarized as follows:

- Appendix A contains results of technology development activities and evaluations of the Warm Water Oxidation (WWO) proposed process.
- Appendix B contains results of technology development activities and evaluations of the proposed Fenton's Reagent Oxidation Process (FROP).
- Appendix C contains results of technology development activities and evaluations of the proposed Peroxide and Carbonate Oxidation Process (PCOP).
- Appendix D contains results of technology development activities and evaluations of the proposed Size Reduction and Water Oxidation Process (SRWOP).
- Appendix E contains results of technology development activities and evaluations of the proposed Nitrate Addition Chemical Inhibitor Process (NCIP).
- Appendix F contains results of technology development activities and evaluations of the In-Container Vitrification™ (ICV™)[1] proposed process.

[1] In Container Vitrification and ICV are registered trademarks of the Geosafe Corporation, a wholly-owned subsidiary of Battelle Memorial Institute of Columbus, Ohio, whose ICV technology is exclusively licensed to Impact Services, Inc., 103 Palladium Way, Oak Ridge, TN 37830; all rights reserved.

- Appendix G contains results of technology engineering analyses and evaluations of the Induction Melter Vitrification (IMV) proposed process.
- Appendix H contains results of technology development activities and evaluations of the proposed Phosphate Ceramic Hydrogen Inhibitor Process (PCIP).
- Appendix I presents sensitivity analyses of results from varying basis or assumption parameters.
- Appendix J contains the bases and assumptions on which the individual process flowsheets were based, as well as data on sludge simulants used in testing.
- Appendix K contains information on K Basin garnet filter material.
- Appendix L contains information on K Basin North Loadout Pit and KE sand filter media.
- Appendix M contains an analysis of the potential for other Hanford RH-TRU to be processed in the same facility containing the K Basin sludge processing.
- Appendix N presents an analysis of regulatory and stakeholder issues.
- Appendix O contains cost and schedule analyses for each of the proposed processes.
- Appendix P contains the final DSB report.

Appendix A

Evaluation Data for Warm Water Oxidation (WWO) – (AREVA)

A1 Introduction

The purpose of the Warm Water Oxidation (WWO) and Immobilization System is to treat and immobilize Hanford K-Basin (KB) sludge, consisting of K-East (KE), K-West (KW), and Settler Tank sludge, for long-term storage as part of Phase 2 of the Sludge Treatment Project (STP). Phase 2 of the STP is defined as the treatment (stabilization) and packaging (immobilization) of the sludge such that it can be transported to and disposed of at the Waste Isolation Pilot Plant (WIPP) as remote-handled transuranic (RH-TRU) waste.

The K-Basin sludge consists of metallic fuel corrosion products (uranium metal particles, uranium oxides, fission and activation products), iron and aluminum oxides and hydroxides, sand, graphoil (graphite seal material), concrete grit, ion exchange beads, cationic polymer flocculent, trace amounts of polychlorinated biphenyls (PCBs), operational debris, and biological debris. Three types of sludge are considered. Sludge from the KE and KW basin floor has been collected into five dedicated engineered containers (ECs) located underwater at KW and sludge retrieved from Settler tanks has been collected into a separate dedicated EC. Information on the characteristics of KE floor, KW floor, and Settler Tank sludge streams and the container types in which they have been stored is compiled in Reference [7]. The sludge will be delivered to the WWO system in Sludge Transport and Storage Containers (STSCs). The delivery of this sludge to the WWO System via this method is given as an enabling assumption in Appendix J.

The WWO treatment system will use warm water (95° to 98° C) to oxidize the uranium metal particles to uranium oxides in order to sufficiently reduce hydrogen generation so that it will be safe during transportation, interim storage, and disposal. The oxidized sludge will be mixed with a cement-mix or other absorbent for immobilization and then packaged in drums for final disposal. The waste form that results from applying Phase 2 treatment and packaging technologies are required to meet the WIPP waste acceptance criteria (WAC) for transportation and final disposal as RH-TRU waste [10] as well as the Hanford Site's waste acceptance criteria [11] for its interim storage. The packaged RH-TRU waste form must also meet shipping requirements as established in Remote-Handled Transuranic Waste Authorized Methods for Payload Control (RH TRAMPAC) [8]. The WWO treatment system will be operated in a controlled-access environment using remotely controlled manipulators, process controls, sensors, actuators, and other technologies as necessary to increase process efficiency. The configuration will take into account access, maneuverability, and the geometry of the radiation environment. The complete, integrated WWO treatment system will include all required instrumentation and process-control technologies for remote operation.

This WWO technology, as well as other technologies, is evaluated for its safety, regulatory and stakeholder acceptance, technical maturity, and operability and maintainability. The safety goals are to determine if the system and its operations ensure worker safety and the protection of the general public. The regulatory goals are to ensure the WWO system, its operation, and processed products will comply with environmental laws and regulations. The operability and maintainability goals of the system are to ensure ease of operation, maintenance, and process control. The technical maturity goals are to maximize confidence in the process implementation with the technology elements and associated technologies identified in the Process Description and Flowsheets of Warm Water Oxidation Process for Treatment of K-Basin Sludge [2].

The technical maturity considers the current scale of the technology, the scale of testing that has been demonstrated, the test environment, and the results of testing. Technical maturity also considers the readiness of the technology for integration into higher scales of system development up to and including the pilot scale. Specific areas of technical maturity evaluation done for WWO included operability, maintainability, safety, process controls, integrated operations, and remotability in a radiologically secure facility. The evaluations also considered the technical maturity with respect to regulatory acceptance, the ability to process K-Basin sludge waste inventory within a prescribed 5-7 year period [9], and the acceptability of secondary waste streams for disposal at the Hanford Site's Environmental Restoration Disposal Facility (ERDF) and Effluent Treatment Facility (ETF). A series of lab-scale tests were conducted to contribute to the evaluation of the maturity of this technology. The details of these tests are described in subsequent sections.

A2 Technology and Flowsheet Summary Description

The WWO treatment system is to use warm water (95° to 98° C) at sub-atmospheric pressure to oxidize the uranium metal particles to uranium oxides in order to reduce hydrogen generation during transportation and long-term storage. The oxidized sludge is to be mixed with grout or other absorbent material for immobilization and packaged in 55-gallon drums for final disposal. Alternatively, the final packaging of the waste may be completed in 30-gallon drums. For the purposes of this report, 55-gallon drums provide the baseline case which is examined. A simplified schematic of the process is given in Figure A-1.

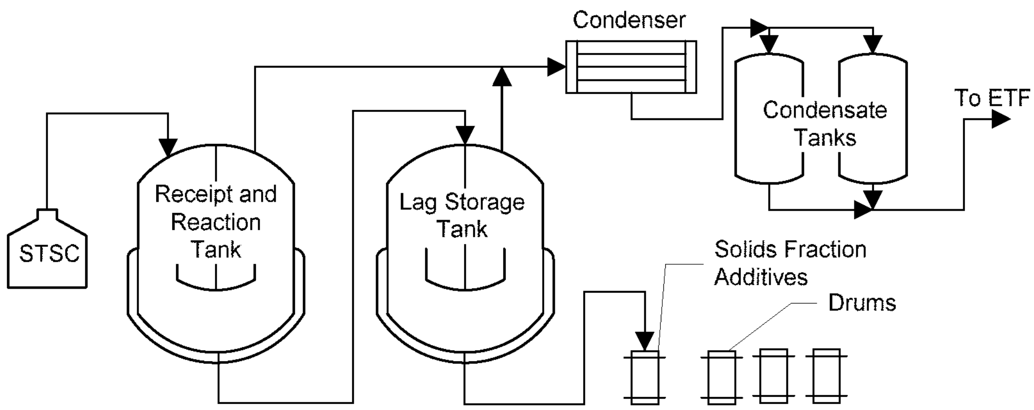

Figure A-1. WWO Process Simplified Flow Diagram

A2.1 Process Description

The overall process is divided into two major parts: 1) in the treatment process the sludge is oxidized to eliminate metallic uranium and water is removed to give the solids concentration desired for the immobilization process. 2) In the immobilization process the concentrated sludge slurry is assayed, metered into drums, and converted to a liquid free solid that is sealed in drums for eventual offsite transport and disposal. Supporting processes such as vent gas treatment, liquid waste disposal, cooling water and process steam supply are included to complete the processes. Figure A-2 is a more detailed flowsheet showing the components of the entire system, the routing of sludge, water, steam, process gases and off-gases, and grouted products within the system, and the relational interfacing of the components.

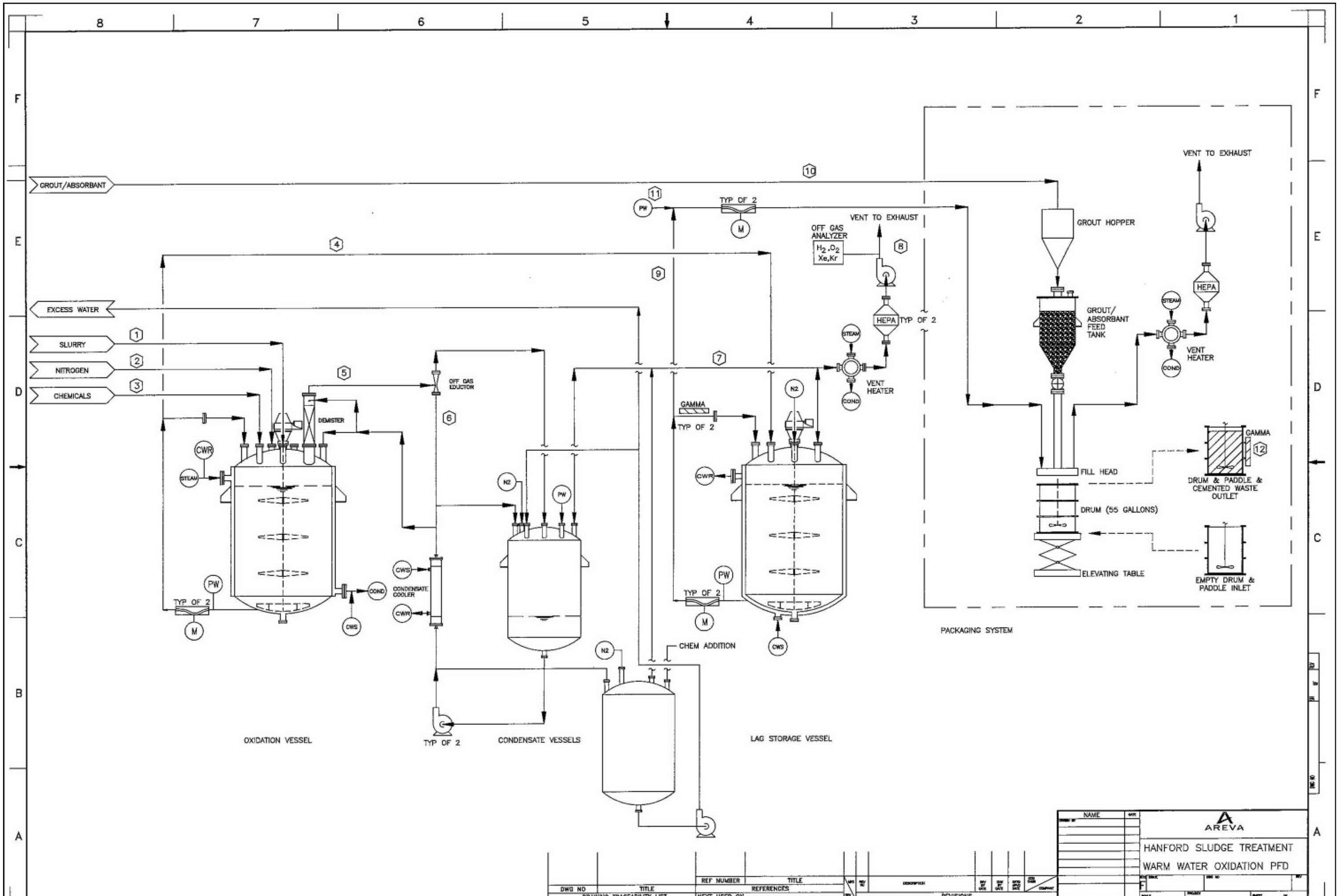

Figure A-2. Detailed WWO Flowsheet

A2.1.1 Treatment Process

The oxidation operational unit of the WWO consists of a Receipt and Reaction Tank (RRT) to oxidize uranium metal, condensate tanks (CT) to collect and temporarily store boil-down water from the RRT, and a Lag Storage Tank (LST) for the temporary storage of oxidized sludge before feeding it to the packaging system.

The RRT includes the following features:

1. An agitation system to continuously stir and mix the sludge slurry in order to keep the sludge particles in suspension, allowing uranium metal to be available for oxidation.
2. An off-gas analysis system to analyze RRT vent gas for fission product gases in order to determine the extent of the oxidation reaction.
3. A High-Efficiency Particulate Air (HEPA) filtration system for all process off-gas streams.

The processes in the RRT will oxidize uranium metal in warm water to yield uranium (IV) dioxide (UO_2). Flowsheet mass balances for KE, KW, and Settler Tank sludge are provided in Reference [2].

Dissolved oxygen inhibits the oxidation of uranium. Therefore, to release dissolved oxygen from the slurry, the oxidation reaction is operated at the boiling point of the solution at reduced pressure by applying steam to the RRT jacket and reducing pressure though the condenser vent system. Reduced pressure boiling improves heat transfer and temperature uniformity within the RRT, releases absorbed oxygen from the water, and permits the removal of excess water from the slurry by evaporation. Steam generated during the evaporation step flows first to a demister to remove any entrained material and then to a water cooled condenser. Non-condensed vent gas is warmed and filtered prior to discharge. Condensate drains to a Condensate Tank. Where feasible, clean condensate is recycled for retrieval, line flushes and the immobilization step. Excess condensate is sampled and shipped by truck to ETF for disposal.

Because the oxidation reaction liberates hydrogen gas, flammability concerns are reduced by excluding oxygen from the vapor spaces of the RRT by purging with nitrogen gas. The system uses a constant nitrogen feed to sweep hydrogen from the RRT headspace.

Oxidized sludge is transferred to the LST, which holds the entire contents of the oxidation reaction vessel product prior to packaging. The Lag Storage Tank is sized to hold at least a full concentrated batch from the RRT. Once the RRT is emptied, preparation of the next sludge batch can be started while the previous batch is processed by the drumming system. The LST is continuously agitated when a sludge batch is present, and is cooled with a water cooling jacket. A sensor system will provide gamma activity measurements, which will be used to calculate the dose-to-curie rate and estimate the Fissile Gram Equivalent (FGE) in the oxidized sludge in the recirculation loop of the LST. Concentrated sludge is transferred to the assay and drumming system in smaller batches as needed.

Similar to other oxidation treatment processes, one important issue is verification that metallic uranium has been adequately eliminated. For WWO a combination of the following methods will be used:

- Process validation. This method involves performing tests which define process performance sufficiently to provide confidence that the process will perform as expected. This can include both pre-commissioning testing and test data collected during initial hot operations.
- Monitoring of fission product gas generation. Past work on warm water oxidation of actual spent fuel has demonstrated that the fission product gasses (Kr and Xe) are released when the fuel is oxidized.

Release of fission product gasses has been used in laboratory tests to track the oxidation reaction and has also been proposed as a potential method of tracking the in-plant process during hot operation of the warm water oxidation process [2].

- Monitoring of hydrogen generation in the RRT. Hydrogen gas is not expected to be generated by the chemical oxidation process. However, once the chemical oxidation is believed to be complete, the next step is to heat the batch to drive off excess water. There will normally be a small amount of continued hydrogen production during this step due to radiolytic splitting of water. If in fact all of the uranium metal has not been oxidized, additional hydrogen will be produced during this step by warm water oxidation of the uranium metal. Sampling of the vent gas during this step to detect excess hydrogen could be one approach for determining if there is significant residual uranium metal present.

- Monitoring of hydrogen generation in the product drums. Monitoring hydrogen generation rates in product drums could be used to prove significant U metal is not present in the drums. This would involve holding selected drums for a period of time at an elevated temperature (60 ºC for example) and measuring the hydrogen evolution rate. A limited number of drums could be tested using a statistical sampling or process validation approach. An advantage of this method is that it directly correlates with the applicable hydrogen generation limit from drums during shipping. The disadvantage is that it will take a substantial amount of time for each test, likely days or weeks.

A2.1.2 Immobilization Process

The grouting and packaging system will receive oxidized slurry from the LST and receive cement mix (or other absorbent) from bulk storage. The system will blend the oxidized sludge and a cement mix or other absorbent in 55-gallon drums to produce a grouted product suitable for disposal. The WWO and Immobilization System will have a ventilation system with all required instrumentation and controls for remote operation.

The waste form resulting from the oxidation and immobilization process must meet WIPP waste acceptance criteria (WAC) for final disposal as RH-TRU waste [10], the Hanford Site's waste acceptance criteria [11] for interim storage, and TRAMPAC requirements for transportation payload control [8]. To meet these requirements, the oxidized product will be assayed prior to packaging and the waste loading in the storage drums will be adjusted during the drum-filling operation as necessary. The assay approach selected for WWO includes gamma radiation measurements on a recirculation stream from the Lag Storage Tank. These measurements are then used to estimate concentration of WIPP fissile isotopes using a dose to curie methodology.

This data is in turn used to determine the amount of sludge loaded to each drum. Sludge transfer to the drum is controlled by a metering pump which draws from the recirculation stream. Sludge and flush water transferred to the drum are solidified by addition of dry Portland cement based additives. A "lost paddle" in-drum mixing technique is used to blend the dry additives with the sludge slurry, resulting in a solid product with no free liquids. Gamma radiation measurements are taken on the finished drum. Based on these measurements, the content of WIPP reportable isotopes is estimated based on a dose to curie methodology. The storage drums will be loaded into a transport cask, which will undergo the required standard inspection and validation before being shipped from the WWO and Immobilization System facility. An important assumption for this evaluation is that the Hanford Interim Storage Facility will be able to accept the treated and packaged RH-TRU waste sludge.

A2.1.3 Process Chemistry

The function of the WWO system is to oxidize solid uranium metal ($U_{(0)}$) in warm water (boiling temperature at pressure slightly reduced from atmospheric) to create uranium (IV) dioxide ($U_{(IV)}O_2$) by the following reaction:

$$U_{(0)} + 2H_2O \rightarrow U_{(IV)}O_2 + 2H_{2(g)}$$

Other oxidation reactions may occur to create other uranium oxides, but the primary reaction is considered to be the oxidation of the uranium metal to uranium dioxide. Since the Receipt and Reaction Tank is kept free of oxygen gas and dissolved oxygen, the further oxidation of a significant amount of the uranium to a more oxidized form is considered less likely.

The Spent Nuclear Fuel Project Technical Databook [13] gives a temperature-dependent reaction equation to predict the uranium oxidation rate. This equation, given below, is based on the best fit of available WWO data.

$\log_{10}(\text{base rate}) = (9.694\text{-}3{,}565/T)$

Where T = Temperature, Kelvin

base rate = The rate that the uranium metal surface is reacted away, producing

uranium oxide, μm/hr

The Databook [13] also discusses the use of an "enhancement factor" as a numerical value which is multiplied by the calculated rate to obtain an adjusted rate or range of rates to compensate for uncertainty in the rate calculation observed for various sludge and uranium metal samples. The Databook suggests an EF range of 1/3 to 3.0 to be used for safety analyses and design. The least-squares fit to the entire population of uranium-water reaction data gives an EF of 1.

A3 Technology Development Status

The WWO process has undergone a separate technology maturity evaluation (TME). The results of that evaluation are given in Reference 12. This TME was performed in accordance with the CHPRC Buyer Technical Representative's (BTR) statement of work for the STP Phase 2 Alternatives Analysis Support that includes AREVA proof-of-concept testing. This TME was performed in a manner that would allow its results to provide input to technology maturation planning as discussed in the DOE Technology Readiness Assessment (TRA) Guide [14]. The DOE TRA process begins with a list of technology elements from which, based on evaluations of the nature of these elements, a subset of this list is selected as "critical" technology elements. The TME that AREVA prepared did not select a sub-list of "critical" technology elements. Instead, the report selects the technology elements that were considered most important for the system to function as designed. The DOE TRA uses three categories for evaluation of the critical technology elements. They consist of T-Technology, technical aspects; M-Manufacturing and quality; and P-Programmatic, customer focus, documentation. At this very early stage of the project there is little meaningful information concerning the last two categories, the last two categories of M and P were not considered in the TME. Only the technology and technical aspects were considered. On the basis of preliminary evaluations conducted by CHPRC and its subcontractors, the key significant uncertainties of each of the proposed technologies were identified in order to provide statements of work to the potential vendors for subsequent testing and analysis [12]. The main purpose of this evaluation was to determine if any fundamental issues associated with each of the technologies would make the technology unworkable.

The TME describes the primary technology elements, and then provides the results of the evaluation of the technical maturity and technical risks of the key technical elements and their associated technologies. It provides strategies to mitigate the technical risks at the appropriate stages of technology element development and testing. The TME includes tables that summarize the maturity risks and potential strategies to mitigate the risks. It also provides general observations and recommendations for further actions and technology development needed to bring the technologies to the pilot-scale level vis-à-vis the DOE Technology Readiness Assessment Guide. Specific areas of technical maturity evaluation included operability, maintainability, safety, process controls, integrated operations, and remotability in a radiologically secure facility. The evaluations also considered the technical maturity with respect to regulatory acceptance, the ability to process K-Basins sludge waste inventory within a prescribed 5-7 year period [9], and the acceptability of secondary waste streams for disposal at the Hanford Site's Environmental Restoration Disposal Facility (ERDF) and Effluent Treatment Facility (ETF). For Warm Water Oxidation, the main technology development issues were determined to be confirmation of previously reported reaction rates and the corresponding "enhancement factor," the determination of the end of reaction, the physical properties of sludge after long reaction times, the ability to run the process remotely, and the method of assaying the final product for the determination of the packaged quantities that would be shipped to WIPP. This was further refined to include uncertainties associated with the resulting physical properties of the slurry that would affect its ability to be transported and managed. As a result of these analyses, a testing program was initiated that focused mainly on corroborating previously reported reaction rates and determining operating conditions that might affect the ability of the resulting sludge to be transported and managed to meet product specifications. In the latter category, agitation was the focus of the testing.

A3.1 Chemistry and Phenomenology

Much of what is known about the process chemistry for warm water oxidation of metallic uranium in K-Basin sludge has already been compiled in the Spent Nuclear Fuel Project Technical Databook [13]. Much of what is known about the physical properties of the sludge, such as agglomeration, is compiled in an additional document, Reference [17]. In a previous sludge treatment project, changes in the physical properties during oxidation were one of the primary technical issues that resulted in the project's cancellation. At this proof-of-concept stage in the Phase 2 evaluation the primary technical feasibility issues identified for testing were the reaction rate under the proposed WWO operating conditions and the potential for problems associated with agglomeration of the sludge at these temperatures and operating conditions.

A3.1.1 Summary of Testing Performed

Testing was performed to evaluate the feasibility of the Warm Water Oxidation process. The initial tests completed were small scale, and additional, larger-scale stirred reactor tests were completed later. Below is a summary of the test results[1].

A3.1.1.1 Initial Test Scheme

Tests were performed for the purpose of evaluating the effects of agitation and pH adjustment on simulant sludge agglomeration and uranium metal oxidation rates. Two uranium-containing simulant sludge types were used: a full-spectrum uranium-containing KW simulant with nine predominant sludge components, and a bounding 50:50 uranium-mole basis mixture of uraninite (UO_2) and metaschoepite (UO_3) that is intended to simulate settler sludge.

The 27 experiments carried out included 22 conducted at the nominal 95°C WWO temperature and 5 controls conducted at room temperature. Of the 22 experiments at 95°C, half were conducted with agitation (deemed Run #1) and the others were conducted without agitation (Run #2). Within each group (Run #1, Run #2, and the control group), tests were run with each type of simulant sludge and with or without pH adjustment to 12 using sodium hydroxide (NaOH) or sodium phosphate (Na_3PO_4).

Each experiment was carried out in a 50-mL centrifuge tube modified to have a flat bottom. First, approximately 3 ml of simulant (approximately 4.15 g of the KW simulant or 5 g of the 50:50 UO_2:UO_3 simulant) was added to the centrifuge tube. Approximately 0.092 grams of uranium beads (of average diameter 780 μm) were then added. For those tests requiring adjustment to pH 12, either 0.2 M NaOH (1.2 mL) or 0.2 M Na_3PO_4 (2.4 mL) were introduced to the solution. Deionized water was added to the tube to result in a total volume of 25 mL, and the solution was agitated and left overnight to settle. The pH of each sample was determined by removing approximately 0.5 mL of supernatant and testing with a pH electrode. Digital images were also taken to establish settled solids levels and densities.

The first step in each experiment was a 96 hour oxidation rate test carried out at 95° C. The samples from Run #1 were agitated and were placed in an aluminum heating block and agitated at 1,000 rpm. These samples maintained an average temperature of 95.3 ° C. Samples from Run #2 were not agitated and were heated in an oven (with an average temperature of 96° C). Both agitated and unagitated tests were conducted to determine if agitation would be required for the production system. At the end of the 96 hours, each tube was weighed and the solids and water levels were recorded. The pH was once again tested by removing approximately 0.5 mL of the supernatant, and additional digital images were taken.

After the first round of heating, 5 tests each from Round #1 (tests 1, 3, 7, 8, 10)and Round #2 (tests 13, 15, 19, 20, 22) underwent a slump test, during which the test vessel was turned on its side and the amount of time required to initiate slumping was noted. The slump test had previously been developed by PNNL as a quick evaluation of slurry stiffness and could be related to more formal sludge shear stress measurements taken in earlier sampling and testing efforts [20]. A strength test was also done by

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[1] Test results from a preliminary test report from PNNL that is pending (53451-RPT16, Rev. B, Client Review Draft: Warm Water Oxidation Verification – Scoping and Stirred Reactor Tests).

standing a 6.0 gram mass spatula vertically on its end and determining if the sludge bed structure provided sufficient strength to support it. Finally, these samples were destructively evaluated for uranium oxidation rate. The solids in each sample (excluding the uranium beads) were dissolved by adding 8-10 ml of a reagent containing 85% Na_3PO_4 and 0.14 M Na_2SO_4 and heating to 80° C. This reagent has been found to be effective in dissolving the non-metallic uranium oxide solids and still preserving the uranium oxidation state distribution [17]. This reagent also dissolves ferrihydrite and the $Al(OH)_3$ but is not effective for silicates and the OIER and does not dissolve the uranium metal. Once the dissolution was complete, the solution was analyzed via spectrophotometric ultraviolet-visible analysis (UV-Vis). The uraninite/metaschoepite ratio in each sample was determined by comparing the spectrophotometric absorbances of the sample with the spectra of dissolved uranium of known concentration and oxidation state. The remaining uranium metal beads were also collected and weighed.

The remaining 6 test each from Runs #1 and #2 were allowed to settle under static conditions for another 2 weeks. During this time, the samples were either maintained at ambient temperature or heated in the oven to 95° C. After the 2 week settling period, the samples were re-agitated at ambient temperature and then subjected to the slump and strength tests mentioned above.

A3.1.1.2 Initial Test Results

Uranium Metal Corrosion Rates

As shown in the results given in Table A-1 below, the uranium metal corrosion rates were generally equal to or greater than the rate predicted by the Sludge Databook. The calculated rate enhancement factors ranged from 0.90 to 1.74, which are well within the 95% confidence range of the rate equation given in the Databook (corresponding to a rate enhancement factor range of 0.33 to 3). The WWO flowsheet uses an enabling assumption that a rate enhancement factor of 1 can be used; the data from these tests support this assumption.

The corrosion rates for the agitated (Run #1) and static (Run #2) samples are comparable, with any differences falling within one standard deviation. Corrosion rate inhibition caused by sludge blanketing was therefore not considered an issue in the tests.

The pH adjustments done on some samples appear to have little or no effect on the uranium metal corrosion rates. Comparing the results of tests within groupings that only differ in pH (1, 3, 7), (8, 10), (13, 15, 19), and (20, 22) shows that there are no significant trends regarding pH and corrosion rates.

The tests done using the KW simulant had higher uranium metal corrosion rates than those done using the uranium oxide slurry. The tests using the uranium oxide slurry had rates comparable to the Databook predictions. The increased rate with the KW simulant suggests that a solid component, potentially ferrihydrite, could be acting as a redox shuttle or redox agent for the uranium metal oxidation [6].

Table A-1. Uranium Oxidation Information After 96-Hour Heating for both Uranium Metal and 50:50 Uranium Oxide Slurry.

<table>
<tr><th colspan="2"></th><th>Test</th><th>Initial pH</th><th>Average Final pH (a)</th><th>Salt for pH Adj.</th><th>% U(VI)</th><th>Change in % U(VI)</th><th>Corrosion Rate (µm/hr)</th><th>Ratio of Measured Rate to Predicted (Enhancement Factor)</th></tr>
<tr><td rowspan="3">RUN 1</td><td rowspan="3">KW Simulant</td><td>1</td><td>7</td><td>8.4</td><td>none</td><td>59.7</td><td>9.7</td><td>1.554</td><td>1.42</td></tr>
<tr><td>3</td><td>12</td><td>9.1</td><td>NaOH</td><td>73.9</td><td>23.9</td><td>1.524</td><td>1.4</td></tr>
<tr><td>7</td><td>12</td><td>8.4</td><td>Na_3PO_4</td><td>61.5</td><td>11.5</td><td>1.519</td><td>1.39</td></tr>
</table>

		Test	Initial pH	Average Final pH [(a)]	Salt for pH Adj.	% U(VI)	Change in % U(VI)	Corrosion Rate (µm/hr)	Ratio of Measured Rate to Predicted (Enhancement Factor)
	UO_2/UO_3 slurry	8	7	9.4	none	59.6	9.6	1.037	0.95
		10	12	8.7	NaOH	62.2	12.2	0.981	0.9
RUN 2	KW Simulant	13	7	9.3	none	60.4	10.4	1.812	1.73
		15	12	9.1	NaOH	59	9	1.821	1.74
		19	12	9.4	Na_3PO_4	56.2	6.2	1.429	1.37
	UO_2/UO_3 slurry	20	7	8.7	none	58.5	8.5	1.366	1.31
		22	12	8.8	NaOH	57.1	7.1	1.047	1

Sludge Technical Databook Corrosion Rate Predictions

Temperature (°C)	Corrosion Rate (µm/h)	
92	0.854	
95.3	1.045	Average for Tests 1, 3, 7, 8, 10
96	1.09	Average for Tests 13, 15, 19, 20, 22
98	1.229	

(a) Of duplicate tests
(b) The Sludge Technical Databook (Schmidt 2010) reaction rate of uranium metal with anoxic liquid water, expressed as a linear penetration rate (depth of uranium metal reacted per unit time) is as follows:

$$\log 10 \text{rate}, \mu m/h = 9.694 - 3565/T$$, where T is temperature in K.

Note: Agitated tests and static tests were conducted at 96.0°C ± 0.2°C and 95.3°C ± 0.6°C, respectively. The initial U(IV):U(VI) composition was 50:50.

Physical Behavior of Solids

The physical testing involved in the experiments included appearance, settled solids volume (and thus density), and rheology by probing and slumping when tilted. The results of these tests are summarized in Tables A-2 and A-3.

The tests done using uranium-containing KW container simulant (tests 1-7, 13-19) showed that no strong agglomerates were formed in any of the samples, regardless of the conditions used. The length of heating of the samples increased the strength of the KW simulant solids, but even after 2 weeks at 95° C, none of the settled solids could support the weight of the 6.0 gram spatula. Additionally, slumping was observed in all samples within the 5 minute time window. Agitation of the samples expedited the dispersion of solids in the supernatant. Using NaOH to increase pH appears to encourage solids dispersion, and using Na_3PO_4 appears to encourage solids consolidation. Results indicate that the KW simulant solids can migrate into suspension even under static or non-pH adjusted conditions. The adjustment of pH appears to show no significant benefit in terms of physical properties under the conditions tested. Table A-2 below visually shows the effects of pH adjustment on the KW simulant tests.

The tests done using the uranium oxide slurry (tests 8-11, 20-23) showed that the solids morphology was highly dependent on agitation. In agitated tests, the solids material formed a soft, granular bed with some solid agglomerates that were readily suspended after 96 hours of heating. The solids were strong enough to not slump, but could not support the weight of the spatula. Agitated samples kept static for an additional 2 weeks were found to maintain their morphology at room temperature, and to gain strength and stiffness at 95° C. Table A-3 below shows examples of samples affected by agitation.

Table A-2. The Effects of pH Adjustment on KW Simulant Tests

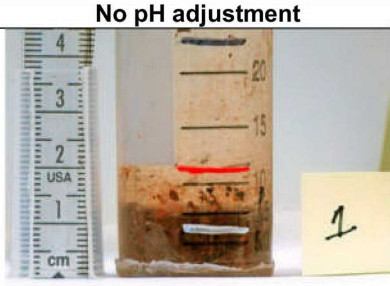
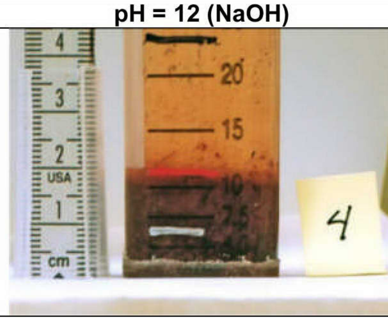
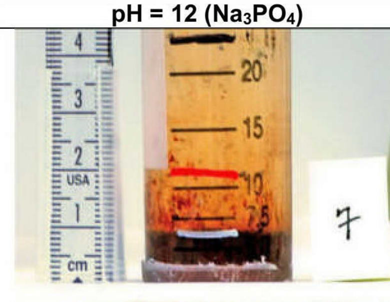
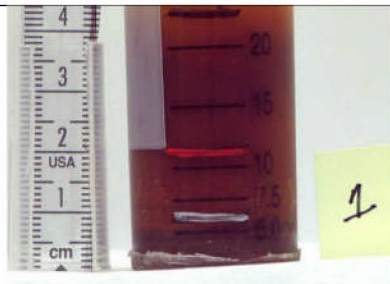
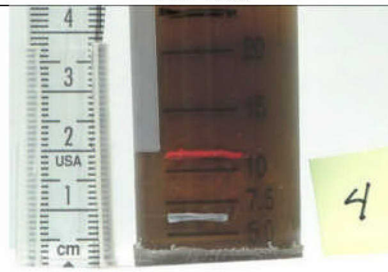
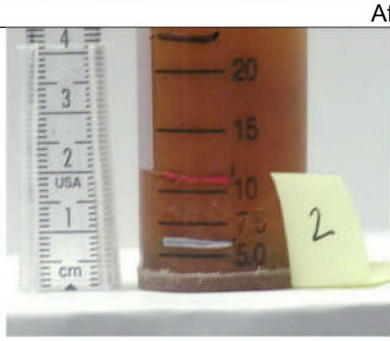
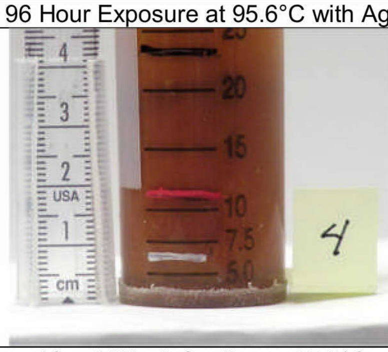
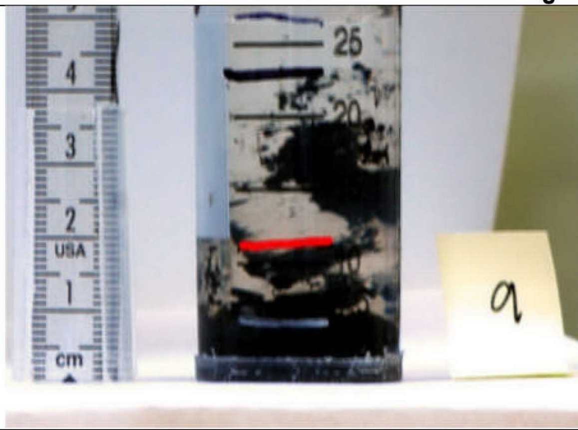
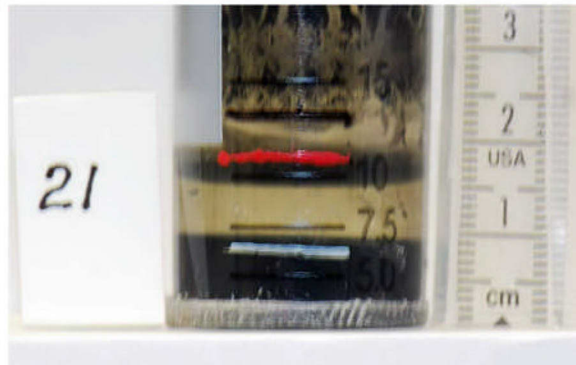
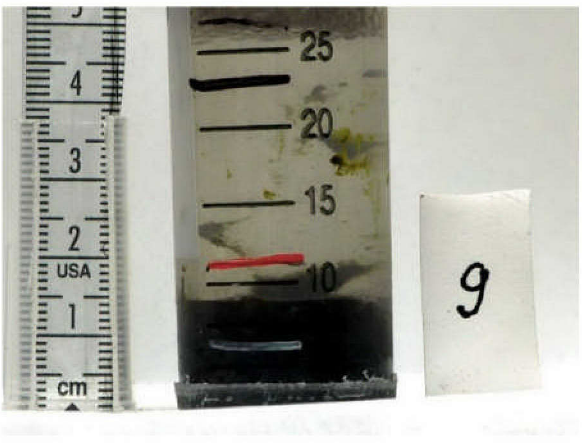
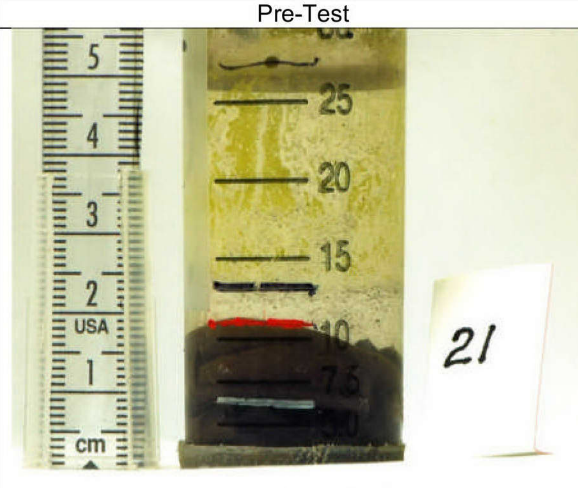
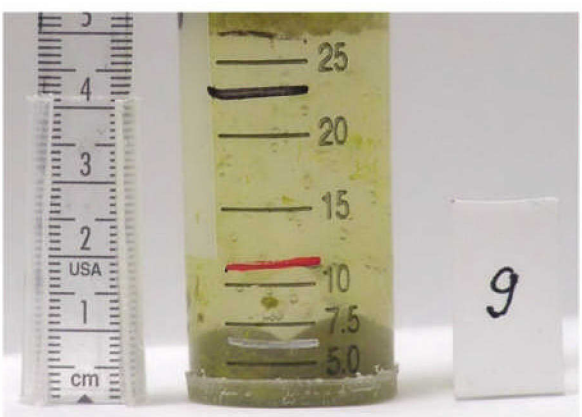
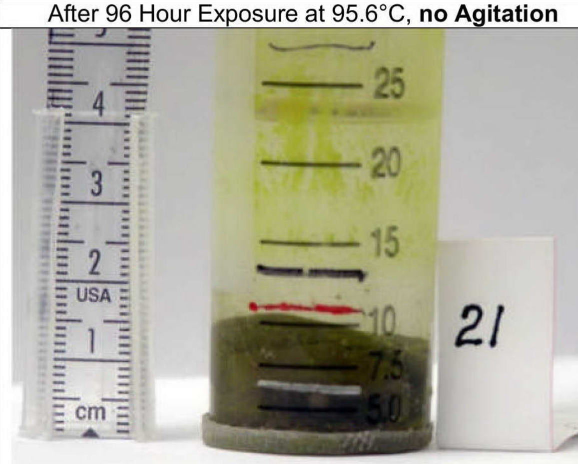
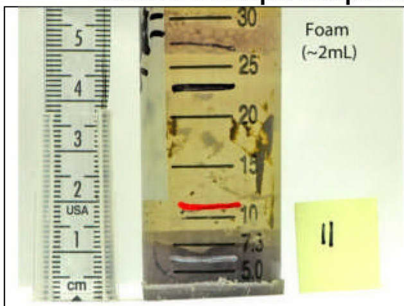
No pH adjustment	pH = 12 (NaOH)	pH = 12 (Na_3PO_4)
		
Pre-Test		
		
After 96 Hour Exposure at 95.6°C with Agitation		
		N/A (Destructively analyzed for oxidation)
After 2 Week Settling at 95.3°C		
Note: Tests 1 and 2 are duplicates and representative samples without pH adjustment. The pH was adjusted to 12 using NaOH and Na_3PO_4 for tests 4 and 7, respectively. All tests were agitated during the initial 96 hour heating. The white, red, thick black, and thin black lines represent 3, 8, 20, and 27 mL volumes.		

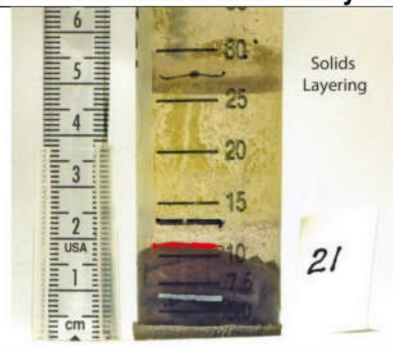
Table A-3. The Effects of Agitation on 50:50 Uranium Oxide Slurry

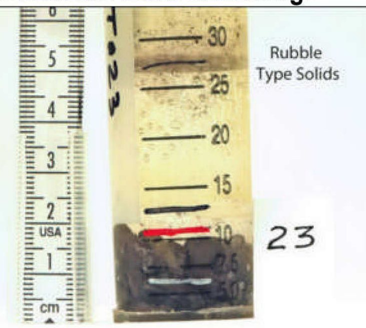
	
Pre-Test	Pre-Test
	
After 96 Hour Exposure at 95.6°C, **with Agitation**	After 96 Hour Exposure at 95.6°C, **no Agitation**
	
After 2 Week Settling at 95.3°C	After 2 Week Settling at 95.3°C
Note: Tests 9 and 21 indicate samples that were agitated and static during oxidation at 95°C, respectively. Neither test was agitated during the 2 week settling period. The pH was not adjusted for any samples. The white line, red line, and thin black line represent 3, 8, and 25-mL volumes. For tests 9 and 21, the thick black line represents 20 and 10 mL, respectively.	

In the static tests, agglomeration was observed within 24 hours of heating at 95° C, though the morphology was highly irregular as shown below in Table A-4. The solids were strong enough to both not slump and to support the weight of the spatula. For all tests, post-test agitation and mixing eroded the formed agglomerates. The pH adjustment did not seem to affect the formation of any agglomerates.

Table A-4. Unique Morphology of 50:50 Uranium Oxide Slurry Mixtures after 96 Hours of Heating.







None of the samples were pH adjusted before heating. Test 11 (left) was agitated during the first interval, the crack in the fine solids maintained over the course of agitation provides indication that the fine and relatively weak solids actually contain a microstructure. Foamed bubbles are present at the top of the supernatant. Test 21 (center) was a static heated test; the plates formed would move independent of each other and did begin to break down after prolonged (2-week) settling at room temperature (not shown). Test 23 (right) is another static heated test. Here the solids more closely represent rocks or rubble.

Table A-5. Test Heights Before Heating and After Heating for 96 Hours

Agitated				Static			
Test & Conditions	Pre-Test Height (cm)	Pre-Test Density (g/mL)	Post 96-Hour Height (cm)	Test & Conditions	Pre-Test Height (cm)	Pre-Test Density (g/mL)	Post 96-Hour Height (cm)
1, pH = 7	1.15	1.4	0.55, D	13, pH = 7	1.15	1.4	0.75, D
2, pH = 7	1.15	1.4	0.35, D	14, pH = 7	1.05	1.4	0.55, D
3, pH = 12 (NaOH)	1.55	1.3	N.D.	15, pH = 12 (NaOH)	0.93	1.5	0.45, D
4, pH = 12 (NaOH)	1.75	1.3	0.15, D	16, pH = 12 (NaOH)	0.86	1.6	0.65, D
5, pH = 7	1.05	1.6	N.D.	17, pH = 7	1.15	1.4	0.65, D
6, pH = 12 (NaOH)	1.25	1.4	0.35, D	18, pH = 12 (NaOH)	0.85	1.6	0.45, D
7, pH = 12 (Na_3PO_4)	0.7	2	N.D.	19, pH = 12 (Na_3PO_4)	0.65	1.8	0.65
8, pH = 7	0.75	2.2	0.95	20, pH = 7	0.75	2.2	1.05, V.F.
9, pH = 7	0.75	2.2	0.85	21, pH = 7	0.65	2.3	1.65. V.F.
10, pH = 12 (NaOH)	0.75	2.2	0.45, D	22, pH = 12 (NaOH)	0.75	2.2	0.75
11, pH = 7	0.75	2.2	1.05	23, pH = 7	0.75	2.2	1.65, V.F.

Agitated					Static			
Test & Conditions	Pre-Test Height (cm)	Pre-Test Density (g/mL)	Post 96-Hour Height (cm)		Test & Conditions	Pre-Test Height (cm)	Pre-Test Density (g/mL)	Post 96-Hour Height (cm)
N.D. - solid presence was "Not Discernible" D - significant sample "Dispersion" observed V.F. - "Void Formation" *Grey-shaded rows indicate samples with only uranium slurry present. All other tests include KW simulant.*								

A3.1.1.3 Stirred Reactor Testing

The initial tests performed (Runs #1 and #2) indicated that the uranium oxidation rates were generally consistent with the rates predicted at 95°C by the Databook rate equation. Agitation was shown to minimize the formation of agglomerates in the 50:50 uranium oxide slurry. Agglomeration did not appear to be an issue in any of the tests using KW simulant. In order to verify the results of Run #1 and Run #2 and examine the scalability of the WWO process, stirred reactor tests were done using larger sample sizes [6].

The larger scale tests were performed in a 300 mL stirred reactor (see Figure A-3) that is more prototypical of the one proposed in the pre-conceptual flowsheet. A constant agitator stir rate of approximately 550 rpm was used, with twice-daily, five minute increases to 1,000 rpm for the 50:50 uranium oxide slurry tests to ensure adequate slurry movement. The reactor was heated using a heating mantle, and maintained by a thermocouple feedback control to the power supply.

The slurry for the KW simulant test contained 100-g (dry basis) simulant, with water added to achieve 15-20 vol% solids. The 50:50 mole percent uranium oxide slurry contained 200-g (dry basis) with water added to achieve 12 vol% solids. Periodic water additions were made to maintain these concentrations. Each test also contained 100 700-µm uranium metal spheres (approximately 0.4 g). Prior to the start of the test, pH was recorded and a photograph was taken.

Each stirred reactor test was heated to and maintained at 95.5°C ± 0.1°C for the entire test duration of 96 hours. Throughout the tests, temperature, slurry level, and agitator rpm were monitored and recorded, as were any additional observations. Post-test analyses were chemical- and physical-based, including settled and total slurry volume, density, pH, visual (photograph), U metal concentration and oxidation state, and solids strength.

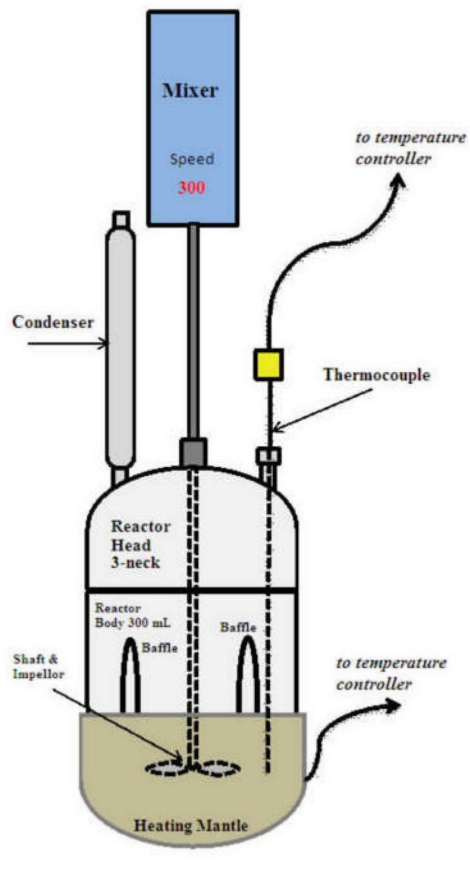


Figure A-3. Diagram of the 300-mL Stirred Reactor Test System

A3.1.1.4 Stirred Reactor Test Results

Table A-6 below summarizes the uranium metal oxidation information after the 96-hour heating test in the stirred reactor. The stirred reactor tests gave uranium metal corrosion rates of 1.74 µm/hr and 1.42 µm/hr for the KW simulant and 50:50 U oxide slurry, respectively, which are very close to those observed in the analogous small-scale tests.

The uranium oxidation state distribution (U(IV):U(VI)) was analyzed as well. In the KW simulant-containing test, three stratified layers emerged after a 72-hour settling period (shown below in Figure A-6), so the oxidation state analysis was done for each layer; the uranium oxide slurry test remained homogenous, so only one test was done. The results of these analyses significantly differed from the small-scale tests. KW simulant test conditions appeared to be highly oxidizing based on the absolute increase in U(VI) of at least 20% for each layer, with the U(VI) fraction increasing with proximity to the surface of the simulant. The 50:50 uranium oxide slurry showed a minimal increase in U(VI), which is much lower than the average absolute increase of 9 ± 2% given by the small scale tests. The discrepancy in these values is thought to be due to better oxygenation in the more shallow small-scale tests.

Table A-6. Uranium Oxidation Information after 96-Hour Heating for stirred reactor testing.

Matrix	Initial pH	Final pH	Final %U(VI)	Change in %U(VI)	Corr. Rate (µm/h)	Ratio of Exp. Corr. Rate to Lit. Corr. Rate
KW Simulant	8.33	6.96	*Top – 73.8*	*Top – 28.8*	1.74	1.64
			Middle – 70.1	*Middle – 25.1*		
			Bottom – 65.7	*Bottom – 20.7*		
Slurry	7.36	8.04	45.7	0.7	1.42	1.34

* Tests were performed at 95.5°C ± 0.1°C. The initial U(IV):U(VI) composition was 55:45.

Because the KW simulant tests showed higher oxidation rates than the uranium oxide tests, it was thought that different oxidation methods may be at play. To further examine this possibility, photographic and SEM images were taken of U metal beads before and after oxidation with each of the simulants. Figures A-4 and A-5 below show the optical images and the SEM images of the starting bead and product beads from the two 96 hour tests.

The images of the beads prior to testing show that they initially have a blue interference oxide coating and a smooth bead surface. After the 96-hour heated oxidation test in KW simulant, the uranium beads appeared to have a smooth, faceted surface with concave conchoidal divots and small raised striations. The uranium metal bead oxidized in the 50:50 uranium oxide slurry, however, had a very rugged, pitted, and layered surface.

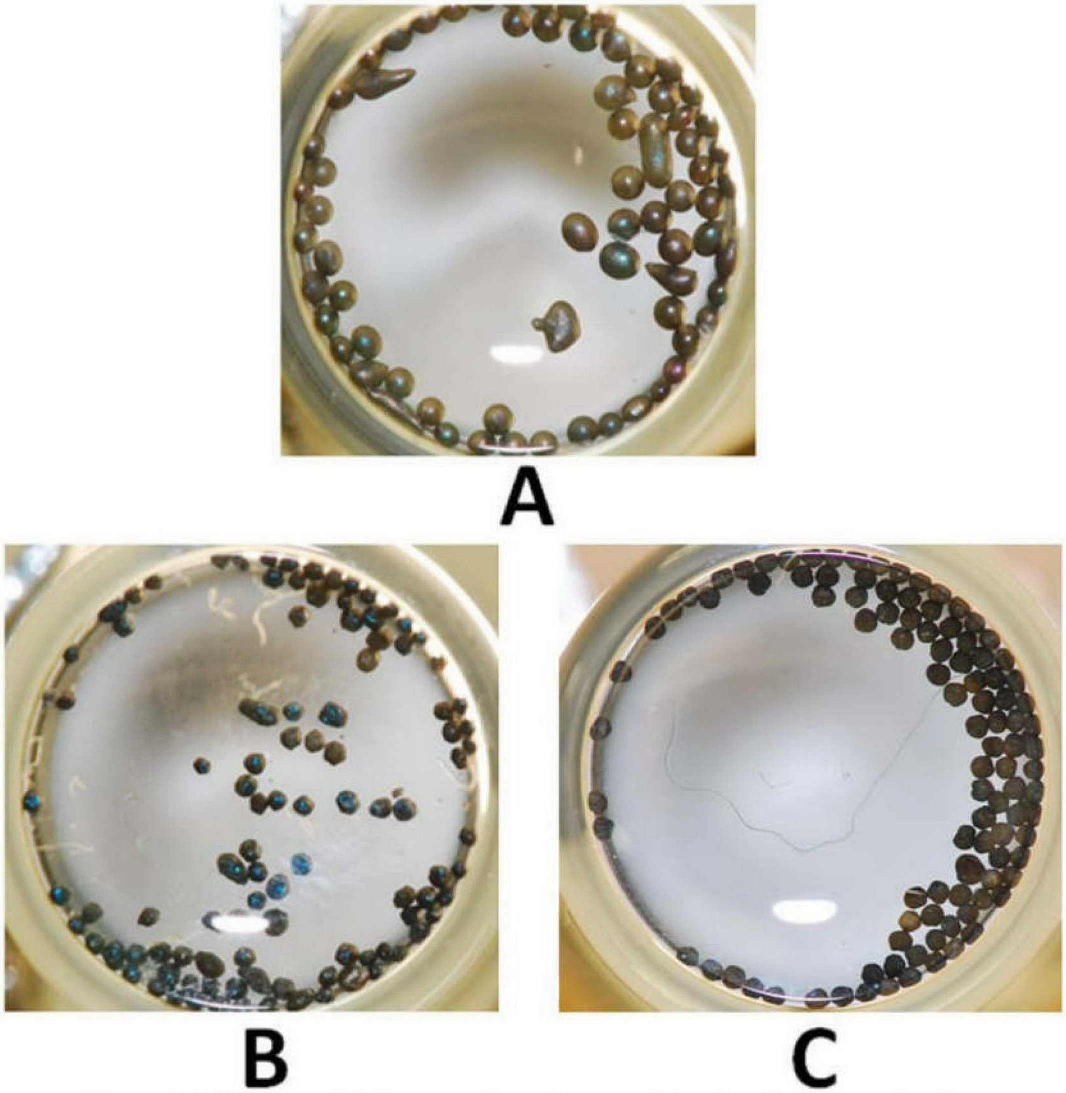


Figure A-4. Photographic images of uranium metal beads relevant to stirred reactor testing

(A) is the initial uranium metal bead condition. B) Beads after 96-hour, 95°C heating in KW simulant, and C) Beads after 96-hour, 95°C heating in 50:50 uranium oxide slurry

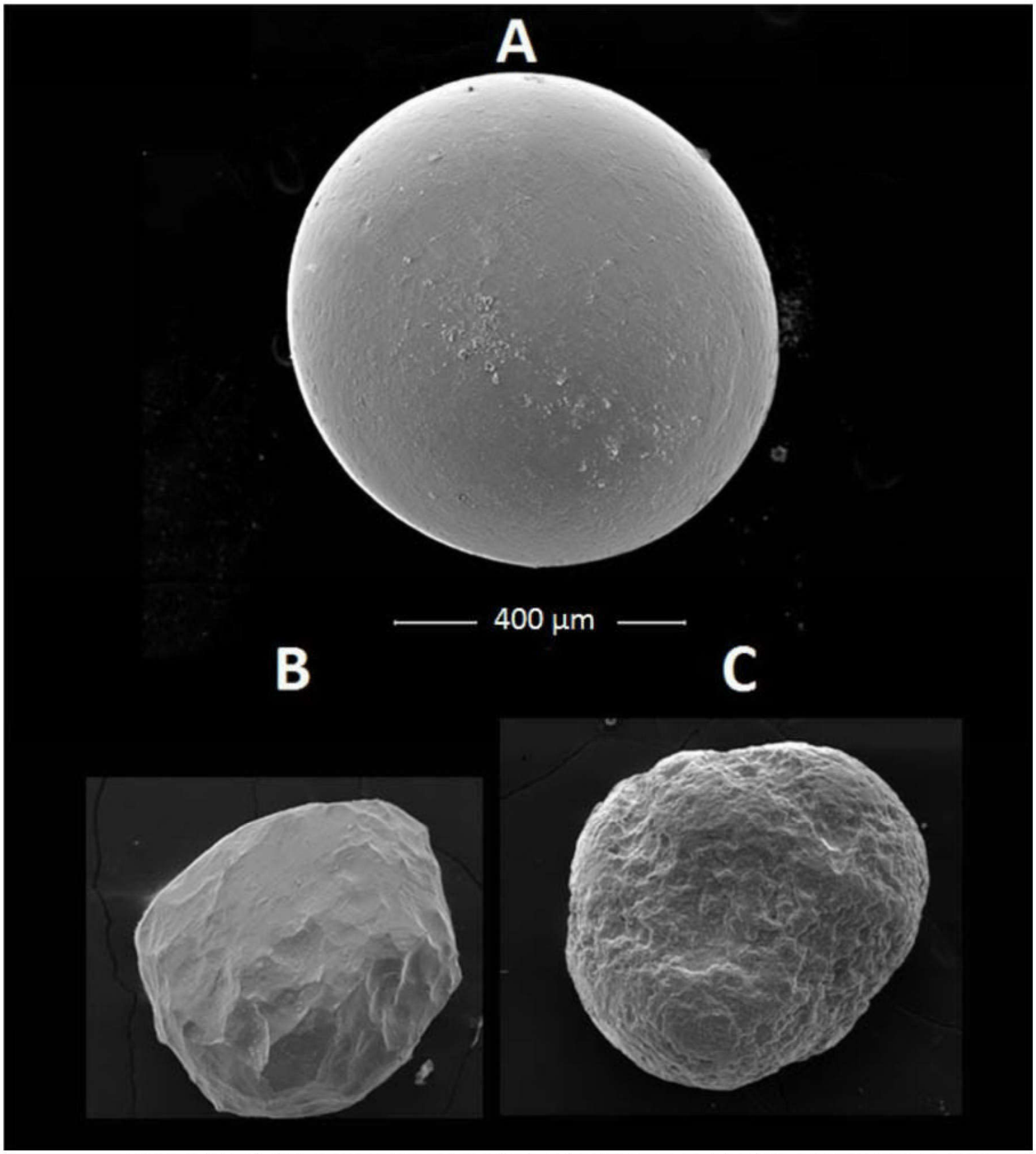


Figure A-5. SEM Images of Uranium Metal Beads Relevant to Stirred Reactor Testing

Images are scaled with respect to each other. A) Initial uranium metal bead condition. B) Bead after 96-hour, 95ºC heating in KW simulant. C) Bead after 96-hour, 95ºC heating in 50:50 uranium oxide slurry.

The differences seen in oxidation rates and surface appearance of the uranium metal beads in the different simulant tests is thought to be due to the presence of ferrihydrite, $Fe_5O_7(OH)\cdot 4H_2O$, in the KW simulant. Uraninite forms as an oxide coating during the oxidation of uranium metal, somewhat protecting it from further oxidation. Studies have shown that ferrihydrite encourages UO_2 oxidation to the more soluble U(VI) species, which would create fresh surfaces for oxidation. This theory is supported by the higher oxidation rate in the KW simulant tests as opposed to the 50:50 uranium oxide test that did not contain ferrihydrite.

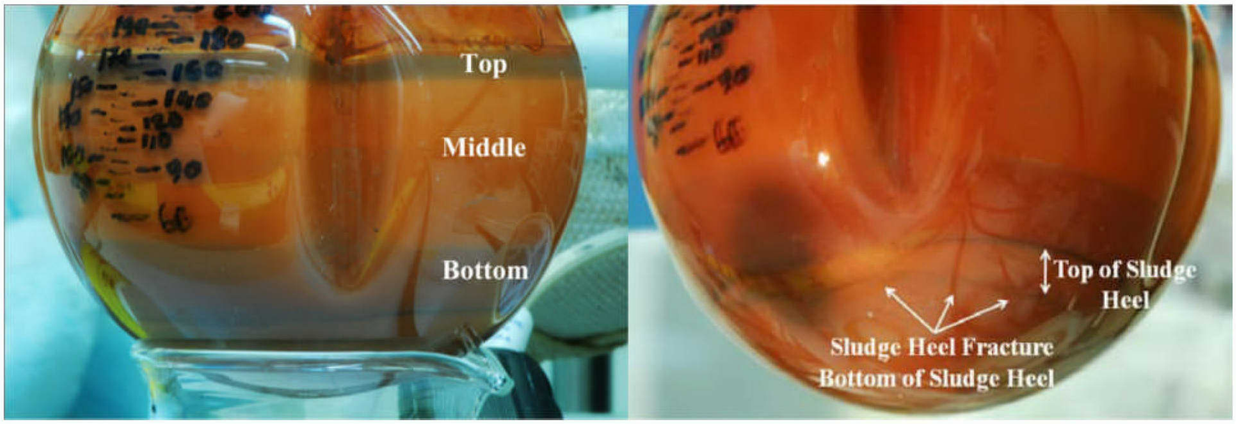


Figure A-6. Images of KW Simulant after 72 hour settling period

(Left) Stratified KW Simulant observed after 72-hour settling period. Samples for UV-Vis analysis were aliquoted from the top, middle, and bottom phases. (Right) Composition of sludge heel. The top layer of the sludge heel slumps readily and separately from the bottom of the sludge heel. The "sludge heel fracture" delineates the slumping solids from solids of sufficient strength. The solids strength of the sludge heel bottom is estimated at 150 kPa.

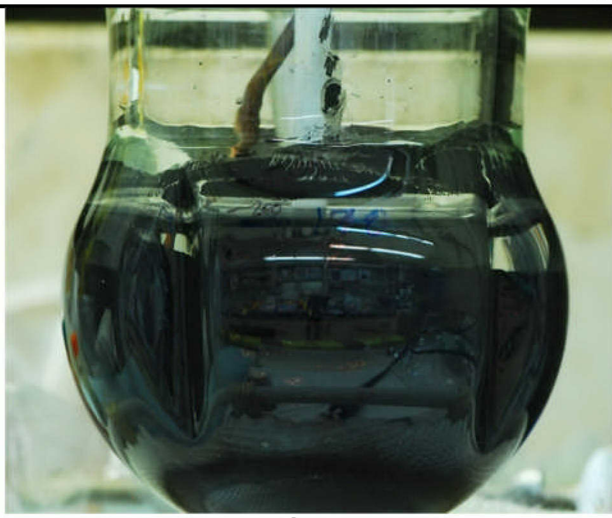
Physical Behavior of Solids

As mentioned above, the KW simulant test formed three stratified liquid layers during the 72-hour settling period. The top layer constituted 20 mL (of a total of 125 mL), had low solids content, and flowed like water. The middle layer, 65 mL, had the consistency of thin paint. The bottom layer constituted 40 mL and had the consistency of thick paint. The KW simulant also contained a sludge heel with two portions. The top portion of the heel constituted 20-25 mL, and the material slumped within 3 minutes. The material remaining in the bottom portion (approximately 25 mL) on the heel was described to be stiff to very stiff, corresponding to a shear strength of 100-200 kPa.

In the initial small-scale tests, there was no evidence of such a strong heel formation in the KW simulant. Insufficient mixing during the reaction is one potential explanation for the formation of agglomerates in the bottom of the mixer. It was also possible that the agglomerated material acted as a barrier to heat transfer, causing an increase in temperature in the solids region. This hypothesis was confirmed by employing an additional thermocouple in the uranium oxide tests.

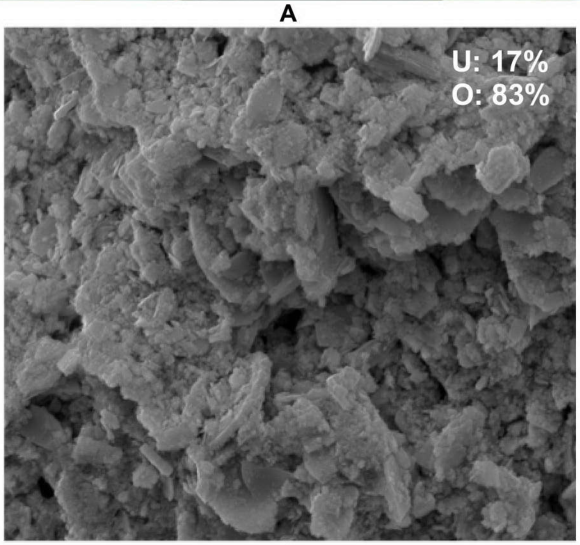
The solids morphology of the 50:50 uranium oxide stirred reactor test were very similar to the solids of the small-scale testing. No solids agglomerates were identified, and the material flowed freely, indicating a likely shear stress of less than several hundred Pa. As mentioned above, the atomic compositions for the initial and final uranium oxide data were found to be nearly identical, and so the majority of the differences between the two are physical and are shown below in Table A-7. Larger plates were observed in the initial slurry, and the final slurry exhibited more irregular particulate matter. The decreased shear strength in the final slurry is expected to be due to less plate-to-plate interactions.

Table A-7. Photographic and SEM Comparison of Initial and Final Compositions of 50:50 Uranium Oxide Slurry

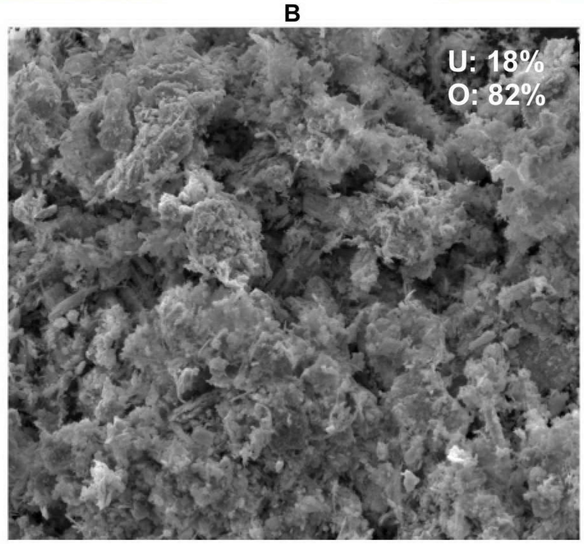


A

B



C



D

(a) Photograph of initial oxide slurry; (b) photograph of oxide slurry after 96-hour heating at 95°C (Note the presence of fine particulate ridges in the final product); (c) SEM image of initial oxide slurry at 40 μm full width; (d) SEM image of final oxide slurry after 96-hour heating at 95°C at 40 μm full width.

The % PSD was also examined for the 50:50 uranium oxide stirred reactor tests. The % PSD was analyzed at 1 minute of recirculation, during sonication, and post sonication for both before and after WWO treatment respectively. The untreated solids did not clump, though large granular material was detected when mixing the solids before analysis. This observation is consistent with the increased fraction of particles in the 100 μm range as shown in Figure A-7. The treated material was difficult to homogenize and was creamy and sticky in nature rather than gritty. This observation is consistent with the decreased fraction of 100 μm particles as shown in Figure A-8.

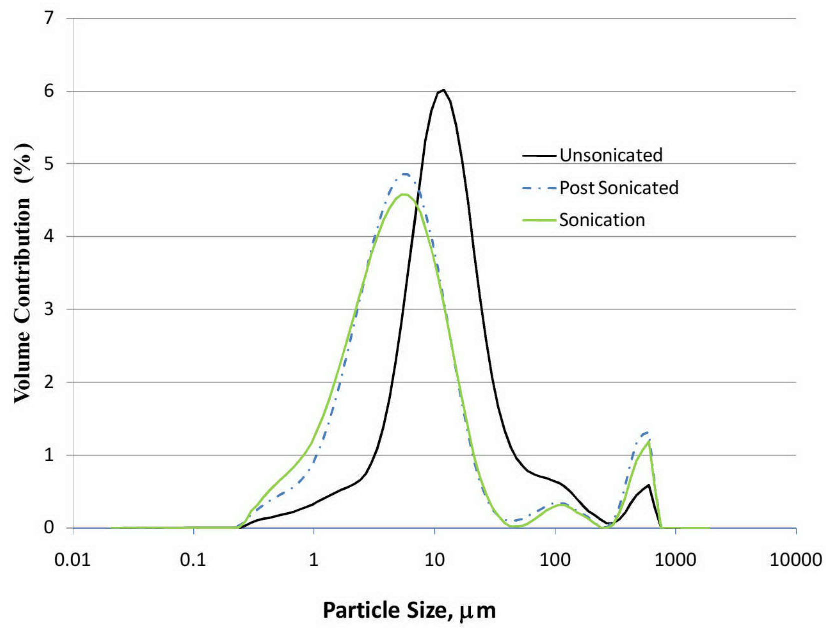


Figure A-7. Average Volume % PSD of Sample 50/50 Uranium Oxide Slurry Before WWO Treatment

Figure Note: PSD is based on the average of 9 PSD measurements generated from 3 aliquots of sample PSD U-50/50.

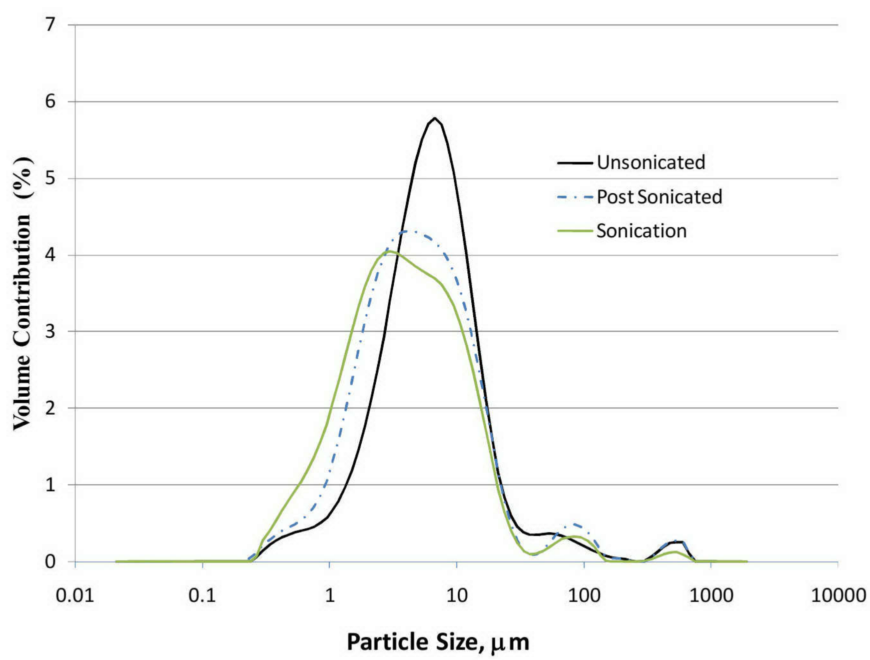


Figure A-8. Average Volume % PSD of 50/50 Uranium Oxide Slurry after WWO Treatment (96 hr at 95°C in Stirred Reactor)

Figure Note: PSD is based on the average of 9 PSD measurements generated from 3 aliquots of sample PSD U-50/50 Final.

A summary of a select number of percentiles is given in Table A-8 for the two PSD samples. The table provides a brief overview of the particle sizes present and in particular, in the tails of the PSD. Comparison of the SEM images with PSD results provides reasonable agreement.

Table A-8. Summary of Selected Percentile Values Describing Particle Size Distribution

Percentile	Before WWO, µm (PSD U-50/50 Initial)			After WWO Treatment, µm (PSD U-50/50 Final)		
	1-min Recirc.	Sonication	Post Sonication	1-min Recirc.	Sonication	Post Sonication
d(0.01)	0.64	0.39	0.42	0.45	0.38	0.40
d(0.05)	2.1	0.77	0.96	1.17	0.65	0.89
d(0.10)	3.9	1.23	1.52	1.88	0.97	1.34
d(0.50)	12.0	5.08	5.48	6.15	3.83	4.79
d(0.90)	49.7	20.3	27.2	17.6	14.7	17.3
d(0.95)	110	319	413	33.0	21.3	40.6
d(0.99)	546	605	608	409	106	431

A3.1.2 Technical Issues and Unknowns Related to Chemical and Physical Behavior

At an operating temperature of 95ºC, the diametral penetration of oxidation on uranium particles is approximately 2.0 µm/hour ($8x10^{-5}$ inches/hour), based on data in Reference [13]. Oxidation batch time for KE and KW container sludge is estimated to be approximately 130 days (19 weeks) for uranium particles with a maximum diameter of ¼-inch and a uranium oxidation enhancement factor (EF) of 1. Oxidation time for settler sludge, with a maximum particle size of 600 µm ($2.4x10^{-3}$ in) is estimated to be approximately 300 hours (12.5 days). Actual batch times will depend on the true particle size and oxidation rate of uranium metal in each batch and the time required for transferring, heating, and cooling. The extent of reaction will be monitored by measuring fission gases (Kr, Xe) released to the off-gas system.

The preliminary data from the testing done at PNNL for WWO proof-of-concept reaction rates exhibit oxidation rates are higher than those in the Databook [13]. These tests were conducted using simulants. Further testing and analysis needs to be completed to further refine the reaction rates for the various K-Basins sludges under the conditions of the WWO process. In the event an EF significantly less than 1 emerges from future testing (including testing of real waste samples), additional throughput capacity can be provided by deploying two or three trains of treatment components. In a worst case where the actual sludge oxidation rate exhibits an EF of 1/3, up to three WWO process oxidation trains may be needed to achieve treatment within the 5-year duration established for the production window for STP Phase 2 treatment and packaging. It is estimated that the single packaging line would be adequate for any potential WWO scenarios.

The testing done at PNNL on simulated sludges has produced mixed results relative to the issue of agglomeration. All the tests done under Round 2 of this project have indicated that there is minimal concern about agglomeration of the sludge under normal operating conditions. Previous testinghad indicated that smaller particles could agglomerate to larger particles at these temperatures for some of the sludges [22, 23]. Also, the last stirred test using uranium beads in a simulated slurry showed that in regions of poor agitation, under relatively large temperature gradient, there is the possibility of the slurry to form a cohesive mass that is difficult to dislodge and re-combine with the rest of the slurry. The degree of agitation required to prevent agglomeration has yet to be determined, which means that there is currently insufficient information on which to base the agitation system design.

In addition to the Receipt and Reaction Tank chemistry and physical properties, there is another risk associated with the final form of the processed and drummed sludge. The final oxidized form of the uranium metal in this process is uranium dioxide. Uranium dioxide has two issues associated with it in the final drumming. First, uranium dioxide is identified as a RCRA pyrophoric material in powdered form. The WIPP WAC specifies an acceptance criterion that limits the content of radioactive pyrophoric materials in waste packages to less than 1 percent by weight. The form of the waste in the drums is not powdered, but a determination will have to be made as to whether or not it is pyrophoric in its final form.

The second issue is one of change of density by continuing chemical reaction. The main design assumption for drumming the processed sludge is that it could be grouted in the disposal drum. It would be anticipated that the uranium dioxide would further oxidize in the presence of oxygen to uranium trioxide. The density of uranium trioxide is approximately one half the density of uranium dioxide. This means that the uranium trioxide will displace about twice as much volume as the uranium dioxide. This could cause problems in a cemented grout in drums. The expansion could be sufficient to split the drum. Additional evaluation is needed to determine if the potential volume expansion with actual UO_2 content of the drums would be sufficient to cause significant problems. It has been documented that the oxidation of the U-metal contained in grouted drums can cause expansion whish results in distortion of the waste package, and failure in some cases [18].

A3.2 Technical Issues and Risks Related to Equipment and Process Integration

A3.2.1 Technical Risks Related to Equipment

Table A-9. Technical Risks Related to Equipment

Component of Process	Key Aspects of Uncertainty
Oxidation Reaction in the RRT	• Use of xenon and krypton gas analysis to estimate oxidation reaction endpoint • Potential for runaway reaction • Flammable gas generation
Agitation System	• Buildup of un-reacted U-metal fraction that could impact safety basis • Agglomeration due to insufficient mixing
Off-gas Control and Monitoring System	• Accuracy of off-gas analyzer
Discharge Locations	• Agglomeration and/or plugging at the RRT sludge outlet
Nitrogen Injection and Sweep System	• Insufficient sweep to dilute the evolving potentially flammable hydrogen gases
Lag Storage Tank	• Ability to determine the correct amount of oxidized sludge to be sent to drumming (in-line gamma probe)
Slurry Transfer	• Unknown sludge conditions after storage in STSCs • Plugging and/or abrasion of pumps • Plugging of transfer lines

In-Drum Grouting and Packaging System	• Ability to manage input of sludge and cement mix to meet FGE restriction • Inadequate mixing, resulting in radiological hot spots • Swelling of drum contents due to oxidation of uranium dioxide to uranium trioxide
System Controls	• General process control issues

A3.2.2 Integrated Process Risks

The concept of maturity for the WWO Integrated Operations indicates the degree to which the technologies are developed and ready to use as off-the-shelf items. The degree of maturity considers the criteria in the DOE Technology Readiness Assessment Guide [14], as described in Section A2.1, which identifies the three major categories of maturity in technology evaluation as technical maturity, manufacturing maturity, and programmatic maturity. There are numerous mature commercially available options for implementing integration of all WWO technology elements, including operational and maintenance equipment that is remotely operated. The selection, integration, testing, and evaluation of operational technologies will be deferred until later in the design phase after completing the identification of process requirements and definition of process milestones such as FGE that meet WIPP WAC. Mature technologies will be preferentially chosen in order to optimize the efficiency of the WWO system with respect to throughput of sludge and ALARA considerations with respect to safety to workers and the general public. The process of choosing the mature operational technologies for the WWO system will be part of the scale up of operations from engineering to pilot scale. The following table summarizes integration risk issues.

Table A-10. Risk Resolution Strategy for Integrated Operations

<table>
<tr><th>Technical Element</th><th>Risk</th><th>Risk Resolution Strategy</th></tr>
<tr><td>Remote operability</td><td rowspan="6">• There is a risk that the remotely operated manipulator and/or robotic equipment will not be adequate or will not function as anticipated in the pre-conceptual design study.
• There is a technical and integration risk associated with the connectivity and integration of monitors, sensors, and other surveillance and communications technology required for implementation of these technologies.</td><td rowspan="6">• The full-scale cold-test mock up of the WWO will be used to validate the use and applicability of the remotely operated manipulators and/or robotic equipment, and evaluate the WWO system design, refine procedures and tool designs, and train operators.
• The technologies used for Integrated Operations are technically mature and widely used commercially but their use individually and together on the WWO must be designed and tested as the system moves from bench to pilot scale.
• There are numerous technically mature commercial options for implementing all of the technologies associated with this technology element using Integrated Operations. The selection, integration, evaluation, and acceptance testing of these technologies can be deferred until later in the design phase after a more complete definition of requirements for Integrated Operations</td></tr>
<tr><td>Production and performance reporting</td></tr>
<tr><td>Condition based monitoring</td></tr>
<tr><td>Intelligent alerts and events management</td></tr>
<tr><td>Key performance indicators and production calculations</td></tr>
<tr><td>Collaboration for decision-making</td></tr>
</table>

A3.3 Technology Development Needs

Some of the fundamental reaction chemistry data for the WWO process was generated in previous projects and collected in previous reports [7,13]. However, relatively little testing or engineering evaluation work specific to the conditions of the proposed WWO process has been completed to date. The use of a warm water oxidation approach appears to be a potentially attractive option based on the testing under the current program and published information on somewhat similar oxidation systems. If this option is to be pursued further, a number of initial activities should be performed to better define the process, evaluate performance, determine if there are unexpected problems or complications related to processing actual sludge, and provide engineering data to support more detailed engineering studies and eventually design.

Development needs can be considered in terms of the design phases of a project. In the preconceptual and early conceptual design phases, data is needed to verify basic feasibility, understand any complicating factors (e.g. side reactions or adverse physical property changes), and develop preliminary performance information. This data needs to be developed to a level of detail sufficient to support engineering studies used to select the final flowsheet to be used as the basis for conceptual design. In addition, topical engineering studies/evaluations are needed to better delineate certain aspects of the process. The assay system concept, updated estimates of achievable total measurement uncertainty, feasibility of using fission product gas measurements to verify completion of reaction, potential for uncontrolled/runaway reactions are examples.

During the conceptual design phase process alternatives are typically evaluated and a single preferred alternative is selected. Additional data is needed for the selected alternative to develop and optimize system conceptual design, define the basis for sizing of unit operations, resolve any safety or regulatory issues, and provide a firm basis for moving into preliminary design and later detailed design.

For the WWO, most work in the preconceptual and conceptual design phases involves development of a more detailed understanding of chemical and physical phenomenology/behavior of the sludge under actual process conditions. Unless the project elects to pursue novel remote equipment or facility concepts, little if any mechanical/equipment oriented testing or development work is expected to be needed during the preconceptual and conceptual design phases. Possible exceptions are the assay system used to determine isotope concentrations in the drummed waste, and offgas analysis equipment that may be considered for verifying completion of reaction. These unit operations are currently not well defined and may need early equipment oriented testing. Similarly, the drumming system is not currently well defined. If the selected drumming system design concept incorporates significant novel or untested features, early proof of concept testing will be needed at least for those features.

In the detailed design phase, development activities are expected to primarily focus on design verification testing. This phase will be primarily equipment oriented and will include testing of individual components or physical features and testing of integrated systems or subsystems.

The evaluation relies mainly on information from the proposed Process Description and Flowsheet (Reference [2]) and the results of a technology evaluation workshop. The purpose of the evaluation is to identify the primary technology elements and their associated technologies and to identify and evaluate risks associated with each technology element. Based on these evaluations, the risks are observed to fall into the following two categories:

1. Risks associated with incomplete knowledge of the processes, dependency on design studies and testing, and uncertainties to be investigated in the design of the facility. Further design evaluation will involve investigation of uncertainties regarding sludge rheology, determination of the end point

of the oxidation reaction using Xe and Kr analysis, and transferability of the sludge depending on sludge concentration

2. Risks that are related to integration of the operational technologies that need to be investigated as the project continues to progress and the design matures. These risks will require validation through testing and evaluation from the engineering scale up to and including the pilot scale. These risks do not represent major issues for the facility design and include overfilling of the RRT, leaks in the transfer lines, pumps, and valves, and control of sludge concentration using reflux condensate, the vacuum eductor, and other process-control technologies.

The following sections provide a preliminary identification of needed activities, with primary focus on initial or near term activities. The resolutions consider the technical maturity of the technologies and the level of testing and evaluation needed to mature and validate the technologies for completion of conceptual design at TRL 4 and implementation in an integrated pilot-scale system at TRL 6 [14].

A3.3.1 Near Term Development Activities

A3.3.1.1 Chemical and Physical Behavior

The following are near term development needs regarding chemical and physical behavior:

1. Laboratory process testing with simulants:
    a. Conduct tests on a larger scale than have been performed to date. The design of the WWO and Immobilization System will be advanced from the laboratory- and bench-scale to the pilot scale using a Phase 1 designed waste simulant and appropriately scaled technologies and surrogate systems. The tests should include more careful control and monitoring of reaction conditions, including off-gas collection. The results should be more definitive with respect to anticipated rheology of the processed slurry.
    b. Provide more complete material balances, including off-gas measurements.
    c. Explore the effect of additional sludge components not in the initial simulants tested.
2. Bench scale process flowsheet testing with simulants. This will typically be performed at 0.5 to 4 liter scale with more prototypic mixing and possibly more prototypic materials of construction.
3. More comprehensive testing on sludge physical properties/physical behavior under process conditions: slurry rheology, density, water, and solids content of settled sludge, tendency to agglomerate or set up, ability to concentrate to target solids concentrations, etc. Run tests using real sludge if possible.
4. Based in part on results of laboratory testing above, supporting engineering studies, and literature review, develop a more comprehensive and optimized flowsheet.

A3.3.1.2 Equipment and Materials

The following are near term development needs regarding equipment and materials:

1. There will need to be modeling and laboratory-scale investigations concerning potential volume change during continuing oxidation of UO_2. If oxidation reaction were to proceed to UO_3 while in

storage after the sludge and cement-mix are solidified in the drums, the result could be swelling and failure of the drums or disintegration of the grout, because of the lower density of the UO_3.

2. Evaluate various possible waste forms, from various cement mixtures to various granular absorbents. Refine the analysis of achievable waste loading estimates.
3. Engineering evaluation of materials of construction: Receipt and Reaction Tank, Lag Storage Tank, agitator, pumps, piping, HVAC, valves, drums, etc.
4. Topical engineering study on immobilization and packaging design concepts to support selection of the conceptual design system and equipment configuration.

A3.3.1.3 Longer Term Development Needs

The process is expected to use conventional proven commercial equipment adapted for remote operation and maintenance. However, some equipment-oriented process testing will be needed for equipment, such as agitators and pumps. Testing and development work is also expected to be needed for the drumming system and likely some remote equipment features. This testing and development work will be performed primarily during the preliminary design and detailed design phases of the project. The following are some of the longer term development needs:

1. Design, testing, and integration of the remote equipment and the supporting control system and logic of the remotely operated and maintained packaging facility will need to be conducted first at the component level, and ultimately integrated into integrated system testing at full scale with a range of simulants to assure that the system can be operated and maintained in a remote environment.
    a. Refinement of process, equipment, and process qualification concepts for the dose-to-curie assay system. Include evaluation of methods to deal with batch to batch variability of dose-to-curie relationships.
    b. Perform development testing of assay components and systems.
    c. Evaluate need, costs, and benefits of additional physical sampling of sludge to reduce total measurement uncertainty.
    d. Topical engineering study on methods for verifying completion of reaction.
2. Evaluate nitrogen addition to the headspace of the RRT, CT, and LST versus sparging of nitrogen from the lower part of one or all of the vessels.
3. Study and evaluate the robotic technologies for robust maintenance, decontamination, and other remote O&M functions. This would include study and evaluation of a remote-control operating system to be used to operate the WWO and Immobilization System.
4. Perform tests on agitator systems for the purpose of evaluation for operation at full scale. Develop specifications for the agitators to be used in the Retrieval and Reaction Tank and the Lag Storage Tank.

A3.4 Hazard Considerations

A hazard evaluation was completed for the Warm Water Oxidation Process in order to provide input to the cost, schedule, and risk considerations for the continued alternatives selection process. This hazard evaluation was completed by a team of representatives from Engineering, Industrial Safety, Fire Protection, RadCon, and Operations [21].

A list of the activities constituting the WWO alternative was compiled. Hazards (or nodes) associated with each were then identified along with potential engineered and administrative controls. Table A-11 below summarizes the results of the hazards considerations for WWO. The primary hazards identified are common to all alternatives handling K Basin sludge slurries. No hazards unique to the WWO were identified that would significantly increase overall hazards as compared to other alternatives.

Table A-11. WWO Treatment Hazard Considerations

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01 – MOBILIZE, RETRIEVE, TRANSFER STORE AND AGITATE						
RET.01.01	Internal Explosion	Sludge contamination	H^2 accumulation and ignition in STSC headspace	Purge system Ventilation system	Equipment surveillance	—
RET.01.02	Spray Leak	Sludge	Crack leak of slurry being removed from STSC and transferred to receiver vessel	Double contained transfer line.	—	—
RET.01.03	Splash / Splatter	Sludge	Leak of slurry being transferred from the STSC to the receiver vessel	Double contained transfer line Tank High Level Alarm and pump interlock	—	—
RET.01.04	Loss of Confinement	Sludge Contamination	Plugged vent path causes an unfiltered release from tank	Pressure transmitter to monitor the tank	—	—
RET.01.05	Internal Explosion	Sludge Contamination	H_2 accumulates in the receiver tank headspace and lines, resulting in a deflagration of the tank headspace or lines	Inerting or Alternate purge path.	—	—
RET.01.06	Direct Rad	Cs-137 release to water during storage or sludge in line or in STSC	Backflow of sludge through a line above the STSC, or exposure to storage water high in Cs-137 or sludge in STSC due to liquid draw down	Interface system design (check valves and system pressure), remote STSC unloading	Transfer access control	—
RET.01.07	Load Drop	Sludge contamination	Dropping equipment onto the STSC during removal of cask head or installation of transfer system resulting in a leak	—	*Hanford Site Hoisting and Rigging Manual*	—
REC.01 – RECEIVER VESSEL STAGING AND DEWATERING Note: this includes the boil down dewatering both before reaction and during/after reaction, and agitation and circulation during staging and reaction.						
REC.01.01	Internal Explosion	Sludge Contamination	H_2 accumulation and ignition in tank headspace	Purge system Ventilation system	Equipment surveillance	Note: hydrogen evolution may be very rapid following size reduction, especially if agitation is ineffective and the settled

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
						metal is self heating
REC.01.02	Spray Leak	Sludge	Circulating sludge spray leak	Low pressure circulation Secondary confinement	—	—
REC.01.03	Splash / Splatter	Sludge	Leak from circulating system	Secondary confinement	—	—
REC.01.04	Overpressure Loss of Confinement	Sludge Contamination	Plugged vent path and overpressure causes an unfiltered release from tank	Pressure transmitter to monitor the tank, pressure relief, open vent path	—	—
REC.01.05	Direct Rad	Sludge in line or Exposure to vessel	Backflow of sludge through a flush line or in a recycle line, exposure to receiver vessel	Flush water system design (check valves and system pressure), Shielded recirc lines Shielded receiver vessel, remote maintenance for agitation	—	—
REC.01.06	Criticality	—	Accumulation of separated metal, unsafe geometry	Vessel geometry, sludge process limits, sludge material final characterization	—	
REC.01.07	Steam agitation / ejection of slurry	Slurry in tank	Steam leak into receiver vessel agitates and volatilizes slurry into off gas system	Steam Jacket design	—	—
REC.01.08	NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
REC.01.09	Facility Fire, spill	Sludge	Facility fire results in failure of confinement vessel and release of rad material	Materials of construction, Fire Protection System	Combustibles limits	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
TRS.02 –TRANSFER AND STAGING OF TREATED SLUDGE. NOTE: Applies to transfer and staging for Alternatives 1, 2, 3, 4, 6						
TRS.01.01	Spray Leak	Sludge	Line failure during pressure transfer results in a release of radiological material outside of the facility	Piping design, secondary piping design, confinement design	—	—
TRS.01.02	Overpressure	Sludge Contamination	Accumulation of gas in the isolated staging tank results in a potential overpressure and release of radiological material	Ventilation system Confinement design	—	—
TRS.01.04	Splash / Splatter	Sludge	Transfer Line failure results in a release of slurry	Piping design, secondary piping design, confinement design	—	—
TRS.01.05	Direct Rad	Released fission products or sludge in lines or containers	Sludge in lines or vessels not adequately shielded	Facility design	Radiological Control Program access controls	—
TRS.01.06	Seismic Event	Sludge	SSC failure results in spill / spray and spread of rad material	Facility design	—	—
TRS.01.07	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
PKG.03 – IMMOBILIZATION AND PACKAGING OF TREATED SLURRY.						
PKG.03.01	Spray Leak	Sludge	Pressure transfer line failure results in a release of radiological material	Piping design, Secondary piping design, confinement design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
PKG.03.02	Facility Fire	Sludge	Facility fire results in a release of rad material	Materials of construction, Fire Protection System	Combustibles control	—
PKG.03.03	Seismic Event	Sludge	Seismic forces result in a line break and potential release	Facility design	—	—
PKG.03.04	Splash / Splatter	Sludge	Pressure transfer line failure results in a release of rad material	Piping design, secondary piping design, confinement design	—	—
PKG.03.05	Direct Rad	Released fission products or sludge in lines and containers	Direct exposure to sludge rad shine	Shielding design	Radiological Control Program access controls	—
PKG.03.06	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
STG.01 – SHIELDED STORAGE OF TREATED DRUMS.						
STG.01.01	Load Drop	Sludge	Container drop resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.02	Load Drop	Sludge	Load dropped onto container resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.03	Seismic Event	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.04	Other NPH	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.05	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
					controls	
STG.01.06	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Facility design, Fire Protection Design	—	—
LSC.01 – LOAD SHIPPING CONTAINER. REMOVE FROM ISC, LOAD 72-B LINER, LOAD CASK.						
LSC.01.01	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
LSC.01.02	Load Drop	Sludge contamination	Impact fails package and damages grout	Contamination control ventilation	Hoisting and rigging controls, DOE-RL-92-36	—
LSC.01.03	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Fire Protection System	—	—
LSC.01.04	Seismic Event	Contamination	SSC failure results in package impact and spread of rad material	Facility design	—	—
LSC.01.05	Other NPH	Contamination	Missile or structure failure results in package impact and spread of rad material	Facility design	—	—

DOE-RL-92-36, 2007, *Hanford Site Hoisting and Rigging Manual,* Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

FW = facility worker.
HC-2 = Hazard Category 2 (facility).
HEPA = high-efficiency particulate air (filter).
HVAC = heating, ventilation, and air conditioning.
ISC = interim storage container.
LFL = lower flammability limit.
MAR = material at risk.
NPH = natural phenomenon hazard.
SSC = structure, system, and component.

A3.5 Additional Considerations

There are additional risks, issues and potential optimization items associated with the WWO and immobilization process. A number of these are summarized below.

1. The WWO and Immobilization System will be housed in a stand alone, enclosed ~4,000 ft^2 pre-cast concrete structure with controlled access to the entire structure and individual cells within the structure as needed. The facility will be capable of being operated remotely via a control room and, to the extent necessary, will include robotic technology for routine maintenance, and decontamination. The size of the full-scale WWO facility could be reduced by one-third to one-half by using modular facility to manage drum filling, mixing, and handling. The exploration of modular construction should be investigated.
2. The capacity of the RRT will be optimized as the operational design moves from bench-scale to pilot-scale dimensions. The estimated batch size is from two to eight STSCs depending on the sludge concentration in the individual STSCs.
3. The RRT will have a dish-shaped base to assure agitation and help prevent agglomeration at the bottom of the vessel. It is likely that a series of agitation paddle/mixers to keep the sludge in suspension and provide maximum exposure of the sludge particles to the heated water will be required in the final design. Experimental studies performed at vendor sites will be used to determine the stirring/mixing strategy and whether or not, and in what configuration, baffles could be installed on the inner walls of the vessel to promote mixing and prevent areas of stagnation and agglomeration, which would prevent efficient circulation of the oxidized sludge.
4. Empirical testing should be used to determine the optimum method to pre-add dry Portland-cement-based grout to the 55-gallon drums before the drums are moved into the controlled environment of the WWO and Immobilization System facility and/or the use of a modular facility to add flexibility to loading/unloading operations and reduce the footprint of the overall WWO and Immobilization System.
5. Review and evaluate currently operating integrated grout-filling operations in the US and abroad to determine the most efficient technologies to use for the In-drum Grouting and Packaging System.
6. Develop a failure mode analysis, supplemented by testing, to determine the extent of redundancy/versus maintenance replacement is needed to meet the production requirements. .
7. Use design studies to optimize the order of batching of K-West, K-East, and Settler Sludge to optimize water consumption and accelerate throughput and minimize the need to transfer excess water to the Hanford ETF.
8. Develop and test Integrated Operations procedures to insure safe conditions if there is a failure of one or more systems.

A4 Process Design and Performance Estimates

This section provides a summary of sizing for major process equipment, estimates of the time required to process all of the K-Basin sludge, and facility size information.

The base case flowsheet assumes the Receipt and Reaction Tank is to be operated on a double-batch basis with a batch time for KE and KW Container sludges of ~150 days and a batch time of ~30 days for Settler Tank sludge (including durations allowed for the operating steps of oxidation, vessel heat-up/cool-down, and transfer). During the oxidation process, slurry is concentrated from ~4vol% solids to 20vol% solids by evaporation to minimize the volume of oxidized waste slurry (i.e. reduced from 3,500 to 700 gallons slurry). The contents of the Receipt and Reaction Tank are to be concentrated down in approximately 3.4 days, at which point, the contents of an additional STSC are to be added and subsequently evaporated to increase the working inventory of the Receipt and Reaction Tank. "Double-batching" refers to the addition of the contents of two STSCs per process batch. This is the proposed baseline case for the WWO process evaluation [19].

Batch time for WWO processing is derived from:

- The maximum uranium metal particle size expected (¼-inch for KE and KW Container sludges, 600 µm for Settler Tank sludges);
- The oxidation rate predicted at 97°C (2 µm diametral/hr) with an enhancement factor of 1 [13]; and,
- The volume of sluiced feed material loaded in the Receipt and Reaction Tank.

A4.1 Estimated Processing Duration for Treating all K Basins Sludge

The estimated operating duration to process all the sludge is shown in Table A-12. The estimated processing time is 59 months at 70% total operating efficiency (TOE) for the base case.

The ability of the WWO process to complete processing within 60 months relies on each oxidation batch processing multiple STSC batches (two STSCs per oxidation batch for the base case). The base case time cycle calculation for treatment of an oxidation batch of Engineered Container sludge is based on the following sequence and time allowances (at 100% operating efficiency): 1 day to transfer first batch from STSC, 3.4 days to boil down the first STSC batch, 1 day to transfer in the second STSC batch, 117.9 days to heat the batch and oxidize the U metal and concentrate to final solids concentration, and 2 days to cool and transfer the batch to the Lag Storage Tank. The total time to process is 125.3 days per oxidation batch. It is assumed that transfer from an STSC for the next oxidation batch can start as soon as the transfer of the previous batch to the Lag Storage Tank has been completed. The calculation for a batch of settler tank sludge is the same except that the time allowance to heat and oxidize a batch is reduced from 117.9 to 14.2 days giving a total batch preparation time of 21.6 days. In both cases the reaction time is estimated based on a 97°C reaction temperature and a reaction rate "enhancement factor" of 1.0.

Average drumming time per oxidation batch is shown in Table A-13 and estimated for the base case at 14 days for KE EC sludge, 18.8 days for KW EC sludge, and 58 days for settler tank sludge based on a base case drumming rate of 30 drums per week [19]. Comparing the oxidation batch preparation times with the estimated drumming times shows that the processing rate for KE and KW EC sludge is controlled by the oxidation batch preparation time, while the settler tank sludge processing rate is controlled by the drumming rate.

The current time cycle estimate assumes that delivery of the second STSC batch to the RRT can be started about 4.4 days after the first batch. If the actual schedule for sequential STSC batch retrievals is longer it directly impacts the WWO processing schedule. Similarly, if the retrieval concept is able to deliver 3 or more batches in a relatively short time for processing in a single WWO batch, it would reduce the WWO processing duration. Additional sensitivity cases are discussed in Appendix I.

Table A-12. Estimated Sludge Processing Durations for WW Oxidation Process

Case	Sludge Processing Time at 100% TOE	Sludge Processing Time at 70% TOE	Comments
Base Case[1]	41 months	59 months	40 FGE per drum, 30 drums per week drumming rate.
[1]Other sensitivity cases are considered in Appendix I			

Table A-13. Total drums needed to package sludge waste at 40 239Pu FGE level [19].

	KE Engineered Containers	KW Engineered Containers	Settler	Total
FGE (g/m^3) [sludge concentration]	702	1,560	7,340	-
Total Number of drums at 40 FGE per drum	323	199	991	1,513
Number of STSCs	11	5	8	24
Average Number of drums per STSC	30	40	124	-
Average Time to Drum each Batch[1] (days)	14.0	18.8	58	-
Average Time to Drum each Batch (hours)[1]	168	226	696	-
[1]Each WWO batch consists of 2 STSCs				

A4.2 Major Process Equipment

In order to compare the various technologies under consideration, normalized flowsheet estimates were made to evaluate differences in major equipment and facility size, and to estimate potential differences in sludge processing rate and the associated duration required to process all of the sludge [15]. The normalized flowsheet estimates are based on input from AREVA [2] with adjustments as needed to assure that all technologies are evaluated on a reasonably consistent basis.

For the WWO process tank size estimates are given in Table A-10 based on the nominal base case set of assumptions [15].

The following is a list of major components of the system:

Table 14. WWO Process System Components

EQUIPMENT	SIZE	QUANTITY	NOTES
Receipt and Reaction Tank T-001	6,250 Gallons	1	With steam jacket (See Attachment 14)
Condensate Tank T-002A & B	4,500 Gallons	2	
Lag Storage Tank T-003	3,070 Gallons	1	With cooling jacket
Receipt and Reaction Tank Pumps P-001A & B	89 GPM, 42.3 PSI	2	(See Attachment 5A/5B)
Lag Storage Tank Recirc Pumps P-003A & B	89 GPM, 42.3 PSI	2	(See Attachment 5A/5B)
LST Transfer Pumps P-004A & B	15 GPM	2	Moyno progressive cavity pump

EQUIPMENT	SIZE	QUANTITY	NOTES
Condensate Tank Pumps P-002A1 & 2, P-002B	30 GPM, 36 PSI	3	(See Attachment 7)
Mixer M-001	50 HP	1	
Mixer M-003	25 HP	1	
Eductor	1 1/2"	1	(See Attachment 6)
Exhaust Duct Heat Exchanger HX-002	300 BTU/HR	1	Very small coil
Condensate Tank Heat Exchanger HX-001	256,000 BTU/HR	1	(See Attachment 8)
Remote Handling Device RH-001		1	KUKA Model KR16 or equal
Predator Arm	500 pound lift, 79” reach	1	(See Attachment 13)
Crane for Pump Room	2 ton	1	(See layouts - Attachments 2, 3, and 4)
Crane for Packaging sub-system	2 ton	1	(See layouts - Attachments 2, 3, and 4)
Nitrogen Dewers	50 liters	3	
Closed Circuit Cooler	350,000 BTU/HR	1	(See Attachment 9)
Closed Circuit Cooler Pump	45 GPM	1	Centrifugal type
Refrigerant chiller	10 ton	1	
Refrigerant Chiller Pump	24 GPM	1	Centrifugal type
Boiler SG-001	208 lbs/HR	1	(See Attachment 10)
Process Exhaust HEPA Housings	100 SCFM	3	Model GRF (See Attachment 11)
Main Exhaust HEPA Housing	3,000 SCFM	2	K Series (See Attachment 11)
Exhaust Fan	3,000 SCFM at 12” water	2	
Exhaust Stack	16” diameter, 40’ tall	1	
Air Handling Unit	3,000 SCFM	1	Unit to have inlet filter, bag filter, cooling coil, heating element, and a fan
Outdoor Direct Expansion (DX) Refrigeration Unit	20 ton	1	
Drum Loading Station Hood	6” steel walls	1	See layouts, Attachments 2, 3, and 4, first floor
Contaminated Equipment Maintenance Hood		1	See layouts, Attachments 2 and 4, second floor
Drum Loading Station		1	Includes motorized rollers, fill equipment, rotation motor for mixer, plug removal device, drip pans, and a rotary table.
Gamma sensors for sludge recirculation line		4	(See Attachment 12)
Off-gas analyzer- mass spectrometer		1	For krypton, xenon, hydrogen and oxygen samples from cryogenic cold trap
Gamma sensor station for drums		1 station, 12 sensors	Located in packaging sub-system room
Tank differential pressure transmitters	Capillary type	4	
Scales	24” by 24’	2	For drum loading station and final drum weight

EQUIPMENT	SIZE	QUANTITY	NOTES
Level Transmitters		6	
Flow meters	1" diameter	2	Coriolis mass flow meter
Process controls and software		1	
Motor Control Center		1	See Section 5.1
Exhaust stack monitor		1	Monitor for alpha and beta.

A4.3 Facility Requirements

Two different layouts for the WWO system were considered: a stand-alone purpose-built facility, and an existing Hanford Site facility (not defined). The stand-alone, purpose-built facility is assumed to have a modular design concept.

The stand-alone purpose-built facility would be fabricated from precast concrete panels to enclose major process vessels. Pre-fabricated structures would house the packaging sub-system and operator working areas. An overlap design is incorporated for panels that enclose WWO process vessels, pumps, and packaging sub-system elements to ensure effective shielding of the radiological materials contained within the process.

For the existing facility layout, general facility attributes are not defined. It is assumed the facility consists of a concrete structure with areas segregated for containment of radiological materials and shielded to mitigate potential dose to workers and a nuclear zoned ventilation system for contamination control and HEPA filtration of discharges.

Each layout would incorporate approaches to minimize potential contamination, and identifies tools and processes to be relied on for decontamination in areas that might be expected to become contaminated during upset conditions. All process cells will be lined with stainless steel to support decontamination and maintenance activities. Adequate sumps and drains will be provided along with curbs and raised doors to assure that the largest radioactive volume can be contained within the Zone 1 confinement area.

For the stand-alone layout, a High Efficiency Particulate Air (HEPA) filter room would be established that is separated from the remainder of the facility with 2-hour fire walls and doors, to ensure compliance with DOE-STD-1066 [16]. The existing Hanford Site facility is assumed to have adequate zoned HEPA filtration to support the entire process volume, though supplemental offgas treatment may be required.

Emergency access to process vessel and pump rooms would be included in each layout and all equipment would be designed for decontamination to a level that allows for worker access under controlled conditions. There would be no black cells.

Commercial off-the-shelf equipment would be selected for use where feasible to establish the WWO system design, in order to mitigate cost, enhance reliability, and reduce the effort required to develop and qualify the process for operation. See Figures A-9 and A-10 below for the conceptual layouts of the facility. Figure A-13 provides information on the dimensions of the footprint of the facility.

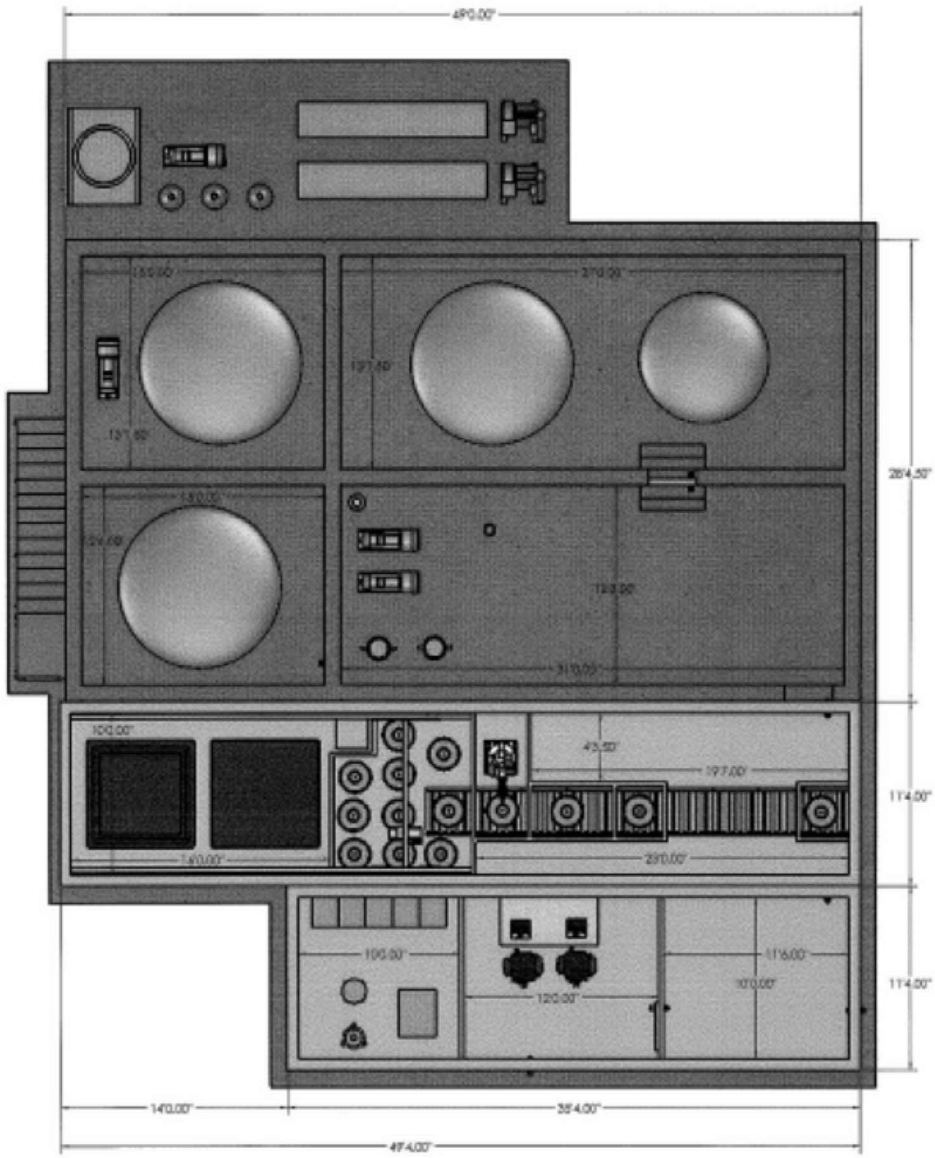


Figure A-9. Plan View of Facility Layout.

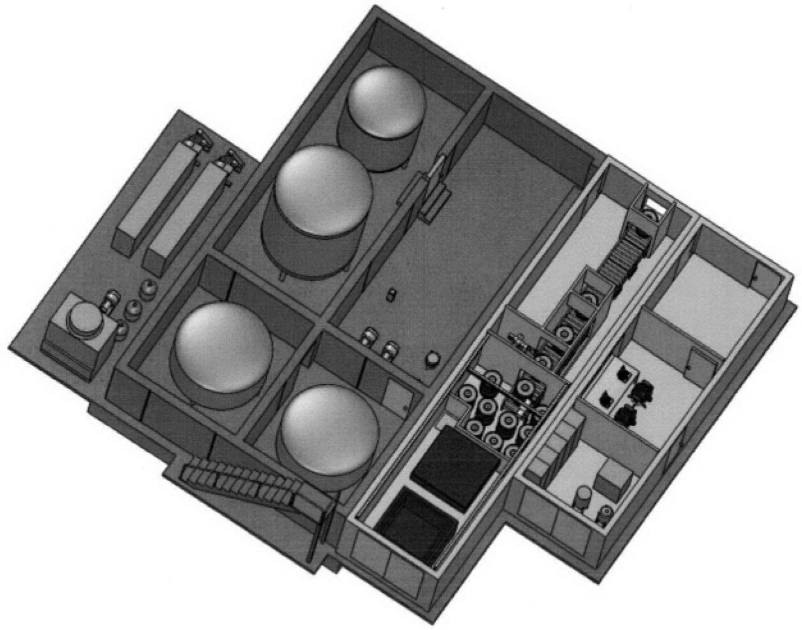


Figure A-10. Isometric View of Facility Layout.

A5 Characteristics of the Alternative Relative to Evaluation Criteria

This section provides an evaluation of the WWO process concept relative to the evaluation criteria outlined in the CHPRC Decision Plan [5]. The project scope and requirements assume that any alternative must be capable of receiving full STSC batches of K Basin sludge and processing them to meet criteria for shipment to WIPP. As such, all alternatives will need certain minimum capabilities and will present minimum safety (public and worker) and environmental risks, and minimum costs, and technical requirement. This section notes characteristics, advantages, and disadvantages of the WWO alternative that would need to be considered in making decisions of whether to proceed or how to proceed with the development of WWO technology.

A5.1 Potential Beneficial Attributes of WWO

- The WWO reaction has been studied significantly over a wide range of temperatures, so the process can be relatively well-predicted. Tests have indicated that the reaction rates should be at least as fast as those predicted in the Sludge Technical Data Book [13].
- Process chemical and physical behavior tests have shown that the WWO process does not significantly impact the flow ability of the sludge.
- The tank sizes for the RRT and the LST needed for the WWO process are only slightly larger than the minimum sized tanks (RRT and LST) needed to accept and process a full STSC batch. Minimizing process tank size also minimizes remote cell space requirements and presents an easier mixing problem for slurry.
- WWO reaction time is expected to meet the 5 year processing criterion. This is expected to occur with a single process train and the minimum tank size.
- WWO is relatively simple and safe process that does not require chemical additives or high temperature or pressure.
- No exotic construction materials are anticipated to be required for the WWO process.
- The equipment required for construction of the facility is generally readily available with little to no required modifications. Remote handling and radiation shielding for this process is typical and similar to what is required for other processes that handle and process highly radioactive slurries.
- The WWO process could easily be modified to handle a wider range of TRU feeds by the addition of a sorting or grinding pretreatment process.
- Material upgrades to process equipment and additional chemical addition capabilities included in the FROP alternative also increase flexibility for chemical treatment and processing other future (undefined) waste streams with a variety of chemical agents.
- The processing rate is estimated based on the maximum theoretical particle diameter. The actual diameter of uranium particles is anticipated to be smaller than the theoretical value due to reactions occurring in storage. This could potentially shorten the overall processing time.
- Back-end packaging is essentially the same as for all the other water-based processes and differs only from the vitrification processes.

A5.2 Potential Risks in WWO Development.

- The development of a method to accurately determine the end point of reaction is required.
- The development of a method to accurately determine the FGE loading of drums is required. This is a problem common to all candidate processes.

Table A-15 illustrates how the identified characteristics, advantages, and disadvantages relate to the Decision Criteria identified in the Decision Plan [5].

Table A-15. Evaluation of WWO against the Decision Criteria [5].

Decision Criteria from Decision Plan [5]			Attributes of WWO Process Technology Related to Decision Criteria
Criteria	**Goals**	**Measures**	
Safety	Ensure worker safety.	Relative ease/difficulty in implementing adequate safety measures as measured by number of passive(inherently safe) vs. active engineered safety features. Ensure protection of the nuclear the general public.	• No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries [21]. • Minimum material at risk (MAR)/inventory of sludge. • No chemical additives required. • Relatively long processing time results in longer risk period.
Regulatory/ stakeholder acceptance.	Ensure compliance with environmental laws and regulations and DOE orders. Address sludge management concerns in *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* record of decision.	Achieve acceptance of regulators and other Stakeholders.	• Analysis by CHPRC showed no significant regulatory or stakeholder concerns.
Technical maturity	Maximize confidence in process implementation	Projected Technical Readiness Level (based on technical criteria only at this stage of the project) Estimated volume of waste going to WIPP	• WWO is estimated to be at TRL 3. Some aspects of TRL 4 have been addressed (e.g., sludge rheology). • Proof of principle tests successfully demonstrated process functionality under several conditions. • WWO process has been studied at various temperatures to give reliable reaction rates. • Process chemical and physical testing showed that the WWO process has minimal effect on

Decision Criteria from Decision Plan [5]			Attributes of WWO Process Technology Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			sludge flow ability. • Modest size slurry tanks, slightly larger than the minimum required to process a single full STSC batch. Smaller size tanks present and easier mixing problem as compared to processes that require larger tanks. • Estimated volume of waste is expected to be ^{239}Pu FGE limited, i.e. the process is not expected to increase number of drums to WIPP above the minimum. • Methods to determine reaction end point and drum FGE loading need to be developed.
Operability and maintainability	Maximize operability Maximize maintainability	Ability for process to be remotized Ability to treat and package K Basin sludge inventory in 5 to 7 years Acceptability of secondary waste streams for disposal at Environmental Remediation Disposal Facility (solids) and 200 Area Effluent Treatment Facility (liquids)	• The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. The drumming system will use primarily industrially proven equipment and designs with some custom features to be developed and proven for this specific application. • The treatment system can be easily adapted for other waste streams with the addition of pre-treatment processes. • No additional chemical handling is required. • The total processing time is very close to the 5 year criterion, leaving little room for adjustment in retrieval schedule or unexpected downtime.
Life-cycle cost and schedule	Optimize life-cycle costs for sludge treatment and packaging facility Provide acceptable schedule to stakeholders	**Cost** Cost of maturing technology to Technology Readiness Level-6 Capital cost	• Relatively small process slurry tanks and no added equipment result in lower costs. • Longer processing time results in higher operating costs.

Decision Criteria from Decision Plan [5]			Attributes of WWO Process Technology Related to Decision Criteria
Criteria	**Goals**	**Measures**	
		Operating and maintenance cost Deactivation and decommissioning cost **Schedule** Facility startup Complete treatment and packaging	
Potential for beneficial integration with ongoing STP - Phase 1 activities	• Optimize cost or schedule for STP - Phase 2 • Consider co-location of needed facilities provided by STP - Phase 1	• Potential for integration of treatment and/or packaging with interim storage in T Plant • Potential for shared functions with those being provided by STP Phase 1 • Optimization of location of reduce/eliminate intermediate shipping or repackaging of the sludge material	• Process is compatible with Phase 1 design concept. • No identified positive or negative impacts to currently planned Phase 1 Project activities • Co-location near T Plant is possible, but overall siting studies have not been completed. • No significant integration issues noted.
Integration with Site-wide RH-TRU processing/packaging planning, schedule, and approach	Optimize processes, equipment, and facilities for K Basin sludge treatment and packaging with other Hanford Site RH-TRU waste streams	• Number of other Hanford Site RH-TRU waste streams that can be treated with candidate process • Number of other Hanford site RH-TRU waste streams that can be packaged with candidate packaging process	• With minor modifications, the process is capable of processing additional K Basins TRU waste streams that have been identified. • Other than the additional K Basins wastes, no specific RH TRU streams have been identified for integration at this time.

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Appendix B

Evaluation Data for Fenton's Reagent Oxidation Process (FROP) – (Ceradyne)

B1 Introduction

Use of Fenton's Reagent for oxidation of U metal was proposed by the Boron Products, LLC subsidiary of Ceradyne, Inc. (Ceradyne) in response to a formal Request for Information. After further definition of the concept and approach for testing, CHRPC awarded Contract 42402 to Ceradyne to perform proof of principle testing and related engineering support work needed to evaluate and define how this approach could be implemented. The testing and support work completed to date indicate that the Ceradyne Fenton's Reagent Oxidation Process (FROP) is a viable alternative for use in Phase 2 of the STP [1, 2].

B2 Technology and Flowsheet Summary Description

The unique feature of the FROP is use of hydrogen peroxide and soluble iron (Fenton's Reagent) together with chloride to achieve relatively rapid U metal oxidation at moderate temperatures. The oxidized sludge is concentrated by evaporation and solidified in drums by use of additives.

The overall process is divided into two major parts:

1. Sludge receipt and preparation for immobilization: the sludge batch is received from retrieval, oxidized to eliminate metallic uranium and water is removed to give the solids concentration desired for the immobilization process.
2. In the immobilization and packaging process, the concentrated sludge slurry is assayed, metered into drums, and converted to a liquid free solid that is sealed in drums for eventual offsite transport and disposal.

Supporting processes such as vent gas treatment, liquid waste disposal, cooling water and process steam supply are assumed to be similar to those identified for WWO (Appendix A) and are not further discussed for the FROP option.

B2.1 Sludge Receipt and Preparation for Immobilization

The FROP is illustrated in Figure B-1. Dilute sludge from an STSC is delivered as a single batch to the Receipt and Reaction Tank (RRT). The RRT is normally maintained at slightly below atmospheric pressure and is agitated continuously when it contains a batch of sludge. The batch is heated to about 90-95°C using a steam jacket and concentrated by evaporating excess water. The batch is then cooled to the reaction temperature (about 35°C) using a cooling water jacket. A small amount (about 0.1 to 0.2 mole/L) of chloride is added, soluble iron is added if needed, and pH is adjusted to between 1 and 4 if needed by adding acid (HCl or H_2SO_4). Addition of hydrogen peroxide solution (nominal 30 weight %) is then started at a controlled rate. In the presence of sludge components the hydrogen peroxide decomposes too fast to allow for a single batch addition at the start of reaction. Therefore, continuous peroxide addition is maintained through most of the reaction period. When the U metal oxidation reaction is complete (or nearly complete), peroxide addition is stopped. The batch is then heated to near the boiling point and is concentrated to the desired solids concentration by evaporation. The post reaction evaporation step also destroys any residual peroxide. The oxidized and concentrated sludge batch is then transferred to the Lag Storage Tank (LST).

The LST is continuously agitated when a sludge batch is present, and is cooled with a water cooling jacket. Concentrated sludge is transferred to the assay and drumming system in smaller batches as needed. The LST is sized to hold at least a full concentrated batch from the RRT. Once the RRT batch is transferred to the LST, transfer and preparation of the next STSC sludge batch can be started in the RRT while the previous batch is processed by the drumming system.

Steam generated during the evaporation step flows first to a demister to remove any entrained material and then to a water-cooled condenser. Non-condensed vent gas is heated and filtered prior to discharge. Condensate drains to a Condensate Tank. Where feasible, clean condensate is recycled for line flushes and for the immobilization step. Excess condensate is sampled and shipped by truck to ETF for disposal.

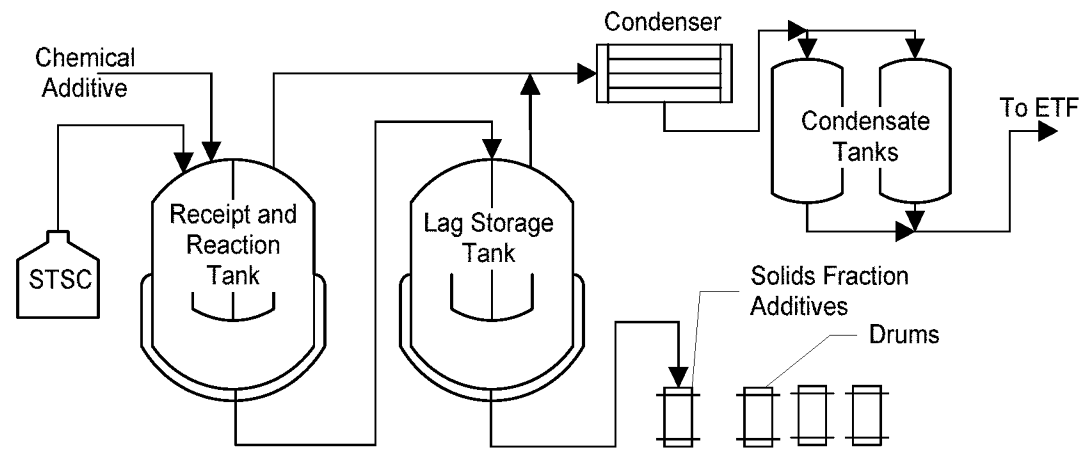

Figure B-1. Fenton's Reagent Oxidation Process Simplified Flow Diagram.

Similar to other oxidation treatment processes, methods are needed to assure metallic uranium has been adequately eliminated. For the FROP a combination of the following methods could be used:

- Process validation. This method involves performing process validation tests which define process performance sufficiently to provide confidence the process will perform as expected. This can include both pre-commissioning testing and test data collected during initial hot operations.

- Monitoring of fission product gas. Past work on Warm Water Oxidation of actual spent fuel has demonstrated that fission product gasses (Kr and Xe) are released when the fuel is oxidized. Release of fission product gasses has been used in laboratory tests to track the U metal oxidation reaction and has also been proposed as a potential method of tracking the in-plant Warm Water Oxidation process [7]. This method may be easier to apply to FROP because the reaction times are much shorter than for WWO, which is expected to result in a higher release rate producing higher concentrations that are easier to detect.

- Monitoring of hydrogen generation in the RRT. If at the end of the expected reaction period all of the uranium metal has not been oxidized, hydrogen will continue to be produced by of the reaction of water with residual U metal during the final concentration step. Monitoring vent gas for hydrogen content during the water oxidation and concentration steps to detect excess hydrogen could be used to determine if there is significant residual uranium metal present. A small amount of hydrogen production will also continue via radiolytic splitting of water, which may reduce the sensitivity for detecting residual metallic U by measuring total hydrogen generation.

- Monitoring of hydrogen generation in the product drums. Monitoring hydrogen generation rates in product drums could be used to prove significant U metal is not present in the drums. This would involve holding selected drums for a period of time at an elevated temperature (60ºC for example) and measuring the hydrogen evolution rate. A limited number of drums could be tested using a statistical sampling or process validation approach. An advantage of this method is that it directly correlates with the applicable hydrogen generation limit for drums during shipping. The disadvantage is that it will take a substantial amount of time for each test, likely days or weeks.

B2.2 Process Chemistry

Fenton's Reagent is a powerful oxidation system that combines hydrogen peroxide and iron catalyst. This well-known mixture is used extensively in hazardous waste treatment [1, 2, 3]. The Fenton system is based on the catalytic reaction of iron with hydrogen peroxide to produce hydroxyl and perhydroxyl radicals:

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH\cdot + OH^- \qquad \text{(Eq. B1)}$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + OOH\cdot + H^+ \qquad \text{(Eq. B2)}$$

The reaction is normally carried out at slightly acidic conditions ($pH<5$) to avoid precipitation of the Fe ions [3].

Based on testing performed in the current program and other published information, it has been determined that chloride accelerates the U metal oxidation rate [1, 2, 4, 5, 9]. Therefore, for the FROP, chloride is also added and appears to act as a catalyst or reaction intermediate; however, this chemistry has not yet been fully defined. In a somewhat similar reaction of U metal with hypochlorite the primary reaction product has been identified as UO_3 [5]. The sludge is also expected to initially have a significant fraction of UO_2 and some additional UO_2 could be produced by oxidation of U metal. However, UO_2 is known to react with oxygen gas (O_2) and the sludge slurry will be saturated with O_2 during the reaction period due to decomposition of peroxide. Therefore, most of the UO_2 is expected to be oxidized to UO_3 as a secondary effect of the primary U metal oxidation step. No product characterization was done for the current reaction; however, based on the above information, the overall reactions of hydrogen peroxide with U metal and UO_2 are expected to be as follows:

$$U + 2H_2O_2 \rightarrow UO_2 + 2H_2O \qquad \text{(Eq. B3)}$$

$$U + 3H_2O_2 \rightarrow UO_3 + 3H_2O \qquad \text{(Eq. B4)}$$

$$UO_2 + H_2O_2 \rightarrow UO_3 + H_2O \qquad \text{(Eq. B5)}$$

B2.3 Immobilization and Packaging Process

Ceradyne proposed that either a Portland cement-based grouting approach or their proprietary phosphate bonded ceramic could be used to solidify the concentrated sludge and eliminate free liquids. For the purpose of the current evaluation, the Portland cement-based approach used for WWO is assumed. Within the accuracy of current data, there is not a significant difference between the Portland cement and phosphate ceramic approach relative to waste loading, operations or equipment required. The WWO assay approach described in Appendix A is also assumed for immobilization. The approach selected for WWO includes gamma radiation measurements on a recirculation stream from the Lag Storage tank. These measurements are then used to estimate concentration of WIPP fissile isotopes using a dose-to-curie methodology. This data is in turn used to determine the amount of sludge loaded to each drum. Sludge transfer to the drum is controlled by a metering pump which draws from the recirculation stream. Sludge and flush water transferred to the drum is solidified by addition of dry Portland cement-based additives. A "lost paddle" in-drum mixing technique is used to blend the dry additives with the sludge slurry, resulting in a solid product with no free liquids. Gamma radiation measurements are taken on the finished drum. Based on these measurements, the content of WIPP reportable isotopes is estimated based on a dose-to-curie methodology. Use of the dose-to-curie methodology will require qualified measurement systems together with isotopic ratios and dose-to-curie relationships for each type of waste processed. See Appendix A for additional information on the assay and drumming system concept.

B3 Technology Development Status

The sludge receipt and preparation for immobilization process steps are expected to utilize conventional proven commercial equipment adapted for remote operation, e.g. jacketed tanks with mechanical agitators, demisters, scrubbers, positive displacement pumps, valves, metal or flexible hoses, and instrumentation. The only identified equipment that may be novel or near the edge of demonstrated use is the equipment for monitoring of fission product gasses, which support one of the alternative methods identified for demonstrating completion of reaction. Less mature aspects of the treatment system technology are related to knowledge of chemical and physical behavior of the actual sludge in the treatment equipment. The assay and drumming systems, and the remote equipment and operating concepts are assumed to be essentially the same as for WWO. The development status of those aspects is discussed in Appendix A and Reference 11.

As part of the current evaluation, proof of concept tests were completed to validate basic functionality of the process chemistry and obtain preliminary information on reaction rates and reagent requirements needed to develop a preliminary flowsheet. Process equipment for the treatment system is expected to be nearly identical to WWO, with the possible exception that some materials of construction may need to be upgraded due to chloride added as part of the FROP. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO.

A formal TRA, as defined in DOE G 413.3-4 [10], has not been performed for FROP. Based on the success of the proof of concept tests and use of commercially proven equipment some aspects of the primary FROP process could be considered to be developed to approximately TRL-3 as defined in DOE G 413.3-4 [10]. However, many aspects of the overall process are not yet well defined. The technical maturity evaluation for the WWO process [11] identified specific areas of further study, testing, and evaluation that would also be required for development of the FROP. Based on results of the Technology Maturity Evaluation for WWO it is concluded that, the overall development status of the FROP should be considered to be lower than TRL 3. More details on the FROP technology development status can be found in the following subsections, which focus on key aspects that are unique to the FROP and on differences between the FROP and WWO. Development status of the many features that are similar to WWO are discussed in Appendix A and Reference 11.

B3.1 Chemistry and Phenomenology

Initial screening tests were performed by Ceradyne to evaluate use of different mineral acids for initial pH adjustment. The screening tests clearly demonstrated U metal reaction rates were much higher when HCl was added, as compared to HNO_3, H_3PO_4, and H_2SO_4. The importance of chloride ion was further demonstrated in later testing.

It appears clear from previous work summarized below and current testing that addition of chloride can substantially increase the rate of U metal oxidation. Chemical mechanisms involving chloride are not yet clear. Chloride-induced cracking of the U metal structure is one mechanism that has been postulated [1, 2]. The literature also suggests that the presence of multivalent metal ions may be important (e.g. $Fe^{+2,+3}$ or $Cu^{+1,+2}$)[1]. Prior work at Lawrence Livermore National Laboratory (LLNL) identified bleach solution (sodium hypochlorite) as effective for oxidizing U metal [4]. A study by LLNL showed relatively fast U metal reaction rates using 1 molar sodium hypochlorite (NaOCl) solution [4]. An earlier patent was issued to DOE for a process using hypochlorite to oxidize metallic uranium and other actinides [5]. This patent also notes prior use of hypochlorite at pH 7.5 to 10 for oxidizing uranium oxide from the +4 valence state to the +6 state. While hypochlorite is somewhat different than a mixture of chloride and peroxide, they both contain a strong oxidizer and chloride ion and the actual reactions with U metal may be similar. More recently PNNL performed scoping tests on oxidation of U metal with $CuCl_2$ solution. This testing showed relatively rapid U metal oxidation but resulted in reduction of some of the copper to the metallic state. Most of the oxidation seemed to occur by facilitating the reaction of the U metal with water[1]. As part of the current technology evaluation program EnergySolutions tested a U metal oxidation process based on use of hydrogen peroxide and carbonate at neutral to moderately alkaline pH [9]. In this testing it was also found that addition of chloride significantly increased reaction rates.

B3.1.1 Summary of Testing Performed

Tests to explore feasibility of the FROP were divided into two segments or "Layers." In Layer 1, the basic experimental method and four alternative acids were tested in order to establish the basis for proof-of-concept tests in Layer 2. Uranium metal coupons (1/4 inch cubes) were oxidized using an aqueous solution at temperatures between about 20 and 40 ºC. The tests were started with about 25 ml of solution containing selected sludge components plus a single metal coupon. Final volumes varied up to about 125 ml depending on the amount of reagents added. Typical test steps included 1) pH adjustment by addition of a mineral acid; 2) addition of soluble ferrous ion as $FeSO_4$; and 3) addition of hydrogen peroxide. Rate of metal loss was determined by periodically removing the U metal coupon from the solution for weighing. It is assumed that the metal removed was oxidized, although it is possible that small metallic particles could have been removed from the coupon surface which would exaggerate the measured U metal oxidation rate. No offgas or solution composition measurements were taken at this early state. Results are reported in Reference 1, and are summarized below.

- Layer 1. In Layer 1, four mineral acids (nitric, sulfuric, phosphoric, and hydrochloric) were tested for the initial pH adjustment step with approximately 50 ml of 30 wt.% hydrogen peroxide added. Sludge components were limited to iron oxide-hydroxide, aluminum hydroxide, and U metal. The results demonstrated that reaction rates with hydrochloric acid were much faster than with any of the other acids tested. In the Layer 1 tests the hydrogen peroxide was added fairly rapidly (<20 minutes). The results indicated that the hydrogen peroxide decomposition caused the reaction to essentially stop before the U metal coupon was completely oxidized. Based on the Layer 1 results it was decided to perform Layer 2 tests using hydrochloric acid, and to add the hydrogen peroxide gradually over several days' time using a metering pump.

- Layer 2. Layer 2 was performed in several rounds so that the results of initial tests could be used as the basis to select conditions for subsequent tests. Sludge simulant components in the early tests were limited to iron oxide hydroxide, aluminum hydroxide and U metal. In two of the later tests the Uranium Containing K West Container Simulant [6] prepared by PNNL was used. The early tests explored the effects of peroxide addition quantity (50 to 100 ml), ferrous ion ($FeSO_4$) addition, pH, and temperature. Later tests explored the effect of using the Uranium Containing K West Container Simulant, chloride ion concentration and pH.

Layer 2 test results are summarized in Table B-1. Most tests were performed at ambient laboratory temperatures (about 20ºC). Comparison of Test 6 run at 35 ºC with Test 1 run at ambient temperature shows about a factor of 2 increase in reaction rate. Test 9 run at 35ºC with Test 7 were run under the same conditions but at ambient temperature. Comparison results for these two tests shows almost 50% reduction of reaction completion time at 35ºC. Tests have not yet been performed at higher temperatures.

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[1] SI Sinkov and CH Delegard, internal memorandum to AJ Schmidt, "Results from Informal Scoping Tests: Uranium Metal Corrosion in the Presence of Copper(II) Chloride", January 24, 2011, Pacific Northwest National Laboratory, Richland, Washington.

These results indicate that 35°C is a desirable temperature for the oxidation process but additional testing is needed to determine the optimum temperature.

Comparison of Test 3 and Test 12 clearly illustrates the substantial increase in reaction rate resulting from chloride addition. The initial chloride concentration in Test 12 was about 0.13 molar and dropped to about 1/3 this value by the end of the test due to dilution from added hydrogen peroxide solution. Test 3 had no added chloride.

The results show that the reaction rate is relatively insensitive to pH within the 1 to 4 range tested. In Tests 10 and 11 the "full" Uranium Containing K West Container Simulant [6] was added. For all other tests the only sludge simulant components added were FeO(OH), $Al(OH)_3$, and the U metal coupon. Within the uncertainty of the test results, no significant effect was seen from use of the "full" simulant compared to only FeO(OH) and $Al(OH)_3$.

The oxidation tests are considered to be successful in that they demonstrated 10 sets of conditions that resulted in total disintegration of the ¼ inch U metal cubes in 4 days or less at relatively mild reaction conditions (pH 1 to 4, moderate Cl^- concentration, moderate peroxide addition rate and quantity, and temperatures of 35°C or less).

As part of the testing program Ceradyne also evaluated achievable waste loadings in chemically bonded phosphate ceramic. These tests demonstrated water loading above 60 volume % in the finished solid waste form can be achieved without residual liquid [1]. These tests verified that chemically bonded phosphate ceramic can achieve waste loadings comparable those achievable with Portland cement-based grout formulations. The base case flowsheet analysis indicates the loading per drum for all waste types is expected to be limited by the fissile isotope content rather than physical waste loading capacity of either Portland cement or chemically bonded phosphate ceramic.

Table B-1. Ceradyne Fenton's Reagent Oxidation Process Test Results

#	Simulant Used for Tests	$FeSO_4$	Cl^-	pH	H2O2	Temp	U Metal Loss Rate ($g/cm^2 \cdot h$)[2]	Reaction Completion Time[3]
1	FeO(OH) +$Al(OH)_3$	Base[1]	Base[1]	1-2	Base[1]	Ambient	0.021	N/A
2	FeO(OH) +$Al(OH)_3$	Base	Base	1-2	None	Ambient	0.0023	N/A
3	FeO(OH) +$Al(OH)_3$	Base	None	4	Base	Ambient	0.000	N/A
4	FeO(OH) +$Al(OH)_3$	Base	Base	1-2	2 X Base	Ambient	0.039	70 hrs
6	FeO(OH) +$Al(OH)_3$	Base	Base	1-2	Base	35° C	0.041	48 hrs
7	FeO(OH) +$Al(OH)_3$	3X Base	Base	1-2	Base	Ambient	0.034	94 hrs
8	FeO(OH) +$Al(OH)_3$	0	Base	1-2	Base	Ambient	0.078	24 hrs
9	FeO(OH) +$Al(OH)_3$	3X Base	Base	1-2	Base	35° C	0.040	48 hrs
10	Full	3X Base	2X Base	1-2	Base	Ambient	0.031	89 hrs
11	Full	Base	2X Base	1-2	2 X Base	Ambient	0.068	28 hrs
12	FeO(OH) +$Al(OH)_3$	Base	Base	4	Base	Ambient	0.036	96 hrs
13	FeO(OH) +$Al(OH)_3$	Base	5X Base	4	Base	Ambient	0.024	70 hrs
14	FeO(OH) +$Al(OH)_3$	Base	1/2X Base	1-2	1.5 X Base	Ambient	0.032	96 hrs

[1]Base Case additions (approximate): $FeSO_4$ = 0.52 g; Cl^-= .0033 gmole; H_2O_2 solution = 50 ml.
[2]Average loss for first 48 hours or until reaction completion whichever is less.
[3]Reaction completion = U metal coupon completely gone. N/A indicates this was not achieved.

B3.1.2 Technical Issues and Unknowns Related to Chemical and Physical Behavior

There has been limited testing of the FROP to date, and no testing with actual sludge. Understanding of the process chemistry is incomplete. There are additional components in real sludge that could cause other side reactions, e.g. other catalytic agents may be present in the actual sludge that could decompose peroxide even faster than iron and other components included in the simulants tested to date. Testing to date did not include offgas analysis or sufficient data to perform an overall material balance. There is therefore some potential for other unexpected process behavior as the process is developed and tested in more detail. Some test results suggest that iron in the sludge may provide adequate soluble iron for the Fenton's reaction. If this proves out, it should eliminate the need for $FeSO_4$ chemical addition.

The tests performed measured metal removed from a coupon but did not prove the metal removed was completely oxidized. It could conceivably be removed as fine metal particles. Information on the analogous hypochlorite oxidation process indicates that process results in complete oxidation, producing a low solubility oxide [5]. It appears likely that the U metal removed from the coupon is at least mostly oxidized. However, even if it is found that some metallic U metal particles remain; impacts to the overall process should be minor due to the small particle size. After the oxidation step is complete the next step is to heat the batch to near boiling to decompose residual peroxide and drive off excess water. This step is expected to result in holding the tank contents near boiling for about 3 days. A three day residence time at near boiling temperatures should eliminate U metal particles below about 100 microns diameter via the WWO reaction. Even if it were found that this time needs to be increased by 200 or 300%, the overall time cycle impact is relatively small. Therefore, this issue needs to be investigated, but is not expected to be a major impact even if some residual metallic particles are found.

Effects on physical properties (slurry rheology, yield strength, shear strength) have not yet been measured. The FROP chemistry may make processing harder, easier, or may have no impact. In some cases, similar data is also lacking or limited for WWO. Uncertainties could be substantially reduced with a modest amount of further testing.

The FROP is known to oxidize organics and is likely to do so with the sludge. It is not clear if this may make sludge processing harder, easier, or no different as compared to WWO.

It is expected to be relatively easy to perform additional process chemistry/phenomenology testing on the FROP due to the relatively short reaction time and low process temperatures. This partly mitigates the relatively small amount of testing to date. Robustness is suggested by the fact that 10 of 14 tests with a variety of conditions showed complete elimination of the metallic U coupon in less than 4 days. In 3 tests the coupon was eliminated in less than 2 days.

B3.2 Technical Issues and Risks Related to Equipment and Process Integration

The FROP requires chemical addition equipment for handling the peroxide, chloride and iron sulfate additives. Due to the faster reaction rate, the Receipt and Reaction Tank and possibly the Lag Storage Tanks are expected to be modestly smaller for the FROP than the WWO process. Other than these relatively minor differences, process equipment for the FROP is expected to be essentially identical to the WWO process with the possible exception of materials of construction. Some materials upgrades may be needed to handle the chloride content (<0.2M) of the FROP sludge slurry. Remote equipment technology, remote facility features, assay, and integration concepts are expected to be the same as for WWO. Methods used to verify reaction completion are expected to be similar to WWO; however, this problem may be somewhat easier for the FROP because the much faster reaction rate results in higher concentration of gasses to be measured.

The acceptable amount of residual sludge in tanks at the end of each batch needs to be better defined in order to evaluate need for special methods to achieve, measure, and/or verify that acceptable levels have been achieved.

B3.3 Technology and Process Development Needs

The FROP has been added as an option for K Basins sludge processing only within the last year. As such, relatively little testing or engineering evaluation work has been completed to date. However, use of an oxy-chloride oxidation approach (FROP or similar) appears to be a potentially attractive option based on the testing under the current program and published information on somewhat similar chemical oxidation systems. If this option is to be pursued further a number of initial activities should be performed to better define the process, evaluate performance, determine if there are unexpected problems or complications related to processing actual sludge, and provide engineering data to support more detailed engineering studies and eventually design.

Development needs can be considered in terms of the design phases of a project. In the preconceptual and early conceptual design phases data is needed to verify basic feasibility, understand any complicating factors (e.g. side reactions or adverse physical property changes), and develop preliminary performance information. This data needs to be developed to a level of detail sufficient to support engineering studies used to select the final flowsheet to be used as the basis for conceptual design. In additions, topical engineering studies/evaluations are needed to better define certain aspects of the process. For example, the assay system concept, updated estimates of achievable total measurement uncertainty, feasibility of using fission product gas measurements to verify completion of reaction, potential for uncontrolled/runaway reactions.

During the conceptual design phase process alternatives are typically evaluated and a single preferred alternative is selected. Additional data is needed for the selected alternative to develop and optimize system conceptual design, define the basis for sizing of unit operations, resolve any safety or regulatory issues, and provide a firm basis for moving into preliminary and detailed design.

For the FROP, most work in the preconceptual and conceptual design phases involves development of a more complete understanding of chemical and physical phenomenology/behavior of the sludge under actual process conditions. Unless the project elects to pursue novel remote equipment or facility concepts, little if any mechanical/equipment oriented testing or development work is expected to be needed during the preconceptual and conceptual design phases. Possible exceptions are the assay system used to determine isotope concentrations in the drummed waste, and offgas analysis equipment that may be considered for verifying completion of reaction. These unit operations are currently not well defined and may need early equipment oriented testing. Similarly, the drumming system is not currently well defined. If the selected drumming system design concept incorporates significant novel or untested features early proof of concept testing will be needed at least for those features.

In the detailed design phase, development activities are expected to primarily focus on design verification testing. This phase will be primarily equipment oriented and will include testing of individual components or physical features and testing of integrated systems or subsystems. The following sections provide a preliminary identification of needed activities, with primary focus on initial or near term activities.

The following sections provide a preliminary identification of needed activities, with primary focus on initial or near term activities.

B3.3.1 Critical Near Term Development Activities

A summary of critical near-term development activities is given below. These activities should be completed in the preconceptual and conceptual design phases.

B3.3.1.1 Chemical and Physical Behavior

- Laboratory process testing with simulants.
    - Explore the effect of process variables on reaction performance. Tests should include more careful control and monitoring of reaction conditions. Alternate additives should also be considered (e.g. hypochlorite).
    - Perform tests and literature reviews to develop a better understanding of reaction chemistry.

  - Provide a more complete material balance, including offgas measurements.
  - Determine if U metal is removed as oxide or as fine metal particles.
  - Information on effect of FROP chemical additives on sludge physical properties. This should focus on identifying any problematic behavior. This should include consideration of the post reaction boil down step.
  - Explore the effect of additional sludge components not in the initial simulants tested.
- Based in part on results of laboratory testing above, supporting engineering studies, and literature review, develop a more comprehensive and optimized flowsheet.
- Laboratory testing based on defined flowsheets with simulants, and with actual sludge if feasible.
- Bench scale process flowsheet testing with simulants. This will typically be performed at 0.5 to 4 liter scale with more prototypic mixing and possibly more prototypic materials of construction.
- More comprehensive testing on sludge physical properties/physical behavior under process conditions: slurry rheology; density, water, and solids content of settled sludge; tendency to agglomerate or set up; ability to concentrate to target solids concentrations, etc.

B3.3.1.2 Equipment and Materials

- Engineering evaluation of materials of construction: Receipt and Reaction Tank, Lag Storage Tank, agitator, pumps, piping, HVAC, valves, drums, etc.
- Materials testing (e. g. for corrosion) if needed per results of work above.
- Topical engineering study on immobilization and packaging design concepts to support selection of the conceptual design system and equipment configuration.

B3.3.1.3 Process Control and Integration

- Refinement of process, equipment, and process qualification concepts for the dose-to-curie assay system. Include evaluation of methods to deal with batch to batch variability of dose-to-curie relationships.
- Perform development testing of assay components and systems.
- Evaluate need, costs, and benefits of additional physical sampling of sludge to reduce total measurement uncertainty.
- Topical engineering study on methods for verifying completion of reaction.

B3.3.2 Longer Term Development Needs

The process is expected to use conventional proven commercial equipment with chloride corrosion resistant materials of construction that are adapted for remote operation and maintenance. Some process testing will be needed for equipment, such as agitators, pumps, and assay system. Testing and development work is also expected to be needed for the drumming system and likely some remote equipment features. This equipment and the required testing and development work are assumed to be essentially the same as for Warm Water Oxidation (see Appendix A and the Technology Maturation Evaluation for WWO [11]). This testing will be performed primarily during the preliminary design and detailed design phases of the project.

B3.4 Hazard Considerations

A hazard evaluation was completed for the Fenton's Reagent Oxidation Process in order to provide input to the cost, schedule, and risk considerations for the continued alternatives selection process. This hazard evaluation was completed by a team of representatives from Engineering, Industrial Safety, Fire Protection, RadCon, and Operations [14].

A list of the activities constituting the FROP alternative was compiled. Hazards (or nodes) associated with each were then identified along with potential engineered and administrative controls. Table B-2 below summarizes the results of the hazards considerations for FROP. The primary hazards identified are common to all alternatives handling K Basin sludge slurries. No hazards unique to the FROP were identified that would significantly increase overall hazards as compared to other alternatives.

Table B-2. FROP Treatment Hazard Considerations

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01 – MOBILIZE, RETRIEVE, TRANSFER STORE AND AGITATE						
RET.01.01	Internal Explosion	Sludge contamination	H^2 accumulation and ignition in STSC headspace	Purge system Ventilation system	Equipment surveillance	—
RET.01.02	Spray Leak	Sludge	Crack leak of slurry being removed from STSC and transferred to receiver vessel	Double contained transfer line.	—	—
RET.01.03	Splash / Splatter	Sludge	Leak of slurry being transferred from the STSC to the receiver vessel	Double contained transfer line Tank High Level Alarm and pump interlock	—	—
RET.01.04	Loss of Confinement	Sludge Contamination	Plugged vent path causes an unfiltered release from tank	Pressure transmitter to monitor the tank	—	—
RET.01.05	Internal Explosion	Sludge Contamination	H_2 accumulates in the receiver tank headspace and lines, resulting in a deflagration of the tank headspace or lines	Inerting or Alternate purge path.	—	—
RET.01.06	Direct Rad	Cs-137 release to water during storage or sludge in line or in STSC	Backflow of sludge through a line above the STSC, or exposure to storage water high in Cs-137 or sludge in STSC due to liquid draw down	Interface system design (check valves and system pressure), remote STSC unloading	Transfer access control	—
RET.01.07	Load Drop	Sludge contamination	Dropping equipment onto the STSC during removal of cask head or installation of transfer system resulting in a leak	—	*Hanford Site Hoisting and Rigging Manual*	—
REC.01 – RECEIVER VESSEL STAGING AND DEWATERING Note: this includes the boil down dewatering both before reaction and during/after reaction, and agitation and circulation during staging and reaction.						
REC.01.01	Internal Explosion	Sludge Contamination	H_2 accumulation and ignition in tank headspace	Purge system Ventilation system	Equipment surveillance	Note: hydrogen evolution may be very rapid following size reduction, especially if agitation is ineffective and the settled

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
						metal is self heating
REC.01.02	Spray Leak	Sludge	Circulating sludge spray leak	Low pressure circulation Secondary confinement	—	—
REC.01.03	Splash / Splatter	Sludge	Leak from circulating system	Secondary confinement	—	—
REC.01.04	Overpressure Loss of Confinement	Sludge Contamination	Plugged vent path and overpressure causes an unfiltered release from tank	Pressure transmitter to monitor the tank, pressure relief, open vent path	—	—
REC.01.05	Direct Rad	Sludge in line or Exposure to vessel	Backflow of sludge through a flush line or in a recycle line, exposure to receiver vessel	Flush water system design (check valves and system pressure), Shielded recirc lines Shielded receiver vessel, remote maintenance for agitation	—	—
REC.01.06	Criticality	—	Accumulation of separated metal, unsafe geometry	Vessel geometry, sludge process limits, sludge material final characterization	—	
REC.01.07	Steam agitation / ejection of slurry	Slurry in tank	Steam leak into receiver vessel agitates and volatilizes slurry into off gas system	Steam Jacket design	—	—
REC.01.08	NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
REC.01.09	Facility Fire, spill	Sludge	Facility fire results in failure of confinement vessel and release of rad material	Materials of construction, Fire Protection System	Combustibles limits	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
FRO.02 – FENTON'S REAGENT OXIDATION PROCESS.						
FRO.01.01	Internal Explosion	Sludge contamination	H_2 accumulation in tank if ventilation interrupted during pre-treatment	Active purge	—	**NOTE:** *Minimal hydrogen production during treatment.*
FRO.01.02	Fire in exhaust system	Sludge contamination	Excess oxygen released in reaction or due to peroxide decomposition	Active purge	Combustible control	—
FRO.01.03	Loss of Confinement, splash and splatter	Sludge contamination	Chloride attack on vessel or piping leads to leak	Vessel and piping materials design	—	—
FRO.01.04	Criticality	Direct Radiation	Accumulation of separated metal into an unsafe geometry	Vessel geometry, agitation	Feed Controls	Sludge characterization indicates minimal probability of critical geometry, but batch from 2 STSCs may require explicit analysis.
TRS.02 –TRANSFER AND STAGING OF TREATED SLUDGE. NOTE: Applies to transfer and staging for Alternatives 1, 2, 3, 4, 6						
TRS.01.01	Spray Leak	Sludge	Line failure during pressure transfer results in a release of radiological material outside of the facility	Piping design, secondary piping design, confinement design	—	—
TRS.01.02	Overpressure	Sludge Contamination	Accumulation of gas in the isolated staging tank results in a potential overpressure and release of radiological material	Ventilation system Confinement design	—	—
TRS.01.04	Splash / Splatter	Sludge	Transfer Line failure results in a release of slurry	Piping design, secondary piping design, confinement design	—	—
TRS.01.05	Direct Rad	Released fission products or sludge in lines	Sludge in lines or vessels not adequately shielded	Facility design	Radiological Control Program access controls	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
		or containers				
TRS.01.06	Seismic Event	Sludge	SSC failure results in spill / spray and spread of rad material	Facility design	—	—
TRS.01.07	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
PKG.03 – IMMOBILIZATION AND PACKAGING OF TREATED SLURRY.						
PKG.03.01	Spray Leak	Sludge	Pressure transfer line failure results in a release of radiological material	Piping design, Secondary piping design, confinement design	—	—
PKG.03.02	Facility Fire	Sludge	Facility fire results in a release of rad material	Materials of construction, Fire Protection System	Combustibles control	—
PKG.03.03	Seismic Event	Sludge	Seismic forces result in a line break and potential release	Facility design	—	—
PKG.03.04	Splash / Splatter	Sludge	Pressure transfer line failure results in a release of rad material	Piping design, secondary piping design, confinement design	—	—
PKG.03.05	Direct Rad	Released fission products or sludge in lines and containers	Direct exposure to sludge rad shine	Shielding design	Radiological Control Program access controls	—
PKG.03.06	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
STG.01 – SHIELDED STORAGE OF TREATED DRUMS.						
STG.01.01	Load Drop	Sludge	Container drop resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.02	Load Drop	Sludge	Load dropped onto container resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.03	Seismic Event	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.04	Other NPH	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.05	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
STG.01.06	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Facility design, Fire Protection Design	—	—
LSC.01 – LOAD SHIPPING CONTAINER. REMOVE FROM ISC, LOAD 72-B LINER, LOAD CASK.						
LSC.01.01	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
LSC.01.02	Load Drop	Sludge contamination	Impact fails package and damages grout	Contamination control ventilation	Hoisting and rigging controls, DOE-RL-92-36	—
LSC.01.03	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Fire Protection System	—	—
LSC.01.04	Seismic Event	Contamination	SSC failure results in package impact and spread of rad material	Facility design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
LSC.01.05	Other NPH	Contamination	Missile or structure failure results in package impact and spread of rad material	Facility design	—	—

DOE-RL-92-36, 2007, *Hanford Site Hoisting and Rigging Manual,* Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

FW = facility worker.
HC-2 = Hazard Category 2 (facility).
HEPA = high-efficiency particulate air (filter).
HVAC = heating, ventilation, and air conditioning.
ISC = interim storage container.
LFL = lower flammability limit.
MAR = material at risk.
NPH = natural phenomenon hazard.
SSC = structure, system, and component.

B3.5 Additional Considerations

This section discusses additional miscellaneous items identified as part of the review which may be considered in evaluating this alternative.

Some additional industrial safety risks are expected due handling moderately high concentration (30 %) hydrogen peroxide. This is a relatively common industrial chemical and its properties and safe handling practices are well known. For example, hydrogen peroxide solution is used as a process chemical additive at the Hanford 200 Area Effluent Treatment Facility (ETF). Maximum inventory at ETF is estimated at 2,555 gallons of 50 wt. % hydrogen peroxide solution [8]. The Auditable Safety Analysis for ETF [8] identified some hazards associated with the 50% hydrogen peroxide but did not identify it as a major safety concern. During the Ceradyne Layer 1 testing hydrogen peroxide was added to the flask at more than 200 times the normal rate established in later testing. This resulted in a temperature excursion (increase) of less than 20° C.

One option is to design the treatment facility for the FROP with WWO as a backup/alternate if problems develop. If FROP performance is as expected with no major side problems, the operating duration would be significantly reduced compared to WWO. If problems are found with FROP, the WWO process could be implemented as a backup. The required equipment is essentially the same for both processes except for the need to provide an inert gas atmosphere in the RRT for WWO. For processing settler sludge the required oxidation time with WWO is about 1/10 of that required for the EC sludge. Therefore there is less benefit from using the FROP rather than the WWO process for the settler sludge. An attractive approach could be to use the FROP for Engineered Container sludge (floor and pit sludge) and use WWO for processing Settler Tank sludge using the same equipment.

Upgraded materials of construction that allow dilute chloride solutions and lower pH used in the FROP may increase flexibility to accept waste streams generated by processing other Hanford Site RH TRU wastes, e.g. sludge and decontamination solutions from processing solid waste.

B4 Process Design and Performance Estimates

This section provides a summary of sizing for major process equipment, estimates of the time required to process all of the K Basin sludge, and facility size information. Because most of the design is expected to be similar to the WWO option, the presentation herein focuses on differences between FROP and WWO as given in Appendix A.

B4.1 Process Flowsheet Estimates

In order to compare the various technologies under consideration, normalized flowsheet estimates were made to evaluate differences in major equipment and facility size, and to estimate potential differences in sludge processing rate. The normalized flowsheet estimates are based on input from the vendor [1, 2] with adjustments as needed to assure that all technologies are evaluated on a reasonably consistent basis. Common process bases and assumptions are summarized in Appendix J. Normalized flowsheet calculations summarized below are documented in Reference 12.

The flowsheet calculations start by estimating the size of the RRT and LST needed to process the largest STSCs batches. The batch preparation time is then estimated, i.e. the time to transfer and process an STSC batch to the point that it is ready for transfer to the assay/drumming system. When batch preparation is complete and the batch has been transferred from the RRT to the LST the RRT is ready to begin transfer and processing of the next batch while the batch in the LST is drummed. For the FROP the base case batch preparation time is estimated at 14.3 days [12].

The time to drum each batch is then estimated. Using base case assumptions for achievable waste loading per drum and drumming rate (Appendix J) the average drumming time per STSC batch is estimated at 7, 9.4 and 29 days for KE EC, KW EC, and settler tank sludge respectively. Comparing these values with the estimated 14.3 day batch preparation time indicates that batch preparation is rate controlling for EC sludge and drum production is rate controlling for settler tank sludge. Based on the rate controlling step for each sludge type and the assumed number of batches the total processing time for the base case is estimated at 16 months with 100 % TOE or 23 months assuming 70 % TOE. This is less than 40% of the required processing duration of 5 years or less, and may be compared to the base case WWO processing time estimate of 59 months. The much shorter processing time results from the much faster oxidation step and hence shorter batch preparation time.

The FROP processing time is also less sensitive to retrieval schedule assumptions as compared to WWO. The ability of WWO to complete processing within 60 months relies on each oxidation batch processing multiple STSC batches (two for the base case). The estimated processing schedule for the FROP is largely driven by the processing rate of the drumming system. Therefore, compared to WWO, the estimated processing schedule of the FROP will be more sensitive to changes in assumptions related to the drumming. See Appendix I for additional discussion of sensitivity to changes in the base case assumptions for the FROP and other alternatives under consideration.

The base case process flowsheet estimate indicates that for all waste types the waste loading per drum is limited by the fissile isotope content (^{239}Pu FGE). Within the accuracy of available data there are not significant differences between the FROP and other alternatives relative to the achievable waste loading or number of product drums.

B4.2 Major Process Equipment

FROP equipment sizing calculations [12] include only the major process tanks shown on Figure B-1 plus added cold chemical handling tanks needed for the FROP. Other equipment is assumed to be essentially identical to WWO (Appendix A). FROP process tank size estimates are given in Table B-3 for the nominal base case set of assumptions.

Comparison of Table B-3 with WWO values in Appendix A (19 m^3 RRT and 9.1 m^3 LST working volumes) shows that the estimated RRT and Lag Storage Tank capacities are about 16% and 50% smaller respectively than the WWO process base case estimate. This results primarily from processing a single STSC batch per oxidation batch in the FROP base case versus 2 STSC batches per oxidation batch for the WWO base case estimate. The basic features of the tanks are similar to WWO: steam heating and water cooling jacket(s) on the RRT, water cooling jacket on the Lag Storage Tank and agitators in both tanks. The FROP condensate tanks are about 13 % larger than for the WWO base case because of the increased condensate resulting from chemical additions to the RRT. The FROP also requires additional tanks and support equipment for preparation and addition of required nonradioactive process chemicals to the RRT. The FROP does not require nitrogen purge of the RRT, and instead uses air sweep to prevent buildup of hydrogen in the tank. Other than these items, equipment list and sizing is expected to be identical to that for WWO.

Table B-3. FROP Base Case Process Vessel Size Estimates

Vessel	Working Volume (m^3)	Gross Volume (m^3)
Receipt and Reaction Tank (RRT)	16	20
Lag Storage Tank (LST)	4.5	5.7
Condensate Tank A	17	20
Condensate Tank B	17	20
Hydrogen Peroxide Day Tank	3.7	4.6
Hydrogen Peroxide Bulk Storage Tank	6	6.8
Ferrous Sulfate Day Tank[1]	0.57	0.71
Ferrous Sulfate Make-up Tank[1]	1.0	1.1
Sodium Chloride Day Tank[1]	.016	.019
Sodium Chloride Make-up Tank[1]	0.4	0.45
[1]The Ferrous Sulfate and Sodium Chloride Makeup and Day Tanks can also be used to add hydrochloric and sulfuric acid respectively if needed.		

B4.3 Facility and Equipment Requirements

Separate facility layouts and other facility information were not prepared for the FROP option.

For the purpose of comparative cost estimates it is assumed that equipment and facility is the same as is the same as WWO (Appendix A) with the exceptions noted below.

B4.3.1.1 Equipment changes from WWO

- RRT gross volume is reduced to 20 m^3 from 24 m^3 for WWO.
- LST gross volume is reduced to 5.7 m^3 from 11.4 m^3 for WWO.
- Process Condensate Tank gross volumes are changed to 20 m^3 for FROP compared with 17 m^3 for WWO.

- For conservatism, the preliminary cost estimate for the FROP assumes either Alloy C-276 or Alloy 690 is used for the RRT and LST. These alloys are expected to be suitable for this service; however, other lower cost options may also be acceptable.
- Chemical handling tanks are added for hydrogen peroxide, ferrous sulfate, and sodium chloride solutions (Table B-3).

B4.3.1.2 Facility changes from WWO

- Remote cell space for the RRT and LST are reduced proportional to the reduced tank sizes.
- Space for the condensate tanks is increased proportional to the increased/reduced tank sizes.
- A larger chemical receipt, makeup, and storage tank area is required for nonradioactive chemicals identified in Table B-3.
- Additional space may be needed for chemical addition day tanks identified in Table B-3.

B5 Characteristics of the Alternative Relative to Evaluation Criteria

This section provides an evaluation of the process concept relative to the evaluation criteria.

Section B5.1 identifies attributes of the alternative are identified that distinguish the alternative in the evaluation against other alternatives under consideration. These attributes are categorized as potential advantages or disadvantages compared to other alternatives. Attributes that are common to all alternatives are typically not included. In Section B5.2 the identified attributes, advantages and disadvantages are allocated to the evaluation criteria from the Decision Plan [13].

B5.1 Evaluation Considerations for FROP Relative to Alternatives

The project scope and requirements assume that any alternative must be capable of receiving full STSC batches of K Basin sludge and processing them to meet criteria for shipment to WIPP. As such, all alternatives will need certain minimum capabilities and will present minimum safety (public and worker) and environmental risks, and minimum costs and technical requirements. This section notes characteristics, advantages, and disadvantages to the FROP alternative that may differentiate it relative to other alternatives under consideration.

B5.1.1.1 Potential Advantages or Beneficial Attributes of FROP:

- The minimum sized tanks (RRT and LST) needed to accept and process a full STSC batch are sufficient for use by FROP. Minimizing process tank size also minimizes remote cell space requirements and presents an easier mixing problem for slurry tanks as compared to alternatives that require larger process tanks.
- FROP reaction time is relatively short, resulting in relatively short operating duration with a single process train and minimum tank size (about 2 years versus 5-7 year maximum criteria in the Decision Plan [13]). This is expected to result in the following beneficial attributes:
  - Relatively low overall operating costs due to short plant operating life.
  - Short process operating time results in low operating time on agitators, erosion of agitators and tank walls, and less wear and tear on equipment. This is expected to reduce maintenance costs, worker exposure to radiation, and secondary radioactive waste generation compared to alternatives that require longer operating duration.
  - Low reaction time results in reduced probability and risk from process failures and less sensitivity to down time/maintenance of Receipt and Reaction Tank related components.
  - FROP processing rate (or processing duration) has less dependence on retrieval schedule than some alternatives. FROP processing is expected to be limited by drumming rates much of the time. If there are retrieval delays the FROP treatment process can catch up with limited impact to the drumming process or overall processing schedule.
  - The FROP also requires only a single STSC batch in each oxidation batch. Some alternatives may require either multiple STSC batches in each oxidation or multiple oxidation process trains in order to achieve the required total processing times.
- Short reaction times and near ambient temperature make laboratory testing relatively easy and fast. Reaction tests with maximum U metal particles can be taken to completion in days, as compared to weeks or months for some alternatives. This allows for a moderate cost and schedule for development of the technology to the required maturity level.

- The FROP product is expected to be in a high oxidation state. The peroxide used is expected to oxidize most UO_2 in the sludge to UO_3 prior to drumming. This is expected to eliminate the risk (discussed in Appendix A) of swelling or damaging the drum due to oxidation of the waste after it is placed in drums. In addition, the UO_2 may be designated as pyrophoric. Eliminating UO_2 also eliminates need to address any concerns related to its phyrophoricity.
- Inert gas (nitrogen) blanketing is not required for the Receipt and Reaction Tank (sweep air is acceptable). Air sweep is expected to have low installation and operating costs compared to nitrogen blanketing, which may be required for some alternatives. Air sweep also does not result in worker risk related to oxygen free atmospheres.
- Material upgrades to process equipment and additional chemical addition capabilities included in the FROP alternative also increase flexibility for chemical treatment and processing other future (undefined) waste streams with a variety of chemical agents.
- With minor modifications equipment installed for the FROP can also be used for other process alternatives, e.g. addition of the inert gas (N_2) blanketing capability is the only change expected to use the WWO process in the FROP system.

B5.1.1.2 Potential Disadvantages and Risks of FROP:

- Potential for corrosion problems related to Cl^- added.
- Limited testing has been completed to date on process chemical and physical behavior.
- Potentially complex chemistry and potential for unexpected side reactions.
- Additional safety risks and safety controls associated with handling hydrogen peroxide solutions.
- Additional tankage is needed for cold chemical handling receipt and storage.
- Slightly larger waste water production and commensurate increase in condensate tank volume.

B5.2 Evaluation Considerations for FROP Relative to Decision Criteria

Table B-4 illustrates how the identified advantages, disadvantages, and risks relate to Decision Criteria identified in the Decision Plan [13].

Table B-4. Evaluation Considerations for the FROP Alternative

Decision Criteria from Decision Plan [13]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
Safety	Ensure worker safety.	Relative ease/difficulty in implementing adequate safety measures as measured by number of passive (inherently safe) vs. active engineered safety features. Ensure protection of the nuclear the general public.	**Advantages** • Relatively short operating period. • Inert gas blanketing not required. • Minimum material at risk (MAR)/inventory of sludge. • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries**[14]**. **Disadvantages** • Use of reactive/hazardous chemical additives (30 % hydrogen peroxide) is required. Required chemicals are in use elsewhere at Hanford and for general industrial use.
Regulatory/ stakeholder acceptance.	Ensure compliance with environmental laws and regulations and DOE orders. Address sludge management concerns in *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* record of decision.	Achieve acceptance of regulators and other Stakeholders.	**Advantages** • Short processing time expected to be viewed favorably by stakeholders. **Disadvantages** • None identified
Technical maturity	Maximize confidence in process implementation	Projected Technical Readiness Level (based on technical criteria only at this stage of the project) Estimated volume of waste going to WIPP	**Advantages** • Proof of principle tests successfully demonstrated process functionality under several conditions. • Short reaction times and near ambient temperature allow substantial risk reduction with a modest amount of small scale laboratory testing, reducing cost and schedule for completing the required testing activities.

Decision Criteria from Decision Plan [13]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			• The FROP product is expected to be fully oxidized eliminating potential for post drumming expansion due to oxidation of UO_2 and eliminating pyrophoric material. • Modest size slurry tanks. Smaller size tanks present and easier mixing problem as compared to processes that require larger tanks. • Estimated volume of waste is expected to be ^{239}Pu FGE limited, i.e. the process is not expected to increase number of drums to WIPP above the minimum. **Disadvantages** • Relatively little process testing has been completed to date. • Potentially complex chemistry with possibility of side reactions or other unexpected behavior. • Upgraded materials of construction needed due to added chloride.
Operability and maintainability	Maximize operability Maximize maintainability	Ability for process to be remotized Ability to treat and package K Basin sludge inventory in 5 to 7 years Acceptability of secondary waste streams for disposal at Environmental Remediation Disposal Facility (solids) and 200 Area Effluent Treatment Facility (liquids)	**Advantages** • With a single process train and minimum tank size to accept STSC batches the operating duration relatively short (<2 years) to process all sludge. • Short process operating time results in low operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction tank related components. • Conversely; the short estimated processing time provides more allowance for downtime process performance problems and still meet the 5 year window. • Smaller tanks present an easier mixing problem as compared to alternatives that require larger tanks. • The FROP product is expected to be in a high oxidation state, eliminating pyrophoric material and

Decision Criteria from Decision Plan [13]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			reduced potential for post drumming expansion due to oxidation of UO_2. • The treatment system will use proven, familiar, remote equipment design concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. The drumming system is similar to other alternatives and will use primarily industrially proven equipment and designs with some custom features to be developed and proven for this specific application. • The FROP equipment is very flexible and can also be used for several other process options with minimal modifications. **Disadvantages** • Expected to require upgraded corrosion resistant materials of construction due to potential corrosion problems with Cl present.
Life-cycle cost and schedule	Optimize life-cycle costs for sludge treatment and packaging facility Provide acceptable schedule to stakeholders	**Cost** Cost of maturing technology to Technology Readiness Level-6 Capital cost Operating and maintenance cost Deactivation and decommissioning cost **Schedule** Facility startup Complete treatment and packaging	**Advantages** • Relatively small process slurry tanks and short operating time are expected to result in relatively low operating costs. • Short reaction times and near ambient temperature allow substantial risk reduction with a modest amount of small scale laboratory testing **Disadvantages** • Relatively little process testing has been completed to date. • Added chemicals result in increased waste water and slightly larger (13%) condensate tanks as compared to processes that do not require chemical additions.
Potential for beneficial integration with ongoing STP	• Optimize cost or schedule for STP -	• Potential for integration of treatment and/or packaging	**Advantages** • Compatible with Phase 1 design concept.

Decision Criteria from Decision Plan [13]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
- Phase 1 activities	Phase 2 • Consider co-location of needed facilities provided by STP - Phase 1	with interim storage in T Plant • Potential for shared functions with those being provided by STP Phase 1 • Optimization of location of reduce/eliminate intermediate shipping or repackaging of the sludge material	• No identified positive or negative impacts to currently planned Phase 1 Project activities • Co-location near T Plant is possible, but overall siting studies have not been completed. **Disadvantages** • No significant disadvantages noted
Integration with Site-wide RH-TRU processing/packaging planning, schedule, and approach	Optimize processes, equipment, and facilities for K Basin sludge treatment and packaging with other Hanford Site RH-TRU waste streams	• Number of other Hanford Site RH-TRU waste streams that can be treated with candidate process • Number of other Hanford site RH-TRU waste streams that can be packaged with candidate packaging process	**Advantages** • Upgraded material requirements to allow for moderate chloride levels provide added flexibility for chemical treatment and processing other waste streams (sludge, decontamination solutions, etc.). The process is capable of process additional K Basins TRU waste streams that have been identified. • The chemical oxidation system will destroy many organics, which could be useful in processing other waste streams. • Other than the additional K Basins wastes, no specific RH TRU streams have been identified for integration at this time. **Disadvantages** • None noted

B5.3 Conclusions and Recommendations

B5.3.1.1 Conclusions

- Based on successful completion of proof of principle testing the FROP is judged to be a technically feasible treatment alternative for processing K Basin sludge in STP Phase 2. This conclusion is further supported by literature information on other chemical oxidation processes that use chloride to promote reaction rates.
- The FROP has expected to have relatively favorable performance in terms of processing duration, equipment size, complexity, and flexibility.
- Product is expected to meet WIPP and transportation requirements
  - Hydrogen from U metal reaction eliminated by oxidation of U metal
  - Pyrophoric U metal and UO_2 expected to be eliminated by oxidation reaction
  - Free liquids eliminated by in-drum mixing of dry additives
  - Gamma radiation assay on concentrated sludge used to determine proper sludge addition per drum
  - Final measurements taken on drum to verify FGE, dose rate, and radiolytic heat generation limits are met
- Based on the Decision Plan evaluation criteria the FROP compares favorably with other alternatives.
- In order to finalize definition of the process flowsheet and support final process selection studies during conceptual design, additional laboratory testing, literature review, and topical engineering studies should be performed in the near term. Other chloride catalyzed oxidation should be considered as part of selection and optimization of the final process flowsheet, for example the hypochlorite process previously developed by DOE [4, 5].

B6 References

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Appendix C

Evaluation Data for Peroxide and Carbonate Oxidation Process (PCOP) – (Energy*Solutions*)

C1 Introduction

Use of hydrogen peroxide and ammonium carbonate for oxidation of U metal was proposed by EnergySolutions in response to a formal Request for Information. After further definition of the concept and approach for testing CHRPC awarded Contract 42106 to EnergySolutions to perform proof of principle testing and related engineering support work needed to evaluate and define how a Peroxide and Carbonate Oxidation Process (PCOP) could be implemented. The testing and support work completed to date indicate that the PCOP is a viable alternative for use in Phase 2 of the STP [1].

C2 Technology and Flowsheet Summary Description

The unique feature of the PCOP is use of hydrogen peroxide and carbonate to achieve relatively rapid U metal oxidation at moderate temperatures. The oxidized sludge is concentrated by evaporation and solidified in drums by use of additives.

The overall process is divided into two major parts:

1. In the treatment process, the sludge is oxidized to eliminate metallic uranium and water is removed to give the solids concentration desired for the immobilization process.
2. In the immobilization process, the concentrated sludge slurry is assayed, metered into drums, and converted to a liquid free solid that is sealed in drums for eventual offsite transport and disposal.

Supporting processes such as vent gas treatment, liquid waste disposal, cooling water and process steam supply are assumed to be similar to WWO (Appendix A) and are not further discussed for the PCOP option.

C2.1 Treatment Process

The PCOP as proposed by EnergySolutions is described in Reference 1. The process is illustrated in Figure C-1. Dilute sludge from an STSC is delivered batch wise to the Receipt and Reaction Tank (RRT). The RRT is normally maintained at slightly below atmospheric pressure and is agitated continuously when it contains a batch of sludge. The batch is heated using a steam jacket and concentrated by evaporating excess water. The batch is then cooled using a cooling water jacket. Ammonium bicarbonate is added to achieve a nominal 1 molar concentration in the sludge slurry. Addition of hydrogen peroxide solution (nominal 50 %) is then started at a controlled rate. In the presence of sludge components the hydrogen peroxide decomposes too fast to allow for a single batch addition at the start of reaction. Therefore, continuous peroxide addition is maintained through most of the reaction period. Additional ammonium bicarbonate may also be added as needed to maintain carbonate concentration as the liquid volume increases due to continuing peroxide addition. When the U metal oxidation reaction is complete (or nearly complete), peroxide addition is stopped. The batch is then heated to near the boiling point and is concentrated to the desired solids concentration by evaporation. The post reaction evaporation step also destroys any residual peroxide. The oxidized and concentrated sludge batch is then transferred to the Lag Storage Tank (LST).

The LST is continuously agitated when a sludge batch is present, and is cooled with a water cooling jacket. Concentrated sludge is transferred to the assay and drumming system in smaller batches as needed. The LST is sized to hold at least a full concentrated batch from the RRT. Once the RRT is emptied, preparation of the next sludge batch can be started while the previous batch is processed by the drumming system.

Steam generated during the evaporation step flows first to a demister to remove entrained material and then to a water-cooled condenser. Non-condensed vent gas is heated and filtered prior to discharge. Condensate drains to a Condensate Tank. Ammonia driven off during the heating step may accumulate in the condensate. If needed, hydrogen peroxide is added to the condensate to destroy most of the residual ammonia. Where feasible, clean condensate is recycled for line flushes and for the immobilization step. Excess condensate is sampled and shipped by truck to ETF for disposal.

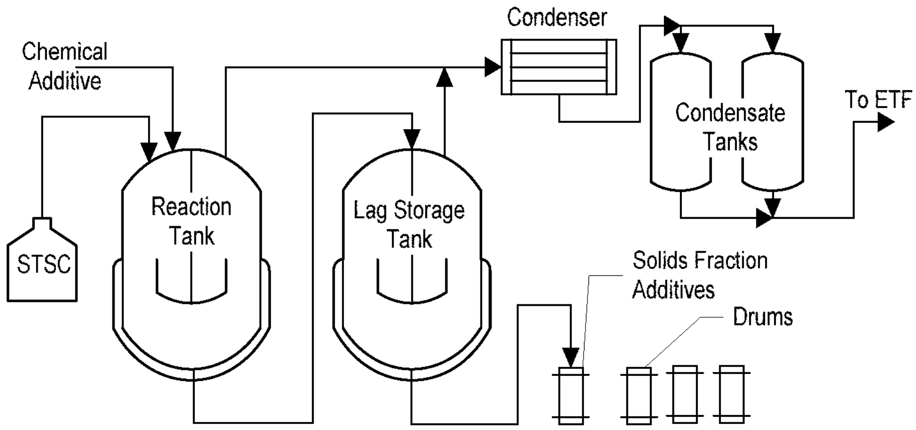

Figure C-1. EnergySolutions Peroxide and Carbonate Oxidation Simplified Flow Diagram

Similar to other oxidation treatment processes, a method is needed to assure that metallic uranium has been adequately eliminated. For the PCOP a combination of the following methods will be used:

- Process validation. This method involves performing process validation tests which define process performance sufficiently to provide confidence the process will perform as expected. This can include both pre-commissioning testing and test data collected during initial hot operations.
- Monitoring of fission product gas. Past work on Warm Water Oxidation of actual spent fuel has demonstrated that fission product gasses (Kr and Xe) are released when the fuel is oxidized. Release of fission product gasses has been used in laboratory tests to track the U metal oxidation reaction and has also been proposed as a potential method of tracking the in-plant Warm Water Oxidation (WWO) process (Appendix A). This method may be easier to apply to PCOP because the reaction times are much shorter than for WWO, which is expected to result in a higher fission product gas release rate producing higher concentrations that are easier to detect.
- Monitoring of hydrogen generation in the RRT. If at the end of the expected reaction period all of the uranium metal has not been oxidized, hydrogen will continue to be produced by WWO of the reaction of water with residual U metal during the final concentration step. Monitoring vent gas for hydrogen content during the water oxidation and concentration steps to detect excess hydrogen could be used to determine if there is significant residual uranium metal present. A small amount of hydrogen production will also continue via radiolytic splitting of water, which may reduce the sensitivity for detecting residual metallic U using this method.
- Monitoring of hydrogen generation in the product drums. Monitoring hydrogen generation rates in product drums could be used to prove significant U metal is not present in the drums. This would involve holding selected drums for a period of time at an elevated temperature (60 °C for example) and measuring the hydrogen evolution rate. A limited number of drums could be tested using a statistical sampling or process validation approach. An advantage of this method is that it directly correlates with the applicable hydrogen generation limit from drums during shipping. The disadvantage is that it will take a substantial amount of time for each test, likely days or weeks.

C2.2 Process Chemistry

The PCOP uses hydrogen peroxide to oxidize uranium metal to U(VI). The U(VI) reacts with carbonate in solution to form uranium carbonate. The stoichiometry of this reaction is usually represented as:

$$U + 3H_2O_2 + 3CO_3^{2-} \rightarrow UO_2(CO_3)_3^{4-} + 2OH^- + 2H_2O \qquad \text{(Eq. C1)}$$

Peper et al. (2004) observed the reaction proceeding further to produce $[(UO_2)_x(CO_3)_y]$, where x and y depend on the peroxide and carbonate concentrations [2]. As well as being an oxidizing reagent, the hydrogen peroxide is a good ligand for uranium. Therefore, some uranium may be present after reaction as a complex with the hydrogen peroxide. A key advantage of this reaction is that no hydrogen is evolved and no uranium hydride is produced (as it is when uranium reacts with water).

Earlier work by Watts et al. (1999) and Shu-Sung and Gurol (1998) showed that ferric oxide hydroxide could promote the decomposition of hydrogen peroxide to oxygen gas [3, 4]. Fenton (1894) first observed the reaction of peroxide with soluble Fe^{2+} to form peroxide radicals (Fenton's reagent) and the reaction of peroxide radicals with additional hydrogen peroxide to produce oxygen gas [5]. Therefore, limiting hydrogen peroxide decomposition was identified early as an overall project objective to minimize the quantity of reagents needed for implementing the process.

C2.3 Immobilization Process

EnergySolutions proposed use of Portland cement to solidify the oxidized and concentrated sludge, eliminating free liquids, similar to WWO. However, the assay and drumming equipment concepts proposed by EnergySolutions [1] are significantly different than what is currently shown for the WWO design. These differences are unrelated to the EnergySolutions oxidation process proposed for treatment. Assuming a different assay and immobilization system concept could obscure comparison of the PCOP with other treatment options. Therefore, for current evaluation of the PCOP, the WWO assay and drumming approach is assumed for immobilization. Alternate assay and drumming equipment concepts will need to be evaluated as part of future project activities.

The assumed assay and immobilization approach for PCOP is the same as WWO (Appendix A), and includes gamma radiation measurements on a recirculation stream from the LST. These measurements are then used to estimate concentration of fissile isotopes using a dose-to-curie methodology. This data is in turn used to determine the amount of sludge loaded to each drum. Sludge transfer to the drum is controlled by a metering pump which draws from the recirculation stream. Sludge and flush water transferred to the drum are solidified by addition of dry Portland cement-based additives. A "lost paddle" in-drum mixing technique is used to blend the dry additives with the sludge slurry resulting in a solid product with no free liquids. Gamma radiation measurements are taken on the finished drum. These measurements are used to estimate the content of WIPP reportable isotopes is estimated based on a dose-to-curie methodology. Use of the dose-to-curie methodology will require qualified measurement systems together with isotopic ratios and dose-to-curie relationships for each type of waste processed. See Appendix A for additional information on the assay and drumming system concept.

C3 Technology Development Status

The treatment process is expected to utilize conventional proven commercial equipment adapted for remote operation, e.g. jacketed tanks with mechanical agitators, demisters, scrubbers, positive displacement pumps, valves, metal or flexible hoses, and instrumentation. The only identified equipment that may be novel or near the edge of demonstrated use is the equipment for monitoring of fission product gasses to support one of the alternative methods identified for demonstrating completion of reaction. Less mature aspects of the treatment system technology are related to knowledge of chemical and physical behavior of the actual sludge in the treatment equipment.

As part of the current evaluation, proof of concept tests were completed to validate basic functionality of the process chemistry and obtain information on reaction rates and reagent requirements needed to develop a preliminary flowsheet. Process equipment for the treatment system is expected to be nearly identical to WWO. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO. Therefore the following discussion focuses on key aspects that are unique to the PCOP and on differences between the PCOP and WWO. The development status of those aspects is similar to WWO as discussed in Appendix A.

Based on the success of the proof of concept tests and use of commercially proven equipment the overall process is developed to approximately TRL-3 as defined in DOE G 413.3-4 [10].

C3.1 Chemistry and Phenomenology

Review of prior literature shows that solutions of peroxide and carbonate have been used in the past for oxidizing uranium oxides to higher oxidation states and for dissolving uranium oxides. Based on this information it was believed that this combination may also accelerate oxidation of U metal by continuously removing the oxide film and exposing fresh U metal to a strong oxidant (peroxide). Limited testing previously performed by Soderquist [6] demonstrated U metal oxidation rates with peroxide plus carbonate that are substantially faster than rates for WWO. However the Soderquist tests were limited to about 1 hour duration and no other sludge components were present in the tests. Other previous work demonstrated that iron oxides can catalyze relatively rapid decomposition of peroxide [3, 4]. Based on this data, it was uncertain if the increased U metal reaction rates found by Soderquist could be maintained for the much longer times needed for complete U metal oxidation. It was also not certain if it is practical to maintain sufficiently high peroxide concentrations in the presence of iron oxide present in the sludge. Because of the significant improvement in reaction rate compared to WWO, it was decided to proceed with laboratory scale testing to attempt to identify a practical process approach.

C3.1.1 Summary of Testing Performed

Three sets of U metal oxidation tests were performed to evaluate the PCOP [7]. The tests were performed at the Oak Ridge National Laboratory. In Task 1, the only sludge simulant components added were U metal (1/4 inch cubes) and ferrihydrite (FeO(OH)). Based on scoping tests it was determined that batch addition of the peroxide was not practical because the peroxide decomposes long before the U metal oxidation reaction is complete. Therefore the tests were performed with essentially continuous peroxide addition. In Task 1 three samples were tested over a 7 day reaction time. These tests demonstrated that reasonably high U metal reaction rates could be maintained for the 7 day duration. Required peroxide addition was relatively high, but was considered to be manageable. Therefore, it was decided to proceed with Task 2 testing.

Task 2 included 6 additional tests with a variety of conditions. A more complete simulant was used [9], which contained mixed uranium oxides and other sludge components in addition to the same ferrihydrite and U metal cubes used for Task 1. Some Task 2 tests were also extended for up to 10 days total oxidation time. Task 2 evaluated the effect of varying selected parameters: temperature, carbonate/bicarbonate concentration, and peroxide addition. In Task 3 the effect of reduced pH was evaluated in 3 tests, each of which used a different acid for pH reduction.

With the exception of preliminary scoping tests, all reaction tests were performed per the following steps. See the test report for additional detailed information [7]:

- Sludge simulant or FeO(OH) water slurry, ammonium bicarbonate and dilution water to achieve a nominal 65 ml total volume were added to a 250 ml flask. Acids were also added to reduce pH for Task 3 tests only.
- A U metal coupon (¼ inch cube) was added to the flask.
- The flask was sealed with a stopper vented to a gas collection bag.
- The flask was placed on a shaker table and addition of hydrogen peroxide (50 wt. % solution) started at a controlled rate.
- Temperature was either maintained at ambient or at 10° C using a temperature control enclosure.
- The U metal cube was periodically removed and weighed to determine the amount of metal loss. It is assumed that the metal removed was oxidized, although it is possible that small metallic particles could have been removed from the coupon surface.
- For certain tests, additional ammonium bicarbonate or acid for pH adjustment were also added periodically.
- For certain tests, offgas samples were collected and analyzed.
- Solution samples were obtained periodically and were checked for peroxide concentration and pH. Some solution samples were also analyzed for dissolved uranium content.

A summary of Task 2 and Task 4 U metal loss rate data is shown in Table C-1. With the exception of Test 4-2, Test 2-4 demonstrated the highest U metal loss rate (0.0052 mm/hour average over the 10 day reaction period). This is approximately 5 times the estimated rate for WWO at 95ºC. Test 2-4 was used as the primary basis for flowsheet developed in Reference 1.

Test 4-2 included use of HCl to reduce pH and produced U metal loss rates more than an order of magnitude higher than any other test, resulting in complete destruction of the U metal cube within 2 days. The chloride concentration in this test was about 1 mole/liter. Reduction of pH with other acids showed minimal effect on U metal loss rates. This test showed promise of significantly increasing the U metal oxidation rate by chloride addition, and thereby reducing the reaction time. However, because there was only one data point available, and it was not feasible to further investigate chloride addition at the time, EnergySolutions elected to use the more conservative results of Test 2-4 as the basis for their initial flowsheet development. Addition of chloride remains a possible optimization approach for further improving the PCOP. Under a separate testing contract, Ceradyne did a more thorough evaluation of chloride addition as part of the Fenton's Reagent Oxidation Process development. They also found a substantial increase in reaction rate from chloride addition, which is included in their proposed flowsheet (see Appendix B).

The PCOP proof of concept tests are considered to be successful in that they demonstrated conditions that resulted in U metal loss rates at 25°C that are significantly higher than achievable with WWO at near atmospheric pressure.

Table C-1. Rate of Uranium Metal Loss in EnergySolutions Task 2 and Task 4 Tests[1]

Test #	Temp.	NH4HCO3 (M)	Acid	pH	U Metal Loss Rate mm/hr	Test Description
2-1	10ºC	2 (initial only)	None	8.4 to 9.2	0.0015 (average)	Peroxide addition at 0.5 ml/hr. Test duration 8 days.
2-2	10ºC	4 (initial only)	None	8.0 to 9.2	0.0025 (average)	Peroxide addition at 0.5 ml/hr. Test duration 8 days.
2-3	10ºC	4 (initial only)	None	9.1	0.0018 (average)	Peroxide addition at 0.5 ml/hr. Test duration 8 days.
2-4	23-25ºC	2	None	7.6 to 8.8	0.0052 (average)	Peroxide addition 7.4 ml/hr first hour then 0.5 ml/hr. Test duration 10 days. NH_4CO_3 added during test to maintain concentration.
2-5	23-25ºC	4	None	7.6 to 8.8	0.0015 (average)	Peroxide addition 7.4 ml/hr first hour then 0.5 ml/hr. Test duration 10 days. NH_4CO_3 added during test to maintain concentration.
2-6	10ºC	4	None	7.7 to 8.7	0.0003 (average)	Peroxide addition 7.4 ml/hr first hour then 0.5 ml/hr. Test duration 10 days. NH_4CO_3 added during test to maintain concentration.
4-1	25ºC	2	HNO_3	6.9 to 8.2	.0032 (average)	Peroxide addition 7.4 ml/hr first hour then 0.5 ml/hr. Test duration 11 days. NH_4CO_3 added during test to maintain concentration. Acid added during test to maintain pH..
4-2	25ºC	2	HCl	7.0 to 8.2	.0895 (first day)	Peroxide addition at 7.4 ml/ hr first hour then 0.5 ml/hr. U metal coupon completely gone after 2 days.
4-3	25ºC	2	H_2SO_4	7.0 to 8.5	.0027 (average)	Peroxide addition 7.4 ml/hr first hour then 0.5 ml/hr. Test duration 11 days. NH_4CO_3 added during test to maintain concentration. Acid added during test to maintain pH.

[1]See EnergySolutions Task 2 and Task 4 Test Report [7] for additional detail.

C3.1.2 Technical Issues and Unknowns Related to Chemical and Physical Behavior

There has been limited testing of the PCOP to date, and no testing with actual sludge. Understanding of process chemistry is therefore incomplete. There are additional components in real sludge that could cause other side reactions, e.g. other catalytic agents may be present in the actual sludge that could decompose peroxide even faster than iron and other components included in the simulants tested to date. Testing to date includes only limited offgas analysis and there is not sufficient data to perform a complete material balance. Some risk remains that potential other unexpected process behavior may be discovered as the process is developed and tested in more detail.

The tests performed measured metal removed from a coupon but did not prove the metal removed was completely oxidized. It is conceivable that fine metal particles were removed from the coupon and remained suspended in the slurry. However, even if it is found that some fine metallic U metal particles remain, impacts to the overall process should be minor. After the oxidation step is complete the next step is to heat the batch to near boiling to decompose residual peroxide and drive off excess water. This step is expected to result in holding the tank contents near boiling for about 3 days. A three day residence time at near boiling temperatures should eliminate any U metal particles below about 100 microns diameter via the WWO reaction. Even if it were found that this time needs to be increased by 200 or 300%, the time cycle impact is relatively small compared to the overall process time cycle. Therefore, this issue needs to be investigated but is not expected to be a major impact even if some residual metallic particles are found.

As currently shown, the PCOP uses ammonium bicarbonate as the carbonate source. This is expected to result in ammonia in the condensate stream, which could exceed the ETF acceptance limits. EnergySolutions identified peroxide addition to the condensate tank as a method of destroying the ammonia if needed to meet ETF requirements. If this turns out to be difficult or problematic an alternate carbonate source can be considered that eliminates the problem, e. g. sodium carbonate or bicarbonate [1]. Addition of sodium carbonate could conceivably increase the volume of waste to be immobilized.

Effects on physical properties (slurry rheology, yield strength, shear strength) have not yet been measured, although no particular difficulties were noted during the proof of concept testing. These uncertainties could be substantially reduced with a modest amount of further testing if the PCOP is selected for further development. It is expected to be relatively easy to perform additional process chemistry/phenomenology testing on the PCOP due to the relatively short reaction time and low process temperatures.

C3.2 Technical Issues and Risks Related to Equipment and Process Integration

Due to the faster reaction rate, the RRT and the LST are expected to be modestly smaller for the PCOP than the WWO process. Other than these relatively minor differences, process equipment for the PCOP is expected to be essentially identical to the WWO process. Remote equipment technology, remote facility features, assay, and integration concepts are expected to be the same as for WWO. Methods used to verify reaction completion are expected to be similar to WWO; however, this problem may be somewhat easier for the PCOP because of the faster reaction rate.

The acceptable amount of residual sludge in tanks at the end of each batch needs to be better defined in order to evaluate need for special methods to achieve, measure, and/or verify that acceptable levels have been achieved.

C3.3 Technology Development Needs

The PCOP is relatively early in the technology and engineering development life cycle. As such, relatively little testing or engineering evaluation work has been completed to date. If this option is to be pursued further a number of initial activities should be performed to better define the process, evaluate performance, determine if there are unexpected problems or complications related to processing actual sludge, and provide engineering data to support more detailed engineering studies and eventually design.

Development needs can be considered in terms of the design phases of a project. In the preconceptual and early conceptual design phases data is needed to verify basic feasibility, understand any complicating factors (e.g. side reactions or adverse physical property changes), and develop preliminary performance information. This data needs to be developed to a level of detail sufficient to support engineering studies used to select the final flowsheet to be used as the basis for conceptual design. In additions, topical engineering studies/evaluations are needed to better define certain aspects of the process. For example, the assay system concept, updated estimates of achievable total measurement uncertainty, feasibility of using fission product gas measurements to verify completion of reaction, potential for uncontrolled/runaway reactions.

During the conceptual design phase process alternatives are typically evaluated and a single preferred alternative is selected. Additional data is needed for the selected alternative to develop and optimize system conceptual design, define the basis for sizing of unit operations, resolve any safety or regulatory issues, and provide a firm basis for moving into preliminary and detailed design.

For the PCOP, most work in the preconceptual and conceptual design phases involves development of a more complete understanding of chemical and physical phenomenology/behavior of the sludge under actual process conditions. Unless the project elects to pursue novel remote equipment or facility concepts, little if any mechanical/equipment oriented testing or development work is expected to be needed during the preconceptual and conceptual design phases. Possible exceptions are the assay system used to determine isotope concentrations in the drummed waste, and offgas analysis equipment that may be considered for verifying completion of reaction. These unit operations are currently not well defined and may need early equipment oriented testing.

In the detailed design phase, development activities are expected to primarily focus on design verification testing. This phase will be primarily equipment oriented and will include testing of individual components or physical features and testing of integrated systems or subsystems. The following sections provide a preliminary identification of needed activities, with primary focus on initial or near term activities.

C3.3.1 Critical Near Term Development Activities

A summary of critical near-term development activities is given below. These activities should be completed in the preconceptual and conceptual design phases.

C3.3.1.1 Chemical and Physical Behavior

- Complete laboratory process testing with simulants:
  - Explore the effect of process variables on reaction performance. Tests should include more careful control and monitoring of reaction conditions.
  - Provide a more complete material balance including offgas volume and composition measurements.

- Determine if U metal is removed as oxide or as fine metal particles.
- Obtain scoping information on effect on sludge physical properties. This should focus on identifying any problematic behavior and should include consideration of the post reaction boildown step.
- Explore the effect of additional sludge components not in the initial simulants tested.

- Based in part on results of laboratory testing above, and supporting engineering studies and literature review, develop a more comprehensive and optimized flowsheet.
- Perform laboratory testing based on flowsheets defined above with simulants, and with actual sludge if feasible.
- Complete bench scale process flowsheet testing with simulants. This will typically be performed at 0.5 to 4 liter scale with more prototypic mixing and possibly more prototypic materials of construction.
- Complete more comprehensive testing on sludge physical properties/physical behavior under process conditions: slurry rheology; density, water, and solids content of settled sludge; tendency to agglomerate or set up, ability to concentrate to target solids concentrations, etc.

C3.3.1.2 Equipment and Materials

- Engineering evaluation of materials of construction: reaction vessel, agitator, pumps, piping, valves, drums, etc.
- Materials testing (e. g. for corrosion) if needed per results of above.

C3.3.1.3 Process Control and Integration

- Refinement of process, equipment, and process qualification concepts for the dose-to-curie assay system. Include evaluation of methods to deal with batch to batch variability of dose-to-curie relationships.
- Perform development testing of assay components and systems.
- Evaluate need, costs, and benefits of additional physical sampling of sludge to reduce total measurement uncertainty.
- Topical engineering study on methods for verifying completion of reaction.

C3.3.2 Longer Term Development Needs

The process is expected to use conventional proven commercial equipment adapted for remote operation and maintenance. However, some equipment oriented process testing will be needed for equipment such as agitators, pumps, and assay system. Testing, development, and demonstration work is also expected to be needed for the drumming system and likely some remote equipment operating and maintenance features. This equipment and the required testing and development work are assumed to be essentially the same as for Warm Water Oxidation (see Appendix A and the Technology Maturation Evaluation for WWO [11]). This testing will be performed primarily during the preliminary design and detailed design phases of the project.

C3.4 Hazard Considerations

A hazards consideration was completed for the Peroxide and Carbonate Oxidation Process in order to provide input to the cost, schedule, and risk considerations for the continued alternatives selection process. This hazards consideration was completed by a team of representatives from Engineering, Industrial Safety, Fire Protection, RadCon, and Operations [16].

A list of the activities constituting the PCOP alternative was compiled. Hazards (or nodes) associated with each were then identified along with potential engineered and administrative controls. Table C-2 below summarizes the results of the hazards considerations for PCOP.

Table C-2. PCOP Treatment Hazard Consideration

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01 – MOBILIZE, RETRIEVE, TRANSFER STORE AND AGITATE.						
RET.01.01	Internal Explosion	Sludge contamination	H^2 accumulation and ignition in STSC headspace	Purge system Ventilation system	Equipment surveillance	—
RET.01.02	Spray Leak	Sludge	Crack leak of slurry being removed from STSC and transferred to receiver vessel	Double contained transfer line.	—	—
RET.01.03	Splash / Splatter	Sludge	Leak of slurry being transferred from the STSC to the receiver vessel	Double contained transfer line Tank High Level Alarm and pump interlock	—	—
RET.01.04	Loss of Confineme nt	Sludge Contamination	Plugged vent path causes an unfiltered release from tank	Pressure transmitter to monitor the tank	—	—
RET.01.05	Internal Explosion	Sludge Contamination	H_2 accumulates in the receiver tank headspace and lines, resulting in a deflagration of the tank headspace or lines	Inerting or Alternate purge path.	—	—
RET.01.06	Direct Rad	Cs-137 release to water during storage or sludge in line or in STSC	Backflow of sludge through a line above the STSC, or exposure to storage water high in Cs-137 or sludge in STSC due to liquid draw down	Interface system design (check valves and system pressure), remote STSC unloading	Transfer access control	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01.07	Load Drop	Sludge contamination	Dropping equipment onto the STSC during removal of cask head or installation of transfer system resulting in a leak	—	*Hanford Site Hoisting and Rigging Manual*	—
REC.01 – RECEIVER VESSEL STAGING AND DEWATERING Note: this includes the boil down dewatering both before reaction and during/after reaction, and agitation and circulation during staging and reaction.						
REC.01.01	Internal Explosion	Sludge Contamination	H_2 accumulation and ignition in tank headspace	Purge system Ventilation system	Equipment surveillance	Note: hydrogen evolution may be very rapid following size reduction, especially if agitation is ineffective and the settled metal is self heating
REC.01.02	Spray Leak	Sludge	Circulating sludge spray leak	Low pressure circulation Secondary confinement	—	—
REC.01.03	Splash / Splatter	Sludge	Leak from circulating system	Secondary confinement	—	—
REC.01.04	Overpressure Loss of Confinement	Sludge Contamination	Plugged vent path and overpressure causes an unfiltered release from tank	Pressure transmitter to monitor the tank, pressure relief, open vent path	—	—
REC.01.05	Direct Rad	Sludge in line or Exposure to vessel	Backflow of sludge through a flush line or in a recycle line, exposure to receiver vessel	Flush water system design (check valves and system pressure), Shielded recirc lines Shielded receiver vessel, remote maintenance for agitation	—	—
REC.01.06	Criticality	—	Accumulation of separated metal, unsafe geometry	Vessel geometry, sludge process limits, sludge material final characterization	—	

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
REC.01.07	Steam agitation / ejection of slurry	Slurry in tank	Steam leak into receiver vessel agitates and volatilizes slurry into off gas system	Steam Jacket design	—	—
REC.01.08	NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
REC.01.09	Facility Fire, spill	Sludge	Facility fire results in failure of confinement vessel and release of rad material	Materials of construction, Fire Protection System	Combustibles limits	—
PCO.01 – PEROXIDE AND CARBONATE OXIDATION TREATMENT PROCESS.						
PCO.01.01	Internal Explosion	Sludge contamination	H_2 accumulation in tank if ventilation interrupted during pre-treatment	Active purge	—	**NOTE:** *Minimal hydrogen production during treatment.*
PCO.01.02	Fire in exhaust system	Sludge contamination	Excess oxygen released in reaction or due to peroxide decomposition	Active purge	Combustible control	—
PCO.01.03	Criticality	Direct Radiation	Relocation of fissile constituents upon metal dissolution	Vessel configuration	Feed controls	—
PCO.01.04	Ammonia release	Ammonia exhaust hazard and waste water contamination	Ammonia release on dewatering	Off gas and waste water treatment	—	—
TRS.02 –TRANSFER AND STAGING OF TREATED SLUDGE						
TRS.01.01	Spray Leak	Sludge	Line failure during pressure transfer results in a release of radiological material outside of the facility	Piping design, secondary piping design, confinement design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
TRS.01.02	Overpressu re	Sludge Contamination	Accumulation of gas in the isolated staging tank results in a potential overpressure and release of radiological material	Ventilation system Confinement design	—	—
TRS.01.04	Splash / Splatter	Sludge	Transfer Line failure results in a release of slurry	Piping design, secondary piping design, confinement design	—	—
TRS.01.05	Direct Rad	Released fission products or sludge in lines or containers	Sludge in lines or vessels not adequately shielded	Facility design	Radiological Control Program access controls	—
TRS.01.06	Seismic Event	Sludge	SSC failure results in spill / spray and spread of rad material	Facility design	—	—
TRS.01.07	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
PKG.03 – IMMOBILIZATION AND PACKAGING OF TREATED SLURRY.						
PKG.03.01	Spray Leak	Sludge	Pressure transfer line failure results in a release of radiological material	Piping design, Secondary piping design, confinement design	—	—
PKG.03.02	Facility Fire	Sludge	Facility fire results in a release of rad material	Materials of construction, Fire Protection System	Combustibles control	—
PKG.03.03	Seismic Event	Sludge	Seismic forces result in a line break and potential release	Facility design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
PKG.03.04	Splash / Splatter	Sludge	Pressure transfer line failure results in a release of rad material	Piping design, secondary piping design, confinement design	—	—
PKG.03.05	Direct Rad	Released fission products or sludge in lines and containers	Direct exposure to sludge rad shine	Shielding design	Radiological Control Program access controls	—
PKG.03.06	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
STG.01 – SHIELDED STORAGE OF TREATED DRUMS.						
STG.01.01	Load Drop	Sludge	Container drop resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.02	Load Drop	Sludge	Load dropped onto container resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.03	Seismic Event	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.04	Other NPH	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.05	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
STG.01.06	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Facility design, Fire Protection Design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
LSC.01 – LOAD SHIPPING CONTAINER. REMOVE FROM ISC, LOAD 72-B LINER, LOAD CASK.						
LSC.01.01	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
LSC.01.02	Load Drop	Sludge contamination	Impact fails package and damages grout	Contamination control ventilation	Hoisting and rigging controls, DOE-RL-92-36	—
LSC.01.03	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Fire Protection System	—	—
LSC.01.04	Seismic Event	Contamination	SSC failure results in package impact and spread of rad material	Facility design	—	—
LSC.01.05	Other NPH	Contamination	Missile or structure failure results in package impact and spread of rad material	Facility design	—	—

DOE-RL-92-36, 2007, *Hanford Site Hoisting and Rigging Manual,* Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

FW = facility worker.
HC-2 = Hazard Category 2 (facility).
HEPA = high-efficiency particulate air (filter).
HVAC = heating, ventilation, and air conditioning.
ISC = interim storage container.
LFL = lower flammability limit.
MAR = material at risk.
NPH = natural phenomenon hazard.
SSC = structure, system, and component.

C3.5 Additional Considerations

This section identifies additional miscellaneous items identified as part of the review which may be considered in evaluating the PCOP alternative.

Some additional industrial safety risks are expected due handling high concentration (50%) hydrogen peroxide. This is a relatively common industrial chemical and its properties and safe handling practices are well known. For example, hydrogen peroxide solution is used as a process chemical additive at the Hanford 200 Area Effluent Treatment Facility (ETF). Maximum inventory at ETF is estimated at 2555 gallons of 50 wt. % hydrogen peroxide solution [12]. The Auditable Safety Analysis for ETF [12] identified some hazards associated with the 50% hydrogen peroxide but did not identify it as a major safety concern. During the Ceradyne Layer 1 testing hydrogen peroxide was added to the flask at more than 200 times the normal rate established in later testing. This resulted in a temperature excursion (increase) of less than 20 C.

One option is to design for the PCOP with WWO as a backup/alternate if problems develop. If PCOP performance is as expected with no major side problems the operating duration would be significantly reduced compared to WWO. If problems are found with PCOP, the WWO could be implemented as a backup the required equipment is essentially the same except for the nitrogen sweep gas required for the WWO RRT. Sensitivity to retrieval schedule and sequence is also reduced with the PCOP since it does not rely on consolidating multiple STSC batches in a single oxidation batch. For processing settler sludge the required oxidation time with WWO is about 1/10 of that required for the EC sludge. Therefore there is less benefit from using the PCOP rather than the WWO process for the settler sludge. An attractive approach could be to use the PCOP for Engineered Container sludge (floor and pit sludge) and use WWO in the same equipment for processing Settler Tank sludge.

Addition of chloride to increase the reaction rate could be considered as optimization of the Energy Solution oxidation process. However, this would make the process similar to the FROP (Appendix B). Therefore, for the current evaluation addition of chloride is considered to be covered by that alternative.

C4 Process Design and Performance Estimates

This section provides a summary of sizing for major process equipment, estimates of the time required to process all of the K Basin sludge, and facility size information. Because most of the design is expected to be similar to the WWO option, the presentation herein focuses on differences with WWO as given in Appendix A.

C4.1 Process Flowsheet Estimates

In order to compare the various technologies under consideration, normalized flowsheet estimates were made to evaluate major equipment and facility size, and to estimate potential differences in sludge processing rate. The normalized flowsheet estimates are based on input from the vendor [1] with adjustments as needed to assure that all technologies are evaluated on a reasonably consistent basis. Common process bases and assumptions are summarized in Appendix J. Normalized flowsheet calculations summarized below are documented in Reference 10.

The flowsheet calculations start by estimating the size of the RRT and LST needed to process the largest STSCs batches. The batch preparation time is then estimated, i.e. the time to transfer and process an STSC batch to the point that it is ready for transfer to the assay/drumming system. When batch preparation is complete and the batch has been transferred from the RRT to the LST, the RRT is ready to begin transfer and processing of the next batch while the batch in the LST is drummed. The PCOP base case batch preparation time is estimated at 50 days for KE and KW EC sludge and 15 day for settler tank sludge.

The time to drum each batch is then estimated. Using base case assumptions for achievable waste loading per drum and drumming rate (Appendix J) the average drumming time per STSC batch is estimated at 7, 9.4 and 29 days for KE EC, KW EC, and settler tank sludge respectively. These values indicate that batch preparation time is rate controlling for EC sludge and drumming time is rate controlling for settler tank sludge. Based on the rate controlling step for each sludge type and the assumed number of batches the total processing time for the base case is estimated at 35.1 months with 100% TOE or 50.1 months assuming 70% TOE. This is about 84% of the required processing duration of 5 years or less, and may be compared to the base case WWO processing time estimate of 59 months. The shorter processing time results from the faster oxidation step and hence shorter batch preparation time.

In the base case processing scenario the RRT working volume is set at 16 m^3 which provides the minimum operational allowance to accept and process the largest STSC batches. Hydrogen peroxide must be added over an extended period to complete the reaction resulting in the need for several intermediate boil downs to provide adequate tank space for continued chemical addition. An alternative is to provide a much larger RRT (57 m^3 working volume) that is sized to hold the sludge plus all chemical additions, eliminating the need for the intermediate boil downs. A time cycle estimate for this case reduces the processing time to 28 months at 100% TOE or 40 months at 70% TOE [13]. The base case and sensitivity case results are summarized in Table C-3.

Table C-3. Estimated Processing Durations-Peroxide and Carbonate Oxidation Process

Case	Sludge Processing Time at 100% TOE	Sludge Processing Time at 70 % TOE	Comments
Base Case	35	50	16 m^3 RRT working volume.
Increase RRT size to avoid intermediate boil downs	28	40	57 m^3 RRT working volume.

The PCOP processing time is also less sensitive to retrieval schedule assumptions as compared to WWO. Ability of WWO to complete processing within 60 months relies on each oxidation batch processing multiple STSC batches (two for the base case). See Appendix I for additional discussion of sensitivity to changes in the base case assumptions for the PCOP and other alternatives that are under consideration.

The base case process flowsheet estimate indicates that for all waste types the waste loading per drum is limited by the fissile isotope content (^{239}Pu FGE). Within the accuracy of available data there are not significant differences between the PCOP and other alternatives relative to the achievable waste loading or number of product drums.

C4.2 Major Process Equipment

PCOP equipment sizing calculations [13] include only the major process tanks shown on Figure C-1 plus added cold chemical handling tanks needed for the PCOP. Other equipment is assumed to be essentially identical to WWO (Appendix A). Process tank size estimates are given in Table C-2 for the nominal base case set of assumptions.

Comparison of Table C-4 with WWO values in Appendix A shows that the estimated RRT and Lag Storage Tank capacities are about 16% and 50% smaller respectively than the WWO base case estimate. This results primarily from processing a single STSC batch per oxidation batch in the PCOP base case versus 2 STSC batches per oxidation batch for the WWO base case estimate. The basic features of the tanks are similar to WWO: steam heating and water cooling jacket(s) on the RRT, water cooing jacket on the Lag Storage Tank and agitators in both tanks. The PCOP condensate tanks are about 100% larger than those for the WWO base case because of the increased condensate resulting from chemical additions to the RRT. The PCOP also requires additional tanks and support equipment for preparation and addition of required nonradioactive process chemicals to the RRT. The PCOP does not require nitrogen purge of the RRT, and instead uses air sweep to prevent buildup of hydrogen in the tank. Other than these items, equipment list and sizing is expected to be identical to that for WWO.

Table C-4. PCOP Base Case Process Vessel Size Estimates

Vessel	Working Volume (m^3)	Gross Volume (m^3)
Receipt and Reaction Tank (RRT)	16	20
Lag Storage Tank (LST)	4.5	5.7
Condensate Tank (CT) A	30	34
Condensate Tank (CT) B	30	34
Hydrogen Peroxide Day Tank	10	12.6
Hydrogen Peroxide Bulk Tank	34	40
Ammonium Bicarbonate Day Tank	1.5	1.8
Ammonium Bicarbonate Makeup Tank	4.2	5.0

C4.3 Facility and Equipment Requirements

Separate facility layouts and other facility information were not prepared for the PCOP option. For the purpose of comparative cost estimates, it is assumed that the equipment and facilities are the same as is the same as WWO (Appendix A) with the exceptions noted below.

C4.3.1.1 Equipment changes from WWO

- RRT gross volume is reduced to 20 m^3 for PCOP from 24m^3 for WWO.
- LST gross volume is reduced to 5.7 m^3 for PCOP from 11.4 m^3 for WWO.
- Process Condensate Tank gross volumes are changed to 34 m^3 for PCOP compared with 17 m^3 for WWO.
- Chemical receipt, storage and handling tanks are added for hydrogen peroxide, ammonium carbonate solutions (Table C-3).

C4.3.1.2 Facility changes from WWO

- Remote cell space for the RRT and LST are reduced proportional to the reduced tank sizes.
- Space for the condensate tanks is increased proportional to the increased tank sizes.
- A larger chemical receipt, makeup, and storage tank area is required for nonradioactive chemicals identified in Table C-3.

Additional space may be needed for chemical addition day tanks identified in Table C-3.

C5 Characteristics of the Alternative Relative to Evaluation Criteria

This section provides an evaluation of the process concept relative to the evaluation criteria.

Section C5.1 identifies attributes of the alternative are identified that distinguish the alternative in the evaluation against other alternatives under consideration. These attributes are categorized as potential advantages or disadvantages compared to other alternatives. Attributes that are common to all alternatives are typically not included. In Section 5.2 the identified attributes, advantages and disadvantages are allocated to the evaluation criteria from the Decision Plan [14].

C5.1 Evaluation of the PCOP Relative to Other Alternatives

The project scope and requirements assume that any alternative must be capable of receiving full STSC batches of K Basin sludge and processing them to meet criteria for shipment to WIPP. As such, all alternatives will need certain minimum capabilities and will present minimum safety (public and worker) and environmental risks, and minimum costs and technical requirements. This section notes characteristics, advantages, and disadvantages to the PCOP alternative that may differentiate it relative to other alternatives under consideration and allocates those to the various decision criteria.

C5.1.1.1 Potential Advantages or Beneficial Attributes of PCOP:

- The minimum sized tanks (RRT and LST) needed to accept and process a full STSC batch are acceptable for use by PCOP. Minimizing process tank size also minimizes remote cell space requirements and presents an easier mixing problem for slurry tanks as compared to alternatives that require larger process tanks.
- The PCOP reaction time is expected to meet the 5 year processing criterion and is moderately lower than some but not all other alternatives. This is expected to provide several advantages:
  - Reduced overall operating costs due to a shorter plant operating life.
  - Reduced process operating time results in less operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment. This is expected to reduce maintenance costs, worker exposure to radiation, and secondary radioactive waste generation.
  - Reduced reaction time results in reduced probability of and risk from process failures and less sensitivity to down time/maintenance of Receipt and Reaction Tank related components.
  - PCOP processing rate (or processing duration) has less dependence on retrieval schedule than some alternatives. The PCOP also requires only a single STSC batch in each oxidation batch. Some alternatives may require either multiple STSC batches in each oxidation or multiple oxidation process trains in order to achieve the required total processing times.
- Short reaction times and near ambient temperature make laboratory testing relatively easy and fast. Reaction tests with maximum U metal particles can be taken to completion in weeks, as compared to months for some alternatives. This allows for a moderate cost and schedule for development of the technology to the required maturity level.
- The PCOP product is expected to be in a high oxidation state. The peroxide used is expected to oxidize most UO_2 in the sludge to UO_3 prior to drumming. This is expected to eliminate the risk (discussed in Appendix A) of swelling or damaging the drum due to oxidation of the waste after it is placed in drums. In addition, the UO_2 may be designated as pyrophoric. Eliminating UO_2 also eliminates need to address any concerns related to phyrophoricity.

- Inert gas (nitrogen) blanketing is not required for the Receipt and Reaction Tank (sweep air is acceptable). Air sweep is expected to have low installation and operating costs compared to nitrogen blanketing, which may be required for some alternatives. Air sweep also does not result in worker risk related to oxygen free atmospheres.
- Equipment installed for the PCOP can also be used for the WWO process (with addition of the inert gas blanketing capability).

C5.1.1.2 Potential Disadvantages and Risks of PCOP as compared to WWO:

- Limited testing has been completed to date on process chemical and physical behavior.
- Potentially complex chemistry and potential for unexpected side reactions.
- Additional safety risks and safety controls associated with handling hydrogen peroxide solutions.
- Additional tankage is needed for cold chemical handling receipt and storage.
- Moderately larger waste water production and commensurate increase in condensate tank volume.

C5.2 Evaluation of PCOP Relative to the Decision Criteria

Table C-5 illustrates how the identified advantages, disadvantages, and risks relate to Decision Criteria identified in the Decision Plan [14].

Table C-5. Evaluation of PCOP against Criteria, Goals, and Measures

Decision Criteria from Decision Plan [14]			Advantages and Disadvantages of Technology Related to Decision Criteria
Criteria	**Goals**	**Measures**	
Safety	Ensure worker safety.	• Relative ease/difficulty in implementing adequate safety measures as measured by number of passive(inherently safe) vs. active engineered safety features. • Ensure protection of the nuclear the general public.	**Advantages** • **No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries [16].** • Moderate operating period. • Inert gas blanketing not required. • Minimum material at risk (MAR)/inventory of sludge. **Disadvantages** • Use of reactive/hazardous chemical additives (50 % hydrogen peroxide) is required. Required chemicals are in use elsewhere at Hanford and for general industrial use.
Regulatory/ stakeholder acceptance.	Ensure compliance with environmental laws and regulations and DOE orders. Address sludge management concerns in *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* record of decision.	Achieve acceptance of regulators and other Stakeholders.	**Advantages** • No significant discriminators noted. **Disadvantages** • Concerns regarding the differences in the process for those discussed in the K Basins ROD. It is not expected to be difficult to modify the permit to allow this process since the same function (U-metal oxidation) is achieved.
Technical maturity	Maximize confidence in process implementation	• Projected Technical Readiness Level (based on technical criteria only at this stage of the project) • Estimated volume of waste going to WIPP	**Advantages** • Proof of principle tests successfully demonstrated process functionality under several conditions. • Short reaction times and near ambient temperature make laboratory testing relatively easy and fast. This reduces the cost and schedule for completing the required testing activities. • The PCOP product is expected to be fully oxidized eliminating potential for post drumming expansion due to oxidation of UO_2 and eliminating pyrophoric material. • Modest size slurry tanks, essentially the minimum

Decision Criteria from Decision Plan [14]			Advantages and Disadvantages of Technology Related to Decision Criteria
Criteria	Goals	Measures	
			required to process full STSC batches. Smaller size tanks present and easier mixing problem as compared to processes that require larger tanks. • Estimated volume of waste is expected to be ^{239}Pu FGE limited, i.e. the process is not expected to increase number of drums to WIPP above the minimum. **Disadvantages** • Relatively little process testing has been completed to date. • Potentially complex chemistry with possibility of side reactions or other unexpected behavior.
Operability and maintainability	Maximize operability Maximize maintainability	• Ability for process to be remotized • Ability to treat and package K Basin sludge inventory in 5 to 7 years • Acceptability of secondary waste streams for disposal at Environmental Remediation Disposal Facility (solids) and 200 Area Effluent Treatment Facility (liquids)	**Advantages** • Moderately short operating duration (<4 years) to process all sludge. • Reduced process operating time results in less operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction Tank related components. • Smaller tanks present an easier mixing problem as compared to the larger WWO tanks. • The PCOP product is expected to be in a high oxidation state, eliminating pyrophoric material and reduced potential for post drumming expansion due to oxidation of UO_2. • PCOP processing rate (or processing duration) requires only a single STSC batch per oxidation batch. • The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. The drumming system is similar to other alternatives and will use primarily industrially proven equipment

Decision Criteria from Decision Plan [14]			Advantages and Disadvantages of Technology Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			and designs with some custom features to be developed and proven for this specific application. • The PCOP equipment is very flexible and can also be used for several other process options with minimal modifications **Disadvantages** More evaporation steps and more condensate produced due to the relatively large amount of peroxide added.
Life-cycle cost and schedule	Optimize life-cycle costs for sludge treatment and packaging facility Provide acceptable schedule to stakeholders	**Cost** • Cost of maturing technology to Technology Readiness Level-6 • Capital cost • Operating and maintenance cost • Deactivation and decommissioning cost **Schedule** • Facility startup • Complete treatment and packaging	**Advantages** • Relatively small process slurry tanks and short operating time are expected to result in relatively low operating costs. • Short reaction times and near ambient temperature make laboratory testing relatively easy and of moderate cost. **Disadvantages** • Relatively little process testing has been completed to date. • Added chemicals result in increased waste water and slightly larger condensate tanks as compared to processes that do not require chemical additions.
Potential for beneficial integration with ongoing STP - Phase 1 activities	• Optimize cost or schedule for STP - Phase 2 • Consider co-location of needed facilities provided by STP - Phase 1	• Potential for integration of treatment and/or packaging with interim storage in T Plant • Potential for shared functions with those being provided by STP Phase 1 • Optimization of location of reduce/eliminate intermediate shipping or repackaging of the sludge material	**Advantages** • Process is compatible with Phase 1 design concept. • No identified positive or negative impacts to currently planned Phase 1 Project activities • Colocation near T Plant is possible, but overall siting studies have not been completed. **Disadvantages** • No significant disadvantages noted
Integration with Site-wide	Optimize processes, equipment,	• Number of other	**Advantages**

Decision Criteria from Decision Plan [14]			Advantages and Disadvantages of Technology Related to Decision Criteria
Criteria	**Goals**	**Measures**	
RH-TRU processing/packaging planning, schedule, and approach	and facilities for K Basin sludge treatment and packaging with other Hanford Site RH-TRU waste streams	Hanford Site RH-TRU waste streams that can be treated with candidate process • Number of other Hanford site RH-TRU waste streams that can be packaged with candidate packaging process	• The chemical oxidation system will destroy many organics, which could be useful in processing other waste streams. • Other than the additional K Basins wastes, no specific RH TRU streams have been identified for integration at this time. **Disadvantages** • None noted

C5.3 Conclusions and Recommendations

- Based on successful completion of proof of principle testing the PCOP is judged to be a technically feasible treatment alternative for processing K Basin sludge in STP Phase 2.
- The PCOP has expected to have performance comparable or slightly better than warm water oxidation (WWO) in terms of processing duration, equipment size, complexity, and flexibility. However, performance is significantly less than the Fenton's Reagent Oxidation Process (FROP) (much longer processing duration, substantially increased peroxide addition, increased secondary waste generation, and additional process complexity resulting from ammonia.
- The PCOP is expected to produce a oxidized product waste form that meets all WIPP criteria.
- Based on the Decision Plan evaluation criteria the PCOP is comparable to WWO but less favorable than the FROP alternatives.

Recommendations

It is recommended that the PCOP not be carried as an alternative into conceptual design for STP Phase 2. Further work on chemical oxidation processes should focus on chloride catalyzed processes such as FROP or the hypochlorite based process developed previously by DOE [15] (see also Appendix B).

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Appendix D

Evaluation Data for Size Reduction and Water Oxidation Process (SRWOP) – (Ceradyne)

D1 Introduction

Size reduction of U metal prior to oxidation using water was proposed by the Boron Products, LLC subsidiary of Ceradyne, Inc. (Ceradyne) in response to a formal Request for Information. After further definition of the concept and approach for testing, CHRPC awarded Contract 42402 to Ceradyne to perform proof of principle testing and related engineering support work needed to evaluate and define how this approach could be implemented. The testing and support work completed to date indicate the Ceradyne Size Reduction and Water Oxidation Process (SRWOP) is a viable alternative for use in Phase 2 of the STP [1,2]. The size reduction step also has potential application as a front end step for other treatment processes.

D2 Technology and Flowsheet Summary Description

The unique feature of the SRWOP is use of an immersion mill to reduce size of U metal particles prior to Warm Water Oxidation. Reduced particle size is expected to substantially reduce the time required to oxidize the U metal using water.

The overall process is divided into two major parts:

1. Sludge receipt and preparation for immobilization: the sludge batch is received from retrieval, oxidized to eliminate metallic uranium and water is removed to give the solids concentration desired for the immobilization process.
2. In the immobilization and packaging process, the concentrated sludge slurry is assayed, metered into drums, and converted to a liquid free solid that is sealed in drums for eventual offsite transport and disposal.

Supporting processes such as vent gas treatment, liquid waste disposal, cooling water and process steam supply are assumed to be similar to WWO (Appendix A) and are not further discussed for the SRWOP option.

D2.1 Sludge Receipt and Preparation for Immobilization

The SRWOP is illustrated in Figures D-1 and D-2. Dilute sludge slurry from an STSC is delivered to the Milling Tank as a batch with up to 13.2 m^3 (3,500 gallons) volume. As shown in Figure D-1, the Milling Tank is located in the top of the RRT. Another option is to locate it outside but near the RRT. Overflow from the Milling Tank flows to the Receipt and Reaction Tank (RRT). The liquid up-flow velocity in the Milling Tank is controlled so that U metal particles above the designated cut size cannot be carried up into the overflow stream. The U metal cut size has tentatively been set at 100 micrometers (μm) diameter for the current flowsheet evaluation. This U metal particle size has about 4 cm/second settling rate in water and appears to be a reasonable choice. However, the actual cut size selection is subject to future optimization. In the Milling Tank the coarse U metal particles are either directed to the inlet of the immersion mill via a hydrocyclone or funnel, or they may settle to the bottom of Milling Tank.

Settled sludge from the bottom of the Milling Tank is picked up using an eductor and delivered to the inlet of the immersion mill. As the size reduction proceeds, additional water may be added to the Milling Tank to flush fine material out via overflow to the RRT. Pumped transfer from the Milling Tank to the RRT may also be used to empty the Milling Tank when milling of a batch is complete. The liquid up-flow velocity in the pump suction leg will be controlled to prevent coarse U metal larger than the cut size from being drawn in. The Milling Tank vents into the RRT freeboard space and any gas and water vapor generated flow out through the RRT demister and condenser.

The RRT is purged with nitrogen to eliminate oxygen, is normally maintained at slightly below atmospheric pressure, and is agitated continuously when it contains a batch of sludge. The RRT contents are heated to near the boiling point of water using a steam jacket. The batch is held at this temperature until all U metal has been oxidized. Excess water is driven off by evaporation, concentrating the batch to the desired end point solids concentration. The oxidized and concentrated batch is then cooled and transferred to the Lag Storage Tank (LST).

The LST is continuously agitated when a sludge batch is present, and is cooled with a water cooling jacket. Concentrated sludge is transferred to the assay and drumming system in smaller batches as needed. The LST is sized to receive at least a full concentrated batch from the RRT. Once the RRT is emptied, preparation of the next sludge batch can be started while the previous batch is processed by the drumming system.

Steam generated during the evaporation step flows first to a demister to remove entrained material and then to a water-cooled condenser. Vent gas from the condenser is heated and filtered prior to discharge. Condensate drains to a Condensate Tank. Where feasible, clean condensate is recycled for line flushes and for the immobilization step. Excess condensate is sampled and shipped by truck to ETF for disposal.

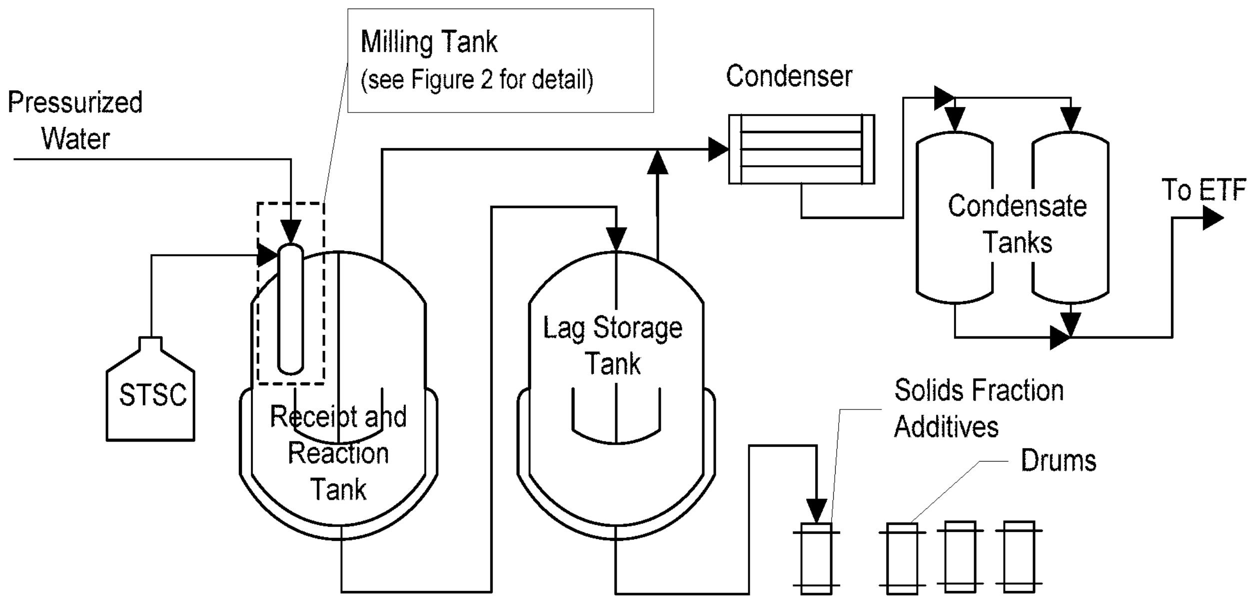

Figure D-1. Size Reduction and Water Oxidation Process Simplified Flow Diagram

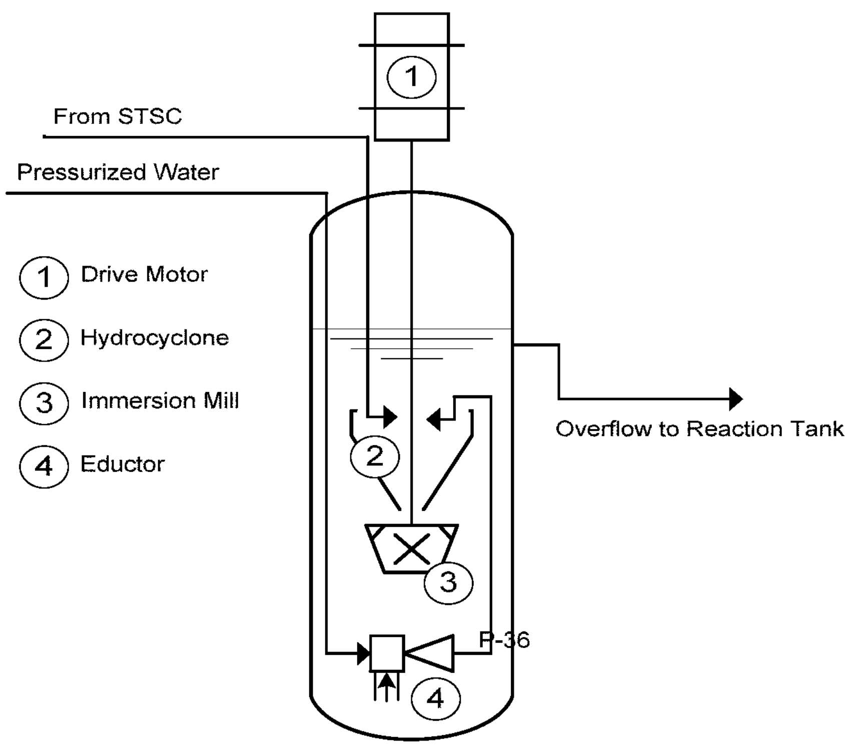

Figure D-2. Milling Tank

Similar to other oxidation treatment processes, a methodology is needed to assure metallic uranium has been adequately eliminated. For the SRWOP a combination of the following methods will be used:

- Process validation. This method involves performing process validation tests which define process performance sufficiently to provide confidence the process will perform as expected. This can include both pre-commissioning testing and data collection during initial hot operations.

- Monitoring of fission product gas. Past work on Warm Water Oxidation (WWO) of actual spent fuel has demonstrated that fission product gasses (Kr and Xe) are released when the fuel is oxidized. Release of fission product gasses has been used in laboratory tests to track the U metal oxidation reaction and has also been proposed as a potential method of tracking the in-plant Warm Water Oxidation process [3]. This method may be easier to apply to SRWOP because the reaction times are much shorter than for WWO, which is expected to result in a higher release rate producing higher fission product gas concentrations that are easier to detect.

- Monitoring of hydrogen generation in the RRT. At the end of the expected reaction period, if all of the uranium metal has not been oxidized, hydrogen will continue to be produced by WWO of residual U metal during the final concentration step. Monitoring vent gas for hydrogen content during the water oxidation and concentration steps to detect excess hydrogen could be used to determine if there is significant residual uranium metal present. A small amount of hydrogen production will also continue via radiolytic splitting of water, which reduces the sensitivity for detecting residual metallic U by measuring total hydrogen generation.

- Monitoring of hydrogen generation in the product drums. Monitoring hydrogen generation rates in product drums could be used to prove significant U metal is not present in the drums. This would involve holding selected drums for a period of time at an elevated temperature (60ºC for example) and measuring the hydrogen evolution rate. A limited number of drums could be tested using a statistical sampling or process validation approach. An advantage of this method is that it directly correlates with the applicable hydrogen generation limit for drums during shipping. The disadvantage is that it will take a substantial amount of time for each test, likely days or weeks.

D2.2 Process Chemistry

A review of uranium/water reaction chemistry is given in Reference 4. A brief summary is provided below. See also Appendix A for additional information.

Uranium metal reacts with anoxic liquid water (i.e. free of dissolved oxygen) in a highly exothermic reaction to form uranium dioxide (UO_2) and hydrogen gas (H_2).

$$U + 2H_2O \rightarrow UO_2 + 2H_2 \qquad \text{(Eq. D1)}$$

Once a small amount of H_2 is generated it can react directly with U metal to form uranium hydride (UH_3), which functions as an intermediate by its reaction with water to form UO_2 and additional hydrogen. The reaction rate has been studied over a wide range of temperatures [4]. Based on the range of data the following correlation for reaction under anoxic conditions is defined in sludge Technical Databook [5]:

$$\log_{10}(\text{base rate}) = (9.694 - 3{,}565/T) \qquad \text{(Eq. D2)}$$

Where,

T = Temperature, Kelvin, and

base rate = the rate that the uranium metal surface is reacted away, producing uranium oxide, µm/hr.

In order to account for the uncertainty in the data, the Technical Databook requires use of a "rate enhancement factor" that ranges from 1/3 to 3. The indicated base rate is multiplied by the rate enhancement factor to define the potential range of reaction rates to be considered for design and safety analyses.

At relatively low temperatures, oxygen is known to poison the U metal/water reaction resulting in a reduced overall reaction rate. However, as the temperature is increased to near the boiling point the poisoning effect is reduced. Use of a nitrogen atmosphere in the RRT has generally been assumed to avoid poisoning the reaction. For the SRWOP the reduction in reaction rate when air is present may be acceptable. If so, this would allow the nitrogen purge system to be deleted reducing cost, operational complexity and industrial hazards to workers related to use of nitrogen.

D2.3 Immobilization and Packaging Process

Ceradyne proposed that either Portland cement-based grout or their proprietary phosphate bonded ceramic could be used to solidify the oxidized and concentrated sludge, eliminating free liquids [1]. The choice of phosphate ceramic versus Portland cement for the immobilization process does not affect comparison of the treatment portion of the process. Therefore, for consistency, the Portland cement option is assumed for the current evaluation. The WWO assay and drumming approach described in Appendix A is also assumed for immobilization in the SRWOP. The approach selected for WWO includes gamma radiation measurements on a recirculation stream from the LST. These measurements are then used to estimate concentration of fissile isotopes using a dose-to-curie methodology. This data is in turn used to determine the amount of sludge loaded to each drum. Sludge transfer to the drum is controlled by a metering pump which draws from the recirculation stream. Sludge and flush water transferred to the drum is solidified by addition of dry Portland cement-based additives. A “lost paddle” in-drum mixing technique is used to blend the dry additives with the sludge slurry resulting in a solid product with no free liquids. Gamma radiation measurements are taken on the finished drum. Based on these measurements, the content of WIPP reportable isotopes is estimated based on a dose-to-curie methodology. Use of the dose-to-curie methodology will require qualified measurement systems together with isotopic ratios and dose-to-curie relationships for each type of waste processed. See Appendix A for additional information on the assay and drumming system concept.

D3 Technology Development Status

Immersion mills are available proven commercial technology for size reduction of a variety of materials [6]. Some modifications to standard features are required for remote operation; however, these are considered to be relatively straightforward. There are no known commercial applications involving size reduction of uranium metal or spent fuel. An immersion mill system has been successfully built and operated for size reduction of coarse material from underground nuclear waste tanks at the Savannah River Site (SRS) [1,7]. The material processed was coarse solids left in the bottom of SRS Tank 18 and Tank 19 after retrieval of the bulk of the waste. The SRS immersion mill was located in a waste mixing chamber (Milling Tank) installed in a 22 inch riser in the receipt tank. Size reduced solids (<38 μm) from the mill were entrained in the liquid stream that flowed into the receipt tank. Other parts of the sludge receipt and preparation for immobilization process are expected to utilize conventional proven commercial equipment adapted for remote operation, e.g. jacketed tanks with mechanical agitators, demisters, scrubbers, positive displacement pumps, valves, metal or flexible hoses, and instrumentation. The only other identified equipment that may be novel or near the edge of demonstrated use is the equipment for monitoring of fission product gasses to support one of the alternative methods identified for demonstrating completion of reaction. Less mature aspects of the treatment system technology are related to knowledge of chemical and physical behavior of the actual sludge in the treatment equipment.

Water oxidation of K Basin sludge may be accelerated by reducing the size of the U metal. Based on Equation D2 a <100 μm diameter U metal particle is expected to oxidize in <3 days at 95° C. Oxidation of U metal by water has been studied extensively, including limited testing with actual spent fuel from K Basins [4]. Some testing has been performed on sludge simulants, actual sludge, and actual spent nuclear fuel (see Appendix A and Reference 4).

As part of the current evaluation, proof of concept tests were completed to validate basic functionality of the milling process and to develop a preliminary flowsheet. With the exception of the size reduction mill, process equipment for the treatment system is expected to be nearly identical to WWO. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO. Therefore the following discussion focuses on key aspects that are unique to the SRWOP and on differences between the SRWOP and WWO processes.

A formal TRA, as defined in DOE G 413.3-4 [8], has not been performed for SRWOP. Based on the success of the proof of concept tests and use of commercially proven equipment some aspects of the primary SRWOP could be considered to be developed to approximately TRL-3 as defined in DOE G 413.3-4 [10]. However, many aspects of the overall process are not yet well defined. The technical maturity evaluation for the WWO process [10] identified specific areas of further study, testing, and evaluation that would also be required for development of the SRWOP. Based on results of the Technology Maturity Evaluation for WWO it is concluded that, the overall development status of the SRWOP should be considered to be lower than TRL 3. More details on the SRWOP technology development status can be found in the following subsections, which focus on key aspects that are unique to the SRWOP and on differences between the SRWOP and WWO. Development status of the many features that are similar to WWO are discussed in Appendix A and Reference 11.

D3.1 Chemistry and Phenomenology

While immersion mills are available commercial technology, no data was available on performance with materials that simulate K Basin sludge. Therefore, proof of principle testing was initiated to better evaluate feasibility for the current application of interest. Measurements show that irradiated uranium metal (spent fuel) has a hardness rating about double that of non-irradiated uranium; 30±8 compared to about 15 on the Rockwell "C" Scale [1,9] Furthermore, though the ductility of uranium is significantly decreased by irradiation the uranium metal in K Basin sludge remains highly resistant to fracture [9]. These unique properties have made past grinding procedures, such as mortar and pestle techniques unsuccessful [1,9]. Densalloy™[1] SD170 was identified as an available tungsten based alloy with density, hardness, and toughness properties similar to irradiated U metal. Testing performed under the current program with Densalloy™ SD170 and K Basin simulants demonstrated Densalloy™ SD170 can be size reduced successfully using commercially available immersion mill technology.

Particle settling behavior related to the size separation step is well known. Substantial testing has previously been performed on the Warm Water Oxidation portion of the SRWOP. Therefore, these aspects of the process were not tested in the current program. Based on visual appearance, there were noticeable changes in physical properties of the simulant during the milling tests. Size reduction is expected to have significant effect on physical properties and will need to be investigated in a more quantitative manner if the SRWOP is pursued further.

D3.1.1 Summary of Testing Performed

Two size reduction tests were performed using a relatively small 2 inch micromill (Figure D-3) at the equipment vendor (Hockmeyer) test facility [2]. Test objectives were to obtain information on both the process performance (rate of size reduction) and equipment performance (functionality and wear). In Test 1 the stimulant was limited to components smaller than 100 µm (Cerium oxide, iron oxide, and aluminum hydroxide) plus Densalloy™ SD170 with a full range of particle sizes up to 6350 µm (¼ inch) diameter. Test 2 included the Test 1 simulant components plus additional physical stimulant components with particle sizes up to 6350 µm (¼ inch) diameter (aggregate, steel grit, sand, zeolite, organic ion exchange resin, and graphoil). Both tests were run for a nominal 12 hour milling time. A 90 µm cut size was selected for the test. The mass of Densalloy™ in three size ranges > 90 µm was measured periodically during the test. The mass of < 90 µm Densalloy™ could not be directly measured, but was estimated by difference.

Densalloy™ size reduction data is summarized in Table D-1 and Figure D-4. The data show that over 70% of the Densalloy™ total mass was reduced to < 90 µm in 2 hours and over 90 % of the total mass was reduced to <90 µm within 4 hours. The coarse material was reduced at a slower rate; however, it continued to be reduced during the full 12 hour grinding time. Because of the small mill used for the tests, grinding media size was limited to 1 mm diameter. A prototypic sized mill would use larger grinding media (up to 10 mm diameter). The larger mill size and larger grinding media are expected to significantly increase grinding rate, particularly for the coarser material.

The mill tested showed a modest amount of wear after 12 hours operation. However it did not utilize components with maximum wear resistance. Mills with more prototypic size and materials are expected to have significantly better performance relative to both grinding rate and mill wear rates [1].

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[1] Densalloy is a registered trademark of ATI Tungsten Materials, 1 Teledyne Place, La Vergne, Tennessee 37086, a business unit of Allegheny Technologies Incorporated (ATI); all rights reserved.

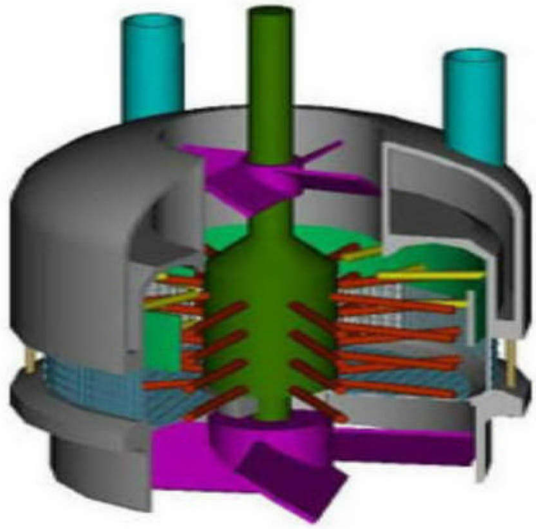

Figure D-3. Immersion Mill, Milling Chamber Configuration

Table D-1. Size Reduction Test Data

Test	Milling Time (hours)	Fine Densalloy™ <90 µm (g)	Fine Densalloy™ >90 µm (g)	Medium Densalloy™ (g)	Coarse Densalloy™ (g)	Total Densalloy™ (g)	Densalloy™ < 90 µm[1] (g)	Densalloy™ < 90 µm[1](Wt. %)
1	0	7.53	82.53	5.19	3.32	98.57	7.53	7.6
	2	70.66	23.0	2.17	2.74	98.57	70.66	71.7
	4	91.38	4.4	0.7	2.09	98.57	91.38	92.7
	6	95.54	1.1	0.16	1.77	98.57	95.54	96.9
2	0	7.53	82.54	3.1	1.77	94.94	7.53	7.9
	2	74.46	16.15	2.67	1.66	94.94	74.46	78.4
	4	86.57	5.08	1.72	1.57	94.94	86.57	91.2
	6	89.11	2.8	1.54	1.49	94.94	89.11	93.9

[1]Fraction above and below 90 µm determined by mass collected on USS No. 170 Sieve

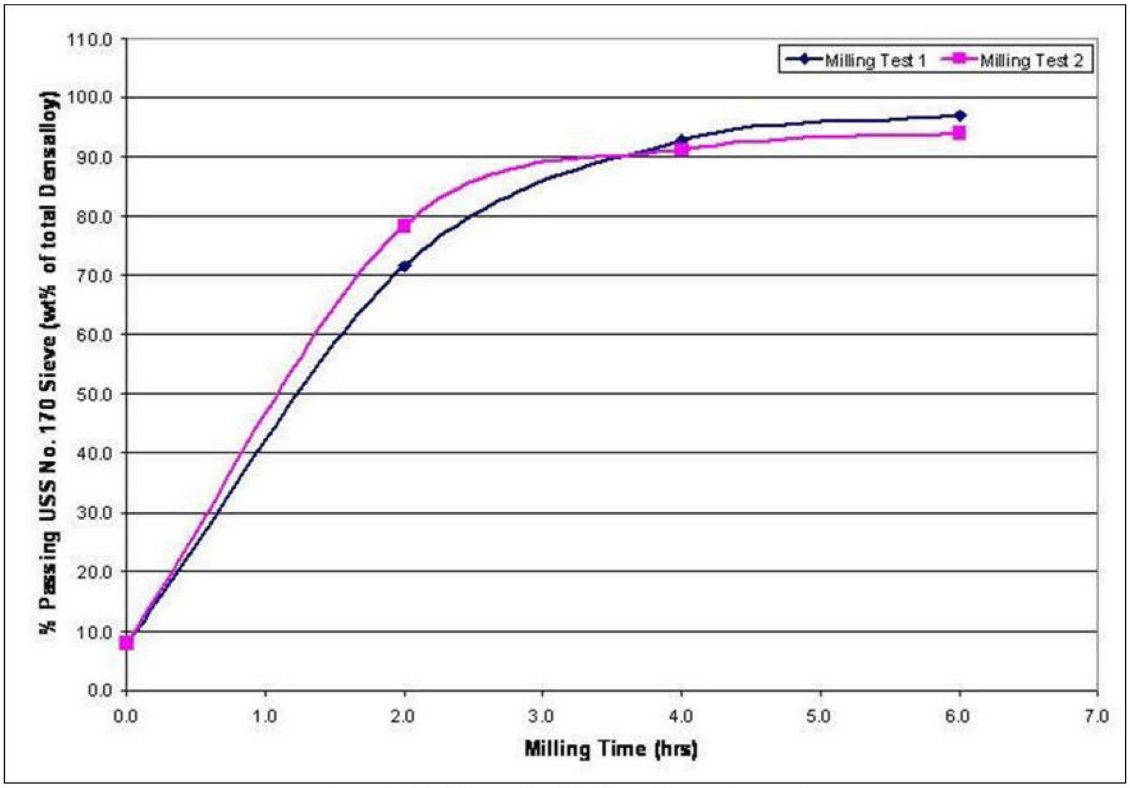

Figure D-4. Densalloy™ Size Reduction Data

This figure shows the data from the two milling tests performed. The percent of Densalloy™ < 90 µm in diameter (as weight percent) was determined by passing the particles through a USS No. 170 sieve (89 µm mesh size).

As part of the testing program Ceradyne also evaluated achievable waste loadings in chemically bonded phosphate ceramic. These tests demonstrated water loadings above 60 volume % in the finished solid waste form can be achieved without residual liquid [1]. These tests verified that chemically bonded phosphate ceramic can achieve waste loadings comparable with Portland cement-based grout formulations.

D3.1.2 Technical Issues and Unknowns Related to Chemical and Physical Behavior

To date there has been substantial testing of the U metal water oxidation step but limited testing of the size reduction step. The milling tests demonstrated that material with a harness similar to irradiated U metal can be successfully size reduced with an immersion mill. However, understanding of chemical and physical behavior in and after the size reduction step is incomplete. There is therefore potential for other unexpected process behavior as the process is developed and tested in more detail. Larger scale equipment oriented testing with K Basin simulants has not been performed and will be needed to verify functionality and performance.

Effects on physical properties (slurry rheology, yield strength, shear strength) have not yet been measured. Processing with an immersion mill eliminates the large, fast settling particles. This is expected to make mixing and pumping significantly easier; however, this remains to be demonstrated. Uncertainties could be substantially reduced with a modest amount of further testing.

The need/benefits of using a nitrogen purge of the Receipt and Reaction Tank need further evaluation. At the expected reaction temperature range (90-100° C) oxygen poisoning of the reaction may not be sufficient to warrant use of nitrogen.

D3.2 Technical Issues and Risks Related to Equipment and Process Integration

The integrated equipment concept for the Milling Tank and associated equipment needs to be detailed out and tested. This involves integration of relatively well understood equipment and processes and is therefore not considered to be a high risk.

Due to the faster reaction rate, the LST is expected to be modestly smaller for the SRWOP than the WWO process. Elimination of large, fast settling particles is expected to ease agitation, pumping, and sampling/assay problems. Other than the additional Milling Tank system and these relatively minor differences, process equipment for the SRWOP is expected to be essentially identical to the WWO process. Remote equipment technology, remote facility features, assay, and integration concepts are expected to be the same as for WWO. Methods used to verify reaction completion are expected to be similar to WWO; however, this problem may be somewhat easier for the SRWOP because of the faster reaction rate.

Acceptable amounts of residual sludge in Milling Tank, RRT, and LST at the end of each batch need to be better defined in order to evaluate need for special methods to achieve, measure, and/or verify that acceptable levels have been achieved.

D3.3 Technology Development Needs

The SRWOP has been added as an option for K Basins sludge processing relatively recently. As such, relatively little testing or engineering evaluation work has been completed to date. However, use of size reduction in conjunction with water oxidation is a potentially attractive option based on the testing under the current program and information on somewhat similar size-reduction systems used at SRS. If this option is to be pursued further, a number of initial activities should be performed to better define the process, evaluate performance, determine if there are unexpected problems or complications related to processing actual sludge, and provide engineering data to support more detailed engineering studies and eventually design and operation.

Development needs can be considered in terms of the design phases of a project. In the preconceptual and early conceptual design phases data is needed to verify basic feasibility, understand any complicating factors (e.g. side reactions or adverse physical property changes), and develop preliminary performance information. This data needs to be developed to a level of detail sufficient to support engineering studies used to select the final flowsheet to be used as the basis for conceptual design. In additions, topical engineering studies/evaluations are needed to better define certain aspects of the process and equipment. For example, the Milling Tank design concept, the assay system concept, updated estimates of achievable total measurement uncertainty, feasibility of using fission product gas measurements to verify completion of reaction, potential for uncontrolled/runaway reactions.

During the conceptual design phase process alternatives are typically evaluated and a single preferred alternative is selected. Additional data is needed for the selected alternative to develop and optimize system conceptual design, define the basis for sizing of unit operations, resolve any safety or regulatory issues, and provide a firm basis for moving into preliminary and detailed design.

For the SRWOP, most work in the preconceptual and conceptual design phases involves development of a more complete definition of the Milling Tank system concept and understanding of chemical and physical phenomenology/behavior of the sludge under actual process conditions. Limited testing of Milling Tank features is expected to be needed to confirm feasibility and better define performance characteristics. Unless the project elects to pursue novel remote equipment or facility concepts, little if any additional mechanical/equipment oriented testing or development work is expected to be needed during the preconcepual and conceptual design phases. Possible exceptions are the assay system used to determine isotope concentrations in the drummed waste, and offgas analysis equipment that may be considered for verifying completion of reaction. These unit operations are currently not well defined and may need early equipment oriented testing. Similarly, the drumming system is not currently well defined. If the selected drumming system design concept incorporates significant novel or untested features early proof of concept testing will be needed at least for those features.

In the detailed design phase, development activities are expected to primarily focus on design verification testing. This phase will be primarily equipment oriented and will include testing of individual components or physical features and testing of integrated systems or subsystems.

The following sections provide a preliminary summary of needed activities, with primary focus on initial or near term activities.

D3.3.1 Critical Near Term Development Activities

A summary of critical near-term development activities is given below. These activities should be completed in the preconceptual and conceptual design phases.

D3.3.1.1 Chemical and Physical Behavior

- Laboratory/bench scale process testing with simulants.
  - Characterize behavior of product slurries produced by size reduction of K Basin sludge.
  - Obtain additional data on classification of sludge components by gravity settling and/or hydrocyclone separation. This work should include development of characterization data on settling and classification behavior of actual K Basin sludge.
  - Provide a more complete material balance for the size reduction process.
  - Perform more comprehensive testing on sludge physical properties/physical behavior under process conditions: slurry rheology; density, water, and solids content of settled sludge; tendency to agglomerate or set up, ability to concentrate to target solids concentrations, etc. This testing should include consideration of the physical properties and behavior during and after the builddown/concentration step.
- Equipment and Subsystems
  - Perform topical engineering studies to develop a more complete design concept for the Milling Tank system.
  - Perform size reduction testing with a larger scale mill with more prototypic wear components. The full scale mill capacity is estimated at 20 L. Engineering scale (about 2 liter capacity) should be considered for the next round of testing to allow more prototypic configuration, grinding media, and material of construction for the mill.
  - Perform Engineering scale (or potentially full scale) tests of the Milling Tank system. Tests to include size classification, methods of feeding the mill, pickup of settled material from the tank

bottom and controlled transfer into the mill, size control of particles in the overflow stream, and general functionality of the integrated system.

- Define design concepts for remote operation and maintenance of the Milling Tank system. If novel or untested remote operating and maintenance features are required, perform verification testing as needed.
- Perform an evaluation of the need for nitrogen purge of the Receipt and Reaction Tank, versus use of a simple air sweep to prevent hydrogen buildup.
- Based in part on results of work listed above, develop a more comprehensive and optimized flowsheet.
- Perform topical engineering studies on immobilization and packaging design concepts to support selection of the conceptual design system and equipment configuration

D3.3.1.2 Process Control and Integration

- Refinement of process, equipment, and process qualification concepts for the dose-to-curie assay system. Include evaluation of methods to deal with batch to batch variability of dose-to-curie relationships.
- Perform development testing of assay components and systems.
- Evaluate need, costs, and benefits of additional physical sampling of sludge to reduce total measurement uncertainty.
- Perform topical engineering study on methods for verifying completion of reaction.

D3.3.2 Longer Term Development Needs

The process is expected to use conventional proven commercial equipment adapted for remote operation and maintenance. However, some equipment oriented process testing will be needed for equipment, such as agitators, pumps, mill, and assay system. Testing and development work is also expected to be needed for the drumming system and likely some remote equipment features. With the exception of the immersion mill, this equipment and the required testing and development work are assumed to be essentially the same as for Warm Water Oxidation (see Appendix A and the Technology Maturation Evaluation for WWO [10]). This testing will be performed primarily during the preliminary design and detailed design phases of the project.

D3.4 Hazard Considerations

A hazards evaluation was completed for the Size Reduction and Water Oxidation Process in order to provide input to the cost, schedule, and risk considerations for the continued alternatives selection process. This hazard evaluation was completed by a team of representatives from Engineering, Industrial Safety, Fire Protection, RadCon, and Operations [13].

A list of the activities constituting the SRWOP alternative was compiled. Hazards (or nodes) associated with each were then identified along with potential engineered and administrative controls. Table D-2 below summarizes the results of the hazards considerations for SRWOP. Primary hazards identified are common to all alternatives handling K Basin sludge slurries. No hazards unique to the SRWOP were identified that would significantly increase overall hazards as compared to other alternatives.

Table D-2. SRWOP Treatment Hazard Considerations

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01 – MOBILIZE, RETRIEVE, TRANSFER STORE AND AGITATE.						
RET.01.01	Internal Explosion	Sludge contamination	H^2 accumulation and ignition in STSC headspace	Purge system Ventilation system	Equipment surveillance	—
RET.01.02	Spray Leak	Sludge	Crack leak of slurry being removed from STSC and transferred to receiver vessel	Double contained transfer line.	—	—
RET.01.03	Splash / Splatter	Sludge	Leak of slurry being transferred from the STSC to the receiver vessel	Double contained transfer line Tank High Level Alarm and pump interlock	—	—
RET.01.04	Loss of Confineme nt	Sludge Contamination	Plugged vent path causes an unfiltered release from tank	Pressure transmitter to monitor the tank	—	—
RET.01.05	Internal Explosion	Sludge Contamination	H_2 accumulates in the receiver tank headspace and lines, resulting in a deflagration of the tank headspace or lines	Inerting or Alternate purge path.	—	—
RET.01.06	Direct Rad	Cs-137 release to water during storage or sludge in line or in STSC	Backflow of sludge through a line above the STSC, or exposure to storage water high in Cs-137 or sludge in STSC due to liquid draw down	Interface system design (check valves and system pressure), remote STSC unloading	Transfer access control	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01.07	Load Drop	Sludge contamination	Dropping equipment onto the STSC during removal of cask head or installation of transfer system resulting in a leak	—	*Hanford Site Hoisting and Rigging Manual*	—
REC.01 – RECEIVER VESSEL STAGING AND DEWATERING. Note: this includes the boil down dewatering both before reaction and during/after reaction, and agitation and circulation during staging and reaction.						
REC.01.01	Internal Explosion	Sludge Contamination	H_2 accumulation and ignition in tank headspace	Purge system Ventilation system	Equipment surveillance	Note: hydrogen evolution may be very rapid following size reduction, especially if agitation is ineffective and the settled metal is self heating
REC.01.02	Spray Leak	Sludge	Circulating sludge spray leak	Low pressure circulation Secondary confinement	—	—
REC.01.03	Splash / Splatter	Sludge	Leak from circulating system	Secondary confinement	—	—
REC.01.04	Overpressure Loss of Confinement	Sludge Contamination	Plugged vent path and overpressure causes an unfiltered release from tank	Pressure transmitter to monitor the tank, pressure relief, open vent path	—	—
REC.01.05	Direct Rad	Sludge in line or Exposure to vessel	Backflow of sludge through a flush line or in a recycle line, exposure to receiver vessel	Flush water system design (check valves and system pressure), Shielded recirc lines Shielded receiver vessel, remote maintenance for agitation	—	—
REC.01.06	Criticality	—	Accumulation of separated metal, unsafe geometry	Vessel geometry, sludge process limits, sludge material final characterization	—	

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
REC.01.07	Steam agitation / ejection of slurry	Slurry in tank	Steam leak into receiver vessel agitates and volatilizes slurry into off gas system	Steam Jacket design	—	—
REC.01.08	NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
REC.01.09	Facility Fire, spill	Sludge	Facility fire results in failure of confinement vessel and release of rad material	Materials of construction, Fire Protection System	Combustibles limits	—
SRO.01 – SIZE REDUCTION WATER OXIDATION PROCESS.						
SRO.01.01	Spray Leak	Sludge	Release of respirable sludge from line or fitting failure of transfer piping	piping secondary confinement, Locate mill in reaction vessel	—	—
SRO.01.02	Splash / Splatter	Sludge	Release of respirable sludge from line or fitting failure	piping secondary confinement, Locate mill in reaction vessel	—	—
SRO.01.03	Direct Rad	Released fission products or sludge in line or container	Vessel and piping shine	piping shielding, vessel shielding	Radiological Control Program access controls	—
SRO.01.06	Internal Explosion	Sludge Contamination	Runaway reaction of collected metal fines in mill, perhaps due to collected material if circulating water shutdown	Inherent heat transfer characteristic of milling vessel	Analysis and loading approach demonstrates loaded sludge safety	**NOTE:** *Explosion due to runaway thermal reaction, over concentration and dry out of slurry.*

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
TRS.02 –TRANSFER AND STAGING OF TREATED SLUDGE. NOTE: Applies to transfer and staging for Alternatives 1, 2, 3, 4, 6						
TRS.01.01	Spray Leak	Sludge	Line failure during pressure transfer results in a release of radiological material outside of the facility	Piping design, secondary piping design, confinement design	—	—
TRS.01.02	Overpressu re	Sludge Contamination	Accumulation of gas in the isolated staging tank results in a potential overpressure and release of radiological material	Ventilation system Confinement design	—	—
TRS.01.04	Splash / Splatter	Sludge	Transfer Line failure results in a release of slurry	Piping design, secondary piping design, confinement design	—	—
TRS.01.05	Direct Rad	Released fission products or sludge in lines or containers	Sludge in lines or vessels not adequately shielded	Facility design	Radiological Control Program access controls	—
TRS.01.06	Seismic Event	Sludge	SSC failure results in spill / spray and spread of rad material	Facility design	—	—
TRS.01.07	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
PKG.03 – IMMOBILIZATION AND PACKAGING OF TREATED SLURRY						
PKG.03.01	Spray Leak	Sludge	Pressure transfer line failure results in a release of radiological material	Piping design, Secondary piping design, confinement design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
PKG.03.02	Facility Fire	Sludge	Facility fire results in a release of rad material	Materials of construction, Fire Protection System	Combustibles control	—
PKG.03.03	Seismic Event	Sludge	Seismic forces result in a line break and potential release	Facility design	—	—
PKG.03.04	Splash / Splatter	Sludge	Pressure transfer line failure results in a release of rad material	Piping design, secondary piping design, confinement design	—	—
PKG.03.05	Direct Rad	Released fission products or sludge in lines and containers	Direct exposure to sludge rad shine	Shielding design	Radiological Control Program access controls	—
PKG.03.06	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
STG.01 – SHIELDED STORAGE OF TREATED DRUMS.						
STG.01.01	Load Drop	Sludge	Container drop resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.02	Load Drop	Sludge	Load dropped onto container resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.03	Seismic Event	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.04	Other NPH	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.05	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
STG.01.06	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Facility design, Fire Protection Design	—	—
LSC.01 – LOAD SHIPPING CONTAINER. REMOVE FROM ISC, LOAD 72-B LINER, LOAD CASK.						
LSC.01.01	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
LSC.01.02	Load Drop	Sludge contamination	Impact fails package and damages grout	Contamination control ventilation	Hoisting and rigging controls, DOE-RL-92-36	—
LSC.01.03	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Fire Protection System	—	—
LSC.01.04	Seismic Event	Contamination	SSC failure results in package impact and spread of rad material	Facility design	—	—
LSC.01.05	Other NPH	Contamination	Missile or structure failure results in package impact and spread of rad material	Facility design	—	—

DOE-RL-92-36, 2007, *Hanford Site Hoisting and Rigging Manual,* Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

FW = facility worker.
HC-2 = Hazard Category 2 (facility).
HEPA = high-efficiency particulate air (filter).
HVAC = heating, ventilation, and air conditioning.
ISC = interim storage container.
LFL = lower flammability limit.
MAR = material at risk.
NPH = natural phenomenon hazard.
SSC = structure, system, and component.

D3.5 Additional Considerations

This section identifies additional miscellaneous items identified as part of the review which may be considered in evaluating this alternative.

One option is to design for the SRWOP with WWO as a backup/alternate if problems develop. If SRWOP performance is as expected with no major side problems the operating duration would be significantly reduced compared to WWO alone. Sensitivity to retrieval schedule and sequence is also reduced with the SRWOP. If problems are found with SRWOP, the WWO process could be implemented without size reduction as a backup. The required equipment is essentially the same. For processing settler sludge the required oxidation time with WWO is about 1/10 of that required for the EC sludge. Therefore there is less benefit from using size reduction rather than the direct WWO process for the settler sludge. One approach could be to use the SRWOP for Engineered Container sludge (floor and pit sludge) and use WWO without size reduction in the same equipment for processing Settler Tank sludge.

Elimination of the coarse fast settling solids is expected to reduce the potential for segregation of sludge solids and therefore allow more uniform mixing of the sludge components. Qualitatively it is reasonable to expect that better uniformity will likely reduce uncertainty in the assay measurements both before drumming and for the finished drummed sludge. This could materially reduce the number of drums required. Similarly, a more uniform distribution in the product drum is expected to increase the allowable ^{137}Cs content of shielded 30 gallon drums, improving overall performance if the shielded 30 gallon drum is pursued further (see Appendix I). More detailed engineering analyses are needed to evaluate these topics to determine if the prospective benefits are minor or substantial.

At near ambient temperatures oxygen is known to poison the U metal/water reaction resulting in a significantly reduced overall reaction rate. However, as the temperature is increased to near the boiling point the poisoning effect is reduced. Use of a nitrogen atmosphere in the RRT has generally been assumed to avoid poisoning the reaction. For the SRWOP the reduction in reaction rate when air is present may be acceptable. If so, this would allow the nitrogen purge system to be removed, reducing cost, operational complexity and industrial hazards to workers related to use of nitrogen.

The size reduction approach used for the SRWOP could also be considered as a front end pretreatment step for many other alternative treatment technologies. Elimination of the coarse, fast settling material should ease problems with agitation, pumping, erosion, and sampling for most of the downstream process options.

D4 Process Design and Performance Estimates

This section provides a summary of sizing for major process equipment, estimates of time required to process all of the K Basin sludge, and facility size information. Because most of the design is expected to be similar to the WWO option, the presentation herein focuses on differences with WWO as given in Appendix A.

D4.1 Process Flowsheet Estimates

In order to compare the various technologies under consideration, normalized flowsheet estimates were made to evaluate differences in major equipment and facility size, and to estimate potential differences in sludge processing rate. The normalized flowsheet estimates are based on input from the vendor [1, 2] with adjustments as needed to assure that all technologies are evaluated on a reasonably consistent basis. Common process bases and assumptions are summarized in Appendix J. Normalized flowsheet calculations summarized below are documented in Reference 11.

The flowsheet calculations start by estimating size of the Milling Tank, RRT and LST needed to process the largest STSCs batches. The batch preparation time is then estimated, i.e. the time to transfer and process an STSC batch to the point that it is ready for transfer from to the assay/drumming system. The milling time per batch is estimated at 10 hours [1]. The largest batch to be processed contains about 2,100 liters of as-settled sludge, i.e. sludge bulk volume after extended settling (Appendix J). Assuming about 80% of the sludge solids overflow directly to the RRT and 20% are processed through the mill, the processing rate through the mill averages about 0.7 liter per minute of as-settled sludge equivalent. The actual flowing volume will be much larger because of dilution of the as-settled sludge with water. Once milling is complete the RRT is heated to near boiling to complete the U metal oxidation reactions and to reduce volume by evaporation of water. When batch preparation is complete and the batch has been transferred from the RRT to the LST the RRT is ready to begin receipt and processing of the next batch while the batch in the LST is drummed. For the SRWOP base case, batch preparation time is estimated at 8.9 days.

The time to drum each batch is then estimated. Using base case assumptions for achievable waste loading per drum and drumming rate (Appendix J) the average drumming time per STSC batch is estimated at 7, 9.4 and 29 days for KE EC, KW EC, and settler tank sludge respectively. Comparison of these values with the estimated 8.9 day batch preparation time indicates drumming time is rate controlling for settler tank sludge. For EC sludge the batch preparation and drumming times are roughly balanced. Based on the rate controlling step for each sludge type and the assumed number of batches the total processing time for the base case is estimated at 13.3 months with 100 % TOE or 19 months assuming 70 % TOE. This is less than 1/3 of the required processing duration of 5 years or less, and may be compared to the base case WWO processing time estimate of 59 months. The much shorter batch preparation and total processing times result from the much shorter oxidation time required for 100 μm U metal particles compared to 6350 μm diameter for WWO without size reduction.

The SRWOP processing time is also less sensitive to retrieval schedule assumptions as compared to WWO. The ability of WWO to complete processing within 60 months relies on each oxidation batch processing multiple STSC batches (two for the base case). The estimated processing schedule for the SRWOP is largely driven by the processing rate of the drumming system. Therefore, compared to WWO, the estimated processing schedule will be more sensitive to changes in assumptions related to the drumming. See Appendix I for additional discussion of sensitivity to changes in the base case assumptions for the SRWOP and other alternatives that are under consideration.

The base case process flowsheet estimates indicate that for all waste types the waste loading per drum is limited by the fissile isotope content (^{239}Pu FGE). Based on engineering judgment it is expected that size reduction may result in some (unquantified) improvement in total measurement uncertainty and hence achievable fissile isotope content. However, for the current analysis no credit is taken for any such improvement. Within the accuracy of available data there are not significant differences between the SRWOP and other alternatives relative to the achievable waste loading or number of product drums.

D4.2 Major Process Equipment

SRWOP equipment sizing calculations [11] include only the major process tanks show on Figure D-1 and D-2. Other equipment is assumed to be essentially identical to WWO (Appendix A). SRWOP process tank size estimates are given in Table D-2 for the nominal base case set of assumptions.

Comparison of Table D-3 with WWO values in Appendix A shows that the LST capacity for SRWOP is about 50% smaller than the WWO process base case estimate. This results primarily from processing a single STSC batch per oxidation batch in the SRWOP base case versus 2 STSC batches per oxidation batch for the WWO base case estimate. The Milling Tank and its contained equipment is an addition for the SRWOP. The Milling Tank is installed in a riser/penetration in the top of the RRT, so the impact on remote cell space is relatively small. Other than the Milling Tank addition, basic features of the tanks are similar to WWO: steam heating and water cooling jacket(s) on the RRT, water cooing jacket on the Lag Storage Tank and agitators in both tanks. The SRWOP condensate tanks are about 17 % larger than the WWO base case condensate tanks because of the increased condensate resulting from water added to the eductor. Other than these items, equipment list and sizing is expected to be identical to that for WWO.

Table D-3. SRWOP Base Case Process Vessel Size Estimates

Vessel	Working Volume (m^3)	Gross Volume (m^3)
Receipt and Reaction Tank (RRT)[1]	18.4	25
Lag Storage Tank (LST)	4.5	5.7
Condensate Tank (CT) A	17	20
Condensate Tank (CT) B	17	20
Milling Tank (MT)[1]	0.95	1.9

[1]The Milling Tank is installed inside the top of the RRT.

D4.3 Facility and Equipment Requirements

A separate facility layout and other facility information were not prepared for the SRWOP option. For the purpose of comparative cost estimates it is assumed the equipment and facility for SRWOP is the same as is the same as WWO (Appendix A) with the exceptions noted below.

D4.3.1.1 Equipment changes from WWO

- RRT gross volume is increased to 25 m^3 for SRWOP from 24 m^3 for WWO.
- A Milling Tank with immersion mill and eductor is added, and installed in the top of the RRT.
- LST gross volume is reduced to 5.7 m^3 for SRWOP from 11.4 m^3 for WWO.
- Process Condensate Tank gross volumes are changed to 20 m^3 for SRWOP compared with 17 m^3 for WWO.

D4.3.1.2 Facility changes from WWO

- Remote cell space for the LST is reduced proportional to the reduced tank sizes.
- Space for the condensate tanks is increased proportional to the increased tank sizes.

D5 Characteristics of the Alternative Relative to Evaluation Criteria

This section provides an evaluation of the process concept relative to the evaluation criteria.

Section D5.1 identifies attributes of the alternative are identified that distinguish the alternative in the evaluation against other alternatives under consideration. These attributes are categorized as potential advantages or disadvantages compared to other alternatives. Attributes that are common to all alternatives are typically not included. In Section 5.2 the identified attributes, advantages and disadvantages are allocated to the evaluation criteria from the Decision Plan [12].

D5.1 Evaluation Considerations for SRWOP Relative to Other Alternatives

The project scope and requirements assume that any alternative must be capable of receiving full STSC batches of K Basin sludge and processing them to meet criteria for shipment to WIPP. As such, all alternatives will need certain minimum capabilities and will present minimum safety (public and worker) and environmental risks, and minimum costs and technical requirements. This section notes characteristics, advantages, and disadvantages to the FROP alternative that may differentiate it relative to other alternatives.

D5.1.1.1 Potential Advantages or Beneficial Attributes of SRWOP:

- The minimum sized tanks (RRT and LST) needed to accept and process a full STSC batch are sufficient for use by SRWOP. Minimizing process tank size also minimizes remote cell space requirements and presents an easier mixing problem for slurry tanks as compared to alternatives that require larger process tanks.
- SRWOP reaction time is relatively short, resulting in relatively short operating duration with a single process train and minimum tank size (about 2 years versus 5-7 year maximum criteria in the Decision Plan). This is expected to result in the following beneficial attributes:
  - Relatively low overall operating costs due to short plant operating life.
  - Short process operating time results in low operating time on agitators, erosion of agitators and tank walls, and less wear and tear on equipment. This is expected to reduce maintenance costs, worker exposure to radiation, and secondary radioactive waste generation compared to alternatives that require longer operating duration.
  - Low reaction time results in reduced probability and risk from process failures and less sensitivity to down time/maintenance of Receipt and Reaction Tank related components.
- The SRWOP also requires only a single STSC batch in each oxidation batch. Some alternatives may require either multiple STSC batches in each oxidation or multiple oxidation process trains in order to achieve the required total processing times.
- The SRWOP has relatively low sensitivity to uncertainty in the U metal/water reaction rate. The Technical Databook currently requires consideration of a range of 1/3 to 3 times the nominal or best estimate reaction rate value. However, because of the relatively small U metal particle size and reaction time, use of even the most conservative reaction rate assumptions has relatively little impact on the overall processing time.
- Elimination of large, fast settling particles is expected to ease problems with agitation, erosion, pumped transfers, sampling, and assay. This may reduce total measurement uncertainty and hence reduce total drum count, however, this remains to be quantified.

- Short reaction times and near ambient temperature make laboratory testing relatively easy and fast. Reaction tests with maximum U metal particles can be taken to completion in days, as compared to weeks or months for some alternatives. This allows for a moderate cost and schedule for development of the technology to the required maturity level.
- Size reduction equipment could increase flexibility for processing other future (undefined) waste streams.
- Equipment installed for the SRWOP can also be used for the WWO process.

D5.1.1.2 Potential Disadvantages and Risks of SRWOP as compared to WWO:

- The SRWOP requires addition of the Milling Tank and associated equipment. This includes an immersion mill that operates at relatively high speed. This equipment may require maintenance of the contaminated portions during the life of the facility. An educator is also needed along with pressurized water as the source of motive power.
- Less testing has been completed to date on equipment and essentially no testing has been performed on process chemical and physical behavior.

D5.2 Evaluation Considerations for SRWOP Relative to Decision Criteria

Table D-4 illustrates how the identified advantages, disadvantages, and risks relate to Decision Criteria identified in the Decision Plan [12].

Table D-4. Evaluation Considerations for the SRWOP Alternative

Decision Criteria from Decision Plan [12]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
Safety	• Ensure worker safety.	• Relative ease/difficulty in implementing adequate safety measures as measured by number of passive (inherently safe) vs. active engineered safety features. • Ensure protection of the nuclear the general public.	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries[13]. • Relatively short operating period. • Minimum material at risk (MAR)/inventory of sludge. **Disadvantages** • Use of high speed rotating equipment (immersion mill). . • Use of pressurized water for educator.
Regulatory/ stakeholder acceptance.	• Ensure compliance with environmental laws and regulations and DOE orders. • Address sludge management concerns in *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* record of decision.	Achieve acceptance of regulators and other Stakeholders.	**Advantages** • Short processing time expected to be viewed favorably by stakeholders. **Disadvantages** • No significant regulatory or stakeholder issues identified.
Technical maturity	• Maximize confidence in process implementation	• Projected Technical Readiness Level (based on technical criteria only at this stage of the project) • Estimated volume of waste going to WIPP	**Advantages** • Proof of principle tests successfully demonstrated ability to size reduce simulant with similar hardness and toughness.

Decision Criteria from Decision Plan [12]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			• Short reaction times at moderate temperature make laboratory testing relatively easy and fast. This reduces the cost and schedule for completing the required testing activities. • Relatively short Warm Water Oxidation step (a few days) reduces uncertainties relative to behavior of sludge on long term exposure to water at near boiling (several months for WWO). • The SRWOP has relatively low sensitivity to uncertainty in the U metal/water reaction rate. The Technical Databook currently requires consideration of a range of 1/3 to 3 times the nominal or best estimate reaction rate value • Modest size slurry tanks, essentially the minimum required to process full STSC batches. Smaller size tanks present and easier mixing problem as compared to processes that require larger tanks. • Estimated volume of waste is expected to be ^{239}Pu FGE limited, i.e. the process is not expected to increase number of drums to WIPP above the minimum. Size reduction could potentially improve accuracy of assay allowing reduced drum count. • Elimination of large, fast settling particles is expected to ease technical problems with agitation, erosion, pumped transfers, sampling, and assay. **<u>Disadvantages</u>** • Relatively little process testing has been

Decision Criteria from Decision Plan [12]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			completed to date. • More complex equipment.
Operability and maintainability	• Maximize operability • Maximize maintainability	• Ability for process to be remotized • Ability to treat and package K Basin sludge inventory in 5 to 7 years • Acceptability of secondary waste streams for disposal at Environmental Remediation Disposal Facility (solids) and 200 Area Effluent Treatment Facility (liquids)	**Advantages** • The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. The drumming system is similar to other alternatives and will use primarily industrially proven equipment and designs with some custom features to be developed and proven for this specific application. • With a single process train and minimum tank size to accept STSC batches the operating duration relatively short (<2 years) to process all sludge. • Short process operating time results in low operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction Tank related components. Conversely; the short estimated processing time provides more allowance for downtime process performance problems and still meet the 5 year window. • Smaller tanks present an easier mixing problem as compared to alternatives that require larger tanks. • Elimination of large/heavy particles is

Decision Criteria from Decision Plan [12]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			expected to reduce erosion of agitators, pumps, tanks, and piping, and is expected to allow more uniform mixing. Could improve assay accuracy. • Smaller LST present an easier mixing problem as compared to the larger WWO tank. • Ability of SRWOP to process all sludge in less than 5 years is less dependent on retrieval schedule. • The SRWOP equipment can also be used for the WWO process without modification. **Disadvantages** • More complex equipment and operations. • Milling Tank equipment may need increased maintenance.
Life-cycle cost and schedule	• Optimize life-cycle costs for sludge treatment and packaging facility • Provide acceptable schedule to stakeholders	**Cost** • Cost of maturing technology to Technology Readiness Level-6 • Capital cost • Operating and maintenance cost • Deactivation and decommissioning cost **Schedule** • Facility startup • Complete treatment and packaging	**Advantages** • Relatively small process slurry tanks and short operating time are expected to result in relatively low operating costs. • Short reaction times and moderate temperature make required testing relatively easy and of moderate cost. **Disadvantages** • Relatively little process testing has been completed to date.

Decision Criteria from Decision Plan [12]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			• Added equipment (milling tank system).
Potential for beneficial integration with ongoing STP - Phase 1 activities	• Optimize cost or schedule for STP - Phase 2 Consider co-location of needed facilities provided by STP - Phase 1	• Potential for integration of treatment and/or packaging with interim storage in T Plant • Potential for shared functions with those being provided by STP Phase 1 • Optimization of location of reduce/eliminate intermediate shipping or repackaging of the sludge material	**Advantages** • Process is compatible with Phase 1 design concept. • No identified positive or negative impacts to currently planned Phase 1 Project activities • Co-location near T Plant is possible, but overall siting studies have not been completed. **Disadvantages** • No significant discriminators noted.
Integration with Site-wide RH-TRU processing/packaging planning, schedule, and approach	• Optimize processes, equipment, and facilities for K Basin sludge treatment and packaging with other Hanford Site RH-TRU waste streams	• Number of other Hanford Site RH-TRU waste streams that can be treated with candidate process • Number of other Hanford site RH-TRU waste streams that can be packaged with candidate packaging process	**Advantages** • Availability of size reduction equipment may increase flexibility for processing other waste streams (granular materials, sludge, decontamination solutions, etc.) • The process is capable of process additional K Basins TRU waste streams that have been identified. • Other than the additional K Basins wastes, no specific RH TRU streams have been identified for integration at this time. **Disadvantages** • None noted

D5.3 Conclusions and Recommendations

D5.3.1 Conclusions

- Based on successful completion of proof of principle testing the SRWOP is judged to be a technically feasible treatment alternative for processing K basin sludge in STP Phase 2.
- The SRWOP has expected to have relatively favorable performance in terms of processing duration, equipment size, complexity, and flexibility.
- Product is expected to meet WIPP and transportation requirements
  - Hydrogen from U metal reaction eliminated by oxidation of U metal
  - Free liquids eliminated by in-drum mixing of dry additives
  - Gamma radiation assay on concentrated sludge used to determine proper sludge addition per drum
  - Final measurements taken on drum to verify FGE, dose rate, and radiolytic heat generation limits are met
- Based on the Decision Plan evaluation criteria the SRWOP compares favorably with other alternatives.
- The additional complexity due to addition of the milling tank system is offset by the much shorter operating duration and reduced difficulty of handling large fast settling solids in downstream process steps.
- In order to finalize definition of the process flowsheet and support final process selection studies during conceptual design, additional testing and topical engineering studies should be performed in the near term. These should focus on verification of immersion mill performance at a larger scale, better definition of the milling tank design concept.
- Use of size reduction as a front end step should be considered for other treatment alternatives. Elimination of large fast settling solids could significantly benefit other alternatives in addition to warm water oxidation.

D6 References

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Appendix E

Evaluation Data for Nitrate Addition Chemical Inhibitor Process (NCIP) – (PNNL)

E1 Introduction

Use of chemical inhibitors to reduce production of hydrogen gas from solidified K Basin sludge was proposed by the Pacific Northwest National Laboratory (PNNL). After initial scoping tests and further definition of the concept and approach for testing, CHRPC approved a task for PNNL to perform additional proof-of-principle testing on use of nitrate addition to suppress hydrogen production in the solidified/drummed waste. The testing and support work completed to date indicates that the PNNL nitrate addition chemical inhibitor process (NCIP) is a viable alternative for use in Phase 2 of the STP [1,2].

E2 Technology and Flowsheet Summary Description

The unique feature of the NCIP is addition of nitrate to the sludge prior to solidification to suppress hydrogen production. This is expected to reduce or eliminate the need to oxidize metallic uranium prior to solidification of the sludge. The sludge is mixed with sodium nitrate, concentrated by evaporation and solidified in drums by use of additives.

The overall process is divided into two major parts:

1. Sludge receipt and preparation for immobilization: the sludge batch is received from retrieval, sodium nitrate solution is added and water is removed to give the solids concentration desired for the immobilization process.
2. In the immobilization and packaging process,, the concentrated sludge slurry is assayed, metered into drums, and converted to a liquid-free solid that is sealed in drums for eventual offsite transport and disposal.

Supporting processes such as vent gas treatment, liquid waste disposal, cooling water and process steam supply are assumed to be the same as for WWO (Appendix A) and are not further discussed for this particular option.

E2.1 Sludge Receipt and Preparation for Immobilization

The NCIP is illustrated in Figure E-1. Dilute sludge from an STSC is delivered batch wise, up to 13.2 m^3 (3,500 gallons) per batch to the Receipt, Concentration, and Mix Tank (RCMT). The RCMT is purged with sweep air to limit hydrogen buildup, is normally maintained at slightly below atmospheric pressure, and is agitated continuously when it contains a batch of sludge. The RCMT contents are heated to near the atmospheric pressure boiling point of water using a steam jacket, and water is driven off by evaporation, concentrating the batch to the desired end point solids concentration. Sodium nitrate solution is added either during or after the evaporation step. The mixed and concentrated batch is then cooled and transferred to the Lag Storage Tank (LST).

The LST is continuously agitated when a sludge batch is present, and is cooled with a water cooling jacket. Concentrated sludge is transferred to the assay and drumming system in smaller batches as needed. The LST is sized to hold at least a full concentrated batch from the RRT. Once the RRT is emptied, preparation of the next sludge batch can be started while the previous batch is processed by the drumming system.

Steam generated during the evaporation step flows first to a demister to remove any entrained material and then to a water-cooled condenser. Vent gas from the condenser is heated and filtered prior to discharge. Condensate drains to a Condensate Tank. Where feasible, clean condensate is recycled for line flushes and for the immobilization step. Excess condensate is sampled and shipped by truck to ETF for disposal.

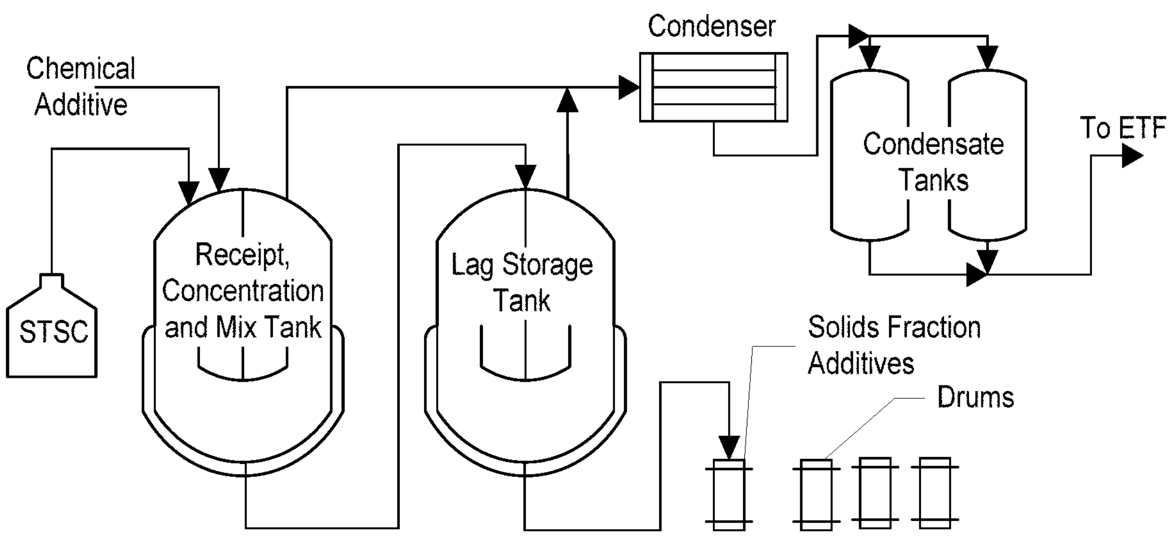

Figure E-1. Nitrate Addition Chemical Inhibitor Process Simplified Flow Diagram

Similar to oxidation treatment processes, one issue is verification that hydrogen production has been adequately reduced. For the NCIP a combination of the following methods may be used:

- Process validation. This method involves performing process validation tests which define process performance sufficiently to provide confidence that the process will perform as expected. This can include both pre-commissioning testing and test data collected during initial hot operations. The testing will need to consider the possibility of extended interim storage prior to shipment to assure adequate hydrogen mitigation during shipment.
- Monitoring of hydrogen generation in the product drums. Monitoring hydrogen generation rates in product drums could be a method used to prove that significant hydrogen generation is not continuing in the drums. This could involve holding selected drums for a period of time at an elevated temperature (say 60°C) and measuring the hydrogen evolution rate. A limited number of drums could be tested using a statistical sampling or process validation approach. An advantage of this method is that it directly correlates with the applicable hydrogen generation limit for drums during shipping. The disadvantage is that it will take a substantial amount of time for each test, likely days or weeks.

E2.2 Process Chemistry

References [1 and 2] provide a comprehensive review of information on chemically inhibiting hydrogen generation from U metal/water reaction. Hydrogen suppression by nitrate appears to result primarily from reaction of the nitrate with nascent hydrogen and highly reactive radicals. By removing these before they are able to combine, production of gaseous H_2 is substantially reduced. Nitrate may also reduce the rate of U metal oxidation but this is a less important secondary contributor. The following overall reactions observed during testing produce ammonia (NH_3) and nitrite (NO_2^-) respectively, from nitrate chemical reduction [1,2]:

$$2\,U + NO_3^- + H_2O \rightarrow 2\,UO_2 + NH_3 + OH^- \quad \text{(Eq. E1)}$$

$$U + 2\,NO_3^- \rightarrow UO_2 + 2\,NO_2^- \quad \text{(Eq. E2)}$$

In the 60°C tests with uranium metal and 0.5 or 1.0 M nitrate solution only (Tests 3 and 4 in Test Series 4, Table 3.7 of [1]), approximately equal contributions from Equations E1 and E2 are observed such that the balanced reaction is:

$$3\ U + 3\ NO_3^- + H_2O \rightarrow 3\ UO_2 + NH_3 + 2\ NO_2^- + OH^- \qquad \text{(Eq. E3)}$$

Material balances were not discerned in the full sludge simulant tests because the amounts of UO_2 produced by uranium metal corrosion were small compared with the amounts of UO_2 present in the simulant [1]. To a first approximation, the reaction is expected to proceed according to the stoichiometry shown in Equation E3.

Secondary reactions produce small amounts of gasses, e.g., NO, N_2O, and N_2, and atmospheric oxygen, O_2, is consumed [1]. However, because of limited air accessibility, consumption of atmospheric oxygen gas is expected to be negligible in prospective plant operations.

Nitrate also is known to significantly decrease radiolytic hydrogen generation [1]. The product of the radiolytic scavenging of hydrogen by nitrate is nitrite [4]. Previous PNNL tests show that nitrite is also effective in mitigating hydrogen generation from U metal corrosion [1,4]. The radiolytic consumption rate (G value) for nitrate in water indicates that sufficient nitrate will survive 30-year radiolysis times to mitigate hydrogen generation from uranium metal corrosion. However, the rates of radiolytic depletion of nitrate within the sludge or solidified sludge matrices are not known.

E2.3 Immobilization and Packaging Process

For the purpose of the current evaluation, the WWO assay and drumming approach described in Appendix A is assumed for immobilization and packaging. The approach selected for WWO includes gamma radiation measurements on a recirculation stream from the LST. These measurements are then used to estimate concentration of WIPP fissile isotopes using a dose-to-curie methodology. This data is in turn used to determine the amount of sludge loaded to each drum. Sludge transfer to the drum is controlled by a metering pump which draws from the recirculation stream. Sludge and flush water transferred to the drum is solidified by addition of dry additives. A “lost paddle” in-drum mixing technique is used to blend the dry additives with the sludge slurry resulting in a solid product with no free liquids. Gamma radiation measurements are taken on the finished drum. Using these measurements, the content of WIPP reportable isotopes is estimated based on a dose-to-curie methodology. See Appendix A for additional information on the assay and drumming system concept.

E3 Technology Development Status

The sludge receipt and preparation for immobilization process steps are expected to utilize conventional proven commercial equipment adapted for remote operation, e.g. jacketed tanks with mechanical agitators, demisters, scrubbers, positive displacement pumps, valves, metal or flexible hoses, and instrumentation. Less mature aspects of the treatment system technology are related to knowledge of chemical and physical behavior of the actual sludge in the treatment equipment.

Oxidation of U metal by water has been studied extensively, including some limited testing with actual spent fuel from K Basins. Some testing has also been performed on sludge simulants and actual sludge (see Appendix A for additional information).

A literature review and screening tests on chemical hydrogen mitigation was previously performed [1]. This work identified nitrate addition as a strong candidate for decreasing hydrogen generation from U metal reaction with water. Therefore, additional testing was initiated to provide proof-of-concept testing for nitrate addition.

With the exception of the nitrate addition and elimination of the need for nitrogen blanketing of the RCMT, the treatment system equipment is expected to be essentially identical to WWO. The immobilization process, facility arrangement, and remote operating and maintenance features are assumed to be identical to WWO. The technology readiness of those aspects is similar to WWO; therefore the technology readiness discussion focuses on key aspects that are unique to the NCIP and on differences between the NCIP and WWO processes.

A formal TRA, as defined in DOE G 413.3-4 [6], has not been performed for NCIP. Based on the success of the proof of concept tests and use of commercially proven equipment some aspects of the primary NCIP could be considered to be developed to approximately TRL-3 as defined in DOE G 413.3-4 [6]. However, many aspects of the overall process are not yet well defined. The technical maturity evaluation for the WWO process [7] identified specific areas of further study, testing, and evaluation that would also be required for development of the NCIP. Based on results of the Technology Maturity Evaluation for WWO it is concluded that, the overall development status of the NCIP should be considered to be lower than TRL 3. More details on the NCIP technology development status can be found in the following subsections, which focus on key aspects that are unique to the NCIP and on differences between the NCIP and WWO. Development status of the many features that are similar to WWO are discussed in Appendix A and Reference 7.

E3.1 Chemistry and Phenomenology

Questions or issues for the NCIP related to chemistry and phenomenology include the following:

- Understanding the basic chemistry of the hydrogen suppression reactions.
- Understanding side reactions including reactions with other sludge components, buildup of intermediates, and secondary reaction products.
- Continuing reactions, depletion and buildup of chemical species and related effects of long term interim storage prior to shipment.
- Effect of temperature cycles, e.g., short term temperature spike during immobilization, temperature during storage, and temperature during shipment.

- Effects on sludge physical properties that could affect concentration, mixing, assay and drumming process steps.
- Effects of radiolysis on nitrate concentration over extended time periods.

Prior literature review and scoping tests [1] verified the ability of nitrate to suppress hydrogen production from U metal corrosion during short-term but temperature-accelerated tests in solution, sludge component, simulated sludge, and actual sludge systems. Based on these initial favorable results, the focus of subsequent testing in the current program was to determine performance with solidified waste forms and for longer test durations. Some of the questions listed above are not fully addressed by this testing and will need to be considered in the future if the NCIP is pursued further.

E3.1.1 Summary of Testing Performed

The primary goal of this phase of testing was to evaluate and confirm efficacy of nitrate addition for hydrogen mitigation in solidified sludge matrices. Specific test objectives:

- Perform tests with full, well characterized sludge simulants.
- Determine product characteristics.
- Evaluate effect of nitrate concentration.
- Evaluate effect of candidate solidifying agents.
- Determine performance over times extended from the usual 4-week duration at 60°C to 8 weeks.
- Evaluate the effect of temperature between 60°C and 95°C.

Tests used K West Container Simulant [3] that contained mixed uranium oxides and uranium metal beads in addition to other sludge components. About 2.8 g of sludge solids and 2.8 g of solidifying agent (Portland cement or Aquaset II®[1] clay products) were typically used per test. The sample was placed in a small glass vial and the gas generated was measured, sampled, and analyzed. To accelerate the acquisition of test data most tests were performed at 60°C with an initial brief period (~3-4 hours) at ~90°C to overcome the induction time normally observed for uranium metal corrosion in the presence of anoxic water. The 60°C test temperature corresponds to the maximum temperature expected during waste for transport to the WIPP. As had been done in most prior testing with aqueous solution and sludge components, simulants, and actual sludge, most test durations at 60°C were four weeks. Some testing at eight weeks duration also was performed. Another set of tests using Aquaset II® clay and the K West simulant sludge also was performed at 80°C and 95°C with ~10-day and ~4-day durations, respectively. About half of the mass of the U metal beads would be expected to corrode according to baseline water/U metal reaction rate equation for the targeted 4-week, 10-day, and 4-day test durations at 60°C, 80°C, and 95°C, respectively.

Measured hydrogen generation rates have been normalized in terms of "attenuation factors." The attenuation factor is defined as the ratio of hydrogen generation rate expected from U metal and pure water, based on the Databook rate equation to the measured hydrogen generation rate. A minimum target value of 100 is typically used for the attenuation factor, i.e. hydrogen generation rate reduced to 1% or less of the rate expected with U metal and pure water. Results of the current tests and earlier scoping tests are summarized in Figure E-2 in the form of attenuation factor versus nitrate concentration. All results

[1] Aquaset II is a registered trademark of Fluid Tech - A Division of IMPACT Services, Inc., 2865 S. Jones Blvd., Suite 200, Las Vegas, NV 89146.

for nitrate concentrations of 1 M and above show attenuation factors of 100 or more and are above ~1000 for samples solidified with Aquaset II®, the sepiolite clay powder. Other tests using Portland cement and Aquaset II® H (a mixture of Portland cement and sepiolite clay) had hydrogen attenuation factors well above 1000 at 0.5 and 1 M nitrate but uncertainties about initiation of corrosion exist in those tests.

These results demonstrate that nitrate addition can be effective in dramatically reducing hydrogen generation. Literature data also shows that nitrate is known to significantly decrease production of radiolytic hydrogen [1, 4]. Secondary reaction may also produce small amounts of gasses, e.g. NO, N_2O, and N_2 [1].

Uranium metal corrosion rates are decreased moderately by the presence of nitrate. The attenuation factors observed in the presence of nitrate for aqueous solution, simulated sludge, and simulated sludge containing Aquaset II® are shown in Figure E-3. It is seen that the attenuation factors are ~10 or less.

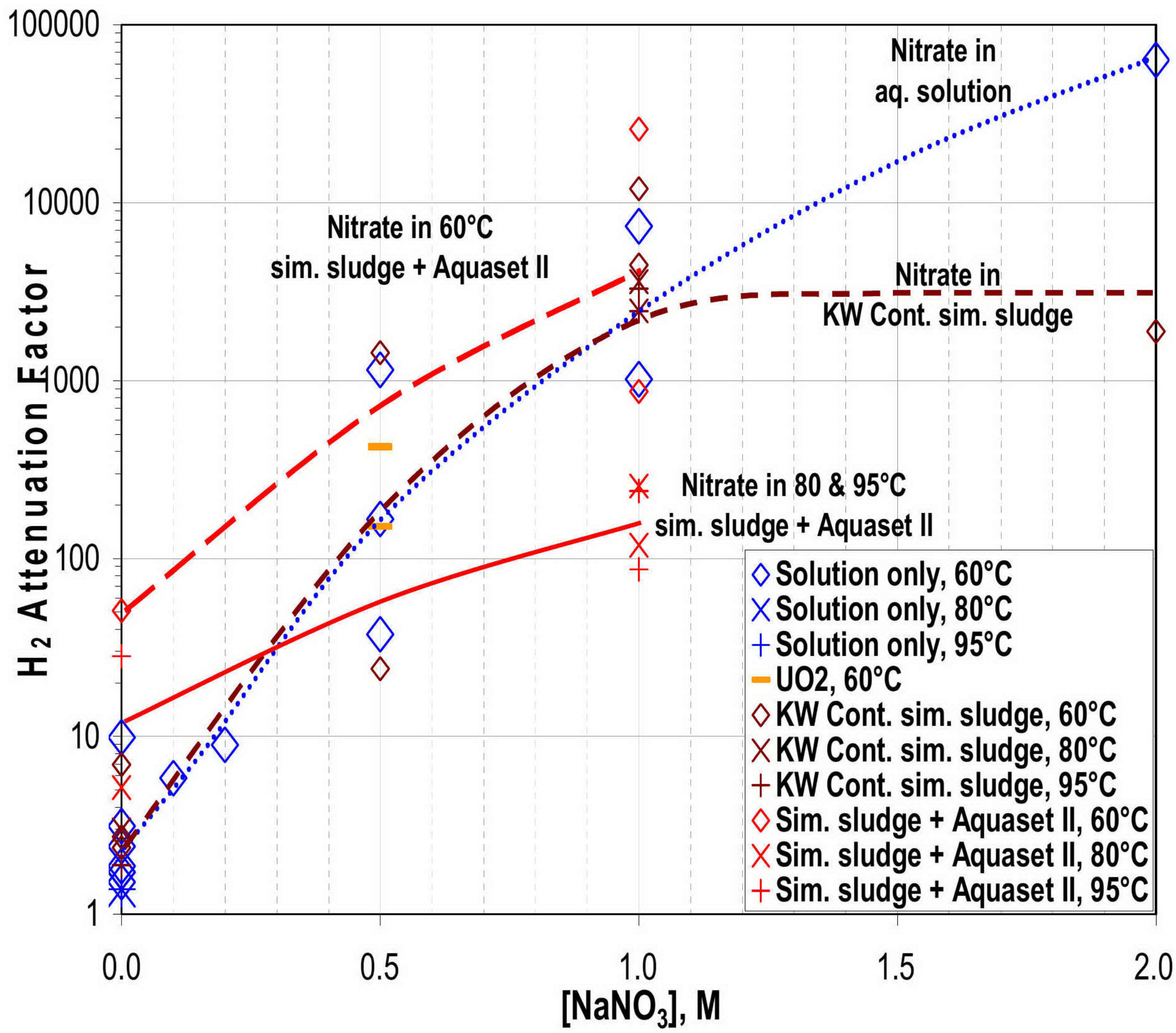

Figure E-2. Attenuation of Hydrogen Production versus Temperature and Nitrate Addition
The attenuation factor used here is defined as the ratio of hydrogen generation rate expected from U metal and water to the hydrogen generation rate observed. This figure shows the H_2 attenuation factor versus nitrate concentration, temperature, and type of simulant solution.

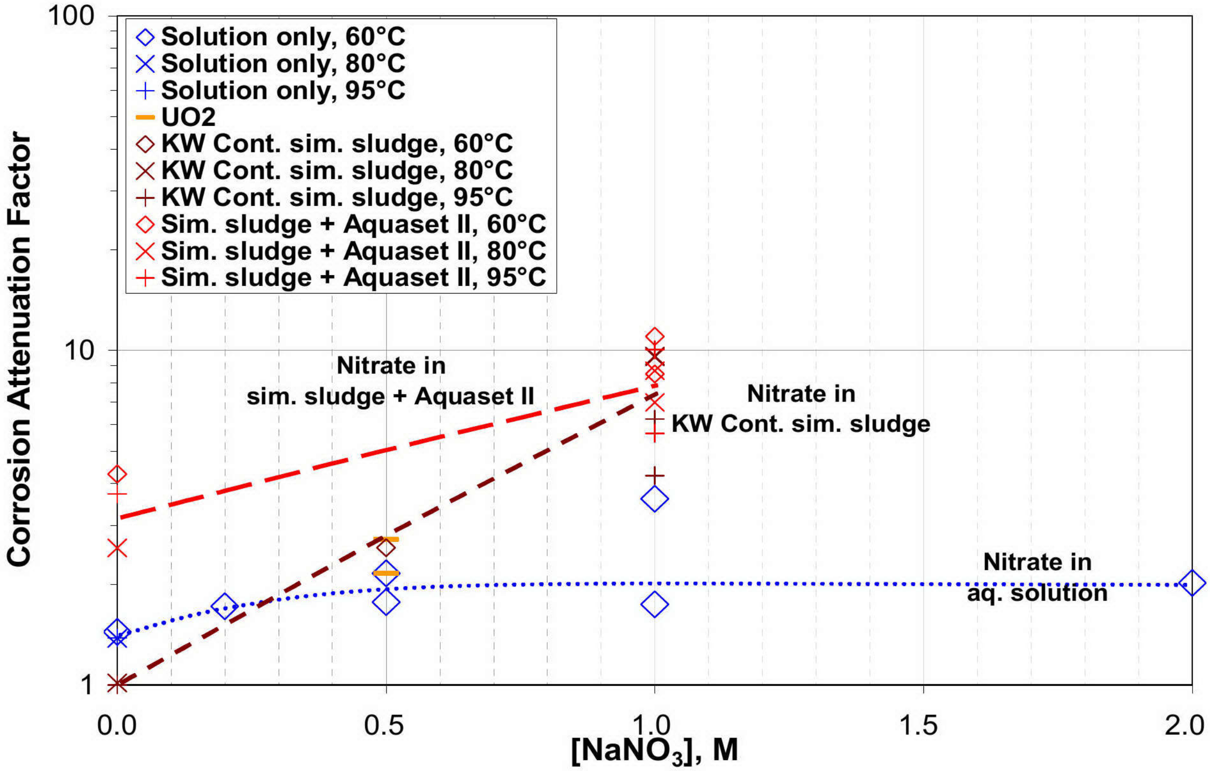

Figure E-3. Attenuation of Uranium Metal Corrosion by Nitrate Addition
The attenuation factor used here is defined as the ratio of uranium metal corrosion rate expected from U metal and water to the uranium metal corrosion rate observed. This figure shows the corrosion attenuation factor versus nitrate concentration, temperature, and type of simulant solution.

E3.1.2 Technical Issues and Unknowns Related to Chemical and Physical Behavior

To date there has been limited short term testing of the NCIP and its product waste form that has demonstrated large reductions in hydrogen generation. All testing has been done at laboratory scale. The NCIP will need to be effective for the entire 60 day window typically required for transportation to WIPP, as well as after an extended interim storage period waiting for shipping to WIPP (possibly 10 years or more for some containers).

Understanding of chemical and physical behavior in the process and product are incomplete. There is therefore some potential for other unexpected behavior as the process and product are developed and tested in more detail. Uncertainties could be substantially reduced with a modest amount of further testing.

E3.2 Technical Issues and Risks Related to Equipment and Process Integration

Due to the relatively short batch preparation time the RCMT and LST are expected to be modestly smaller for the NCIP than the WWO process. Other than these relatively minor differences, process equipment for the SRWOP is expected to be essentially identical to the WWO process. Remote equipment technology, remote facility features, assay, and integration concepts are expected to be the same as for WWO. Methods used to verify that hydrogen generation is acceptable at the time of shipment (after extended storage) have not been fully defined. Some interaction with WIPP is likely to be needed to determine what would be acceptable to them.

E3.3 Technology Development Needs

The NCIP is very early in the technology demonstration/engineering lifecycle. As such, only a moderate amount of testing or engineering evaluation work has been completed to date. However, based on the testing under the current program and literature information use of the NCIP is a potentially attractive option. If this option is to be pursued further a number of initial activities should be performed to better define the process, evaluate performance, determine if there are unexpected problems or complications related to processing actual sludge, and provide engineering data to support more detailed engineering studies and eventually design.

Development needs can be considered in terms of the design phases of a project. In the preconceptual and early conceptual design phases data is needed to verify basic feasibility, understand any complicating factors (e.g. side reactions or adverse physical property changes), and develop preliminary performance information. This data needs to be developed to a level of detail sufficient to support engineering studies used to select the final flowsheet to be used as the basis for conceptual design. In additions, topical engineering studies/evaluations are needed to better define certain aspects of the process. For example, the assay system concept, updated estimates of achievable total measurement uncertainty, feasibility of using fission product gas measurements to verify completion of reaction, potential for uncontrolled/runaway reactions.

The NCIP appears be outside the range of technical approaches typically used for compliance with WIPP/TRAMPAC flammable gas generation requirements. Therefore, early agreement with WIPP on the acceptability and associated requirements are essential for continuing the NCIP alternative past the conceptual design phase.

During the conceptual design phase process alternatives are typically evaluated and a single preferred alternative is selected. Additional data is needed for the selected alternative to develop and optimize system conceptual design, define the basis for sizing of unit operations, resolve any safety or regulatory issues, and provide a firm basis for moving into preliminary and detailed design.

For the FROP, most testing work in the preconceptual and conceptual design phases involves development of a more complete understanding of chemical and physical phenomenology/behavior of the waste form under long term storage and transportation conditions, and of the sludge and under actual process conditions. Unless the project elects to pursue novel remote equipment or facility concepts, little if any mechanical/equipment oriented testing or development work is expected to be needed during the preconcepual and conceptual design phases. Possible exceptions are the assay system used to determine isotope concentrations in the drummed waste, and offgas analysis equipment that may be considered for verifying completion of reaction. These unit operations are currently not well defined and may need early equipment oriented testing. Similarly, the drumming system is not currently well defined. If the selected drumming system design concept incorporates significant novel or untested features early proof of concept testing will be needed at least for those features.

In the detailed design phase, development activities are expected to primarily focus on design verification testing. This phase will be primarily equipment oriented and will include testing of individual components or physical features and testing of integrated systems or subsystems. The following sections provide a preliminary identification of needed activities, with primary focus on initial or near term activities.

The following sections provide a preliminary identification of needed activities, with primary focus on initial or near term activities.

E3.3.1 Critical Near Term Development Activities

A summary of critical near-term development activities is given below. These activities should be completed in the preconceptual and conceptual design phases.

E3.3.1.1 Chemical and Physical Behavior

- Laboratory process testing.
  - Explore the effect of additional sludge components not in the initial simulants tested.
  - Characterize the chemical and physical behavior of product slurries after addition of nitrate.
  - Obtain data on hydrogen generation, generation of other gasses, nitrate depletion, and buildup of secondary or intermediate species under more prototypic temperature cycles and longer interim term storage conditions.
  - Determine effects of radiolysis on nitrate for prototypic sludge/immobilized product compositions.
  - Perform more comprehensive testing on sludge physical properties/physical behavior under process conditions: slurry rheology; density, water, and solids content of settled sludge; tendency to agglomerate or set up, ability to concentrate to target solids concentrations, etc.

E3.3.1.2 Equipment and Subsystems

- Based in part on results of work listed above, develop a more comprehensive and optimized flowsheet.
- Perform laboratory testing based on defined flowsheets with simulants, and with actual sludge if feasible.
- Topical engineering study on immobilization and packaging design concepts to support selection of the conceptual design system and equipment configuration.

E3.3.1.3 Requirements Definition

- Confirm acceptability to WIPP of the general product concept (residual pyrophoric U-metal plus nitrate).
- Development of methods to verify sufficiently low hydrogen generation rate for the production plant and waste form.
- Better define performance requirements and constraints.

E3.3.1.4 Process Control and Integration

- Refinement of process, equipment, and process qualification concepts for the dose-to-curie assay system. Include evaluation of methods to deal with batch to batch variability of dose-to-curie relationships.
- Perform development testing of assay components and systems.
- Evaluate need, costs, and benefits of additional physical sampling of sludge to reduce total measurement uncertainty.

E3.3.2 Longer Term Development Needs

The process is expected to use conventional proven commercial equipment adapted for remote operation and maintenance. However, some equipment oriented process testing will be needed for equipment, such as agitators, pumps, and assay system. Testing, development, and demonstration work is also expected to be needed for the drumming system and likely some remote equipment features. This equipment and the required testing and development work are assumed to be essentially the same as for Warm Water Oxidation (see Appendix A and the Technology Maturation Evaluation for WWO [7]). This testing will be performed primarily during the preliminary design and detailed design phases of the project.

E3.4 Hazard Considerations

A hazard evaluation was completed for the Nitrate Chemical Inhibitor Process in order to provide input to the cost, schedule, and risk considerations for the continued alternatives selection process. This hazard evaluation was completed by a team of representatives from Engineering, Industrial Safety, Fire Protection, RadCon, and Operations [9].

A list of the activities constituting the NCIP alternative was compiled. Hazards (or nodes) associated with each were then identified along with potential engineered and administrative controls. Table E-1 below summarizes the results of the hazards evaluation for NCIP.

The primary hazards identified are common to all alternatives handling K Basin sludge slurries. No hazards unique to the NCIP were identified that would significantly increase overall hazards as compared to other alternatives.

Table E-1. NCIP Treatment Hazard Considerations

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01 – MOBILIZE, RETRIEVE, TRANSFER STORE AND AGITATE						
RET.01.01	Internal Explosion	Sludge contamination	H^2 accumulation and ignition in STSC headspace	Purge system Ventilation system	Equipment surveillance	—
RET.01.02	Spray Leak	Sludge	Crack leak of slurry being removed from STSC and transferred to receiver vessel	Double contained transfer line.	—	—
RET.01.03	Splash / Splatter	Sludge	Leak of slurry being transferred from the STSC to the receiver vessel	Double contained transfer line Tank High Level Alarm and pump interlock	—	—
RET.01.04	Loss of Confineme nt	Sludge Contamination	Plugged vent path causes an unfiltered release from tank	Pressure transmitter to monitor the tank	—	—
RET.01.05	Internal Explosion	Sludge Contamination	H_2 accumulates in the receiver tank headspace and lines, resulting in a deflagration of the tank headspace or lines	Inerting or Alternate purge path.	—	—
RET.01.06	Direct Rad	Cs-137 release to water during storage or sludge in line or in STSC	Backflow of sludge through a line above the STSC, or exposure to storage water high in Cs-137 or sludge in STSC due to liquid draw down	Interface system design (check valves and system pressure), remote STSC unloading	Transfer access control	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01.07	Load Drop	Sludge contamination	Dropping equipment onto the STSC during removal of cask head or installation of transfer system resulting in a leak	—	*Hanford Site Hoisting and Rigging Manual*	—
REC.01 – RECEIVER VESSEL STAGING AND DEWATERING Note: this includes the boil down dewatering both before reaction and during/after reaction, and agitation and circulation during staging and reaction.						
REC.01.01	Internal Explosion	Sludge Contamination	H_2 accumulation and ignition in tank headspace	Purge system Ventilation system	Equipment surveillance	Note: hydrogen evolution may be very rapid following size reduction, especially if agitation is ineffective and the settled metal is self heating
REC.01.02	Spray Leak	Sludge	Circulating sludge spray leak	Low pressure circulation Secondary confinement	—	—
REC.01.03	Splash / Splatter	Sludge	Leak from circulating system	Secondary confinement	—	—
REC.01.04	Overpressure Loss of Confinement	Sludge Contamination	Plugged vent path and overpressure causes an unfiltered release from tank	Pressure transmitter to monitor the tank, pressure relief, open vent path	—	—
REC.01.05	Direct Rad	Sludge in line or Exposure to vessel	Backflow of sludge through a flush line or in a recycle line, exposure to receiver vessel	Flush water system design (check valves and system pressure), Shielded recirc lines Shielded receiver vessel, remote maintenance for agitation	—	—
REC.01.06	Criticality	—	Accumulation of separated metal, unsafe geometry	Vessel geometry, sludge process limits, sludge material final characterization	—	

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
REC.01.07	Steam agitation / ejection of slurry	Slurry in tank	Steam leak into receiver vessel agitates and volatilizes slurry into off gas system	Steam Jacket design	—	—
REC.01.08	NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
REC.01.09	Facility Fire, spill	Sludge	Facility fire results in failure of confinement vessel and release of rad material	Materials of construction, Fire Protection System	Combustibles limits	—
NAI.01 – NITRATE ADDITION CHEMICAL INHIBITOR PROCESS						
NAI.01.01	Internal Explosion	Sludge Contamination	H_2 release during boil down after treatment	Purge system Ventilation system	—	**NOTE:** *Minimal hydrogen production during and after treatment.*
NAI.01.02	Release of noxious gas	Nitrate and ammonia	Ammonia or NOx may be released from the treated sludge, especially if heated	Off gas control system	Process controls to prevent heating	—
TRS.02 –TRANSFER AND STAGING OF TREATED SLUDGE						
TRS.01.01	Spray Leak	Sludge	Line failure during pressure transfer results in a release of radiological material outside of the facility	Piping design, secondary piping design, confinement design	—	—
TRS.01.02	Overpressu re	Sludge Contamination	Accumulation of gas in the isolated staging tank results in a potential overpressure and release of radiological material	Ventilation system Confinement design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
TRS.01.04	Splash / Splatter	Sludge	Transfer Line failure results in a release of slurry	Piping design, secondary piping design, confinement design	—	—
TRS.01.05	Direct Rad	Released fission products or sludge in lines or containers	Sludge in lines or vessels not adequately shielded	Facility design	Radiological Control Program access controls	—
TRS.01.06	Seismic Event	Sludge	SSC failure results in spill / spray and spread of rad material	Facility design	—	—
TRS.01.07	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
PKG.03 – IMMOBILIZATION AND PACKAGING OF TREATED SLURRY						
PKG.03.01	Spray Leak	Sludge	Pressure transfer line failure results in a release of radiological material	Piping design, Secondary piping design, confinement design	—	—
PKG.03.02	Facility Fire	Sludge	Facility fire results in a release of rad material	Materials of construction, Fire Protection System	Combustibles control	—
PKG.03.03	Seismic Event	Sludge	Seismic forces result in a line break and potential release	Facility design	—	—
PKG.03.04	Splash / Splatter	Sludge	Pressure transfer line failure results in a release of rad material	Piping design, secondary piping design, confinement design	—	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
PKG.03.05	Direct Rad	Released fission products or sludge in lines and containers	Direct exposure to sludge rad shine	Shielding design	Radiological Control Program access controls	—
PKG.03.06	Other NPH	Sludge	Missile or structure failure results in spill / spray and spread of rad material	Facility design	—	—
STG.01 – SHIELDED STORAGE OF TREATED DRUMS						
STG.01.01	Load Drop	Sludge	Container drop resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.02	Load Drop	Sludge	Load dropped onto container resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.03	Seismic Event	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.04	Other NPH	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.05	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
STG.01.06	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Facility design, Fire Protection Design	—	—
LSC.01 – LOAD SHIPPING CONTAINER. REMOVE FROM ISC, LOAD 72-B LINER, LOAD CASK						
LSC.01.01	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
LSC.01.02	Load Drop	Sludge contamination	Impact fails package and damages grout	Contamination control ventilation	Hoisting and rigging controls, DOE-RL-92-36	—
LSC.01.03	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Fire Protection System	—	—
LSC.01.04	Seismic Event	Contamination	SSC failure results in package impact and spread of rad material	Facility design	—	—
LSC.01.05	Other NPH	Contamination	Missile or structure failure results in package impact and spread of rad material	Facility design	—	—

DOE-RL-92-36, 2007, *Hanford Site Hoisting and Rigging Manual,* Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

FW = facility worker.
HC-2 = Hazard Category 2 (facility).
HEPA = high-efficiency particulate air (filter).
HVAC = heating, ventilation, and air conditioning.
ISC = interim storage container.
LFL = lower flammability limit.
MAR = material at risk.
NPH = natural phenomenon hazard.
SSC = structure, system, and component.

E3.5 Additional Considerations

This section identifies additional miscellaneous items identified as part of the review which may be considered in evaluating this alternative.

One option is to design for the NCIP with WWO as a backup/alternate if problems develop. If NCIP performance is as expected with no major side problems the operating duration would be significantly reduced compared to WWO. Sensitivity to retrieval schedule and sequence is also reduced with the NCIP. If problems are found with NCIP, the WWO could be implemented as a backup the required equipment is essentially the same. For processing settler sludge the required oxidation time with WWO is about 1/10 of that required for the EC sludge. Therefore there is less benefit from using the NCIP rather than the WWO process for the settler sludge. One approach could be to use the NCIP for Engineered Container sludge (floor and pit sludge) and use WWO in the same equipment for processing Settler Tank sludge.

Another approach would be to use WWO with a reduced time cycle to eliminate the bulk of the U metal and then add nitrate to mitigate the reduced amount of U metal. For example, if WWO is performed at 95°C for 12 days, U metal smaller than 500 µm will be oxidized (assuming an enhancement factor of 1). Addition of nitrate could then be considered to mitigate the relatively small amount of residual U metal. This would substantially reduce the processing time for WWO, while potentially reducing the risk of gradual loss of efficacy of nitrate due to long term storage. The NCIP could also be considered as part of a “belt and suspenders” approach to provide additional assurance of the reduction of hydrogen generation for any of the water or chemical oxidation approaches.

E4 Process Design and Performance Estimates

This section provides a summary of sizing for major process equipment, estimates of the time required to process all of the K Basin sludge, and facility size information. Because most of the design is expected to be similar to the WWO option, the presentation herein focuses on differences with WWO as given in Appendix A.

E4.1 Process Flowsheet Estimates

In order to compare the various technologies under consideration, normalized flowsheet estimates were developed to evaluate differences in major equipment and facility size, and to estimate potential differences in sludge processing rate. The normalized flowsheet estimates are based on input from PNNL [1, 2] with adjustments as needed to assure that all technologies are evaluated on a reasonably consistent basis. Common process bases and assumptions are summarized in Appendix J. Normalized flowsheet calculations summarized below are documented in Reference 5.

The flowsheet calculations start by estimating size of the RCMT and LST needed to process the largest STSCs batches. The batch preparation time is then estimated, i.e. the time to receive and process an STSC batch to the point that it is ready for transfer from to the assay/drumming system. When batch preparation is complete and the batch has been transferred from the RCMT to the LST the RCMT is ready to begin receiving and processing of the next batch while the batch in the LST is drummed. The NCIP base case batch preparation time is estimated at 6.4 days.

The time to drum each batch is then estimated. Using base case assumptions for achievable waste loading per drum and drumming rate (Appendix J) the average drumming time per STSC batch is estimated at 7, 9.4 and 29 days for KE EC, KW EC, and settler tank sludge respectively. Comparison of these values with the estimated 6.4 day batch preparation time indicates that drumming is rate controlling for all sludge types. Based on the rate controlling step for each sludge type and the assumed number of batches the total processing time for the base case is estimated at 12.6 months with 100% TOE or 18 months assuming 70% TOE. This is less than 1/3 of the required processing duration of 5 years or less, and may be compared to the base case WWO processing time estimate of 59 months. The much shorter processing time results from eliminating the oxidation step resulting in a shorter batch preparation time.

The NCIP processing time is also less sensitive to retrieval schedule assumptions as compared to WWO. Ability of WWO to complete processing within 60 months relies on each oxidation batch processing multiple STSC batches (two for the base case). The estimated processing schedule for the NCIP is largely driven by the processing rate of the drumming system. Therefore, compared to WWO, the estimated processing schedule is more sensitive to changes in assumptions related to drumming rate. See Appendix I for additional discussion of sensitivity to changes in the base case assumptions for the NCIP and other alternatives under consideration.

The base case process flowsheet estimate indicates that for all waste types the waste loading per drum is limited by the fissile isotope content (^{239}Pu FGE). Within the accuracy of available data there are not significant differences between the NCIP and other alternatives relative to the achievable waste loading or number of product drums.

E4.2 Major Process Equipment

NCIP equipment sizing calculations [5] include only the major process tanks shown on Figure E-1 plus added cold chemical handling tanks needed for the NCIP. The NCIP does not require the nitrogen storage and blanketing system used for the WWO Receipt and Reaction Tank (RRT). Other equipment is assumed to be essentially identical to WWO (Appendix A).

The NCIP tank size estimates are given in Table E-2 based on the nominal base case set of assumptions [5]. Comparison with WWO values in Appendix A shows that the estimated RCMT and LST are moderately smaller than tanks included for the WWO Process base case estimate. This results primarily from processing a single STSC batch per oxidation batch in the NCIP base case versus 2 STSC batches per oxidation batch for the WWO base case estimate. The basic features of the tanks are similar to the WWO RRT and LST: steam heating and water cooling jacket(s) on the RCMT, water cooing jacket on the LST and agitators in both tanks. Additional out of cell tanks are also needed for addition of nitrate solutions for NCIP. The nitrogen blanking system used for WWO is not required for NCIP. Other than these items, equipment list and sizing is expected to be identical to that for WWO.

Table E-2. NCIP Base Case Process Vessel Size Estimates

Vessel	Working Volume (m^3)	Gross Volume (m^3)
Concentrate/Mix Tank (RCMT)	16	20
Lag Storage Tank (LST)	4.5	5.7
Condensate Tank (CT) A	15	17
Condensate Tank (CT) B	15	17
Sodium Nitrate Makeup/Storage Tank	2.6	3.0
Sodium Nitrate Day Tank	.096	.12

E4.3 Facility and Equipment Requirements

Separate facility layouts and other facility information were not prepared for the NCIP option.

For the purpose of comparative cost estimates it is assumed that equipment and facility is the same as is the same as WWO (Appendix A) with the exceptions noted below.

E4.3.1.1 Equipment changes from WWO:

- RCMT gross volume is reduced to 20 m^3 for NCIP from 24m^3 for the WWO RRT.
- LST gross volume is reduced to 5.7 m^3 for NCIP from 11.4 m^3 for WWO.
- Chemical handling tank is added for sodium nitrate solution (Table E-2).
- Nitrogen storage and supply system used for WWO is not needed for NCIP.

E4.3.1.2 Facility changes from WWO:

- Remote cell space for the RCMT and LST are reduced proportional to the reduced tank sizes.
- A larger chemical receipt, makeup, and storage tank area is required for nonradioactive chemicals identified in Table E-2.
- Additional space may be needed for chemical addition day tanks identified in Table E-2.

E5 Characteristics of the Alternative Relative to Evaluation Criteria

This section provides an evaluation of the process concept relative to the evaluation criteria.

Section E5.1 identifies attributes of the alternative are identified that distinguish the alternative in the evaluation against other alternatives under consideration. These attributes are categorized as potential advantages or disadvantages compared to other alternatives. Attributes that are common to all alternatives are typically not included. In Section E5.2 the identified attributes, advantages and disadvantages are allocated to the evaluation criteria from the Decision Plan [7].

E5.1 Evaluation Considerations for NCIP Relative to Other Alternatives

The project scope and requirements assume that any alternative must be capable of receiving full STSC batches of K Basin sludge and processing them to meet criteria for shipment to WIPP. As such, all alternatives will need certain minimum capabilities and will present minimum safety (public and worker) and environmental risks, and minimum costs and technical requirements. This section notes characteristics, advantages, and disadvantages to the NCIP alternative that may differentiate it relative to other alternatives under consideration and allocates those to the various decision criteria.

E5.1.1.1 Potential Advantages or Beneficial Attributes of NCIP:

- Proof of principle laboratory tests have demonstrated effective suppression of hydrogen generation for durations up to 8 weeks.
- The minimum sized tanks (RCMT and LST) needed to accept and process a full STSC batch are sufficient for use by NCIP. Minimizing process tank size also minimizes remote cell space requirements and presents an easier mixing problem for slurry tanks as compared to alternatives that require larger process tanks.
- NCIP requires no reaction time, resulting in relatively short operating duration with a single process train and minimum tank size (about 2 years versus 5-7 year maximum criteria in the Decision Plan). This is expected to result in the following beneficial attributes:
  - Relatively low overall operating costs due to short plant operating life.
  - Short process operating time results in low operating time on agitators, erosion of agitators and tank walls, and less wear and tear on equipment. This is expected to reduce maintenance costs, worker exposure to radiation, and secondary radioactive waste generation compared to alternatives that require longer operating duration.
  - Low batch processing time results in reduced probability and risk from process failures and less sensitivity to down time/maintenance of Receipt and Reaction Tank related components.
  - NCIP processing rate (or processing duration) has less dependence on retrieval schedule than some alternatives. NCIP processing is expected to be limited by drumming rates most of the time. If there are retrieval delays the NCIP treatment process can catch up with limited impact to the drumming process or overall processing schedule.
- The NCIP also requires only a single STSC batch in each oxidation batch. Some alternatives may require either multiple STSC batches in each oxidation or multiple oxidation process trains in order to achieve the required total processing times.

- Equipment installed for the NCIP can also be used for the WWO process with minimal modifications (e.g. addition of nitrogen blanketing for the RCMT).

E5.1.1.2 Potential Disadvantages and Risks of NCIP as compared to WWO:

Little testing has been completed to date on equipment, and process chemical and physical behavior.

- Testing to conclusively prove performance after long term storage may be difficult and expensive.
- Acceptability to WIPP of using chemical inhibitors is uncertain.

E5.2 Evaluation Considerations for NCIP Relative to Decision Criteria

Table E-3 illustrates how the identified advantages, disadvantages, and risks relate to Decision Criteria identified in the Decision Plan [7].

Table E-3. Evaluation Considerations for the NCIP Alternative

Decision Criteria from Decision Plan [7]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
Safety	• Ensure worker safety.	• Relative ease/difficulty in implementing adequate safety measures as measured by number of passive (inherently safe) vs. active engineered safety features. • Ensure protection of the nuclear the general public.	**Advantages** • No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries[13] • Relatively short operating period. • Inert gas blanketing not required. • Minimum material at risk (MAR)/inventory of sludge. **Disadvantages** • Use of potentially hazardous oxidizer (sodium nitrate).. Required chemicals are in use elsewhere at Hanford and for general industrial use.
Regulatory/ stakeholder acceptance.	• Ensure compliance with environmental laws and regulations and DOE orders. • Address sludge management concerns in *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* record of decision.	Achieve acceptance of regulators and other Stakeholders.	**Advantages** • Short processing time expected to be viewed favorably by stakeholders. **Disadvantages** • Acceptability to WIPP of using chemical inhibitors is uncertain.
Technical maturity	Maximize confidence in process implementation	• Projected Technical Readiness Level (based on technical criteria only at this stage of the project) • Estimated volume of waste going to WIPP	**Advantages** • Proof of principle laboratory tests have demonstrated effective suppression of hydrogen generation for durations up to 8 weeks. • Modest size slurry tanks, essentially the minimum required to process full STSC batches. Smaller size tanks present and easier mixing problem as compared to processes that require larger tanks. • Estimated volume of waste is expected to be ^{239}Pu FGE limited, i.e. the process is not expected to increase number of drums to WIPP above the minimum. **Disadvantages** • A moderate amount of process testing has been completed to date, but significant additional testing is needed. • Relatively long term tests may be needed to demonstrate that the inhibitor remains effective after a long storage period.
Operability and maintainability	• Maximize operability Maximize maintainability	• Ability for process to be remotized • Ability to treat and package K Basin sludge inventory in 5 to 7 years • Acceptability of secondary waste streams for disposal at Environmental Remediation Disposal Facility (solids) and 200 Area Effluent Treatment Facility (liquids)	**Advantages** • The treatment system will use proven, familiar, remote equipment designs concepts. No special or unusual equipment concepts are needed beyond those typical for handling and processing highly radioactive slurries. The drumming system is similar to other alternatives and will use primarily industrially proven equipment and designs with some custom features to be developed and proven for this specific application. • With a single process train and minimum tank size to accept STSC batches the operating duration relatively short (<2 years) to process all sludge.

Decision Criteria from Decision Plan [7]			Considerations Related to Decision Criteria
Criteria	**Goals**	**Measures**	
			• Short process operating time results in low operating time on agitators, less erosion of agitators and tank walls, less wear and tear on equipment, and less sensitivity to down time for maintenance of Receipt and Reaction Tank related components. • Conversely; the short estimated processing time provides more allowance for downtime process performance problems and still meet the 5 year window. • NCIP processing rate (or processing duration) is less dependent on retrieval schedule. • The NCIP equipment can also be used for the WWO process with minimal modification to add nitrogen blanketing.. **Disadvantages** • Requires handing of a chemical oxidizer (sodium nitrate)
Life-cycle cost and schedule	• Optimize life-cycle costs for sludge treatment and packaging facility Provide acceptable schedule to stakeholders	**Cost** • Cost of maturing technology to Technology Readiness Level-6 • Capital cost • Operating and maintenance cost • Deactivation and decommissioning cost **Schedule** • Facility startup • Complete treatment and packaging	**Advantages** • Relatively small process slurry tanks and short operating time are expected to result in relatively low operating costs. **Disadvantages** • Additional process flowsheet and product testing are needed. • Relatively long term tests may be needed to demonstrate that the inhibitor remains effective after a long storage period and in the presence of radiation field.
Potential for beneficial integration with ongoing STP - Phase 1 activities	• Optimize cost or schedule for STP - Phase 2 Consider co-location of needed facilities provided by STP - Phase 1	• Potential for integration of treatment and/or packaging with interim storage in T Plant • Potential for shared functions with those being provided by STP Phase 1 • Optimization of location of reduce/eliminate intermediate shipping or repackaging of the sludge material	**Advantages** • Process is compatible with Phase 1 design concept. • No identified positive or negative impacts to currently planned Phase 1 Project activities • Co-location near T Plant is possible, but overall siting studies have not been completed. **Disadvantages** • No significant discriminators noted.
Integration with Site-wide RH-TRU processing/packaging planning, schedule, and approach	Optimize processes, equipment, and facilities for K Basin sludge treatment and packaging with other Hanford Site RH-TRU waste streams	• Number of other Hanford Site RH-TRU waste streams that can be treated with candidate process • Number of other Hanford site RH-TRU waste streams that can be packaged with candidate packaging process	**Advantages** • The process is capable of process additional K Basins TRU waste streams that have been identified. • Could be applicable to other (unidentified) wastes with high radiolytic hydrogen generations to reduce hydrogen generation rate during shipment. • Other than the additional K Basins wastes, no specific RH TRU streams have been identified for integration at this time. **Disadvantages** • None noted

E5.3 Conclusions and Recommendations

E5.3.1 Conclusions

- Based on successful completion of proof of principle testing the NCIP is judged to be a technically feasible treatment alternative for processing K basin sludge in STP Phase 2.
- Whether the final product will meet WIPP and transportation requirements is uncertain
  - Hydrogen from U metal reaction eliminated by reaction of the nitrate with nascent hydrogen
  - Small amounts of U metal distributed in the waste matrix are not expected to present a pyrophoric material hazard
  - Free liquids eliminated by in-drum mixing of dry additives
  - Gamma radiation assay on concentrated sludge used to determine proper sludge addition per drum
  - Final measurements taken on drum to verify FGE, dose rate, and radiolytic heat generation limits are met
  - Acceptance of the presence of U metal in final waste form by WIPP is uncertain
- Based on the Decision Plan evaluation criteria the NCIP compares favorably with other alternatives. The NCIP has expected to have relatively favorable performance in terms of processing duration, equipment size, and complexity.
- Acceptability of using a chemical inhibitor approach should be discussed with WIPP. This should include discussion of methods for proof of performance that are likely to be acceptable.
- In order to finalize definition of the process flowsheet and support final process selection studies during conceptual design, additional laboratory testing, literature review, and topical engineering studies should be performed in the near term. Primary focus should be on long term performance of the waste form during realistic storage and transpiration conditions.

E6 References

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Appendix F

Evaluation Data for In-Container Vitrification™ (ICV™) – (Impact)

F1 Introduction

The development of technology alternatives for the Sludge Treatment Project was initiated by the request for technology information described in CHPRC, 2009. The technology information request included a description of the overall technology selection process, a preliminary description of K Basin sludge material to be treated, and a preliminary description of the transport package to be used for delivery of K Basin sludge from storage to the treatment process system. Multiple vendors submitted concepts for K Basin sludge treatment based on the technology request preliminary information. In-Container Vitrification (ICV)™ was selected by CHPRC as one technology approach for proof-of-concept testing and selected engineering evaluations.

Application of the ICV™ technology for treatment of the K Basin sludge was proposed by Impact Services, Inc. The complete information response is described in Impact, 2009.

Impact, 2009 summarizes a variety of vitrification test experiences that are considered partially applicable to the proposed K Basin sludge treatment process. Test experience has been obtained in a number of different countries (Australia, United Kingdom, and United States) and includes both in-container and in-situ vitrification work (in-situ vitrification experience with uranium-bearing soils/materials was considered partially applicable to K Basin sludge treatment due to similarity of the materials vitrified), depending on the specific problem being addressed. Laboratory scale crucible melt testing with simulated K Basin sludge, containing depleted U metal, was conducted in 2003. The equivalent of full scale testing with a K Basin sludge simulant, containing misch metal as a surrogate for uranium metal and oxides, was also conducted. Both K Basin sludge simulant tests demonstrate that uranium metal (or surrogate) is oxidized during the vitrification process. The vacuum dryer, dried waste conveyance, and off-gas systems have been tested with simulated LAW and simulated TRU mixed tank waste but not with simulated K Basin sludge.

F2 Technology and Flowsheet Summary Description

The ICV™ technology is based on a joule heated in-container vitrification unit used to stabilize and solidify the sludge. Sludge slurry is transferred to a batch tank and then to a vacuum dryer. The slurry is mixed with solid glass forming components in the dryer and water is removed at about 60 °C. Blended product from the dryer is transferred to the disposal drum, which contains an integral melter with graphite electrodes for electrical heating and a ceramic insulating system. The sludge mixture is heated sufficiently to drive off residual volatile components in the dryer product and melt the remaining waste and glass formers at about 1300°C. When a batch is complete, the melt is allowed to cool and solidify. The drum is then sealed, surveyed, and loaded out. Off gas generated by the melting process is treated by filtration, removed solids are recycle to the dryer, and treated off gas is discharged. A simplified flow diagram is provided in Figure F-1.

F2.1 Treatment Process

The ICV™ process description is generally provided in Impact, 2010i and summarized in the following sections. **Figure F-*2*** provides a description of the process flow diagram that has been excerpted from 2010i.

F2.1.1 Immobilization Feed Preparation

The treatment process begins with transfer of sludge from a sludge storage and transport cask (STSC) into an receiver vessel within the sludge treatment system. The sludge is received as a dilute slurry (95 vol% water) and the receiver vessel is sized to contain the contents of a single STSC.

Figure F-1. In-Container Vitrification System Simplified Block Diagram

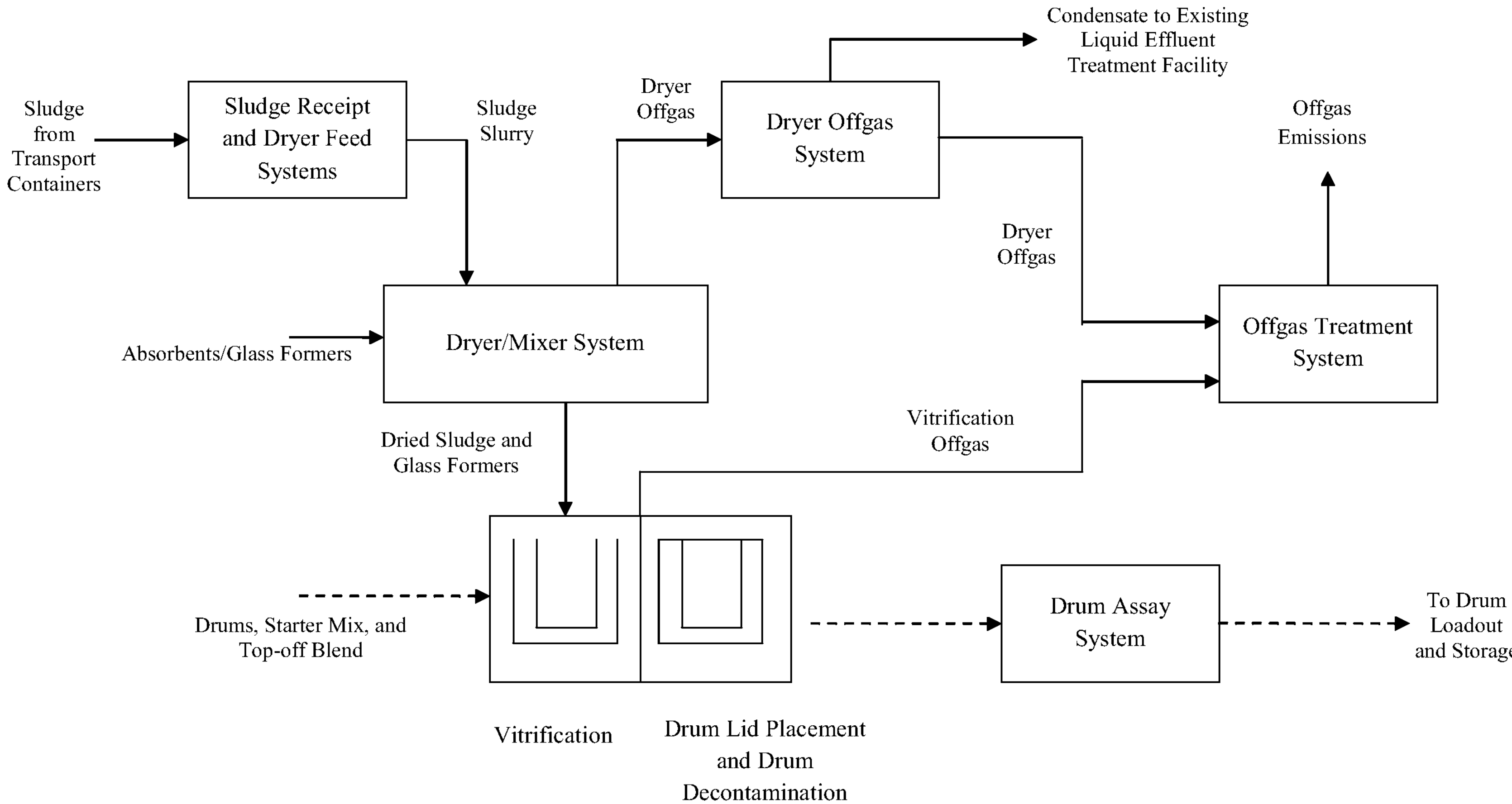
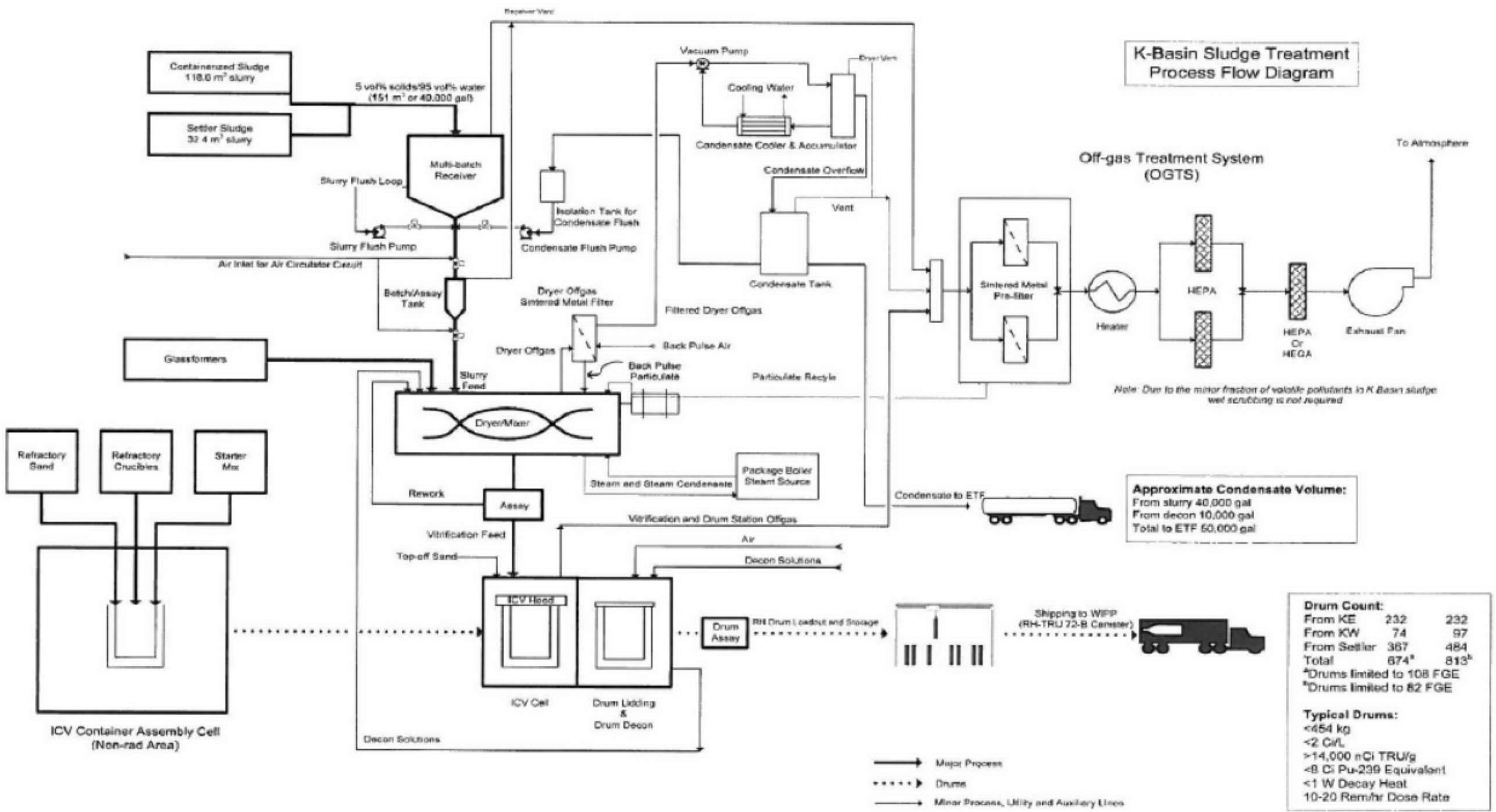


Figure F-2. In-Container Vitrification Process Flow Diagram



Source: Impact, 2010i.

Dilute slurry is transferred from the receiver vessel to a smaller Batch/Assay Tank which is the direct feed vessel for the dryer/mixer. Dilute slurry in the Batch/Assay Tank is discharged by gravity to the dryer/mixer.

For sludge compositions that are not limited by fissile content, Impact, 2010i estimates the Batch/Assay Tank will need to hold up to approximately 105 gal (~400-L) of dilute slurry to produce an inventory of dried sludge suitable to fill the ICV™ crucible. This estimate is based on an ICV™ crucible capacity of 24 gal (91-L) of dried sludge/glass former mixture containing 50 wt% glass formers and 50 wt% sludge components (basis for preliminary material balance calculations). The dilute slurry is added in increments via a remotely operated pinch valve at the bottom of the Batch/Assay Tank.

The Dryer/Mixer is currently projected to be a rotary horizontal shaft, plow style, Dryer/Mixer, similar to that manufactured by Littleford Day, Inc. The dryer vessel is steam jacketed and the contents are kept under vacuum during operation. Operating under vacuum enables a lower boiling temperature for water, and subsequently requires only low temperature steam fed through the dryer jacket to provide the necessary heat input. This lower boiling temperature for the sludge slurry reduces volatilization of organic species or radionuclides during the drying process, which minimizes contamination of dryer condensate that must be disposed via transport to the Hanford Effluent Treatment Facility.

Impact, 2010i indicates that a full batch of glass forming materials is added to the dryer/mixer prior to addition of the sludge slurry. This approach was based on previous experience[1] with waste materials containing high concentrations of soluble sodium salts. Test performed using simulant as part of this effort (described below), indicate that higher water evaporation rates (shorter drying cycle times) were achieved by processing dilute sludge through the dryer/mixer first, adding the glass former material as cullet at the end of the dryer cycle with no detrimental impact on dryer performance. Therefore, it is likely that this modified material addition approach would be preferred in future versions of the process description (no significant change to the material balance).

Sludge slurry is dried to a low moisture content (2 - 5 wt% water). Drying progress is tracked by monitoring dry vessel thermocouple temperature trends and dryer operating pressure. During active dewatering, the temperature of the product remains fairly constant, holding near the boiling point of water. For example, when the dryer vessel absolute pressure is 118 mm Hg (~2.3 psia), water boils at 55 °C (131 °F). When rapid dewatering is nearly completed, the product temperature begins to rise and (based on test experience) the operating pressure begins to decrease, indicating that residual moisture removal is underway. At this point, a metered amount of slurry is again fed into the dryer, and the above process is repeated until all (up to 105 gal) of the slurry has been added.

Once all sludge and glass forming material have been added and mixed in the dryer, the dryer product is ready for discharge to an empty ICV™ melter vessel. The dryer's rotating plows sweep material toward the center bottom off the vessel, and the free-flowing granular product discharges via gravity into the bottom product chute and into the staged ICV™ melter vessel.

The 130-L dryer vessel was selected based on preliminary calculations predicting an average water evaporation rate for the full scale dryer of at least 65 lb/hr. This evaporation rate produces a dryer cycle time such that the ICV™ melt and cooling steps are limiting in the overall process time cycle (dryer operation is not limiting). Testing of a 130-L dryer with sludge simulant produced average water

[1] Prior experience with operation of a similar dryer was obtained during testing that supported investigation of a Bulk Vitrification concept for Low Activity Waste from underground storage tanks at the Hanford site. These tests included equipment with a capacity as large as 10,000 L (~2,600 gal). See AMEC, 2007 for example.

evaporation rates ranging from ~68 to 80 lb/hr (Impact, 2010o). Therefore, the available information indicates the 130-L dryer is projected to be capable of supporting the ICV™ production scale system.

Assay methods have not been investigated as part of the preliminary evaluation work beyond recognizing that fissile content control will be a key attribute for determining the loading of each ICV™ disposal container. Figure F-2 indicates potential assay point that may be considered, including the Batch/Assay Tank used to introduce sludge into the dryer, during transfer of the dried sludge/glass former mixture between the dryer and an ICV™ container, and the ICV™ container after vitrification is complete. Identification of the assay method and proposed control method has been deferred to potential future work.

F2.2 Process Chemistry

A detailed description of the reactions describing process chemistry for the primary ICV™ process unit operations (drying and vitrification) has not been developed for this evaluation. The objective of the drying unit operation is to reduce the water content of the sludge slurry prior to initiating vitrification. This reduces the heat load that must be supplied by the ICV™ electrodes that would need to be supplied to simply boil off water and reduces the physical volume of feed materials to fit within the ICV™ crucible as a single batch. The primary dryer reaction is vaporization of free water. There is no requirement to remove water of hydration from chemical compounds within the dryer.

Some side reactions are expected to occur as the sludge components are dried. In particular, partial oxidation of uranium metal at the dryer conditions (~60-70 °C and 20-75 torr) is expected to generate some hydrogen. The process does not rely on complete oxidation of uranium metal to produce a WIPP compliant ICV™ product. Therefore, hydrogen generation estimates was considered a potential factor that may influence the selection of off-gas system flow rates in the future, but could be deferred to future more detailed evaluation if the technology were selected for further development.

Detailed consideration of the vitrification reactions were also deferred to future evaluation since a full scale test of vitrifying sludge simulant has been performed. AMEC, 2003 provides a description of the full scale test that concluded an acceptable product is produced to satisfy WIPP disposal requirements[2]. This conclusion was based on the following vitrified product observed characteristics:

- No free liquid in the container,
- Not pyrophoric,
- Not ignitable, corrosive, or reactive, and
- Did not contain incompatible materials, or material incompatible with payload container and packaging materials, shipping container materials, other wastes, repository backfill, or seal and panel closure materials.

Further definition of the vitrification chemistry was not considered necessary at this stage in the technology evaluation due the existence of the engineering scale test. It should be noted that the engineering scale test did not produce a uniform mixture of components in the glass matrix. In particular,

[2] Note that AMEC, 2003 describes the vitrification testing performed as an engineering scale test based on implementation in a waste box with internal dimensions of approximately 6 ft × 4 ft × 3 ft (tall). The test scale demonstrated is based on a vitrified zone that began the melt as 12-inches in diameter and 14.5-inches tall. The process described in this study was based on a 91 L crucible that is estimated to begin the melt at approximately 17-inches in diameter and up to 28-inches tall. Therefore, the test scale performed in AMEC, 2003 is considered approximately equivalent to a full scale test in terms of application to the proposed sludge treatment process.

a metal phase (primarily iron) was observed at the bottom of the crucible in test product. It is likely that the use of Hanford sand as the glass forming material and misch metal[3] as a simulant of uranium metal contributed to formation of the observed metal layer. However, production of a uniform glass matrix is not currently considered a requirement for the ICV™ process, as long as the vitrified product complies with the WIPP acceptance criteria.

F2.3 Immobilization

The ICV™ process immobilizes K Basin sludge by incorporating sludge components within a glass material. The process begins by preparing a 55-gal drum to serve as the ICV™ container in which the dried sludge/glass forming material mixture from the dryer is vitrified. The ICV™ drum also serves as the shipping and disposal container that is placed in the WIPP approved transport canister (e.g., RH-72B).

The ICV™ container is assembled in a non-radioactive area of the facility. A standard DOT-7A compliant drum is used as the primary container. The drum is fitted with a two-layer refractory liner composed of refractory sand (silica) and a refractory casting. A pre-measured quantity of sand is first added to the base of the drum and the refractory casting positioned on the center of the sand bed. Additional sand is then added to the annular space formed between the refractory casting and the outer drum wall. Layers of glass former and starter path material are used to line the bottom of the refractory casting cavity. Electrodes are then secured vertically the casting cavity to complete the ICV™ container assembly.

The assembled ICV™ container is then remotely transferred into the vitrification cell where electric connections are attached to the electrodes and an ICV™ hood is attached to the drum. All other ICV™ connections, including ventilation to the off-gas treatment system are already connected via the ICV™ hood.

Once the ICV™ container is positioned in the vitrification cell, the sludge/glass former mixture from the dryer is transferred into the ICV™ container. Top-off glass formers may be added to fill the inner cavity to a predetermined level, depending upon whether the container loading is limited by the cavity volume or sludge fissile loading. Electrical current is applied through the electrodes to initiate and continue melting the crucible contents. The melt proceeds from the bottom up through the sludge mixture until all of the crucible contents have been vitrified.

The target melt temperature is estimated to be 1150 to 1250 °C and is monitored using sacrificial thermocouples located in and adjacent to the melt zone. Melt temperature is controlled via adjustment of the power level applied to the electrodes. The target melt temperature is tailored to meet specific viscosity requirements, taking into account the chemical composition of the materials being processed.

Once the refractory crucible contents have been vitrified, the ICV™ container is allowed to cool, the ICV™ hood and electrodes disconnected, and the drum is moved to a drum-lidding station. The drum lid is installed and the drum surface surveyed and decontaminated as needed. Decontamination solutions are re-cycled back into a subsequent dryer/mixer batch. The decontaminated drum is loaded out and moved to a storage location similar to other technology alternatives.

Off-gas treatment from the ICV™ is tailored to the material being processed to ensure that gaseous emissions comply with applicable discharge regulations. While off-gas treatment systems can represent a significant cost for a process system, a detailed development of the ICV™ off-gas system has been

[3] Misch metal is a mixture of elemental lanthanides used to simulate uranium metal in simulant. Misch metal used in this test was 50 wt% Ce, 22 wt% La, 18 wt% Nd, 6 wt% Pr, and 4 wt% various rare earth metals.

deferred by this evaluation to focus on the primary sludge treatment process. It is projected that the off-gas treatment system will, as a minimum, be composed of a series of filtration steps, as shown on Figure F-2.

F3 Technology Development Status

F3.1 Process Chemistry and Phenomenology

F3.1.1 Summary of Testing Performed

F3.1.1.1 Test Definition Basis

The following describes the approach used to develop the Round 2 testing scope for the ICV™ technology.

F3.1.1.1.1 Preliminary Assessment of In-Container Vitrification Risks

A preliminary assessment of risks associated with each alternative sludge treatment technology was performed, including the ICV™ technology. The preliminary assessment generally judged that the proposed ICV™ sludge treatment process meets characteristics associated with a mature technology in that:

- The process behavior and phenomena are reasonably well understood and/or demonstrated,
- The equipment concept has been previously demonstrated at an engineering (or better scale), but not necessarily for the specific K Basin sludge slurry, and
- It appears reasonable that a system can be developed to satisfy safety, technology maturity, acceptance, and operability/maintainability requirements.

Risks to the ICV™ technology are associated with the potential impact of K Basin sludge components with limited, or no, analogous testing experience for the dryer or vitrification operation. The risks include:

- Potential for conductive waste components (e.g., graphoil) to result in melter failure or hot spots,
- Potential for organic material (e.g., ion exchange resin) concentration fluctuations to impact dryer and melter operation,
- Uncertainty in bulk dryer product density could drive operation to a feed while melt operating approach, increasing system design complexity,
- Off-gas treatment system unit operations (e.g., wet scrubbers vs. dry filtration) required to support K Basin sludge treatment, and
- Potential for graphite electrodes to reduce selected key elements (e.g., plutonium) to a metallic state in the waste melt.

The dryer operation was considered the system containing the most uncertainty within the current process experience base. The bulk of dryer operating experience has been obtained using a waste consisting of a concentrated salt solution, as compared to a waste consisting of multi-density solids dispersed in water that describes the K Basin sludge slurry.

F3.1.1.1.2 Supplemental Risk Evaluation by Vendor

The vendor performed an internal review of potential risks associated with application of the ICV™ process to K Basin sludge treatment (Impact, 2010a). This internal review recognized approximately 30 items potentially needing further evaluation, ranging from process refinement to remote operation issues to selection of key process components. However, recognizing that testing would be limited to consideration of "key issues" that demonstrate the feasibility of the technology approach and to avoid "designing a system" at this phase, the vendor review suggested the following combination of ICV™ related tests and evaluations to support the Round 2 down selection process.

1. Determine characteristics of sludge drying/mixing towards development of a preliminary Dryer Operating Envelope
2. Quantify any physical degradation of a plow-type dryer while drying sludge, especially caused by large (1/4") metal (uranium, etc.) fragments
3. Determine volatility of hazardous species during drying (e.g., Cs, Tc, PCBs, IX Resin compounds)
4. Determine efficiency and method of transporting dried waste from dryer into ICV™
5. Determine operability of the XAGO sludge pump to circulate sludge/water mixture in a receipt/holding tank (this concept was considered out of scope for the current activity)
6. Develop preliminary detailed flowsheet for GeoMelt®[4] System (including unit operations sizing, material balance, etc.)
7. Determine interaction of Pu with other sludge/glass former constituents (e.g., graphoil) during vitrification
8. Determine the maximum carbon (e.g., graphoil mass fraction) in the GeoMelt® ICV™

F3.1.1.1.3 In-Container Vitrification Testing Program for Round 2 Selection

The preliminary assessment (Section F3.1.1.1.1) and vendor risk evaluation (Section F3.1.1.1.20) were used as the basis for defining a test and evaluation work scope supporting Round 2 selection inputs for the ICV™ technology and summarized in **Table F-*1***. The approach used for work scope development was to focus primarily on risk items that could indicate that the ICV™ technology may not be suitable for application to K Basin sludge, or experience difficult implementation problems. The intent of work scope development for Round 2 was to focus on K Basin sludge material characteristics that differ from materials actually demonstrated in the ICV™ drying and vitrification experience base. An attempt was also made to differentiate between a technology issue and an equipment design issue throughout the work scope development for Round 2 testing, deferring equipment design issues to later phases in the design process.

Table F-1. Identified Risks Evaluated by the In-Container Vitrification Test Program

Task	Risk
1	Preliminary information did not include a systematic link of each sludge component to past drying and vitrification experience.
2	Drying experience does not include combination of organic and inorganic materials similar to K Basin sludge.
3	Erosion/abrasion may limit dryer equipment operating life
4	Plutonium may form separable metal phase in presence of electrodes
5	Vitrification using graphite electrodes may not be viable for some K Basin component compositions
6	The process flowsheet may require update based on the test experience
7a	Potential for dryer plugging if glass forming materials are omitted from feed due to operating error
7b	Potential for dryer performance to be different due to equipment scale up

[4] Geomelt is a registered trademark of Geomelt USA, LLC, 1650 Quebec Street, Knoxville, IA 50138; all rights reserved.

The Round 2 work scope development approach resulted in defining the seven tasks described below, which include a combination of testing and engineering studies.

1. Task 1 - Perform an evaluation of the experience base that exists for the drying and ICV™ unit operations process components found in K Basin sludge. This task was considered to be partially completed on an informal basis by the preliminary risk evaluation. The intent of Task 1 is to document a systematic comparison of each K Basin sludge component to drying and vitrification experience, linking each component to a specific test report and verify that the earlier assessments have identified the primary technology risks.

2. Task 2 - Conduct tests of the drying unit operation using K Basin sludge simulant that includes components which Impact Services has little, or no, experience of mixing with glass forming material while drying as a precursor to feeding material to the ICV™ unit operation. This task provides data to address selected risks associated with the dryer/mixer unit operation in the ICV™ process as applied to K Basin sludge treatment. Risks to be investigated are focused on potential changes in the physical properties of a sludge/glass former mixture that may influence distribution of solids within the dryer and impact the flow characteristics of dried solids between the dryer and vitrification unit operations. Bulk dried solid density measurements support updating material balance calculations and determine if a feed while melting vitrification configuration will be needed to achieve package loading during the ICV™ system operation. The primary risk investigated by testing is to fill the experience gap in drying operation for a feed material containing a combination of organic and inorganic materials similar to K Basin sludge. Sludge uranium materials have been omitted from the Round 2 tests, relying on simulant properties to approximate physical property changes that occur during drying. The Round 2 tests are intended to demonstrate basic process feasibility, not to define a complete dryer operating envelope.

3. Task 3 - Conduct a review of past experience with performing the drying unit operation using abrasive/erosive materials and identify potential design solutions that may be required to accommodate the K Basin sludge in drying equipment. This task was included in the work scope in lieu of performing tests to quantify dryer physical degradation. Instead of testing for Round 2, it is assumed that the K Basin sludge material will be an abrasive/erosive material and the technology remains viable as long as design solutions are available to address the risk.

4. Task 4 - Conduct an evaluation of the potential for plutonium compounds in K Basin sludge to be reduced to metal in the presence of carbon electrodes during the ICV™ unit operation. This task was included in the work scope to further investigate the risk identified by preliminary assessments.

5. Task 5 - Conduct a review of previous empirical data, as well as a chemical/physical evaluation of the vitrification process, to identify the bounding graphoil content of material entering the ICV™ unit operation where the process can no longer effectively vitrify the K Basin sludge. This task was included in the work scope to investigate the risk that the vitrification technology, using graphite electrodes, may not be viable for some K Basin component compositions.

6. Task 6 - Provide an updated process flow diagram and achievable container sludge loading estimates. This task was included in the work scope to produce revised estimates of the ICV™ material flows as a K Basin sludge treatment process using information accumulated from Tasks 1 through 5.

7. Task 7 - This task was added based on results from the Task 2 testing. The test objectives were to investigate the impact of drying sludge simulant without including the glass cullet used as glass

forming material, investigate potential drying issues that may occur as a result of scale-up (use a leased test dryer that approximates the production-scale dryer system), and investigate potential method for removing dryer hold up between sludge batches if segregation of sludge composition were required as part of the sludge treatment operation.

F3.1.1.1.4 Identified Risks Deferred to Later Testing

The work scope supporting the Round 2 down section process was intentionally limited to risks that were considered a basic characteristic of the ICV™ technology based on the concept that testing to acquire system design information would be deferred to later phases of the K Basin sludge treatment design process. Therefore, tests and evaluations to address some risks identified by preliminary assessments were deferred. This is not intended to imply that resolution of the identified risks are not considered important at some point in the future.

Evaluation of the following risks were deferred.

1. Sludge Component Volatility and Off-gas Treatment Design - The number of off-gas treatment system unit operations and impact on system cost is frequently under-estimated during the early phases of process design and can become a significant fraction of the system cost. However, off-gas systems to support the ICV™ operation are expected to be similar to off-gas systems that have been incorporated in other facility designs for the Hanford site. Therefore, the off-gas treatment design was not considered an area that would impact the viability of an ICV™ process supporting K Basin sludge treatment.

2. Uranium Metal/Compounds in Test Simulant - Approximately 21,500 lb of waste composed of 65% soil, 20% depleted uranium chips and turnings, and 5% steel drum fragments were processed by the vitrification unit operation as part of work performed on Rocky Flats waste in the vendor experience base (AMEC, 2005). Experience is not reported for the dryer unit operation with the presence of uranium metal in feed materials. It is anticipated that testing of dryer operation that includes uranium material in sludge simulant will be required at some point in development process. Investigation of the potential impact of uranium metal and uranium compounds on the dryer operation has been deferred as a material with relatively low probability of influencing solid mixture physical characteristics at the uranium concentration in average sludge. However, the potential impact of uranium metal/compounds on dryer operation will continue to be considered a risk at the conclusion of the Round 2 evaluation.

F3.1.1.2 Dryer Testing Simulant Selection

A physical simulant modeling the nominal composition of K West container sludge was selected for Round 2 tests investigating the dryer unit operation supporting Impact Service's proposed ICV™ sludge treatment technology from PRC-STP-00034. This simulant contains the primary non-radioactive chemical components identified in K Basin sludge, but replaces uranium metal pieces with tungsten metal pieces and uranium oxides with a combination of steel grit and cerium oxide. Inorganic sludge constituents in the simulant include $Al(OH)_3$, FeOOH, sand, aggregate, zeolite, and graphoil. Organic sludge constituents in the simulant include organic ion exchange resin and flocculent.

The primary objective of the Round 2 dryer testing is to demonstrate that a combination of inorganic and organic materials similar to K Basin sludge, blended with glass formers, can produce a product that:

1. Removes sufficient water for efficient vitrification of the dried material, and
2. Allows gravity transfer the dried solids between the dryer and vitrification unit operations.

The physical simulant was considered adequate for the Round 2 dryer testing objective, recognizing that the results will primarily be of a qualitative nature. Quantitative measurements obtained from the Round 2 testing (e.g., dried sludge/glass former mix bulk density and angle of repose) will be considered provisional information. Applicability of these data to design calculations must continue to be considered a risk until data are obtained using a simulant that is more representative of sludge chemical and physical properties.

Omission of uranium metal and uranium compounds from simulant used in Round 2 dryer testing was considered a compromise between the test equipment available and complete simulant composition accuracy and appropriate to demonstrate basic technology feasibility. The dryer tests were performed using equipment from an earlier project that approaches a 1/6th scale dryer for the K Basin sludge treatment application and a leased test dryer that approximates the production-scale equipment. The quantity of uranium required for a more complete simulant (and waste disposal costs) was not considered justified for these particular technology feasibility tests. Additional tests that include uranium in the simulant would be anticipated to be performed in the future if the ICV™ approach proves to be an attractive sludge treatment technology.

F3.1.1.3 Test Program Products

The ICV™ dryer test program was performed by Impact Services, Inc. personnel, producing a total of 22 submittals (including preliminary and draft versions) containing 14 final reports. Table F-2 provides a summary of the reports generated by the test program contract and an abstract of each final report as a guide to the content of each report.

Table F-2. In-Container Vitrification Test Program Products

Item	Submittal[(1)]	Topic	Abstract
1	1 (Draft) 2 (Final)	Dryer/ICV Experience Base Report (Impact, 2010b)	This report provides a description of the processing experience for the ICV™ dryer and vitrification unit operations derived from past work performed by Impact Services, Inc. Dryer test experience is limited. A systematic description of experience with vitrifying materials containing each of the identified K Basin sludge components is included.
2	3 (Draft) 4 (Final)	22-L Dryer Test Plan (Impact, 2010c)	This report provides the plan defining testing performed using a 22-L pilot-scale dryer with sludge simulant.
3	5 (Preliminary) 6 (Draft) 7 (Final)	22-L Dryer Test Report (Impact, 2010d/ Impact, 2010e)	This report provides a description of the 22-L pilot-scale dryer test results using sludge simulant. Four tests (two operability acceptance tests and two tests for data collection) are described, with residual dryer hold up removed after each test run. The report includes a description of the test equipment, test input materials, test observations, recommendations for future work, test data sheets, test procedure, and photographs obtained during performance of the tests.
4	8 (Draft) 9 (Final)	Dryer Erosion Report (Impact, 2010f)	This report provides a description of equipment design solutions that have been applied by the dryer vendor (LittleFord Day) to extend dryer operating life during processing abrasive/erosive materials.
5	10 (Draft) 11 (Final)	Plutonium Reduction Report (Impact, 2010g)	This report summarizes test experience from prior Impact Services, Inc. work and literature data that support the conclusion that it is unlikely to observe plutonium reduced as a separate phase during ICV™ operation using K Basin sludge as a feed material.
6	12 (Draft) 13 (Final)	Graphoil Report (Impact, 2010h)	This report summarizes test experience from prior Impact Services, Inc. work and literature data that support the conclusion that it is unlikely that the presence of Graphoil in K Basin sludge will impact the operation of the ICV™ process.
7	14 (Draft) 15 (Final)	Process Description Update (Impact, 2010i)	This report provides an update of the ICV™ process description as a K Basin sludge treatment technology incorporating 22-L dryer test data and includes a description of the primary process systems, estimates of the number of ICV™ containers produced during K Basin sludge processing for a range of assumed fissile material loading limits, and basis for production system cycle time estimates.
8	16	Quality Assurance Program and Implementing Procedures	This report describes the Impact Services, Inc. quality assurance program.
9	17	Auxiliary Equipment Documentation purchased as Government Furnished Equipment (Impact, 2010j)	This report describes and documents operating manuals purchased as government furnished equipment as part of the sludge drying test program that were returned at the conclusion of testing.
10	18	Test Plan for Simulant Only 22-L Dryer Test (Impact, 2010k)	This report provides the plan defining a single additional test drying sludge simulant without addition of glass forming materials.
11	19	Preliminary Test Result Summary for Simulant Only 22-L Dryer Test (Impact, 2010l)	This report provides a preliminary summary of the test observations and results obtained from the single 22-L dryer test where simulant was dried without addition of glass forming materials.
12	20	Test Plan for 130-L Dryer Test (Impact, 2010m)	This report provides the plan defining a series of tests drying sludge simulant in a 130-L dryer.
13	21	Preliminary Test Result Summary for 130-L Dryer Test (Impact, 2010n)	This report provides a preliminary summary of the test system description, observations and results obtained from the series of tests drying sludge simulant in a 130-L dryer.

Table F-2. In-Container Vitrification Test Program Products

Item	Submittal[1]	Topic	Abstract
14	22	Final Test Report for Added Dryer Tests (Simulant Only 22-L test and 130-L test) (Impact, 2010o)	This report provides a description of the final 22-L pilot-scale dryer test results and test results from operation of a 130-L production-scale dryer. All tests were performed using a K Basin sludge simulant. Results from a single test using the 22-L dryer without addition of glass formers are included. The 130-L dryer tests consist of processing a single dryer batch, followed by dryer hold up removal as an operability acceptance test. The primary 130-L test consists of preparing a sequence of four dryer batches without hold up removal between batches. The operating sequence concluded with processing three batches where only glass formers were fed to the dryer (no sludge addition), testing a potential method for removing the dryer hold up between sludge batches where component compositions may need to be segregated during production operations. The glass former, only, additions were followed be removal of residual dryer hold up. The report includes a description of the test equipment, test input materials, test observations, lessons learned, recommendations for future work, test data sheets and procedures, photographs taken during performance of the tests, and test equipment calibration certificates.

Notes:

1. Submittals defined by Contract No. 41991 - 004, "CONTRACT Proof of Concept Testing - IMPACT ICV Treatment of K Basin Sludge", CH2MHill Plateau Remediation Company, Richland, Washington, Dated November 15,2010.

Actual dryer test activities were performed under Tasks 2 and 7 described in Section F3.1.1.1.3. Table F-3 provides a summary of the results from the dryer tests.

Table F-3. Dryer Testing Results

Task	Result
2	1. 22-L Dryer Tests 2. Introduction of some glass forming materials (GFM) in a chemical form (e.g., calcium carbonate) can result in dryer caking and components should be introduced as a tailored glass frit 3. Dryer product discharged without significant bridging 4. Measured holdup represents ~15-20 wt % of total solids feed 5. Measured dried sludge/GFM bulk density ~1.4 to 1.45 kg/L for 50 wt % sludge/50 wt % GFM mixture 6. Measured dried sludge/GFM bulk density angle of repose ~28 to 37.5 ° (for a top of cylindrical pour, peak height ~0.25 to 0.4×diameter)
7a	1. 22-L Dryer Test 2. Dryer test performed with no GFM, decreased drying time 3. Measured hold up represents 30 wt % of total solids feed (about same volume based on density difference) 4. Measured dried sludge bulk density ~1.65 kg/L 5. Measured angle of repose ~30-35 ° 6. Vacuum system removed ~90 % of the dryer holdup at conclusion of test
7b	1. 130-L Dryer Test (~production-scale) 2. Primary tests performed drying simulant only, with GFM added to mix at end of dryer cycle, reduced dryer cycle from ~12 hr to ~8-9.5 hr (flowsheet goal less than 18 hr) 3. Dryer holdup ~20 wt % of total solids feed (but may be more concentrated in sludge components) 4. Tested GFM only addition at conclusion of testing as potential method of holdup cleanup between different sludge sources. Glass former, only, addition reduced sludge holdup, but indicates that ideal mixing between GFM and holdup is not obtained using this approach (not as effective as ideal calculation would predict)

F3.1.1.4 Summary Interpretation of Test Results

The completed test program was successful and met all test objectives. The testing demonstrated that the mixer/dryer can be operated to produce simulant materials with the appropriate residual moisture, mix the simulant materials with the necessary glass forming additives, and that simulant/glass forming mixture can flow by gravity from the miser/dryer to the ICV™ container. No basic technology characteristics that would prohibit considering the rotary mixer/dryer as part of the ICV™ system as a viable alternative for K Basin sludge treatment were identified in the current evaluation. The experience obtained with dryer operation by the test program completed as part of this study indicates that a granular dried sludge/glass former material is produced using sludge simulant that can be transferred by gravity between the dryer and ICV™ container without significant pluggage or binding observed in the dryer equipment.

Figure F-3 provides an example of the typical dryer product observed during the test program. Sufficient simulant material was processed through pilot-scale and production-scale dryer equipment to have produced 4 to 5 full-scale ICV™ containers. When combined with vitrification tests described in AMEC, 2003 (see Figure F-4 and Figure F-5), the major individual ICV™ unit operations have been tested with simulant on a production-scale.

Table F-4 provides a summary interpretation of the dryer test results based on the reports developed from the program completed for this evaluation.

Figure F-3. Simulated K Basin Sludge Dryer Test Product

Source: Obtained during 22-L Operational Acceptance Testing.

Figure F-4. Simulated K Basin Sludge Vitrification Testing

Source: Impact, 2010b.

Figure F-5. Engineering-Scale ICV™ Test Vitrified Product

Source: AMEC, 2003.

Table F-4. Summary Interpretation of In-Container Vitrification Test Program Results

Task[1]	Risk	Results Interpretation

1	Preliminary information did not include a systematic link of each sludge component to past drying and vitrification experience.	1. Vitrification
		  1. Uranium bearing (called radioactive) and non-radioactive sludge simulant treated in 2003
		  2. Simulant did not contain full range of potential sludge components
		  3. Evaluation indicates tests exist indicating each sludge component, or a similar analog, has been vitrified in past tests
		2. Drying
		  1. Expect success based on analogies (e.g., clay based surrogates), but no drying experience with drying materials containing uranium

2	Drying experience does not include combination of organic and inorganic materials similar to K-Basin sludge.	3. Pilot scale tests with simulant intended to represent physical properties, including organic and inorganic sludge components, were successful in producing a dried sludge/glass former mixture that appears suitable for gravity transfers between the dryer and vitrification container as intended in the current process flowsheet.
3	Erosion/abrasion may limit dryer equipment operating life	1. Significant experience exists to control mitigate dryer wear when processing abrasive materials 2. Common abrasion at plow blade leading edge 3. Edge treatment produced operating life of ~3-5 yrs drying solvent from slurries of tungsten carbide 4. Edge treatment produced operating life of ~5-10 yrs in mixing grout materials with cement and other materials 5. Appears that design solutions will be available to provide a suitable dryer operating life
4	Plutonium may form separable metal phase in presence of electrodes	1. Based on free energy, Pu unlikely to be reduced in presence of sufficient oxidants, like Fe_2O_3 2. If insufficient oxidant, carbide more likely to form in the presence of carbon electrodes 3. Literature data indicate Pu oxide solubility is 2 to 5 wt % in glass matrices 4. Testing at Maralinga (Australia) indicated that Pu starting as a distribution on a small metal plate was distributed by convection currents throughout a melt 5. Current information indicates that Pu is unlikely to form a separate metal phase during the vitrification process
5	Vitrification using graphite electrodes may not be viable for some K-Basin component compositions	1. Essential no test experience with graphoil, but experience with graphite in form of starter path indicates material graphoil will be pyrolyzed or oxidized 2. Test data support vitrification of material containing up 34 wt % organics 3. Alternative materials available for electrodes (e.g., Mo) if necessary
6	The process flowsheet may require update based on the test experience	4. Updated process description based on dryer test data (no significant change) 5. Updated canister count to include canister counts if loading limited to 20, 40, or 70 FGE by conservatism in dose to Ci conversion.
7a	Potential for dryer plugging if glass forming materials are omitted from feed due to operating error	6. Pilot scale tests indicated that drying times were reduced by omission of the glass forming materials with no significant impact on the ability to discharge dried sludge from the dryer. 7. Interpreted as indicating dryer operation can consider adding glass formers at end of drying cycle
7b	Potential for dryer performance to be different due to equipment scale up	8. No significant difference in dryer performance observed between the test scales using the physical simulant. 9. Current information indicates that the production scale dryer will be successful in producing a dried sludge/glass former mixture that appears suitable for gravity transfers between the dryer and vitrification container as intended in the current process flowsheet.

Note:
1. See Section F3.1.1.1.30 for description of original tasks.

F3.1.2 Technical Issues and Unknowns Related to Chemical and Physical Behavior

The test program completed for this evaluation was not intended to resolve all potential technical issues that may be associated with implementation of the ICV™ technology. Potential issues and unknowns that would likely need to be addressed by future activities include:

1. Uranium metal reactions during drying - The dryer unit operation creates conditions expected to accelerate uranium metal oxidation reaction rates. The process does not rely on complete oxidation to produce a product suitable for transport to WIPP. However, the oxidation reactions represent a potential hydrogen generation source that influences the design of off-gas treatment systems to control flammable gas concentration. This issue will likely influence the process off-gas flow rate and size of off-gas equipment.

2. Volatility of radionuclides during drying and vitrification - The relatively high dryer and vitrification system operating temperatures have the potential to transmit some semi-volatile radionuclides (e.g., ^{137}Cs) to the vapor phase. These semi-volatiles can increase the dose in portions of the off-gas treatment system by plating out on off-gas system internal surfaces. Knowledge of the potential for semi-volatile radionuclide transmission to the off-gas is used to determine plant areas that must be designed with shielding to mitigate higher dose fields.

3. Sludge composition variability - Both dryer and vitrification unit operations have been tested at essentially production scales using a single simulant composition. The impact of sludge composition variations on unit operation performance is considered an unknown that will need to be addressed by future testing.

F3.2 Technical Issues and Risks Related to Equipment and Process Description

The following summarizes technical issues and risks expected to be investigated in the future if the ICV™ technology were selected for further evaluation.

1. Remote operated/maintenance designs, and the potential impact on facility sizing, need to be developed and demonstrated for the ICV™ process equipment.

2. A risk exists that the current system production rate is over-estimated due to potentially under-estimating the cooling cycle time required after performing vitrification in an ICV™ container. This risk can be mitigated by developing temperature criteria for the ICV™ container defining how long a package must be cooled prior to disconnecting the ICV™ hood and allowing the package to be moved from the process cell.

3. Temperature or thermal gradient limits potential to distort ICV™ container dimensions making the container difficult to load in a transport container. This risk would be mitigated by performing thermal analyses of the ICV™ container and may require modification of the crucible dimensions (reduced crucible dimensions could impact the process rate of the system).

4. Transfer of a slurry from a large vessel, in controlled batch sizes, to a small vessel (as required between the sludge feed tank and batch/assay tank used for introducing sludge into the dryer) can become a design issue. Transfer velocities in piping must be sufficient to avoid plugging transfer lines and transfer via a side stream from a circulation loop has been proposed as a design in some similar systems. Risks associated with the selected slurry transfer system will likely require mitigation by demonstration testing of the design ultimately proposed for the ICV™ system.

5. Assay systems are proposed to support controlling the FGE content of each ICV™ container. Specific assay systems have not yet been identified to support the process system and are likely to require demonstration once selected.

F3.3 Technology and Process Development Needs

F3.3.1 Critical Near Term Development Activities

The primary ICV™ unit operations have been tested using simulant in the equivalent of production scale equipment. Therefore, no critical near term development activities are considered necessary from the perspective of demonstrating the basic feasibility of the ICV™ technology using materials similar to K Basin sludge. Testing only on simulant to date is currently viewed as the weakest point in the data available. If selected for further investigation, a near term test program of the drying and vitrification unit operations using actual sludge samples should be considered. Due to the activity of actual sludge samples, this program would need to be performed at a laboratory scale.

Dryer testing performed for this study used simulant as a substitute for uranium compounds. At some point in the development process, pilot or production scale dryer testing using simulant containing depleted uranium compounds should be performed to verify that the physical properties of dried sludge are not significantly modified by uranium. Uranium metal in the dryer feed should be expected to partially oxidize in the dryer, which could change the properties of the dried sludge/glass former mixture. Partial uranium oxidation reactions also have the potential to generate hydrogen, which may influence design of the process off-gas system.

A thermal analysis of the ICV™ container during vitrification was considered an important near-term development activity to confirm the selected crucible size and package configuration provides adequate insulation to control temperatures and thermal gradients experience by the exterior drum. The thermal analysis could also be used to confirm that adequate cooling time has been incorporated in the process cycle time. Each of these thermal considerations potentially influence the predicted process rate provided by a single process line.

F3.3.2 Longer Term Development Needs

Additional testing identified to date is summarized below:

1. Available production scale vitrification tests were performed using Hanford sand as the glass former, while dryer tests were performed using glass frit as the glass former. A decision as to the glass forming material needs to be fixed and tests performed integrating the dryer slurry feed system, dryer and vitrification unit operations.

2. Tests performed to date represent single point compositions for the sludge feed. In actual practice, the ICV™ process must address a range of sludge feed component compositions. Testing should be performed to investigate the operation of unit operations over a range of sludge compositions and operating conditions to establish operating envelopes for the unit operations.

3. While neglected as part of the basic feasibility studies, test data will be required to support the design of off-gas systems. Tests will be needed to determine sludge component volatility at the dryer and vitrification operating conditions to complete the ICV™ off-gas system design. For example, the pathway of cesium and the effectiveness of the sintered metal filters in the ICV™ melter off-gas system should be demonstrated, or it might be possible that the condensate might require cesium removal prior to treatment at the Effluent Treatment Facility.

4. The current process flow diagram identifies three assay points in the ICV™ process: the Dryer Batch/Assay feed tank, dried sludge/glass former feed to the ICV™ container, and the completed ICV™ package. While all three of these assay points may not be required for the final ICV™ system design, development of the assay equipment system that addresses potential non-uniformity in the vitrified product, is needed to support the system design.

F3.4 Hazard Considerations

A hazards consideration was completed for the ICV™ process in order to provide input to the cost, schedule, and risk considerations for the continued alternatives selection process. This hazards consideration was completed by a team of representatives from Engineering, Industrial Safety, Fire Protection, RadCon, and Operations [24].

A list of the activities constituting the FROP alternative was compiled. Hazards (or nodes) associated with each were then identified along with potential engineered and administrative controls. Table F-5 below summarizes the results of the hazards considerations for the ICV™ process.

Table F-5. ICV™ Hazard Consideration

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01 – MOBILIZE, RETRIEVE, TRANSFER STORE AND AGITATE						
RET.01.01	Internal Explosion	Sludge contamination	H^2 accumulation and ignition in STSC headspace	Purge system Ventilation system	Equipment surveillance	—
RET.01.02	Spray Leak	Sludge	Crack leak of slurry being removed from STSC and transferred to receiver vessel	Double contained transfer line.	—	—
RET.01.03	Splash / Splatter	Sludge	Leak of slurry being transferred from the STSC to the receiver vessel	Double contained transfer line Tank High Level Alarm and pump interlock	—	—
RET.01.04	Loss of Confineme nt	Sludge Contamination	Plugged vent path causes an unfiltered release from tank	Pressure transmitter to monitor the tank	—	—
RET.01.05	Internal Explosion	Sludge Contamination	H_2 accumulates in the receiver tank headspace and lines, resulting in a deflagration of the tank headspace or lines	Inerting or Alternate purge path.	—	—
RET.01.06	Direct Rad	Cs-137 release to water during storage or sludge in line or in STSC	Backflow of sludge through a line above the STSC, or exposure to storage water high in Cs-137 or sludge in STSC due to liquid draw down	Interface system design (check valves and system pressure), remote STSC unloading	Transfer access control	—

Table F-5. ICV™ Hazard Consideration

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
RET.01.07	Load Drop	Sludge contamination	Dropping equipment onto the STSC during removal of cask head or installation of transfer system resulting in a leak	—	*Hanford Site Hoisting and Rigging Manual*	—
JHV.01 – JOULE HEATED IN-CONTAINER VITRIFICATION						
JHV.01.01	Direct Rad	Sludge in line or container	Container and piping shine	Vitrification station shielding	Radiological Control Program access controls	—
JHV.01.02	Internal Explosion	Sludge	Inadequately dried material joule heated and explodes due to steam production	Drying process design, inerting system, off gas system design	—	—
JHV.01.03	Melt through	Sludge contamination	Melt goes through container, spread of contamination	Melt container design, remote processing / maintenance	Radiological Control Program access controls	—
JHV.01.04	Off gas Contaminat ion	Sludge or released fission products	Fission products are mobilized by melt temperatures or reaction of sludge constituents	Off gas control system	Analysis and loading approach demonstrates loaded sludge safety	—
DRY.01 – STAGE SLURRY, MIX SLURRY WITH GLASS FORMERS AND VACUUM/HEAT DRY						
DRY.01.01	Splash / Splatter	Sludge	Release of respirable sludge from line or fitting or staging vessel failure	Vessel and piping design, secondary confinement	—	—
DRY.01.02	Spray Leak	Sludge	Release of respirable sludge from line or fitting failure during pressure transfer	Confinement design	—	—
DRY.01.03	Internal Explosion	Sludge Contamination	Hydrogen accumulation and burn in staging vessel or dryer with entrainment of sludge contamination	Vent / purge design and Vacuum design	—	**Note**: Hydrogen quantities are generally small for batches except for a high metal sludge such as safety basis settler, low pressure, low temperature

Table F-5. ICV™ Hazard Consideration

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
DRY.01.04	Spill Dry ingredients	Sludge	Heated and dried ingredients are leaked / spilled from dryer or transfer piping	Vessel design, secondary confinement, transfer mechanism	—	—
DRY.01.05	Overpressure	Sludge Contamination	Ventilation failure and pressurization due to hydrogen production	Ventilation design, temperature	Recovery procedures	—
DRY.01.06	Steam agitation/ejection of slurry	Slurry feed to dryer mixer	Steam leak into dryer/mixer agitates and volatilizes slurry into off gas	Steam Jacket design, off gas system design	—	Low mass of sludge in dryer
DRY.01.07	NPH	Sludge	Seismic, wind missile or structure failure results in spill and spread of rad material	Facility design	—	Low mass of sludge in dryer
DRY.01.08	Facility Fire, spill	Sludge	Facility fire results in failure of confinement vessel and release of rad material	Materials of construction, Fire Protection System	Combustibles limits	Low mass of sludge in dryer
STG.01 – SHIELDED STORAGE OF TREATED DRUMS						
STG.01.01	Load Drop	Sludge	Container drop resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.02	Load Drop	Sludge	Load dropped onto container resulting in a release of rad material	Handling system design, confinement design	Hoisting and rigging controls, DOE-RL-92-36	Minor release from stabilized material
STG.01.03	Seismic Event	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material
STG.01.04	Other NPH	Sludge Contamination	Drum drop or fall, missile impact or structure failure results in spread of rad contamination	Facility design	—	Minor release from stabilized material

Table F-5. ICV™ Hazard Consideration

Node	Accident Type	MAR	Hazard	Potential Controls		Remarks/Assumptions
				Engineered	Administrative	
STG.01.05	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
STG.01.06	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Facility design, Fire Protection Design	—	—
LSC.01 – LOAD SHIPPING CONTAINER. REMOVE FROM ISC, LOAD 72-B LINER, LOAD CASK						
LSC.01.01	Direct Rad	Sludge in packages	Direct rad exposure to drum	Facility design	Radiological Control Program access controls	—
LSC.01.02	Load Drop	Sludge contamination	Impact fails package and damages grout	Contamination control ventilation	Hoisting and rigging controls, DOE-RL-92-36	—
LSC.01.03	Facility Fire	Sludge contamination	Fire results in SSC failure and impact of packages, spread of contamination	Fire Protection System	—	—
LSC.01.04	Seismic Event	Contamination	SSC failure results in package impact and spread of rad material	Facility design	—	—
LSC.01.05	Other NPH	Contamination	Missile or structure failure results in package impact and spread of rad material	Facility design	—	—

DOE-RL-92-36, 2007, *Hanford Site Hoisting and Rigging Manual,* Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

FW = facility worker.
HC-2 = Hazard Category 2 (facility).
HEPA = high-efficiency particulate air (filter).
HVAC = heating, ventilation, and air conditioning.
ISC = interim storage container.
LFL = lower flammability limit.
MAR = material at risk.
NPH = natural phenomenon hazard.
SSC = structure, system, and component.

F3.5 Additional Considerations

Additional items identified as part of the review that may be considered in evaluating this alternative are summarized below.

1. Available dryer testing was performed using equipment available from prior projects or leased existing equipment. Optimization of the dryer plow design could result in a significant reduction in the dried sludge hold up in this equipment. Reduced dryer hold up was considered desirable if segregation of components from different sludge batches becomes a project requirement. In addition, optimization of the dryer design could significantly reduce the particulate load imposed on the dryer filter.

2. The ICV™ process vendor suggested the possibility of using the STSC as the process feed vessel, rather than installing a separate feed vessel. This suggestion was considered a potential optimization approach that could reduce the cost of the ICV™ system by the elimination of feed receipt vessel(s).

3. If selected for further development, interactions with WIPP personnel needs to be pursued to ensure proper interpretation of the waste acceptance criteria for receipt of ICV™ containers at WIPP. For example, current waste acceptance criteria impose lower fissile content constraints on packages containing graphite (typical ICV™ electrodes are composed of graphite). While molybdenum electrodes can be used as an alternative to graphite to mitigate this particular issue, similar waste acceptance issues need to be identified for resolution as the ICV™ design is developed.

F4 Process Design and Performance Estimates

F4.1 Process Flowsheet Estimates

Process flowsheet estimates were provided by the vendor estimating the number of drums produced from different sludge sources (KE, KW, or settler sludge) based on alternative constraints (volume or FGE drum limits). An independent estimate of material balances associated with production of a single ICV™ drum produced similar results and are described by Table F- based on use of a 55-gallon drum as the primary container. The estimates indicate that a total drum mass is produced when the crucible volume limits the sludge loading of an individual drum at ~400 kg (~880 lb). The drum mass is reduced when sludge loading is limited to 40 FGE.

Table F-6. Preliminary Characteristics of Alternative Drum Loadings.

Case Description	KE Sludge at Volume Limit	KE Sludge at 40 FGE Limit	KW Sludge at 40 FGE Limit	Settler Sludge at 40 FGE Limit
Consumables(1,2)				
Glass Frit, kg	61.6	37.8	22.9	10.3
Flake Graphite, kg	0.8	0.8	0.8	0.8
Refractory Silica Sand, kg	153.8	153.8	153.8	153.8
Electrode Graphite, kg(3)	14.2	14.2	14.2	14.2
Backfill Sand, kg	93.1	125.3	145.6	162.5
Drum, crucible, and thermocouples	1 set per drum			
Electricity, kW-hr(4)	400			
Product Drum(1,2)				
Total Mass (excluding drum), kg	377.5	364.5	356.3	349.4
Sludge Solid, kg	60.8	37.0	22.1	9.5
Glass, kg	61.6	37.8	22.9	10.3
Silica Sand, kg	153.8	153.8	153.8	153.8
Backfill Sand, kg	93.1	125.3	145.6	162.5
Residual Electrode Graphite, kg(3)	8.2	10.5	12.0	13.3
FGE	65.7	40.0	40.0	40.0
Liquid Effluent(1,2)				
Water, kg	366.9	223.4	133.0	57.5

Notes:
1. Consumables, product drum and liquid effluent masses based on production of a single ICV™ container from the indicated sludge source.
2. Masses based on 55-gal (218 L) outer drum with 24 gal (91 L) crucible to contain dried sludge/glass former mixture at start of melt step. Glass former addition adjusted to produce ~50 wt % sludge loading in glass for each case considered.
3. Electrode graphite based on 4 electrodes per container, 2 inch (5 cm) diameter from AMEC, 2003 with an assumed length of 30 inch (77 cm). Residual graphite based on depth of glass formed in each case considered.
4. Approximation of power to produce melt during test from AMEC, 2003. Used as bound, independent of glass quantity produced by a particular material balance.

F4.2 Major Process Equipment

Table F- provides a summary of sizing the major process equipment pieces to support preparation of a preliminary facility layout. Equipment sizing is primarily based on input described in Impact, 2010i.

Table F-7. Major Process Equipment Summary

Description	Working Volume, m^3 (gal)	Gross Volume, m^3 (gal)	Comments
Receiver Tank	16 (4200)	20 (5300)	Minimum working volume based on receipt of 3500 gal from a STSC, plus 500 gal allowance to maintain minimum working volume between transfers. Adopted similar size from calculations for other alternatives.
Dryer Batch/Assay Tank	0.06 to 0.6 (15 to 150)	0.08 to 0.8 (20 to 200)	Working volume based on sludge addition at 5 vol% sludge solids. Sizing depends on control philosophy selected. Sludge additions to dryer performed as a sequence of ten (10) 15-gal additions. May be preferred to size Batch/Assay Tank to contain all ten additions for a dryer batch to minimize assay requirements, or limit tank volume to a single addition volume to provide improved control of dryer liquid inventory. Gross volume based on maximum of 80% full.
Dryer Batch Glass Former Addition Bin	0.13 (34)	0.16 (61)	Working volume based on providing up to full capacity of dryer/mixer to fill cavity when processing sludge limited by FGE content. Gross volume based on maximum of 80% full.
Dryer/Mixer - steam heated with condenser, liquid ring sealed vacuum pump, and liquid heat exchanger	0.091 (24)	0.13 (34)	130-Liter dryer/mixer and supporting equipment. Sized to support filling 91-Liter cavity with dried sludge/glass former mix (cavity volume projected for a 55-gal drum ICV™ container). Dryer vendor recommends operating at a maximum of 70% of dryer/mixer capacity. Test data indicate that water boil off rate from sludge simulant will not constrain vitrification time cycle.
Condensate Collection Tank A with Tank Truck Load out System/berms	15 (4000)	19 (5000)	Working volume actually depends on condensate transfer frequency selected as design basis. Working volume consistent with receipt tank volume selected for this study (no significant water additions are shown in the current process basis, neglecting transfer system flush volumes). Provides one tank for accumulation while second tank is being sampled and emptied to transport vehicle.
Condensate Collection Tank B with Tank Truck Load out System/berms	15 (4000)	19 (5000)	
ICV™ Container Assembly Cell (Non-Rad Area)	NA	NA	Process Area for assembling ICV™ Container components. See Figure F-8 for allowance.
ICV™ Cell with Drum Lid fixture for attaching Dryer Discharge Chute, Off-gas System, and Electrode Connections	NA	NA	Process Area containing a single drum at one time. See Figure F-8 for allowance.
Off-gas Treatment System - filtration, off-gas blowers, and stack	NA	NA	Off-gas system not sized. See Figure F-8for allowance.
Drum Lidding, Assay, and Decontamination Station	NA	NA	Process Area, see Figure F-8 for allowance.
Drum Handling and Storage System	NA	NA	Common to all alternatives
Bulk Material Storage	NA	NA	Solid process input material storage. Store drums, electrodes, refractory crucibles, refractory sand, starter mix, and glass cullet. See Figure F-8 for allowance

F4.3 Estimated Processing Duration for Treating all K Basins Sludge

Estimated processing duration for the K Basin sludge depends on the total number of drums projected to be produced and the estimated single drum production cycle time. Assuming drum loading is limited to 40 FGE to provide conservatism in the assay method, a total of 1513 ICV™ containers is estimated to be produced over the sludge processing mission (Table 1 of Impact, 2010i). Dryer sizing is based on making the ICV™ container production the cycle time limiting step in the overall process. Estimates of time to complete the individual ICV™ container production steps are presented in Table 2 of Impact, 2010i and are summarized as follows.

1. ICV™ Container Assembly - 3 hr
2. ICV™ treatment melt and cool - 18 hr (time cycle critical path)
3. Drum Lidding and Decontamination - 1.25 hr
4. Drum Load out - 1 hr

The ICV™ treatment melt and cool activities are performed in parallel with container assembly, decontamination, and load out activities such that the melt and cool steps represent the critical path in the process time cycle. Therefore, the process rate is estimated based on an 18 hr cycle for each ICV™ container. Assuming a 70% operating efficiency, the processing rate becomes 0.93 ICV™ containers/calendar day (1 container/18 hr × 24 hr/operating day × 0.7 operating day/calendar day). The overall processing duration is estimated at 1627 calendar days (1525 ICV™ containers/0.93 ICV™ containers/calendar day), or ~4.5 yr for a single ICV™ production line. This processing duration could be reduced by a factor of 2 by installing a second parallel dryer and ICV™ melt station, if desired.

The critical path cycle time limiting the ICV™ production rates, estimated in Impact, 2010i, is dominated by the melt time (12 hr) and time allowed for partial container cooling prior to disconnecting the ICV™ hood and electrodes (3 hr). The ICV™ container test reported in AMEC, 2003 indicates that the entire container treatment zone was molten after ~8 hrs and 12 hr, used in the Impact, 2010i cycle time estimate as the melt time, is consistent with this test experience. However, the cycle time selected for partial container cooling incorporated in the Impact, 2010i cycle time estimate appears to be somewhat subjective since criteria are not defined that identify a temperature that must be obtained prior to disconnecting the ICV™ hood. For the engineering scale test described in AMEC, 2003, the melt was allowed to cool for 12 hr prior to removal from the ICV™ container for visual inspection. The melt block temperature was ~317 °C at the beginning of the visual inspection. Since there are no temperature criteria currently proposed for removal of the ICV™ hood, there is uncertainty in the time cycle estimate for the cooling period, which may influence production rate estimates in the future.

F4.4 Facility and Equipment Requirements

A preliminary facility layout of the ICV™ sludge processing system was developed to support comparison of alternative sludge treatment technologies. For layout purposes, it has been assumed that the ICV™ process will require a remote operated, remote maintained operating philosophy during processing of K Basin sludge. Process enclosures for remote operated equipment are projected to be modest. Dryer testing for this study included systems similar to the production-scale equipment (130-L dryer). Figure F-6 provides photographs of the 130-L test dryer and condensate system to describe the size of equipment required to prepare the dried sludge/glass former mixture to the ICV™ container. Figure F-7 provides similar photographs for the same test stand with 22-L dry equipment that include test personnel as a perspective of the 130-L system equipment size.

The ICV™ container (55-gal drum) represents the primary process vessel in the vitrification systems. Therefore, process cells sized to enclose a drum were used to characterize the size of cells where vitrification equipment is installed.

Figure F-8 provides the preliminary layout of the ICV™ facility structure assuming a single process line. Figure F-9 provides a simple elevation view of the layout. The layout focused on cell sizes required to enclose the process equipment and may need to be expanded by considering space to support equipment maintenance activities. Area allocations were included for systems, such as the off-gas treatment system, that were not sized as part of this evaluation. In addition, drum handling and storage systems are assumed to be similar for all technologies and identified, but not sized, on Figure F-8.

The simple ICV™ facility layout was compared to the more fully developed layout prepared for the Warm Water Oxidation alternative in AREVA, 2011 shown in Figure F-10. AREVA, 2011 indicates that the purpose built Warm Water Oxidation alternative layout shown in Figure F-10 is essentially composed of three regions that are approximately 18 ft × 48 ft, two stories high, combined with a single region, one story high. A comparison of functions in Figure F-8 and Figure F-10 indicates that approximately 1 1/2 two story regions of the two story Warm Water Oxidation Regions in the layout are available for re-arrangement to locate the following ICV™ systems:

1. ICV™ Assembly and Drum Load In
2. Dryer System
3. ICV™ Treatment
4. Drum Decontamination/Assay, and
5. Cell Operating Galleries.

Figure F-8 indicates that these functions are estimated to be supported by a two story process region of approximately 800 ft^2 ($16 \times 10 + 16 \times 40$). Remaining regions shown on Figure F-8 were considered common to regions existing on, or required for, the Warm Water Oxidation layout. Based on Figure F-10, approximately 1300 ft^2 ($1.5 \times 18 \times 48$) of two story process region are available in the Warm Water Oxidation layout for re-arrangement two support location of ICV™ systems. Therefore, the Warm Water Oxidation structure evaluation was considered a bound for the structure required to support implementation of the ICV™ alternative.

Figure F-6. 130-Liter (Production Scale) Dryer and Condensate System.

Source: Impact, 2010o.

Figure F-7. 22-Liter Dryer Mixer (Pilot Scale) Dryer and Condensate System.

Source: Impact, 2010o.

Figure F-8. In-Container Vitrification System Preliminary Layout

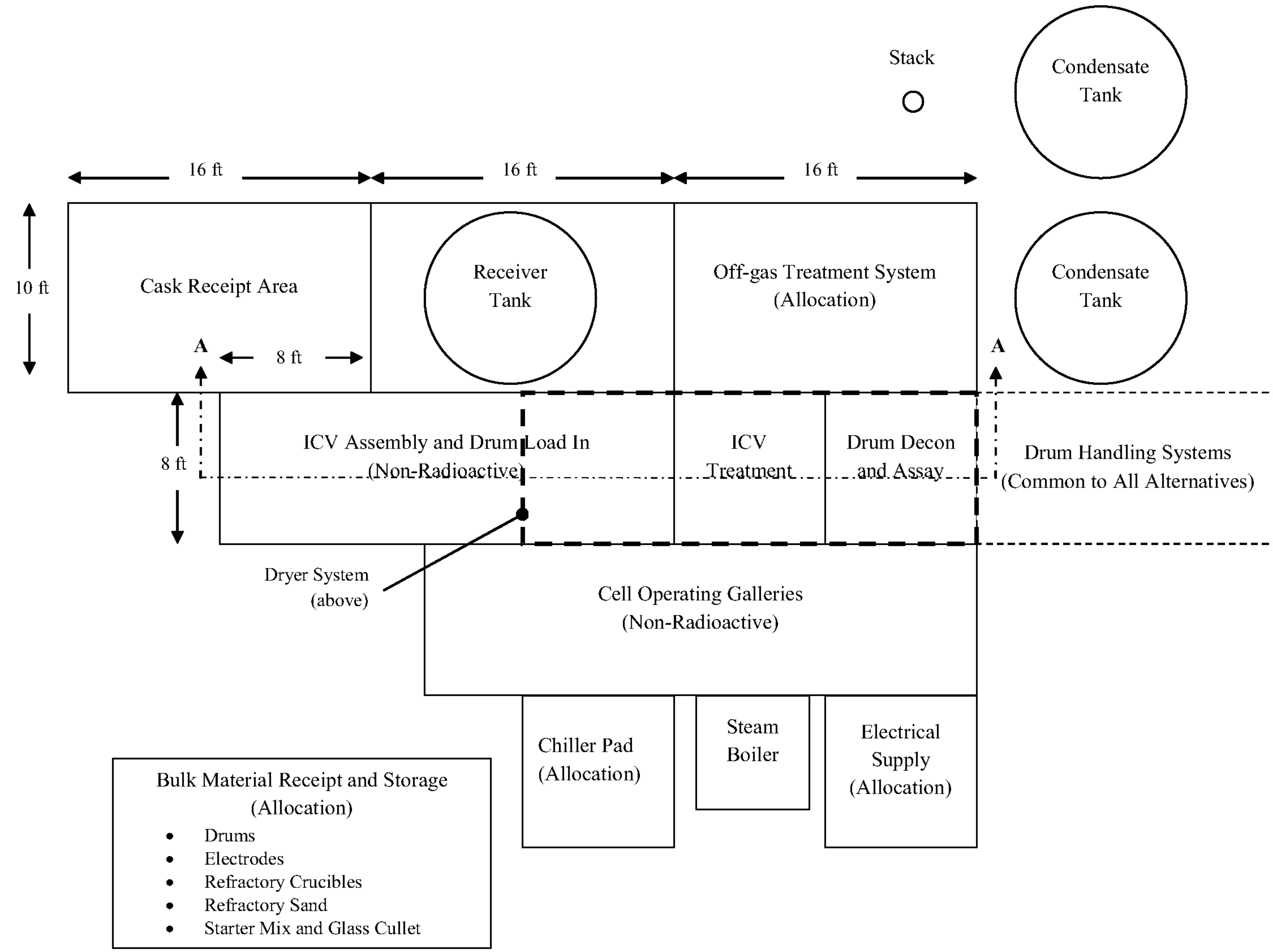


Figure F-9. In-Container Vitrification Preliminary Elevation A-A.

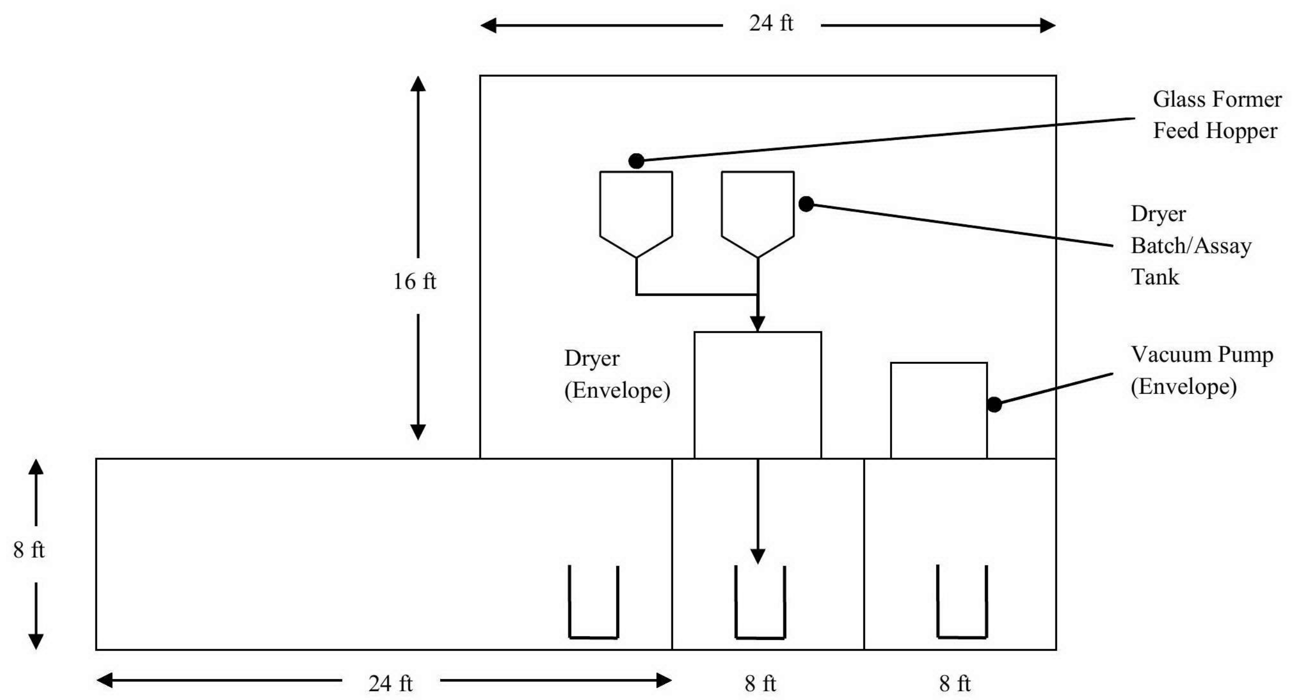
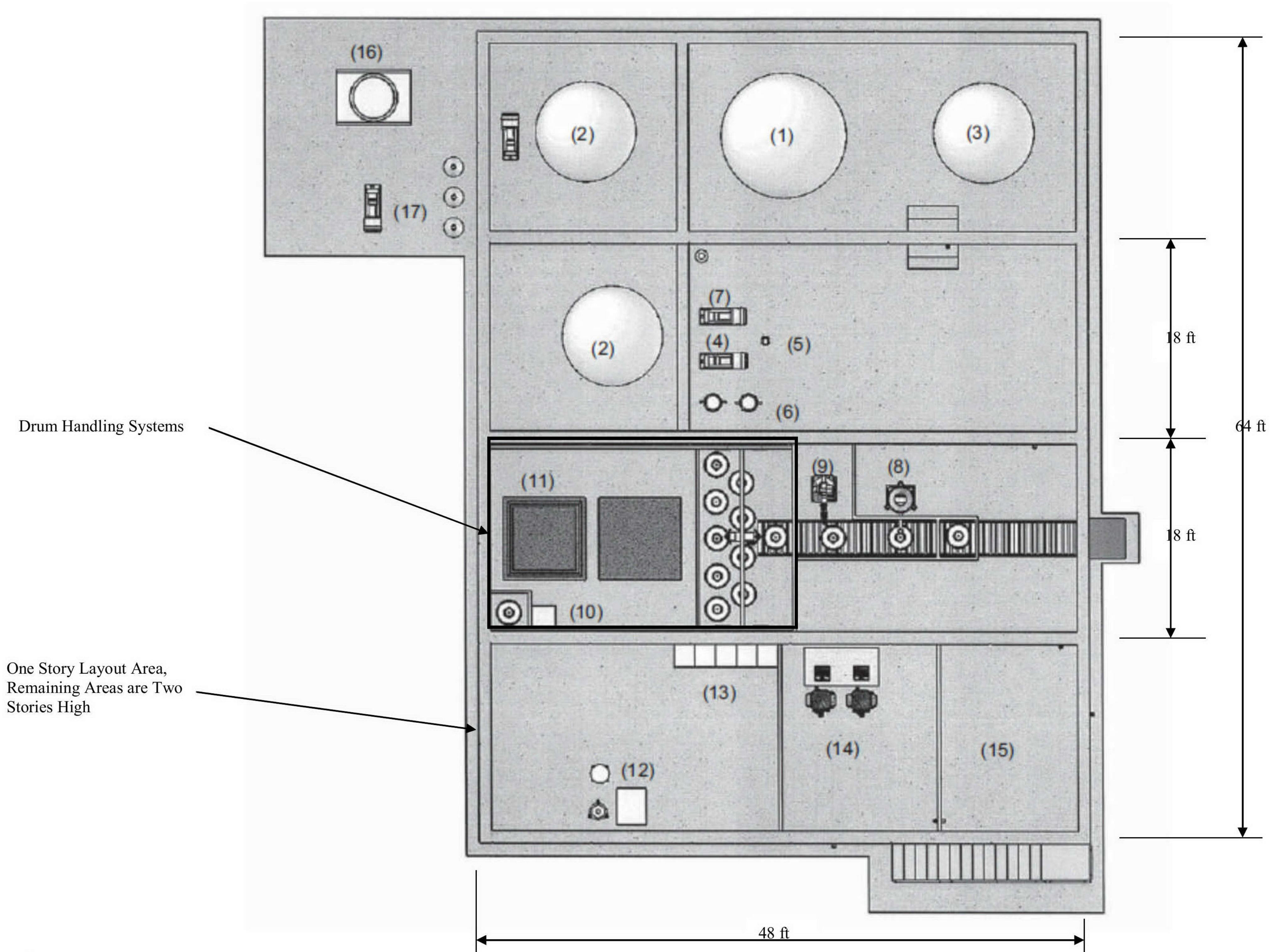


Figure F-10. Preliminary Purpose Built Facility Layout for the Warm Water Oxidation Sludge Treatment Alternative.



Source: AREVA, 2011, Attachment 2.

F5 Summary Cost and Schedule Estimates

See Appendix O.

F6 Characteristics of the Alternative Relative to Evaluation Criteria

The project scope and requirements assume that any alternative must be capable of receiving full STSC batches of K basin sludge and processing them to meet criteria for shipment to WIPP. As such, all alternatives will need certain minimum capabilities and will present minimum safety (public and worker) and environmental risks, and minimum costs and technical requirements. This section notes characteristics, advantages, and disadvantages of the ICV™ alternative that may differentiate it relative to other alternatives under consideration and allocates those to the various decision criteria.

F6.1.1.1 Potential Advantages of ICV™ Technology

1. Large vessels for lag storage limited to the receipt vessel for accepting transfers from an STSC and vessels for accumulating condensate for sampling and transfer to the Effluent Treatment Facility. Remaining processing performed on a single container batch basis, such that the need for large lag storage vessels as approaching the minimum possible for the ICV™ technology.

2. The relatively small size of the production scale dryer/vitrification system could be considered more amenable to installation of parallel processing lines (depending on the size of off-gas treatment systems). Parallel processing lines may be considered attractive, not only as a means of reducing the overall production time, but reduces the potential for a single point failure suspending all production activities.

3. Actual treatment processing (after lag storage of the incoming material from an SCTC) is performed one container at a time. This approach limits the material at risk in active treatment unit operations (i.e., drying and vitrification) to the inventory equivalent to a single container which is the minimum possible for a process system.

4. The primary treatment unit operations (drying and vitrification) are considered demonstrated at the production scale using simulants.

5. Thermal processes have been established as BACT for a wide variety of waste constituents, which may have application to materials beyond the K Basin sludge inventory.

F6.1.1.2 Potential Disadvantages and Risks of the ICV™ Technology

1. The vitrification system operates at a relatively high temperature (~1300 °C). While nominal operation of the system is at atmospheric pressure, the presence of a relatively high, concentrated thermal mass in the process could produce significant energies (e.g., pressures) for mobilizing the material at risk during hypothetical accident scenarios.

2. While not the intent of the ICV™ alternative, the vitrified sludge might be viewed as a high integrity waste form. WIPP may have an issue with could have a concern with accepting material viewed as a high integrity waste form.

3. It may be difficult to extrapolate laboratory scale testing to a production scale system. Therefore, while production scale equipment is relatively small, future testing may be more expensive than alternatives that are amenable to direct scaling from laboratory or pilot scale testing.

4. Risks currently exist that may influence the projected processing rate of a single process line (e.g., thermal considerations discussed in Section F3.2). Mitigation of these risks may result in requiring a second process line, increasing projected capital costs)

Table F- provides a preliminary listing of the ICV™ process characteristics relative to evaluation criteria.

Table F-8. In-Container Vitrification Evaluation Criteria Characteristics.

Decision Criteria from Decision Plan			Advantages and Disadvantages of Technology Related to Decision Criteria
Criteria	**Goals**	**Measures**	
Safety.	Ensure worker safety.	Relative ease/difficulty in implementing adequate Ensure protection of the nuclear safety measures as measured **by** the general public Number of passive (inherently safe) vs. active engineered safety features	**<u>Advantages</u>** Small radionuclide inventory in process equipment other than the primary receipt vessel. No significant safety hazards have been identified beyond those typical of all processes that handle (move, mix, pump, and package) bulk quantities of the highly radioactive K Basin sludge slurries [24]. **<u>Disadvantages</u>** High temperature (~1300 °C) process at near atmospheric pressure.
Regulatory/ stakeholder acceptance.	Ensure compliance with environmental laws and regulations and **DOE** orders. Address sludge management concerns in *Comprehensive Environmental Response ,Compensation, and Liability Act of* ***1980*** record of decision.	Achieve acceptance of regulators and other Stakeholders.	**<u>Advantages</u>** Stakeholders might consider a more attractive onsite waste form for interim storage since glass is being produced from tank waste processing **<u>Disadvantages</u>** WIPP may have a concern that accepting glass sets a precedent for disposing of a more leach resistant waste form which could initiate questioning the material forms already disposed in the repository.
Technical maturity	Maximize confidence in process implementation	Projected Technical Readiness Level (based on technical criteria only at this stage of the project) Estimated volume of waste going to WIPP	**<u>Advantages</u>** Primary unit operations demonstrated at production scale using simulant. **<u>Disadvantages</u>** Could be considered difficult to extrapolate actual simulant laboratory scale testing to the production scale
Operability and maintainability	Maximize operability Maximize maintainability	Ability for process to be remotized Ability to treat and package K Basin sludge inventory in **5** to **7** years Acceptability of secondary waste streams for disposal at Environmental Remediation Disposal Facility (solids) and 200 Area Effluent Treatment Facility (liquids)	**<u>Advantages</u>** Production scale equipment is relatively small. **<u>Disadvantages</u>** Designs for remote operation/remote maintenance are not currently available.
Life-cycle cost and schedule	Optimize life-cycle costs for sludge treatment and packaging facility Provide acceptable schedule to stakeholders	Cost * Cost of maturing technology to Technology Readiness Level-6 * Capital cost * Operating and maintenance cost * Deactivation and decommissioning cost Schedule * Facility startup * Complete treatment and packaging	**<u>Advantages</u>** Development demonstration activities to achieve TRL 4 and TRL 6 can be completed within the identified conceptual design and final design intervals due to the scale already demonstrated with simulants. **<u>Disadvantages</u>** Risks exist that may result in increasing the projected capital costs.
Potential for beneficial integration with ongoing **STP -** Phase ***I*** activities	Optimize cost or schedule for STP - Phase 2 Consider co-location of needed facilities provided by STP - Phase 1	Potential for integration of treatment and/or packaging with interim storage in T Plant Potential for shared functions with those being Optimization of location to reduce/eliminate intermediate shipping or repackaging of the sludge material	No impacts to ongoing STP Phase 1 project from implementation of this technology has been identified.
Integration with Site-wide RH-TRU processing/packaging planning, schedule, and approach	Optimize processes, equipment, and facilities for K Basin sludge treatment and packaging with other Hanford Site RH-TRU waste streams	Number of other Hanford Site RH-TRU waste streams that can be treated with candidate treatment process. Number of other Hanford Site RH-TRU waste streams that can be packaged with candidate packaging process.	**<u>Advantages</u>** Thermal processes established as BACT for a wide variety of waste constituents, which may have broader application beyond K Basin sludge. **<u>Disadvantages</u>** None noted

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Appendix G

Evaluation Data for Induction-Heated In-Container Vitrification (IVS) – (Kurion)

G1 Introduction

The development of technology alternatives for the Sludge Treatment Project was initiated by the request for technology information described in CHPRC, 2009. The technology information request included a description of the overall technology selection process, a preliminary description of K Basin sludge material to be treated, and a preliminary description of the transport package to be used for delivery of K Basin sludge from storage to the treatment process system. Multiple vendors submitted concepts for K Basin sludge treatment based on the technology request preliminary information.

Kurion, Incorporated offered its Modular Vitrification System®[1], an inductively heated In-Container Vitrification (IVS) approach to waste treatment in response to the request for technology information. Though previous testing demonstrated feasibility of the process at bench scale for other waste form applications, CHPRC determined that the IVS technology required a significant advance in STP-specific equipment development and process design before applicability and feasibility could be determined. As such, Kurion was asked to prepare engineering reports on IVS summarizing their proposed flowsheet and technology maturation plan for application to the K Basin sludge waste stream. The IVS technology is not currently considered to be a viable alternative for use in Phase 2 of the STP in the near term.

Kurion is pursuing an aggressive privately funded development program for the demonstration of IVS technology application to Hanford LAW waste. Many of the key technology elements are similar, and the size and scale of the planned development system approach full scale for the K-Basin sludge application. DOE should monitor this development as it finalizes its plans for the treatment of K-Basin Sludge materials. If the conceptual design of the phase 2 treatment system is delayed for some time, it is possible that a data and design information from a successful testing and demonstration program of the IVS technology may be available at that future date. DOE could re-evaluate the potential for IVS technology application to K-Basin sludge material at that future time.

[1] Modular Vitrification System is the registered trademark of Kurion, 2040 Main St., Irvine, CA 92614-7216; all rights reserved.

G2 Technology and Flowsheet Summary Description

The Kurion IVS technology is based on an induction-heated vitrification unit used to stabilize and solidify the sludge. Sludge slurry from a Sludge Transport and Storage Container (STSC) is transferred to a Feed Receipt and Preparation Tank. The slurry is mixed with glass forming components and then transferred via a metering pump to a melter unit. The melter unit uses external inductive heaters to generate high melt temperatures in a stainless steel drum pre-fitted with a graphite susceptor. High melt temperatures encapsulate the sludge while driving off free water in order to meet waste acceptance criteria regarding hydrogen evolution and pyrophoric content. A simplified flow diagram is provided in Figure G-1.

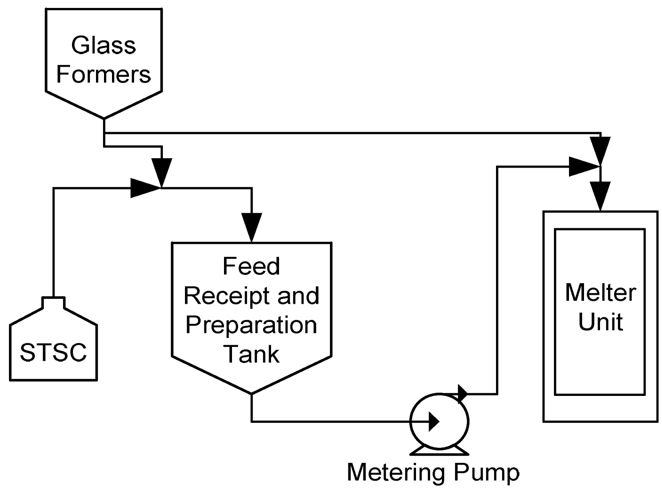

Figure G-1. Simplified Process Flow Diagram for the Kurion IVS melter

G2.1 Process Description

The IVS process description is summarized in the following sections and can be found in References 1 and 2. A simplified flow diagram in shown in Figure G-1, and a more detailed process flow diagram is given in Figure G-2.

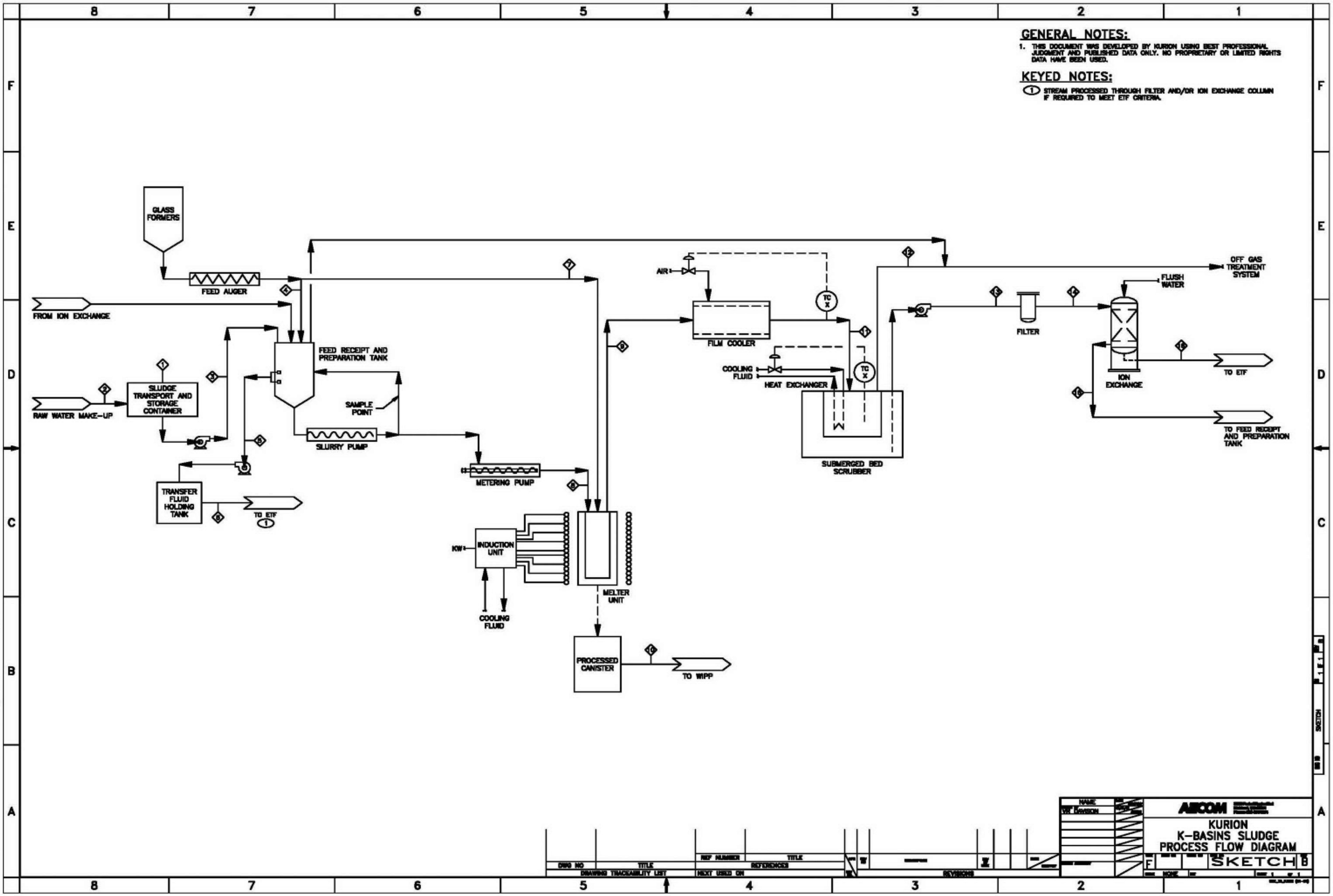

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Figure G-2. Kurion IVS Process Flow Diagram [2]

G2.1.1 Treatment Process

The proposed treatment process begins with transfer of sludge from an STSC into the Feed Receipt and Preparation Tank (FRPT). The FRPT is a well-mixed, continuously recirculating tank sized to receive the entire contents of a single STSC after dilution to 5 volume percent solids during retrieval. Samples are taken from the recirculating line to establish dose to curie relationships for characterization of the waste. Fissile Gram Equivalent (FGE) and TRU content per unit volume will determine the required drum loading to meet acceptance criteria.

Glass forming materials are mixed with the sludge in the FRPT to create slurry with 40 wt% solids. Potential glass formulations include both borosilicate and iron phosphate glass frit. The slurry will be continuously mixed to prevent the settling of solids and to assure that the frit and waste are thoroughly mixed prior to introduction to the melter unit.

The melter is an induction-heated unit which vitrifies waste in stainless steel drums outfitted with a graphite crucible and insulating materials. The graphite crucible is heated to up to 1500 °C by a low frequency external AC transformer coil. The active induction coils, and therefore melt zone, move from lower to higher elevations within the drum as material is introduced through the fill head. Prior to the addition of the waste slurry, pure glass former is added to the drum and melted to create an end cap. Capping the melt with pure glass is done to both control FGE content and void space in the product container. Once the caps are complete, waste slurry is then slowly added to the drum using a metering pump and vitrified. Once the desired amount of waste slurry has been added to the drum, a second end cap of pure glass is added to the top.

After an IVS container has been filled, it is moved to a cool-down area. Once cool, final compliance verification is performed and the container is placed in a removable lid canister (RLC) and transported to interim on-site storage.

The proposed IVS system also includes an off-gas film cooler, submerged bed scrubber, filter, and an ion exchange unit as part of the off-gas system. The bulk of the material exiting as off-gas from the melter is water vapor with entrained solids. The film cooler is a double-walled pipe that introduces air along the walls through a series of holes or slots in the inner wall. The air that is introduced cools the off gas below the glass-sticking temperature to approximately 315 °C to minimize solids deposition on the off gas piping walls. The submerged bed scrubber is packed bed column submerged in water for further cooling of the off gas. It is a passive device that quenches steam and removes entrained particulates and some aerosols from the off gas. The filter and ion exchange units are used to polish the liquid waste streams prior to transfer to the Effluent Treatment Facility (ETF).

G2.1.2 Immobilization Process

The IVS process immobilizes K Basin sludge by incorporating sludge components within a glass material. The IVS container is a 55 gallon stainless steel drum pre-fitted with a proprietary combination of graphite susceptor and insulating materials. This drum also serves as the shipping container that is placed in a WIPP-approved transport container, likely a removable lid canister (RLC).

Empty IVS containers are remotely positioned in the process cell using a powered roller conveyer system. This system will place the container under the IVS fill head and heating module and raise it up to attach. After the container has been filled, it is remotely lowered down and moved to a cool down area. Once cool, the drum is transferred to the dose measuring area where it the exterior is remotely scanned for final compliance verification.

G2.1.3 Process Chemistry

A detailed description of the reactions describing process chemistry for the primary IVS operations has not been developed for this evaluation. Hydrogen generation during vitrification is a potential issue, but would likely be addressed in further development of the off-gas system.

G3 Technology Development Status

The Kurion IVS treatment process was deemed technically immature relative to the other proposed technologies due to the amount of STP-specific equipment development and process design that would be required before the applicability and feasibility could be determined. Kurion prepared both a system material balance and a Technology Maturation Plan (TMP) as Phase 2 activities under Contract No. 42869.

Kurion is currently working to mature the baseline approach for their IVS technology under a separate equipment development plan and demonstration activities. As a part of that effort, Kurion prepared at Technology Readiness Assessment (TRA) [5] and TMP consistent with the DOE Technology Readiness Assessment Guide [3]. The baseline technology maturation program centers on using the IVS process to treat Hanford Low Activity Waste (LAW).

The purpose of the TMP done for STP Phase 2 was to describe the technology development and engineering activities required to mature Critical Technology Elements (CTEs) to a Technology Readiness Level (TRL) 6 or higher. The CTEs identified for the K-Basin sludge treatment using IVS are very similar to those identified for LAW treatment, which were already addressed in the baseline TMP. However, a number of design elements are different for the K-Basin case. The TMP prepared for the Phase 2 TEAA focuses on the incremental steps required to adapt the baseline TMP to the K-Basin treatment application.

Previous IVS TRA

The previous TRA completed by Kurion identified five CTEs and determined the Technology Readiness Level (TRL) and the Advancement Degree of Difficulty (ADD) of each. Table G-1 below shows the results of this TRA.

Table G-1. Results of the Kurion IVS TRA

Critical Technology Element (CTE)	Technology Readiness Level (TRL)	Advancement Degree of Difficulty (ADD)
Induction Module Sub-System	3	5
Induction Module Heating and Cooling Sub-System	3	5
Induction Module Fillhead Sub-System	3	2
Module In-process Integrity Sensing Sub-System	3	2
Off-Gas Sub-System)	4	1

Previous IVS TMP

The baseline Kurion TMP focuses on simultaneous maturation of all CTEs as an integrated system. The plan has different phases of maturation including progressive increases in scale and fidelity, as well as testing with both simulants and actual waste material. Table 2 below shows the baseline TMP.

Table G-2. Kurion Baseline Technology Maturation Plan

Timing	System Scale	Milestones	TRL
March to October 2010	Scoping Test	• Scoping Tests justify TRL 3 • Design & Fabricate Lab Scale System	3
January to December 2011	5.5" Lab Scale (Selected components, includes all CTEs)	• Efficacy testing enhances customer down-selection evaluation • 222-S Hot cell actual waste demo enables ≥TRL4 on larger systems	3
	~9"-10" Pilot Scale (Small prototype, includes all CTEs)	• Bench scale for Hanford LAW Supplemental Technology	4
		• Engineering scale for other relevant environment, potentially K Basin	6
June to December 2012	~19" Pilot Scale (Working Prototype)	• Engineering scale for Hanford supplemental LAW	6
		• Full scale commercial unit for non-LAW applications, including K Basin sludge	7

G3.1 Chemistry and Phenomenology

Due to its relative technical immaturity for the K Basin sludge material application, CHPRC decided to not pursue laboratory testing of the IVS technology during the Phase 2 TEAA. Because no testing was completed with simulants or actual sludge, some uncertainty regarding process behavior still exists. Discussion of potential testing of the IVS technology can be found in Section G3.3.

G3.2 Technical Issues and Risks Related to Equipment and Process Integration

A preliminary risk assessment was performed for the application of IVS to the K Basin sludge treatment based on the objectives of the current baseline Kurion TMP. The IVS process flowsheet prepared by Kurion (Figure G-2) consists of five major process functions for the K Basin sludge material application:

1. Perform feed receipt and preparation,
2. Operate IVS melter and fillhead,
3. Seal and inspect shielded drum containing the melter/canister,
4. Process melter off gas, and
5. Process condensate.

These process functions were further broken down into sub-functions, each of which can be accomplished with one or more possible equipment items or configurations. The optimum equipment item or configuration is selected based on either previous successful application of an item or on a formal test program. A complete list of the sub-functions and required risks for the treatment of K Basin sludge are documented in [4]. The major areas of concern related to the IVS flowsheet for K Basin sludge are:

1. **Use of simulants:** The simulants used in baseline TMP testing may significantly differ from K Basin sludge. Additional testing using K Basin simulants at the engineering scale (at minimum) is recommended.

2. **Waste/glass frit formulations:** The formulations of waste and glass frit used in baseline TMP testing may significantly differ from those required for K Basin sludge. Additional testing using K Basin simulants at the engineering scale (at minimum) is recommended.

3. **Equipment/canister configurations:** The equipment/canister configurations used in baseline TMP testing may significantly differ from those for K Basin sludge. Additional testing with K Basin equipment configurations at the engineering scale (at minimum) is recommended.

4. **Off gas nozzle:** An off gas nozzle configuration needs to be designed as part of the baseline TMP. This configuration is expected to be appropriate for the K Basin case as well.

5. **Canister shell cooling:** The melter is to be designed such that there is a continuous cooling air flow across external surface of the container. This is part of the baseline TMP and is expected to be appropriate for the K Basin case as well.

6. **Monitor/control melt and shell temperature:** A pyrometer and other instrumentation will be developed to enable monitoring and controlling of the melt and shell temperatures. This is part of the baseline TMP and is expected to be appropriate for the K Basin case as well.

7. **Remote handling of melter containers:** As a part of the TMP, equipment will be designed for handling empty and filled melter canisters. This is part of the baseline TMP and is expected to be appropriate for the K Basin case as well.

8. **Verify WIPP WAC compliance:** Verifying compliance as part of the TMP may be different from verifying compliance of K Basin waste products. Additional testing with K Basin equipment configurations at the engineering scale (at minimum) is recommended.

9. **Off gas film cooler:** The film cooler will be designed as a part of the TMP. It is expected to be appropriate for the K Basin case as well.

10. **SBS design:** The SBS design, including cooling configurations and periodic removal of particulates, is to take place as part of the TMP. It is expected to be appropriate for the K Basin case as well.

G3.3 Technology Development Needs

Kurion compared the K Basin flowsheet to their baseline flowsheet for Hanford LAW in order to develop the TMP for the K Basin sludge treatment process. The following sub-systems were found to be specific to the K-Basin treatment and require incorporation into the baseline process concept:

1. Sludge receipt, dewatering, sampling, mixing, and transfer of the sludge from the FRPT to the IVS module.

2. Ion exchange of the secondary liquid waste

3. Overpacking of the module in a shielded shipping and disposal container

These three sub-systems are not considered CTEs by the Kurion team because they were deemed by the Kurion team to be commercially available and demonstrated technologies that do not require their own maturation plan. The CHPRC team concurs with this assessment for items 2 and 3 above; however, the team feels that the solid-liquid separation of material with a broad density range over a broad particle size distribution has repeatedly been shown to be problematic and not generally considered 'commercially available'. As such, there may be some new CTEs which may require development outside of the baseline TMP prepared by Kurion. In order to demonstrate sufficient technology maturity for the treatment of K Basin sludge, further work must be done. Testing with K Basin simulants and actual sludge must be completed, and tests need to be completed at engineering scale. The following work is proposed to properly mature the IVS technology:

1. Perform K-Basin sludge simulant tests on 5.5" lab scale system (to enable reaching TRL 4)
2. Perform real waste tests on 5.5" lab scale system (to achieve TRL 4)
3. Perform simulant tests to confirm scalability and performance on 9" engineering scale system (to achieve TRL 5)
4. Perform simulant tests to confirm full scale performance on 19" prototype (to achieve TRL 7)

TMP for K Basin IVS

CTE 1: Induction Module Sub-System

The Induction Module Sub-System includes both the inductively heated melter and the disposal package. The melter serves as the reactor to evaporate the water and melt the waste and glass to form a monolithic glass material. After vitrification, the module including the glass form containing the radioactive elements must successfully meet all criteria for acceptance at WIPP.

The module consists of up to four nested cylinders that perform specific functions for melting and containing the waste. The outermost layer is the stainless steel shell. Within the shell is an insulation layer, which protects the stainless shell. A graphite susceptor that is inductively heated is the third layer, and it is protected by the innermost layer.

Lab scale tests have been completed for the four different components of the Module Sub-System. Because this CTE is being matured as a part of the LAW TMP, the only testing proposed for the K Basin project is of the integrate, high-fidelity system test. The integration tests would be performed using a bounding range of K Basin simulants. The Module Sub-System would be tested to ensure that no failure from contact with molten glass and waste will occur. Alternative susceptors would also be evaluated if graphite is found to be unacceptable to WIPP.

CTE 2: Induction Module Heating and Cooling Sub-System

The Induction Module Heating and Cooling Sub-System provides power to the module in order to evaporate water and melt the waste feed. It also provides cooling to the inductive coil and the exterior of the module. The cooling system is a readily available component, but it has not been tested for the IVS application. Copper inductive coils have been used industrially for decades. The only testing specific to the K Basin project would be integration testing to demonstrate performance of the Heating and Cooling Sub-System in a relevant environment with a range of bounding simulants.

CTE 3: Module Fillhead Sub-System

The Induction Module Fillhead Sub-System remotely connects the fill port of the Module Sub-System, introduces the waste feed slurry, and allows for the removal of the heated off-gas. Remotely operated Fillheads are widely used in the nuclear industry, but their use in the IVS melter system is unique. The testing specific to the K Basin project would be integration testing to demonstrate performance of the Fillhead Sub-System in a relevant environment with a range of bounding simulants.

CTE 4: Induction Module In-Process Integrity Sensing Sub-System

The Induction Module In-Process Integrity Sensing Sub-System ensures that the integrity of the Module Sub-System containment function is maintained during processing and operations. This sub-system will be based on systems that are commercially-available from induction heating power supply providers.

While these systems have been available to monitor induction melting processes for years, they have not been testing in the nuclear field. The testing specific to the K Basin project would be integration testing to demonstrate performance of the Sub-System in a relevant environment with a range of bounding simulants.

CTE 5: Off Gas Sub-System

The Off Gas Sub-System is designed to cool the off-gas and to remove aerosols and particulates generated during the melting process. In addition to the steam generated by the melter, the decomposition of salts and organic material also yields carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxide (NO and NO_2), chloride (Cl), and fluoride (F). The two major components of the Off Gas Sub-System are the off-gas film cooler and the Submerged Bed Scrubbers (SBS), which are described in Section G2.1.1. Off gas systems are a standard part of every facility that handles nuclear waste, and the key technology elements of the IVS Off Gas Sub-System have been tested at the bench scale for Hanford LAW. The testing specific to the K Basin project would be integration testing to demonstrate performance of the Off Gas Sub-System in a relevant environment with a range of bounding simulants.

G4 Process Design and Performance Estimates

G4.1 Estimated Processing Duration for Treating all K Basins Sludge

For the conditions specified in Appendix J, the ^{239}Pu FGE value is the limiting factor for the amount of waste that can be added to a container. The baseline case is the use of 55-gallon drums with a 40 FGE limit. Based on that ^{239}Pu FGE loading, a total of 1,512 containers will be required to package all of the K Basin waste.

The IVS throughput is based on the assumption that 3.5 metric tons of glass per square meter of melt surface per day can be processed [2]. The total time to process a single melter unit container includes an allowance for staging a container for processing, time to heat the internals to receive material, cooling after processing, and moving to a staging area. It is estimated that each container will take 18 hours to be processed. With a total operating efficiency (TOE) of 100%, the IVS technology would process all K Basin sludge (1,512 containers) in 3.2 years. With a TOE of 70%, the total processing duration is 4.6 years, which is within the 5 year processing time constraint.

G4.2 Major Process Equipment

The major pieces of process equipment for IVS include a Feed Receipt and Preparation Tank (FRPT), melter unity, and an off gas system including an off-gas film cooler, submerged bed scrubber (SBS), filter, and an ion exchange unit. Sizing of these was not completed for this technology.

G4.3 Facility Requirements

Facility layouts and other facility information were not prepared for the IVS option.

G5 Characteristics of the Alternative Relative to Evaluation Criteria

The IVS technology was determined by CHPRC to require a significant advance in equipment development and process design before applicability and feasibility could be determined for the K Basin sludge material application. Therefore, a formal evaluation of IVS characteristics relative to the evaluation criteria was not developed as a part of the Phase 2 TEAA.

G6 References

1. *Response to: Sludge Treatment Project, Phase 2 Technology Selection and Alternatives Analysis – RFI 196456.* Kurion Inc., November 13, 2009.
2. 60162041-001-PCAL-001, *K-Basin Material Balance*, Kurion Inc., October 25, 2010.
3. DOE G 413.3-4, *U.S. Department of Energy Technology Readiness Assessment Guide,* October 12, 2009.
4. 42869.TRPT.001, *Technology Maturation Plan for Contract No: 42869,* Kurion Inc., October 29, 2010.
5. KUR_MVS_01_02_TRA, *Modular Vitrification System Technology Readiness Assessment*, Kurion Inc., July 2010.

Appendix H

Evaluation Data for Phosphate Ceramic Hydrogen Inhibitor Process (PCIP) – (Ceradyne)

H1 Introduction

Use of BoroBond™[1] chemically bonded phosphate ceramic to reduce production of hydrogen gas from solidified K Basin sludge was proposed by the Boron Products, LLC subsidiary of Ceradyne, Inc. (Ceradyne) in response to formal Request for Information. After further definition of the approach for testing, CHRPC awarded Ceradyne Contract 42402 Task 1 to perform proof-of-principle testing on use of phosphate based ceramics to suppress hydrogen production in solidified/drummed waste. Testing and support work completed to date indicates the Ceradyne phosphate-ceramic hydrogen-inhibitor process (PCIP) does not provide adequate suppression of hydrogen production. It is therefore not currently considered to be a viable alternative for use in Phase 2 of the STP [1, 2].

[1] Borobond is the registered trademark of Ceradyne, Inc., Boron Products LLC, 3250 South 614 Road, Quapaw, OK 74363; all rights reserved.

H2 Technology and Flowsheet Summary Description

The unique feature of the phosphate-ceramic hydrogen-inhibitor process (PCIP) is use of chemically bonded phosphate ceramic to function as both the solidification agent and to suppress hydrogen production. If successful, this approach is expected to reduce or eliminate the need to oxidize metallic uranium prior to solidification of the sludge.

The overall process is divided into two major parts:

1. Sludge receipt and preparation for immobilization: the sludge batch is received from retrieval and water is removed to give the solids concentration desired for the immobilization process.
2. In the immobilization and packaging process,, the concentrated sludge slurry is assayed, metered into drums, and converted to a liquid-free solid that is sealed in drums for eventual offsite transport and disposal. The solidification process uses chemical additives that are expected to reduce hydrogen generation from the finished drummed waste form.

Supporting processes such as vent gas treatment, liquid waste disposal, cooling water and process steam supply are assumed to be the same as for WWO (Appendix A) and are not further discussed separately for this particular option.

H2.1 Sludge Receipt and Preparation for Immobilization

The overall process is illustrated in Figure H-1. Dilute sludge from an STSC is delivered batch wise, up to 13.2 m^3 (3,500 gallons) per batch to the Reciept Concentration and Mix Tank (RCMT). The RCMT is purged with sweep air to limit hydrogen buildup, is normally maintained at slightly below atmospheric pressure, and is agitated continuously when it contains a batch of sludge. The RCMT contents are heated to near the atmospheric pressure boiling point of water using a steam jacket and water is driven off by evaporation, concentrating the batch to the desired end point solids concentration. The mixed and concentrated batch is then cooled and transferred to the Lag Storage Tank (LST).

The LST is continuously agitated when a sludge batch is present, and is cooled with a water cooling jacket. Concentrated sludge is transferred to the assay and drumming system in smaller batches as needed. The LST is sized to hold at least a full concentrated batch from the RCMT. Once the RCMT is emptied, preparation of the next sludge batch can be started while the previous batch is processed by the drumming system.

Steam generated during the evaporation step flows first to a demister to remove any entrained material and then to a water-cooled condenser. Vent gas from the condenser is heated and filtered prior to discharge. Condensate drains to a Condensate Tank. Where feasible, clean condensate is recycled for line flushes and for the immobilization step. Excess condensate is sampled and shipped by truck to ETF for disposal.

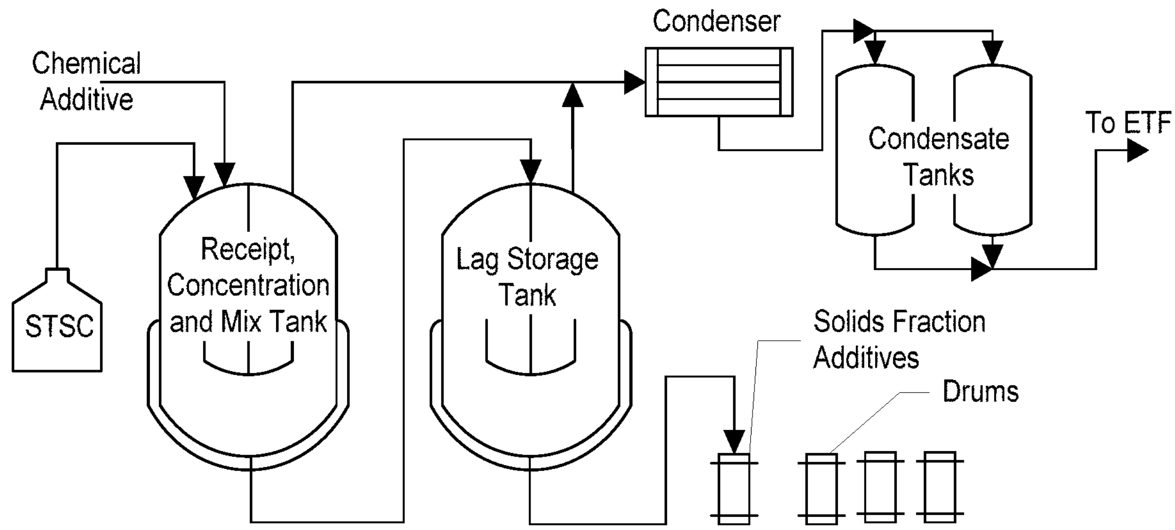

Figure H-1. Phosphate Ceramic Hydrogen Inhibitor Process Simplified Flow Diagram

Similar to oxidation treatment processes, one issue is verification that hydrogen production has been adequately reduced. For the PCIP a combination of the following methods may be used:

- Process validation. This method involves performing process validation tests which define process performance sufficiently to provide confidence that the process will perform as expected. This can include both pre-commissioning testing and test data collected during initial hot operations. The testing will need to consider the possibility of extended interim storage prior to shipment to assure adequate hydrogen mitigation during shipment.
- Monitoring of hydrogen generation in the product drums. Monitoring hydrogen generation rates in product drums could be a method used to prove that significant hydrogen generation is not continuing in the drums. This could involve holding selected drums for a period of time at an elevated temperature (say 60° C) and measuring the hydrogen evolution rate. A limited number of drums could be tested using a statistical sampling or process validation approach. This method has the advantage that it directly correlates with the applicable hydrogen generation limit from drums during shipping. The disadvantage is that it will take a substantial amount of time for each test, likely days or weeks.

H2.2 Process Chemistry

The presence of uranium metal (up to 0.052 g cm^{-3}) leads to the production of hydrogen through a water oxidation pathway according to Reaction H1:

$$U + 1.5\ H_2 \rightarrow UH_3 \qquad \text{(Eq. H1a)}$$

$$UH_3 + 2\ H_2O \rightarrow UO_2 + 3.5\ H_2 \qquad \text{(Eq. H1b)}$$

$$\text{Overall: } U + 2\ H_2O \rightarrow UO_2 + 2\ H_2 \qquad \text{(Eq. H1)}$$

BoroBond™ chemically bonded phosphate ceramic is formed by the following reaction:

$$MgO + KH_2PO_4 + 5H_2O \rightarrow MgKPO_4{\bullet}6H_2O. \qquad \text{(Eq. H2)}$$

Reaction H2 chemically binds water, potentially making it less available for Reaction H1. The proposition behind this technology is that if the if the water activity is reduced to very low levels by reaction H2 the rate of hydrogen production via reaction H1 should be substantially reduced.

In order to assure hydrogen concentration limits are achieved during transportation it is estimated that hydrogen generation must be decreased by roughly a factor of 100 compared to the reaction of uranium metal with anoxic water at 60 °C [3, 4].

H2.3 Immobilization and Packaging Process

With the exception of the specific chemical additives used for solidification, the WWO assay and drumming approach described in Appendix A is assumed for immobilization. The approach selected for WWO includes gamma radiation measurements on a recirculation stream from the LST. These measurements are then used to estimate concentration of WIPP fissile isotopes using a dose-to-curie methodology. This data is in turn used to determine the amount of sludge loaded to each drum. Sludge transfer to the drum is controlled by a metering pump which draws from the recirculation stream. Sludge and flush water transferred to the drum is solidified by addition of dry additives. A "lost paddle" in-drum mixing technique is used to blend the dry additives with the sludge slurry resulting in a solid product with no free liquids. Gamma radiation measurements are taken on the finished drum. Based on these measurements the content of WIPP reportable isotopes is estimated based on a dose-to-curie methodology. See Appendix A for additional information on the assay and drumming system concept.

H3 Technology Development Status

Because the PCIP demonstrated inadequate performance during the proof-of-concept testing the technical development status is considered to be insufficient for further consideration at this time. Process and/or product changes required to give acceptable performance are currently unknown.

H3.1 Chemistry and Phenomenology

Questions or issues for the PCIP related to chemistry and phenomenology include the following:

- Understanding the basic chemistry of the hydrogen suppression reactions.
- Understanding side reactions including reactions with other sludge components, buildup of intermediates, and secondary reaction products.
- Continuing reactions, depletion and buildup of chemical species and related effects of long term interim storage prior to shipment.
- Effect of temperature cycles, e.g. short term temperature spike during immobilization, temperature during storage, and temperature during shipment.

Delegard and co-workers have summarized past uranium oxidation by water and investigated hydrogen mitigation in grouts [3, 5, 6]. The four Portland cement and two magnesium ammonium phosphate ceramic formulations investigated decreased hydrogen generation by only a factor of two to three compared to the reaction of uranium metal in anoxic water. Though liquid water was not present, the water vapor produced at temperature was sufficient to result in uranium metal corrosion. Ceradyne proposed alternate formulations for phosphate bonded ceramics that appeared to hold some promise for improved hydrogen mitigation performance compared to the earlier testing work. Therefore, testing of the alternate formulations was initiated under the current program.

H3.1.1 Summary of Testing Performed

Testing was performed by Ceradyne per Contract 42402 Task 1, and a detailed test report is available [2]. The following provides a summary of the testing and results.

Hydrogen generation mitigation for K Basin sludge was examined by encapsulation of uranium metal in BoroBond™ chemically bonded phosphate ceramic ($MgKPO_4 \cdot 6H_2O$). Each ceramic form was placed into a sealed pressure vessel and hydrogen generation at 60 °C was monitored by the increase in pressure and compared to a uranium metal in water standard that was run in parallel. Sampling of accumulated gasses near the end of the tests confirmed that the pressure changes resulted primarily from generated hydrogen. The various ceramic compositions considered excess of water, shortage of water, decreased aggregate (i.e. fly ash or sludge solids), increased uranium loadings and presence of some KW sludge simulant components.

Pressure increase data is summarized in Table H-1, and pressure increase rates are normalized against a uranium metal in water standard. Slopes were determined from ~200 hours to the end of the experiment in order to ensure any induction period had passed. Similar to the previous PNNL work with cement-based grouts, the $MgKPO_4 \cdot 6H_2O$ matrix only decreased hydrogen generation rates by a factor of ~2. In general, the data follows the expected trends. Sample 2 with increased bond phase (i.e. $MgKPO_4 \cdot 6H_2O$) and Sample 4 with 10 % more water than needed to satisfy the bond phase stoichiometry, showed higher rates of hydrogen generation. However, the water starved samples 5 and 6 do not show marked decreases in hydrogen generation compared to the baseline samples. Sample 9 with nearly double the uranium metal loading showed a pressure increase to about double that of the baseline samples 1a/b. The increase in rate of pressure rise is as expected. The presence of KW sludge simulant constituents FeO(OH) and $Al(OH)_3$ had little to no effect on the performance of the hydrogen generation rate.

Table H-1. Pressure Rise Data for Uranium Encapsulation in BoroBond™ MgKPO4•6H2O

Sample	Description	Headspace (mL)	Slope (torr/h)	Normalized[b] Slope (torr/h)	Relative to Sample 10
1a	Baseline 55% bond phase	216.3	0.1186	0.1198	0.61
1b	Baseline duplicate	223.8	0.1268	0.1325	0.65
2	65% bond phase	211.7	0.1878	0.1856	0.97
3	45% bond phase	216.9	0.1190	0.1205	0.61
4	55% bond phase, 10% excess water	213.0	0.1654	0.1644	0.85
5	55% bond phase, 9% water shortage	231.4	0.1329	0.1435	0.68
6	55% bond phase, 17% water shortage	231.6	0.1002	0.1083	0.52
7	KH_2PO_4 Pre-stir[a]	222.4	0.1511	0.1569	0.78
8	contains FeO(OH) and $Al(OH)_3$	231.5	0.1272	0.1375	0.66
9	1.8 times uranium loading	232.1	0.2648	0.2869	1.36
10	U metal in water	214.2	0.1941	0.1941	1.00
11	No U metal	215.6	---		---

[a]Uranium metal stirred in KH_2PO_4 slurry for 20 hours
[b]Normalized to a 214.2 mL headspace (Sample 10)

H3.1.1.1 Conclusions

Direct encapsulation of uranium metal into the BoroBond™ $MgKPO_4 \cdot 6H_2O$ matrix resulted in a twofold decrease in the hydrogen generation rate. This agrees with previous findings from PNNL. As tested in the most basic formulation, chemically bonded phosphate ceramic does not show the necessary hydrogen inhibition to be used for direct immobilization of this waste stream. Ceradyne has indicated that they may try some additional formulations under their own funding to attempt to improve performance; however, this work is not currently supported by CHPRC.

H3.1.2 Technical Issues and Unknowns Related to Chemical and Physical Behavior

To date, the limited short term testing of the BoroBond™ $MgKPO_4 \cdot 6H_2O$ matrix has not been successful in substantially reducing hydrogen generation rates. Understanding of chemical and physical behavior in the process and product are incomplete.

H3.2 Technical Issues and Risks Related to Equipment and Process Integration

If successful, the PCIP is expected to be similar to the nitrate chemical inhibitor process with the exception of the identity and location of the added chemicals. Because of the relatively short batch preparation time, the RRT and LST are expected to be modestly smaller for the PCIP than for the WWO process. Other than these relatively minor differences, process equipment for the PCIP is expected to be essentially identical to the WWO process. Remote equipment technology, remote facility features, assay, and integration concepts are expected to be the same as for WWO. For related technical issues and risks see Appendix A and Reference [7].

Methods used to verify hydrogen generation is acceptable at the time of shipment (after extended storage) have not been fully defined. Some interaction with WIPP is likely to be needed to determine what would be acceptable to them.

H3.3 Technology Development Needs

The primary technology need is to identify chemically bonded phosphate ceramic formulations or other process changes that reduce hydrogen generation to acceptable levels. Testing in both the current program and the past PNNL work has failed to demonstrate an effective formulation. As such, this option is not currently being activity considered for the Sludge Treatment Project Phase 2.

H4 Process Design and Performance Estimates

Since a process and product concept have not been defined that meet minimum performance requirements, no process design and performance estimates were developed for the PCIP.

H5 Characteristics of the Alternative Relative to Evaluation Criteria

Since process and product concepts have not been defined that meet minimum performance requirements, a formal evaluation of characteristic of the PCIP relative to the evaluation criteria was not developed.

H5.1 Conclusions

Based on results of the proof of principle testing the PCIP has not demonstrated technical feasibility for use in processing K Basin sludge in STP Phase 2. Since a process concept has not been defined that meets minimum performance requirements, the PCIP performance in terms of processing duration, equipment size, complexity, and flexibility cannot be determined.

H6 References

1. "Task 4-Technical Support Final Report (Rev.1)," Boron Products, LLC, Contract 42402 Submittal 18 V2, January 25, 2011.

2. "Task 1 Testing Final Report", Boron Products, LLC, 42402 Submittal 5 V1, December 22, 2011.

3. Delegard, C. H.; Schmidt, A. J.; Sell, R. L.; Sinkov, S. I.; Bryan, S. A.; Gano, S. R.;

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5. Mellinger, G. B.; Delegard, C. H.; Gerber, M. A.; Naft, B. N.; Schmidt, A. J.; Walton, T. L. *Disposition Options for Hanford Site K-Basin Spent Nuclear Fuel Sludge*; Pacific Northwest National Laboratory: Richland, WA, 2004; PNNL-14729.

6. Delegard, C. H.; Schmidt, A. J. *Uranium Metal Reaction Behavior in Water, Sludge, and Grout Matrices*; Pacific Northwest National Laboratory: Richland, WA, 2008; PNNL-17815.

7. Sinkov, S. I.; Delegard, C. H.; Schmidt, A. J. *Mitigation of Hydrogen Gas Generation from the Reaction of Water with Uranium Metal in K Basin Sludge*; Pacific Northwest National Laboratory: Richland, WA, 2010; PNNL-19135.

8. Massie, H., "Initial Technology Maturity Evaluation: K Basin Sludge Warm-Water Oxidation and Immobilization System, PLN-3003611-000B, January 2011 (draft), AREVA Federal Services LLC, Richland WA.

Appendix I

Sensitivity Analyses

I1 Introduction

In Phase 1 of the sludge treatment project (STP) sludge will be removed from the 105 KW Basin, placed in sludge transport and storage containers (STSCs) and transported to T Plant for interim storage. The primary purpose of the current K Basin STP Phase 2 – Technology Alternatives Analysis is to compare technology alternatives in order to support a decision on technology alternatives to be developed further. As part of this evaluation, normalized base case flowsheets were prepared to estimate the size and performance of specific technology alternatives. This in turn required definition of a number of bases and assumptions, many of which are unverified or preliminary in nature. The purpose of this Appendix is to evaluate impacts on the relative comparison of candidate technologies resulting from changes to specific bases and assumptions.

Overall process sequence for STP Phase 2 is illustrated in Figure I-1. The Phase 2 process starts with a sludge batch in an STSC in storage at T Plant and proceeds through the following overall process sequence:

- <u>Retrieval.</u> The first steps include removal of an STSC from storage in T Plant, retrieval of sludge from the STSC and transfer to the Treatment System. The current assumption is that some type of hydraulic approach (e.g. sluicing) is used for sludge retrieval resulting in a diluted sludge slurry delivered as a relatively large batch (up to 13.2 m^3 or 3,500 gallons) to Treatment. The retrieval process is outside the scope of the current sludge treatment technology evaluation.

- <u>Reciept and Preparation for Immobilization</u> systems act as a buffer to prepare each batch for transfer to the Immobilization and Packaging System. Process details vary depending on the specific alternative. However, in all these systems receive and interim store the STSC batch; concentrate the dilute sludge slurry by removing water; and deliver smaller batches of concentrated sludge to the Immobilization and Packaging System.

- <u>Immobilization and Packaging</u>. The Immobilization and Packaging System accepts batches of concentrated sludge and packages it in drums that are sealed, decontaminated if needed, assayed to determine content of WIPP reportable isotopes, and transferred to on-site storage or shipping facilities. Details of the immobilization and packaging processes vary by alternative. Key functions are to eliminate any free liquids, reduce hydrogen generation to acceptable rates, and determine content of WIPP reportable isotopes in each drum.

- <u>Storage and Shipping</u>. Finished drums will be stored on-site and eventually shipped to WIPP for disposal. The storage and shipping functions are outside the scope of the STP Phase 2 – Technology Alternatives Analysis

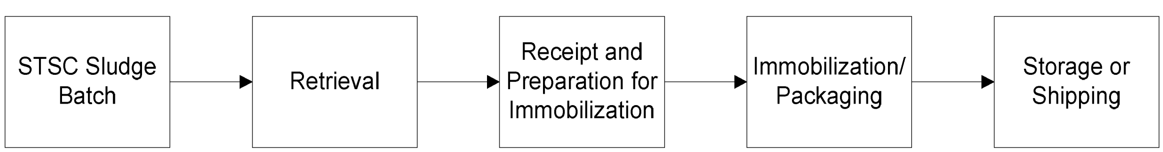

Figure I-1. STP Phase 2 Overall Process Steps

The STP Phase 2 – Technology Alternatives Analysis is primarily concerned with the Receipt and Preparation for Immobilization, the Immobilization and Packaging steps. The current evaluation considers impacts of changes to assumptions for the interface between retrieval and treatment; however, internal steps within retrieval are not directly considered.

As shown in Figure I-1, the overall process is sequential. However, it should be noted that multiple process steps may be in progress at any given time and lag storage is provided at various points within the process. Therefore, the processing capacity (or batch processing time) of several process steps may dictate the overall processing rate. Evaluation of the effect of bases and assumptions on the rate limiting steps, processing rates, and associated overall processing durations for the various alternatives is therefore a significant part of the overall sensitivity analysis.

The body of the current report and other appendices should be consulted for background information, process descriptions, results of base case normalized flowsheet calculations, testing results, and other supporting information on technologies under consideration. This information is typically not repeated in the discussion below, which assumes the reader is familiar with current evaluation and technology information on technologies presented in other Appendices.

I2 Summary

Sensitivity evaluation results indicate that most identified assumption changes do not have a material impact on the relative comparison of currently identified alternatives. However, several parameters have sufficient impacts to justify consideration as part of the overall evaluation process. The primary impacts of many of the changes are to increase or decrease the total operating duration and/or number of product drums. There were no cases where changes to bases or assumptions would render any alternatives incapable of processing the sludge; however, in some cases it was found that assumption changes could increase processing duration beyond the current 5 year criterion (Appendix J Section J3.2). This could result in either redesign to increase effective processing capacity or acceptance of the longer processing duration. The sensitivity analyses did not develop estimates for design changes required to meet the base case 5 year processing criterion. Table I-1 provides a summary of conclusions for changes to specific bases and assumptions, and also identifies the Section where each item is discussed in more detail.

Table I-1. Sensitivity to Changes in Bases and Assumptions

Parameter	Evaluation Summary	Report Section
Immobilization and Packaging System Drum Production Capacity	Increased or reduced Immobilization and Packaging System drum production capacity has a larger effect on ICV™ than other alternatives due to the lower base case drum production capacity for ICV™. Moderate reduction in drum production capacity increases estimated processing time beyond 5 years for some alternatives. With the exception of ICV™, changes to the expected drum production capacity do not change the relative ranking of alternatives in terms of estimated processing duration.	I3.1
Turn-Around-Time for STSC Retrievals (time between sequential batch retrievals)	Impact of the time between sequential STSC retrieval batches on total processing duration varies significantly depending on the alternative. However, the relative ranking in terms of total processing duration is not significantly affected. Increasing the time between sequential STSC retrieval batches to 30 days or more has substantial impacts to the processing duration for all alternatives.	I3.2.1
Sludge Batch Volume and Solids Concentration.	All identified alternatives are expected to be affected about equally by changes to sludge batch volume and solids concentration.	I3.2.2
Waste Water Recycle to Retrieval	All identified alternatives are expected to be affected about equally by including or eliminating recycle of waste water to retrieval.	I3.2.3
Processing additional waste streams	Known additional waste streams can be processed by all current alternatives with a moderate increase in drum count and total processing duration. Alternatives are expected to be affected about equally except for ICV™, which has a larger increase in estimated processing duration than the others.	I3.3

Parameter	Evaluation Summary	Report Section
Updated Sludge Composition,	Reduced radioisotope concentrations for KE and KW sludge result in: • KE sludge drum loading being volume limited, versus ^{239}Pu FGE limited previously; • Reduced total drum count estimate; and • Reduced total processing duration. Because of slower drum production capacity, the ICV™ alternative tends to benefit more from reduced drum count. Otherwise, all identified alternatives are expected to be affected about equally.	I3.4.1
Updated Sludge Quantity, and Number of STSC batches	Reduced quantity of settler tank sludge results in reduced total drum count and processing duration. Increased number of STSCs and reduced volume of settler tank sludge per STSC result in moderate increase in processing duration. Because of slower expected drum production capacity, the ICV™ alternative tends to benefit more from reduced drum count. Otherwise, all identified alternatives are expected to be affected about equally.	I3.4.2
Sludge Property Changes During Phase 1 Storage	Sludge changes during storage are expected to primarily affect retrieval of STSC batches, which is outside the scope of the current sludge treatment technology evaluation. Sludge property changes during storage are not expected to significantly affect processing in any currently identified treatment alternatives.	I3.4.3
Shielded 30 Gallon Drums.	Use of the shielded 30 gallon drum is expected to increase total drum count. Magnitude of the drum count increase and fraction of drums that can be reclassified as CH TRU depend strongly on the allowable ^{137}Cs loading and operating strategy. More detailed analyses are needed to refine estimates for Cs^{137}loading limits as a function of waste form and packaging characteristics. There may be differences in the relative impact to current alternatives, but this cannot be determined from currently available information.	I3.5
Drum Count (a function of achievable FGE, waste properties, achievable waste loading per drum, etc.)	Increased or reduced drum count has a larger effect on Impact ICV™ than the other alternatives due to the lower drum production capacity for ICV™. Other than ICV™ changes to expected drum count do not change relative ranking of alternatives in terms of estimated processing duration. However, for the WWO and ICV™ alternatives the maximum drum count increases processing time beyond the 5 year criterion.	I3.6
Total Operating Efficiency (TOE) and Process Performance	The FROP, SRWOP, and NCIP alternatives can accept relatively large reduction in average effective TOE and/or estimated process performance while continuing to meet the 5 year processing duration criterion. Processing time for the other alternatives (WWO, PCOP, and ICV™) will exceed the 5 year processing time criterion with relatively modest reduction in TOE and/or estimated process performance.	I3.7

I3 Evaluation of Specific Bases and Assumptions

The STP Phase 2 – Technology Alternatives Analysis is primarily concerned with the Reciept,Preparation for Immobilization, the Immobilization and Packaging steps (Figure I-1). The following Sections consider relative impacts on technology alternatives for those steps that result from changes to bases and enabling assumptions. The current evaluation considers impacts of changes to assumptions for the interface between retrieval and treatment; however, internal steps within retrieval are not directly considered.

I3.1 Immobilization and Packaging System Drum Production Capacity

It can be seen from Figure I-1 that the Phase 2 sludge processing time (or processing rate) could potentially be constrained by any one of several steps. This section considers the effect on overall sludge processing duration resulting from changes to assumptions for the Immobilization and Packaging System processing capacity.

The Immobilization and Packaging System concepts for five of the six alternatives under consideration use additives mixed with sludge in the drums to react with or absorb water in order to eliminate free liquid in the finished drums. Portland cement is a common additive used for this purpose. For convenience these 5 are referred to herein as the Portland cement-based systems, even though alternate additives may be considered. The sixth alternative (ICV™) uses high temperatures to drive off water, eliminating free liquid and metallic uranium in the same step. For the Portland cement-based systems an immobilization and packaging system drum unconstrained production capacity of 30 drums per week was selected for the base case, while 10 and 49 drums were defined as minimum and maximum sensitivity case values respectively [1]. These rates are based on a range of estimates provided by several of the contractors performing work to support the STP Phase 2 – Technology Alternatives Analysis.

In the case of Joule-heated In-Container Vitrification (ICV™) only a single unconstrained production capacity estimate of 9.3 drums per week was provide by the contractor. This is considered to be a best estimate value with significant uncertainty. For the current analysis maximum and minimum unconstrained drumming rates for ICV™ are assumed to be 14 and 5 drums per week, or about ½ and 1 ½ times the base case (best estimate) value. Note that all production capacities listed above are based on 100 % total operating efficiency and assume that prepared sludge feed material is always available for transfer to immobilization.

The immobilization and packaging system unconstrained drum production capacity can significantly affect the total time required to process all of the K Basin sludge. Depending on the particular technology option, sludge type, and associated performance assumptions drum production is often, but not always estimated to be the rate limiting step in the overall process.

To estimate the effect of unconstrained drum production capacity on overall processing duration, the "Batch preparation time" was calculated for each treatment method; where batch preparation time includes all steps required to receive an STSC batch and prepare it for transfer to the immobilization and packaging system. The average drumming time per batch was then calculated based on the average number of drums per batch and each drum production rate assumption. The longer of the two times then determines the rate limiting step for each waste type and each set of assumptions. Note that with the base case assumptions retrieval is never the rate limiting step. However, with alternate assumptions retrieval may be rate limiting as discussed in Section I3.2. A summary of average drumming and batch preparation times for each processing method and drum production rate is given in Table I-2. All Table I-2 values are based on 100% total operating efficiency (TOE).

Calculation of the overall processing time is performed as follows:

1. For each technology alternative and drum production rate combination, estimated batch drumming time is compared to batch preparation time for each sludge type in order to determine the rate-limiting step.
2. Total processing times for each sludge type (KE EC, KW EC, and settler tank sludge) are then calculated using the limiting processing step and the base case number of STSC batches for each sludge type.
3. Overall total processing time for each alternative is then calculated. This includes processing time of the KE EC, KW EC, and settler tank sludge, plus an allowance for drumming the final batch after all batch preparation has been completed. As a conservative basis, it is assumed that the last batch is settler tank sludge. The allowance for the last batch is not applied for ICV™ because it has a negligible effective batch preparation time.

Elements of the calculation and the estimated total processing times at 100% and 70% TOE are shown in Table I-3. The estimated total processing times (assuming 70% TOE) for each of the three drum production capacities is compared for each process method in Table I-4 and Figure I-2. As drum production capacity is increased from the base case rate to the maximum rate total processing time is reduced by 4 to 6 months for all alternatives except ICV™, which is reduced by 18 months. Similarly as drum production capacity is reduced from the base case to the minimum, the processing time for ICV™ increases by 46 months, which is significantly larger than for the other alternatives. The results show that ICV™ is significantly more sensitive to the drumming rate assumption. Between the minimum and maximum rate assumptions its relative ranking in terms of total processing duration changes. The other alternatives are sensitive to the drumming rate assumption; however, the effect does not differ substantially between alternatives. Between the minimum and maximum rate assumptions there is no change in their relative rankings in terms of total processing duration.

Table I-2. Batch Preparation and Drumming Times for Drumming Sensitivity Cases

		Warm Water Oxidation (WWO)[1]	Peroxide Carbonate Oxidation (PCOP)	Fenton's Reagent Oxidation (FROP)	Size Reduction and Water Oxidation (SRWOP)	Nitrate Chemical Inhibitor (NCIP)	Joule Heated In-Container Vitrification (ICV™)
KE Sludge Batch Preparation Time (Days)		124.8	50.2	14.3	8.9	6.4	N/A[3]
KE Sludge Batch Drumming Times (Days)	**Minimum rate[2]**	42.0	21.0	21.0	21.0	21.0	42
	Base case rate[2]	14.0	7.0	7.0	7.0	7.0	22.6
	Maximum rate[2]	8.6	4.3	4.3	4.3	4.3	15
KW Batch Preparation Time (Days)		124.8	50.2	14.3	8.9	6.4	N/A[3]
KW Sludge Batch Drumming Times (Days)	**Minimum rate[2]**	56.0	28.0	28.0	28.0	28.0	56
	Base case rate[2]	18.8	9.4	9.4	9.4	9.4	30.2
	Maximum rate[2]	11.6	5.8	5.8	5.8	5.8	20
Settler Tank Sludge Batch Preparation Time (Days)		10.8	15.0	14.3	8.9	6.4	N/A[3]
Settler Tank Sludge Batch Drumming Times (Days)	**Minimum rate[2]**	173.6	86.8	86.8	86.8	86.8	173.6
	Base case rate[2]	58.0	29.0	29.0	29.0	29.0	93.4
	Maximum rate[2]	35.6	17.8	17.8	17.8	17.8	62

1. In the WWO base case, 2 STSCs are processed per batch, all others assume 1 STSC per batch.
2. Minimum, base case, and maximum drum production rate for ICV™ are 5, 9.3, and 14 drums per week, all others are 10, 30, and 49 drums per week respectively.
3. The effective batch preparation time for ICV™ is considered to be negligible for all cases.

Table I-3. Total Processing Time for Drumming Sensitivity Cases

	Drumming Rate Case	Warm Water Oxidation (WWO)[1]	Peroxide Carbonate Oxidation (PCOP)	Fenton's Reagent Oxidation (FROP)	Size Reduction and Water Oxidation (SRWOP)	Nitrate Chemical Inhibitor (NCIP)	Joule Heated In-Container Vitrification (ICV™)
Total KE Sludge Processing Time at 100% TOE (Months)	Minimum rate[2]	16.4	18.2	7.6	7.6	7.6	15.2
	Base case rate[2]	16.4	18.2	5.2	3.2	2.5	8.2
	Maximum rate[2]	16.4	18.2	5.2	3.2	2.3	5.4
Total KW Sludge Processing Time at 100% TOE (Months)	Minimum rate[2]	16.4	8.3	4.6	4.6	4.6	9.2
	Base case rate[2]	16.4	8.3	2.4	1.5	1.5	5
	Maximum rate[2]	16.4	8.3	2.4	1.5	1.1	3.3
Total Settler Tank Sludge Processing Time at 100% TOE (Months)	Minimum rate[2]	22.8	22.8	22.8	22.8	22.8	45.7
	Base case rate[2]	7.6	7.6	7.6	7.6	7.6	24.6
	Maximum rate[2]	4.7	4.7	4.7	4.7	4.7	16.3
Drumming Time of Last Batch at 100% TOE (Months)	Minimum rate[2]	5.8	2.9	2.9	2.9	2.9	N/A[3]
	Base case rate[2]	1.9	1.0	1.0	1.0	1.0	N/A[3]
	Maximum rate[2]	1.2	0.6	0.6	0.6	0.6	N/A[3]
Total Processing Time (Months) at 100% TOE for all STSCs	Minimum rate[2]	61.4	52.2	37.9	37.9	37.9	70.1
	Base case rate[2]	41.3	35.1	16.2	13.3	12.6	37.8
	Maximum rate[2]	38.7	31.8	12.9	10.0	8.7	25
Total Processing Time (Months) at 70% TOE for all STSCs	Minimum rate[2]	87.7	74.6	54.1	54.1	54.1	100.1
	Base case rate[2]	59.0	50.1	23.1	19.0	18.0	54
	Maximum rate[2]	55.3	45.4	18.4	14.3	12.4	35.7

1. In the WWO base case, 2 STSCs are processed per batch, all others assume 1 STSC per batch.
2. Minimum, base case, and maximum drum production rate for ICV™ are 5, 9.3, and 14 drums per week, all others are 10, 30, and 49 drums per week respectively.
3. In the ICV™ process, the drumming time of the last batch is not considered separately.

Table I-4. Total Processing Times at 70% TOE using Drumming Capacity Sensitivity Cases

	Total Processing Time (Months) At 70% TOE for all STSCs with Various Drum Production Capacities		
	Minimum rate[2]	Base case rate[2]	Maximum rate[2]
Warm Water Oxidation (WWO)[1]	88	59	55
Peroxide Carbonate Oxidation (PCOP)	75	50	45
Fenton's Reagent Oxidation (FROP)	54	23	18.4
Size Reduction and Water Oxidation (SRWOP)	54	19	14.3
Nitrate Chemical Inhibitor (NCIP)	54	18	12.4
Joule Heated In-Container Vitrification (ICV™)	100	54	36

1. In the WWO base case, 2 STSCs are processed per batch, all others assume 1 STSC per batch.
2. Minimum, base case, and maximum drum production capacity for ICV™ are 5, 9.3, and 14 drums per week, all others are 10, 30, and 49 drums per week respectively.

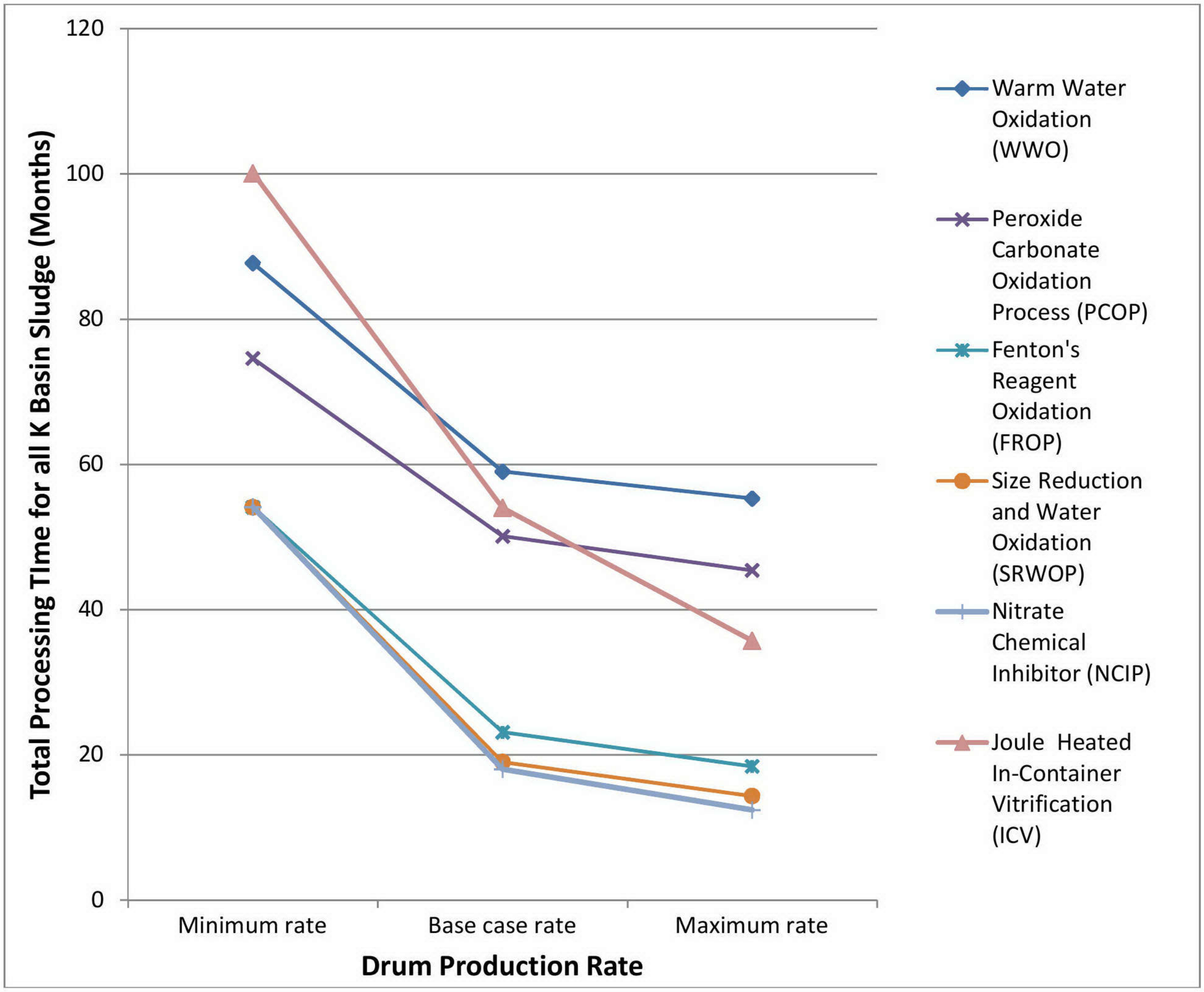

Figure I-2. Effect of Drum Production Capacity on Total Processing Time

The total processing time for each method was calculating using the minimum, base case, and maximum drumming rates.

I3.2 Retrieval Interface Assumptions

The Phase 2 design and operating concepts for retrieval of sludge from STSCs have not yet been defined. As such, a number of enabling assumptions were required to develop normalized flowsheets for technology alternatives.

I3.2.1 Turn-Around-Time for Sequential STSC Retrievals

Base case time cycle estimates assume that sludge processing is essentially not constrained by the STSC batch retrieval rate or schedule. Sensitivity analyses were performed to evaluate the effect of changes in the assumption for STSC Retrieval Turn-Around-Time, defined as the elapsed time from starting retrieval of one STSC batch until starting retrieval of the next succeeding STSC batch.

For example, the WWO calculation is based on processing two STSC batches per oxidation batch and assumes an STSC Retrieval Turn-Around-Time of 4.4 days or less (Appendix A). If the actual STSC Retrieval Turn-Around-Time is longer it may extend the batch preparation time and hence increase the total time required to process all the K basin sludge. The estimated effects of different assumptions for STSC Retrieval Turn-Around-Time are shown in Table I-5 and Figure I-3:

- Two week to 30 day interval. The effect of increasing the STSC Retrieval Turn-Around-Time to between 14 and 30 days varies depending on the alternative. The small advantage for SRWOP and NCIP over FROP are eliminated for STSC Retrieval Turn-Around-Times of 14 days or more because retrieval becomes the rate limiting step for the EC sludge batches. For two of the slower processes (PCOP and ICV™) there is no effect for up to 14 days retrieval intervals, and only a small effect for intervals up to 30 days. The effect on WWO is larger because is relies on processing two STSC batches in each oxidation batch. For a 30 day STSC Retrieval Turn-Around-Time the overall processing time for WWO is estimated to increase by about 9.6 months to 69 months, which exceeds the 60 processing time criterion.

- Two month STSC Retrieval Turn-Around-Time. Increasing the STSC Retrieval Turn-Around-Time to 60 days substantially impacts all processing durations. On a relative basis, the two processes that are slowest for shorter retrieval delays (WWO and ICV™) remain the slowest. However, differences in estimated processing durations for the 4 fastest are essentially eliminated (within the accuracy of the simplified estimates).

- Longer delays. For STSC Retrieval Turn-Around-Times of 90 days or more the estimated processing durations are essentially equal for all alternatives because STSC retrieval is the rate limiting step for all alternatives.

Table I-5. Effect of STSC Retrieval Turn-Around-Time on Processing Time

STSC Retrieval Turn-Around-Time (Days)	4.4[1]	10	14	30	60
Alternative	**Total Processing Time at 70 % TOE (Months)**				
Warm Water Oxidation (WWO)	59	61	63	69	92
Carbonate Peroxide Oxidation (CPOP)	50	50	50	50	69
Impact In-Container Vitrification (ICV™)	54	54	54	58	81
Fenton's Reagent Oxidation (FROP)	23	23	23	35	69
Size Reduction and Water Oxidation (SRWOP)	19	20	23	35	69
Nitrate Chemical Inhibitor (NCIP)	18	20	23	35	69

[1]4.4 is effectively the base case assumption.

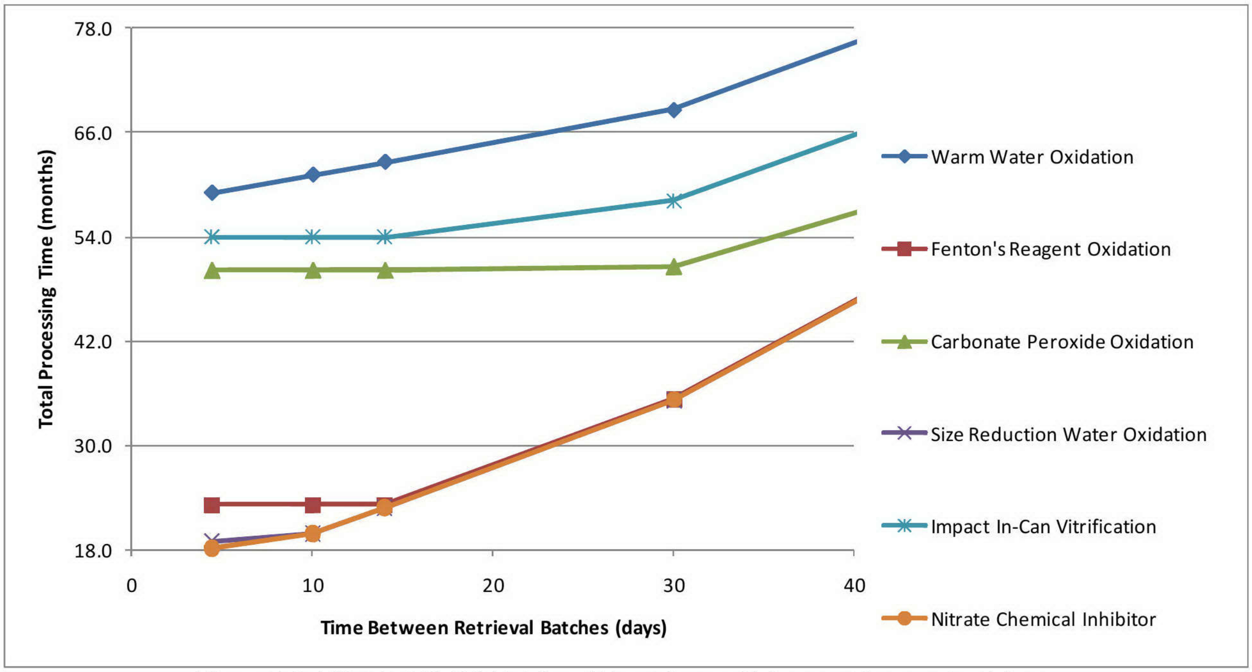

Figure I-3. Effect of STSC Retrieval Turn-Around-Time on Processing Time

I3.2.2 Sludge Batch Volume and Solids Concentration

A current base case assumption is that the sludge from each STSC must be delivered in a single batch transfer of up to 3500 gallons. Solids content is assumed to be 5 % by volume for the base transfer or 4% by volume when water for line flushes is considered. The Phase 2 sludge treatment system must be able to accept the entire transfer including flush water without interruption. Alternate retrieval assumptions could be contemplated. Examples:

1. Retrieval and transfer of each STSC batch in multiple steps, e.g. first pass, second pass, and possibly final cleanout pass. Slurry solids concentration would be more dilute in the second and final passes compared to the first pass.

2. Increase or decrease the assumed amount of dilution and flush water.

These assumption/requirement changes primarily affect the sizing of the initial receipt tank, wastewater volume, and sizing of condensate tanks. Some retrieval process changes may also imply delays to the overall retrieval schedule, which is addressed in Section 3.2.1. With the exception of retrieval schedule effects, it is expected that changes to batch volume and solids content assumptions would affect all of the currently identified technologies about equally. These assumptions are therefore not considered to be important to the relative evaluation of the candidate technologies.

I3.2.3 Wastewater Recycle to Retrieval

For the normalized flowsheets, an interface assumption/requirement was established that all wastewater must be treated to allow disposal via the 200 Area Effluent Treatment Facility (ETF). The retrieval process will require dilution and flush water, and slightly contaminated wastewater from the treatment process could potentially be used for those purposes to limit (or eliminate) wastewater discharge to ETF. Actual volumes of wastewater are not large compared to the ETF capacity and will depend largely on how efficiently process condensate can be recycled internally. Based on the currently identified technologies and flowsheet alternatives, this assumption appears to affect all about equally. Changing the assumption is not expected to materially change the relative comparison of the technologies.

I3.3 Processing of Additional Sludge Waste Streams

For the base case analysis the quantity and properties of sludge to be processed in Phase 2 is defined in Appendix J. The following additional sludge wastes have been identified that may also need to be processed by the Phase 2 sludge treatment system:

- Garnet filter media and comingled sludge from the K West Basin. It has been proposed that approximately 6.9 cubic meters bulk settled volume of garnet filter media be loaded into 3 STSCs, transported to T Plant and eventually processed by the Phase 2 treatment system.
- A large diameter container (LDC) filled with sand filter media from the K East Basin was loaded and transported to T Plant in 2008, where it remains in storage. The sand filter media may be removed and processed by the Phase 2 sludge treatment system.
- Approximately 262 pounds of residual north loadout pit (NLOP) sludge was left in an LDC at the end of the NLOP grouting campaign. This material may be removed and processed by the Phase 2 sludge treatment system.
- HNF-41051 Rev 6 states: "Planned disposition activities for ….the estimated 0.57 to 0.83 m^3 of sludge located in the north load-out pit of the K West Basin may increase the volumes of sludge in the Engineered Containers."[2]

As discussed below, all currently identified Phase 2 alternatives are expected to be capable of processing these additional sludge streams with little difficulty. Roughly 140 additional drums of immobilized waste will be produced assuming 55 gallon drums are used. If shielded 30 gallon drums are used about 255 additional drums will be required to process the identified added waste streams. Addition of this material to the sludge treatment scope will results in a larger increase in processing duration for ICV™ than for the other alternatives, but otherwise does not appear to create any additional significant discriminators between identified alternatives.

I3.3.1 K Basin Garnet Filter and Sand Filter Media

Garnet filters have been in use for a number of years to remove suspended solids from K West Basin settler tank effluent. The filter media and collected sludge solids must be removed prior to closure of the K West Basin. A proposed disposal path is to remove the garnet filter media and comingled sludge solids, place this material in STSCs to be stored at T Plant and eventually process it using the Phase 2 process system. Available information on garnet filter media characteristics is provided in Appendix K. Total volume of the filter media is estimated at 6.9 m^3. The filter bed consists of a mixture of fine silica sand, garnet sand, and coarse silica sand with a maximum particle diameter of 3,360 microns (μm). It is estimated to contain about 0.28 m^3 of settler tank sludge with a maximum U metal particle diameter of 8 μm.

An estimated 2.8 cubic meters of filter media from a sand filter used to filter water from in the K East Basin has already been removed, placed in a large diameter container (LDC) and moved to T Plant for interim storage and eventual processing for disposal at WIPP. Additional information on the sand filter media is provided in Appendix L.

Based on available information on their properties (Appendix K and L), it is expected to be feasible to process the garnet filter media and sand filter media in all Phase 2 technology alternatives currently under consideration. Particle sizes and densities are in the same range as the Engineered Container (EC) sludge. Total ^{239}Pu FGE content per cubic meter is estimated at less than half the base case level for the KE EC sludge. As such, waste loading in drums is expected to normally be volume limited, resulting in about

126 addition drums of remote handled TRU waste to be produced, stored, and disposed. All current alternatives except the Impact ICV™ process include a step to concentrate the sludge batch by evaporation. Because of the relatively small size of U metal particles in this waste, the sludge concentration step is expected to be sufficient to eliminate all residual U metal without the need for any other treatment. Therefore, after the initial concentration step the concentrated sludge batch can be transferred directly to the lag storage tank for drumming. Based on 3 additional STSCs of garnet filter media and 1 LDC of sand filter media, 126 additional product drums, and other base case assumptions, the additional processing time is estimated at 1.4 months for all alternatives except ICV™. Due to the lower estimated drumming rate, additional processing time is estimated at 4.4 months for ICV™.

I3.3.2 Residual North Loadout Pit Sludge

During an earlier sludge processing campaign North Loadout Pit sludge from the 105 K East Basin was transported to T Plant in LDCs and processed into a drummed waste form for disposal at WIPP as contact handled(CH)TRU waste. One of the LDCs could not be completely emptied during this campaign and has an estimated 262 pounds of North Loadout Pit sludge remaining in it. Available information suggests that the residual material is hung up in the internal filter assemblies. Efforts to remove this sludge by sluicing during the earlier campaign were not successful. The amount of residual sludge needs to be reduced sufficiently to allow the LDC to be disposed of at the Hanford burial grounds. A number of methods could be considered to remove the sludge or sludge components including physical methods to breakup and dislodge the retained sludge allowing it to be sluiced out; or chemical dissolution to remove problem components (primarily the actinide radioisotopes). Chemical dissolution of actinides could use common chemicals such as nitric acid, oxalic acid, or sodium carbonate plus hydrogen peroxide. These chemicals are expected to be compatible with all treatment alternatives currently under consideration. While an overall removal approach has not yet been defined, it appears very likely that all of the alternatives currently being considered will be able to process solutions or slurries generated with little difficultly. Because all options include methods for concentrating solutions or slurries very few additional product drums (1 to 3) are expected to be needed to dispose of this material.

There is also an estimated 0.57 to 0.83 m^3 of sludge located in the north load-out pit of the K West Basin that could be added to STP Phase 2 scope. While specific sample based characterization data is not available, this is expected to be similar to other sludge streams and should not present any additional processing problems for currently identified alternatives. Assuming waste loading is volume limited, adding this waste is estimated to add a maximum of eleven 55-gallon product drums.

I3.4 Updated Sludge Quantity and Properties

The current STP Phase 2 – Technology Alternatives Analysis is based primarily on Sludge Treatment Project baseline data as of mid 2009, including sludge property data, estimated sludge quantities, number and fill level of STSCs, product drum configuration, and the assumption that delivered sludge will be similar to sludge as it currently exists in the K Basins. Since that time potential changes to sludge compositions, quantities, and other assumptions have been identified as a result of sludge sampling and Sludge Treatment Project Phase 1 flowsheet development work [2, 3, 4]. This section discusses impacts to the sludge treatment technology evaluation based on known or potential changes to the base case assumptions.

I3.4.1 Sludge Property Data

Recent improved characterization data for the KE and KW engineered container sludge generally shows lower concentrations of radionuclides than the baseline data used for the base case analyses [3, 4]. The weight percent metallic uranium and total uranium was found to be less than prior estimates, and relatively little uranium metal was found in the coarse (>2000 µm) size cut. Based on these differences waste loading in drums is more likely to be volume limited as opposed to ^{239}Pu FGE limited for the base case and total drum count is estimated to be moderately reduced. Additional discussion of the more significant data is provided below.

Cesium Concentration

Analysis of recent core samples showed the concentration of ^{137}Cs in KE EC sludge of 18% to 33 % (average 26%) of the decay corrected baseline values [3]. For KW EC sludge the core sample analyses were 35 to 76 % (average 48%) of the decay corrected baseline values.

For waste to be disposed as RH TRU, the lower ^{137}Cs content will moderately reduce radiolytic hydrogen generation rates, but overall the reduced cesium is expected to have no significant impact to equipment, facility, waste loading, drum count, or operating performance. There are also potential impacts related to the alternative for disposing of the EC sludge as CH TRU in shielded 30 gallon drums, which is discussed in Section I3.5.

Fissile Isotope Content

The concentration of fissile isotopes in KE EC samples is less than ½ of the base case value for the KE EC sludge. For the KW EC sludge samples the fissile content is also modestly lower; about 20% less than the base case values [3, 4]. Implications are 1) the KE EC sludge is expected be volume limited based on the new data versus ^{239}Pu fissile gram equivalent (FGE) limited based on the baseline data used for the base case analysis; and 2) total drum count is expected to be modestly reduced. Table I-6 provides a rough estimate of drum count reductions related to the reduce fissile isotope content. Note that the updated estimates are based on the average sample analysis data, whereas the base case estimates use the project baseline "design basis" values. Therefore, the estimates shown may overstate actual drum reductions since design basis values typically include some margin above average sample analyses. Because of slower expected drum production rate, the ICV™ alternative tends to benefit more from reduced drum count. Otherwise, all identified alternatives are expected to be affected about equally.

Table I-6. Effect on Drum Count of Lower Fissile Isotope Concentration[3]

	KE EC Sludge[2]	KW EC Sludge[2]
Base case estimate 55 gallon drums[1]	323	199
Estimate based on new data- 55 gallon drums[1]	236	161
% change	-27%	-19%

[1]Estimated reduction may be overstated because the new estimate is based on average sample analysis while the old estimate is based on "design basis" values which typically include some conservatism.
[2]For the base case estimate KE EC sludge loading per drum is ^{239}Pu FGE limited versus physical volume limited per the new data, KW EC sludge loading is ^{239}Pu FGE limited for both cases.
[3]Settler tank sludge has been sampled and is being analyzed but results are not yet available. Therefore, there is currently no change to the drum count estimate based on new sludge property data.

I3.4.2 Changes to Number of STSCs and Sludge Volume

Most of the settler tank sludge has been removed from the settler tanks and transferred to an engineered container in the 105 KW Basin. Updated measurements of settler tank sludge in the engineered container indicate the volume is significantly smaller (about 3.5 m^3) than the baseline data (5.4 m^3) [5]. Even if modest amounts of additional setter sludge are accumulated due to final basin cleanout the total amount is expected to be substantially less than the current STP baseline quantity. Samples of settler tank sludge are currently being characterized; however, results are not yet available. The number of settler tank sludge product drums is expected to drop by about 1/3 assuming that the new sludge characterization data is not higher than current baseline fissile isotope content and minimal additional settler tank sludge is added during final basin cleanout.

Several estimated values for the number of STSCs to be processed are included in Reference 2. While the final number is not yet certain it is clear that the total number of STSCs will increase compared to the base case value. The maximum volume of settler tank sludge per STSC has also been reduced [2]. The increased number of STSCs is expected to slightly increase processing time. The reduced volume of settler tank sludge per STSC is expected to have minimal impact to Phase 2 processing. Table I-7 provides updated overall drum count estimates based both the lower fissile isotope content for EC sludge (Section I3.4.1) and 1/3 reduction in settler tank sludge volume. Overall reduction in drum count is on the order of 30 % based on 55-gallon product drums and other base case assumptions. Because of slower expected drum production rate, the ICV™ alternative tends to benefit more from reduced drum count. Otherwise, all identified alternatives are expected to be affected about equally.

Table I-7. Drum Count with Reduced Fissile Isotope Concentration and Settler Sludge Volume

	KE EC Sludge[2]	KW EC Sludge[2]	Settler Tank Sludge[3]	Total
Base case estimate 55 gallon drums[1]	323	199	991	1513
Estimate based on new data-55 gallon drums[1]	236	161	661	1058
% change	-27%	-19%	-33%	-30%

[1]Estimated reduction may be overstated because the new estimate is based on average sample analysis while the old estimate is based on “design basis” values which typically include some conservatism.
[2]For the base case estimate KE EC sludge loading per drum is ^{239}Pu FGE limited versus physical volume limited per the new data, KW EC sludge loading is ^{239}Pu FGE limited for both cases.
[3]Based on an assumed 1/3 reduction in settler tank sludge volume with no change to composition. Settler tank sludge has been sampled and is being analyzed but results are not yet available.

I3.4.3 Changes in Sludge Properties During Storage

The K Basin sludge contains a mixture of particulate materials including irradiated metallic uranium reactor fuel, fuel corrosion products, wind borne soil, filter sand, corrosion products from racks (iron and aluminum), canisters (aluminum), and walls (concrete), organic and inorganic Ion Exchange Module (IXM) media (mixed bed organic cation/anion resin and mordenite), cationic polymer flocculent, graphoil (graphite seal material), and other minor constituents. K Basin sludge is defined as any particulate material originating from K Basins that can pass through a screen with 1/4-in. (6350 μm) openings [7].

Beginning in 1993, a significant number of characterization campaigns and laboratory studies were conducted on the K Basin sludge [reference 9 Table 1-1]. The physical and chemical characterization of the sludge has been summarized in the design basis feed documents and in the sludge data book [10]. These documents provide specific characterization data used to develop processes for disposition of the sludge inventory. Concerns in the transport of sludge at various points in the process include:

- The formation of high shear strength slurries.
- Mitigation of high shear strength slurries, if formed.
- Further process chemical and physical property changes that could affect transport.

The sludge may be stored at T Plant for an extended time period prior to retrieval and processing by the Phase 2 project. One concern is that changes to the sludge during storage could change the conclusions of the current sludge treatment technology evaluation. The potential sludge property changes and related effects are discussed below.

- Content of dissolved species in the liquid phase. Currently the sludge is stored in chilled water with low dissolved solids content. Basin water is processed through ion exchange, which removes most dissolved solids, including radioisotopes that leach from the sludge solids. During storage in the STSCs the temperature will increase to ambient and water treatment will no longer be performed. Consequently an increase in the dissolved solids and radioisotope content of the liquid/water phase can be expected over time. At the current level of flowsheet analysis a moderate increase in the dissolved fractions would make no difference to the technology alternative comparisons. All identified alternatives process suspended and dissolved solids in the same way. The only potential impact identified is that contamination levels in process condensate could increase because the decontamination factors for suspended solids are typically better than for dissolved solids. This is considered to be a minor design/operations issue since evaporators at the Hanford Site (e. g. 242-A) have operated in the past with much higher levels of dissolved solids and radioisotopes while producing condensate that meets ETF acceptance criteria.

- Oxidation of U metal during storage. Uranium (U) metal will continue to react with water during storage of sludge in the STSCs. If the amount of U metal is substantially reduced it could potentially simplify processing of the sludge in Phase 2. A previous study evaluated this topic and found that oxidation during storage is expected to be relatively minor under planned storage conditions [6]. No credit for oxidation during storage was taken for any of the current alternatives. Consequently, it is concluded that U metal oxidation during storage has little or no effect on the current comparison of alternatives.

- Agglomeration of sludge particles during storage. Past experience has shown that solid particles in contact with one another may form agglomerates during storage. The presence of large agglomerates in the sludge could present processing difficulties. Some testing work has been performed to evaluate potential for agglomeration during long term storage. Agglomeration during storage appears to be primarily an issue related to design of the retrieval system, which is outside the scope of the current Technology Alternatives Analysis. However, there could be some impacts to the treatment and packaging systems. If the sludge character (as received from retrieval) were changed to include a large fraction of large, coarse solids it could complicate agitation, pumped transfers, and assay. Because the processes are already designed to handle dense solids up to ¼ inch diameter, this is not expected to be a significant issue. If it does become an issue, some alternatives may offer better ability to deal with it. Specific examples:

  - The Size Reduction and Water Oxidation Process (SRWOP) includes a milling step on the front end to size reduce coarse, fast settling solid. This process is likely to be well equipped to handle a significant increase in size or quantity of coarse material.

  - The Fenton's Reagent Oxidation Process (FROP) requires use of upgraded materials for process equipment to withstand corrosion resulting from added chemicals (chloride, ferrous ion, and peroxide). Use of the upgraded materials of construction will also increase flexibility for using other chemicals to break up agglomerates if needed.

  - Retrieval difficulties related to particle agglomeration could affect the retrieval rate or time between batch transfers, batch size, and number of batches transferred. These types of changes are considered earlier in Section I3.2 of this report.

- If problems with solids agglomeration result in a substantial change to the retrieval interface concept there could be significant impacts to the treatment systems. For example, some or all of the sludge could be transferred from retrieval to treatment as granular material in containers rather than as a slurry via a pump and piping system. Since this event is considered to be very unlikely it has not been specifically evaluated.

I3.4.4 Conclusions Relative to Changes to Sludge Quantity and Properties.

Overall, the updated data is expected to modestly reduce total drum count, reduce estimated overall processing time, and increase the importance of achievable physical waste loading (equivalent liters of as-settled sludge per drum). There may also be an increased incentive to blend KE and KW container sludge types in order to reduce total drum count.

Because of lower expected drum production capacity, the ICV™ alternative tends to benefit more from reduced drum count. Otherwise, all identified alternatives are expected to be affected about equally.

I3.5 Shielded 30 Gallon Drums

For the base case evaluation, the K Basin sludge is assumed to be disposed of as RH TRU waste in 55 gallon drums. However, to alleviate constraints on capacity for RH TRU waste disposal a proposed alternate is to use a 30 gallon drum concept wherein each 30 gallon drum is placed in shielded container for transportation and disposal at WIPP. With this approach, filled 30 gallon drums with acceptable radioactivity levels would be handled as CH TRU waste (shielded container external surface dose rate <200 mR/hour). The shielded container external dimensions are similar to a standard 55 gallon drum. Shielded containers that meet the <200 mR/hour surface dose rate criterion would be transported to WIPP using a HalfPACT shipping container [8]. The shielded container has not yet been approved for use and some technical aspects remain to be more fully defined and evaluated. The following discussion is based on available preliminary information. Only a scoping evaluation has been performed to date.

I3.5.1 Loading Limits for 137Cs in Shielded 30 Gallon Drums

The only identified advantage of using 30 gallon drums in a shielded container is to allow RH TRU waste to be handled as CH TRU waste. To be classified as CH TRU the dose rate cannot exceed 200 mR/hour at any point on the external surface of the shielded container. The primary contributor to external radiation levels is ^{137}Cs. There is currently uncertainty as to the amount of ^{137}Cs that can be placed in each drum while assuring the external dose rates will not exceed the 200 mR/hour criterion. The external dose rate will depend not only on the amount of ^{137}Cs; but also on how it is distributed in the drum; any self-shielding provided by the waste form; and the thickness, density, and uniformity of shielding provided by the shielded container. Preliminary informal estimates indicate a range from about 2 to 11.3 Curie (Ci) of ^{137}Cs per drum will result in surface dose equal to the maximum 200 mR/hr criterion [9, 10]. The lower value is based on no self shielding of the waste form in the 30 gallon drum, while the maximum value is for a uniform ^{137}Cs concentration throughout the 30 gallon drum with significant self shielding from a cement type waste form. Other values include 8.7 Ci per drum if the maximum concentration is 2 times the average and 6.8 Ci per drum if the ^{137}Cs concentration is eight times larger at the bottom than at the top. Both of these values take credit for the self shielding provided by the cemented waste form. The curie limits may be lower for waste forms that provide less self shielding. Average values achievable during actual operations will be lower than the limiting values to provide assurance that individual drums will not exceed the limit, considering measurement and control uncertainties and other typical operational allowances.

I3.5.2 Impacts to Estimated Drum Count

The base case analyses generally consider two limits in evaluating the quantity of waste that can be placed in each drum: 1) physical volume of sludge, and 2) fissile isotope content in terms of ^{239}Pu fissile gram equivalents (FGE). In the base case analysis it is assumed that 1) the average achievable physical volume is 78 liters of as-settled sludge per 55-gallon drum for all alternatives except ICV™ (see Appendix J Section 3.12.2); and 2) the average achievable fissile isotope content is 40 ^{239}Pu FGE per drum for all alternatives (Appendix J Section 3.7). Note that these are not “limits” but rather they are assumed average achievable operational loadings that will assure all drums are within the applicable limits. For scoping evaluation it is assumed that the achievable volumetric loading is reduced to 42.5 liters as-settled sludge per 30-gallon drum based on the smaller drum volume, while it is assumed that the achievable fissile isotope loading is 40 ^{239}Pu FGE per drum, the same as the 55-gallon drum.

For the sensitivity evaluation two data sources were use for the ^{137}Cs and fissile isotope concentration in the sludge:

- Baseline “design” values provided in HNF-41051 Rev. 2, as compiled in Appendix J. The provided values are as of a May 31, 1998 decay date. The values were decayed to October 1, 2013 for the current evaluation (approximately 30 % loss of ^{137}Cs to decay).
- Values based on recent sample analysis [3, 4] for KE EC and KW EC sludge. The settler tank sludge has been sampled but analyses are not yet available.

KE EC Sludge

Table I-8 shows the effect of drum size and assumed cesium limit for the KE EC sludge. Using the baseline sludge property data the estimated number of drums increases by 34% (from 323 to 433) due to switching to the 30 gallon drum if there is no consideration of a ^{137}Cs limit. This increase results from the smaller volume of the drum, which also results in the limiting parameter changing from ^{239}Pu FGE content to physical volume. For the unconstrained case with no ^{137}Cs limit the average ^{137}Cs content is estimated at 9.3 Ci/ drum. If the average achievable ^{137}Cs content is reduced below that value, the number of drums may increase significantly as show in the table.

Results based on the new sample analysis are somewhat different. Switching to the 30 gallon drum is estimated to increase the number of drums by about 83 %. However, even in the unconstrained case the average ^{137}Cs is only 3 Ci/ per drum, so that imposing a ^{137}Cs content limit is expected to have little or no impact beyond the 83 % increase in drum count resulting from the smaller drum.

Table I-8. KE EC sludge-effect of drum size and cesium limit assumptions

Case	Limiting Parameter	Ave ^{137}Cs Content [1]	Number of Drums
	Results Based on Current Baseline, Design Sludge Properties[1]		
Base case, 55 gallon drums	^{239}Pu FGE limited[2], no constraint on ^{137}Cs content	12.4 Ci/Drum	323
Baseline waste 30 gallon drums	Volume limited[2], no ^{137}Cs limitation	9.3 Ci/ Drum	433
Baseline waste 30 gallon drums	Cs limited	4 Ci/Drum	1002
Baseline waste 30 gallon drums	Cs limited	5 Ci/Drum	802

Baseline waste 30 gallon drums	Cs limited	6 Ci/Drum	668
Baseline waste 30 gallon drums	Cs limited	7 Ci/Drum	573
	Results Based on New Sample Analysis[3]		
New sample data 55 gallon drums	Volume limited,	5.6 Ci/Drum	236
New sample data 30 gallon drums	Volume limited	3.0 Ci/Drum	433

1. Table shows the average ^{137}Cs content if the drums are loaded per the indicated limiting parameter. Based on HNF-41051 Rev. 2 values decayed to October 1, 2013
2. Volume limitation based on average 42.5 liters as-settled sludge per 30 gallon drum or 78 liters per 55 gallon drum, ^{239}Pu FGE limitation is based on average 40 ^{239}Pu FGE per drum.
3. Based on new sample analyses and draft Databook value of 71.6 Ci/m^3

KW EC Sludge

Table I-9 shows the drum size and ^{137}Cs content assumptions for the KW EC sludge. Using the baseline sludge property data the estimated number of drum for both the 55 and 30 gallon drums are the same if there is no consideration of a ^{137}Cs limit. Both cases are limited by fissile isotope content. For the unconstrained case the average ^{137}Cs content is estimated at 13.9 Ci/ drum. If the average achievable ^{137}Cs content is limited to less than that value, the number of drums may increase significantly as show in the table. Results based on the new sample analysis show a reduction in the estimated drum count and a reduction in the impact of potential ^{137}Cs loading limits for the shielded 30 gallon drum.

Table I-9. KW EC sludge-effect of drum size and cesium limit assumptions

Case	Limiting Parameter	Ave Ci ^{237}Cs per Drum	Number of Drums
	Results Based on Current Baseline, Design Sludge Properties[1]		
Base case, 55 gallon drum	FGE Limited, no constraint on ^{137}Cs	13.9	199
Baseline waste 30 gallon drums	FGE Limited, no constraint on ^{137}Cs	13.9	199
Baseline waste 30 gallon drum	Cs limited	4	690
Baseline waste 30 gallon drum	Cs limited	5	552
Baseline waste 30 gallon drum	Cs limited	6	460
Baseline waste 30 gallon drum	Cs limited	7	394
Baseline waste 30 gallon drum	Cs limited	8	345
	Results Based on New Sample Analysis[2]		
New sample data 55 gallon	FGE Limited, no constraint on ^{137}Cs	8.3	161
New sample data 30 gallon	FGE Limited, no constraint on ^{137}Cs	8.3	161
New sample data 30 gallon	Cs limited	4	334
New sample data 30 gallon	Cs limited	5	267
New sample data 30 gallon	Cs limited	6	223
New sample data 30 gallon	Cs limited	7	191
New sample data 30 gallon	Cs limited	8	167

1. Table shows average ^{137}Cs content if the drums are loaded per the indicated limiting parameter. Based on HNF-41051 Rev. 2 values decayed to October 1, 2013

2. Volume limitation based on average 42.5 liters as-settled sludge per 30 gallon drum or 78 liters per 55 gallon drum, ^{239}Pu FGE limitation is based on average 40 ^{239}Pu FGE per drum.
3. Based on new sample analyses and draft Databook value of 262 Ci ^{237}Cs/m3

Settler Tank Sludge

Table I-10 shows the results for settler tank sludge. Using baseline sludge property data the estimated number of drum for both the 55 and 30 gallon drums are the same if there is no consideration of a ^{137}Cs limit. Both cases are limited by fissile isotope content. For the unconstrained case the average 137Cs content is estimated at 9.2 Ci/ drum. If the achievable ^{137}Cs content is below that value, the number of drums may increase significantly. Data from sample analysis is not yet available for settler tank sludge. Recent estimates indicate total settler tank sludge volume to be processed is about 1/3 less than the current baseline value (see Section I3.4.2). Pending results of sample analysis, the sludge volume reduction is expected to reduce drum count proportionally for all cases shown in Table I-10.

Table I-10. Settler Tank Sludge-effect of drum size and cesium limit assumptions

Case	Limiting Parameter	Ave Ci ^{137}Cs per Drum[1]	Number of Drums [3]
Base case, 55 gallon drum	FGE Limited no constraint on ^{137}Cs content	9.2	991
Baseline waste 30 gallon drum	FGE Limited no constraint on ^{137}Cs content	9.2	991
Baseline waste 30 gallon drum	Cs limited	4	2278
Baseline waste 30 gallon drum	Cs limited	5	1822
Baseline waste 30 gallon drum	Cs limited	6	1518
Baseline waste 30 gallon drum	Cs limited	7	1302

1. Table shows average ^{137}Cs content if the drums are loaded per the indicated limiting parameter. Based on HNF-41051 Rev. 2 values decayed to October 1, 2013
2. Volume limitation based on average 42.5 liters as-settled sludge per 30 gallon drum or 78 liters per 55 gallon drum, ^{239}Pu FGE limitation is based on average 40 ^{239}Pu FGE per drum.
3. Number of drums shown is based on baseline sludge quantity. Based on more recent measurements the estimated quantities are reduced by about 1/3.

Overall Drum Count Impacts

There are multiple strategies that could be considered for use of shielded 30 gallon drums. For example:

1. Load volume limited waste in 55 gallon drums and FGE limited waste in 30 gallon drums. Then, on a drum by drum basis determine if each 30 gallon drum will meet the 200 mR/hour surface dose limit when placed in a shielded container. Put 30 gallon drums that meet the limit in shielded containers and dispose as CH TRU. Put 30 gallon drums that do not meet the dose rate limit in unshielded 55 gallon drum over packs and dispose as RH TRU. All 55 gallon drums are expected to be RH TRU.

2. Put all sludge in 30 gallon drums loaded without considering potential ^{137}Cs limitations, i.e. load drum to according to the volumetric or ^{239}Pu FGE limits, whichever is more limiting. Then, on a drum by drum basis determine if each drum will meet the 200 mR/hour surface dose limit when place in a shielded container. Put drums that meet the limit in shielded containers and dispose as CH TRU.

Put 30 gallon drums that do not meet the dose rate limit in unshielded 55 gallon drum over packs and dispose as RH TRU.

3. Put all sludge in 30 gallon drums and reduce waste loading as needed such that all shielded 30 gallon drums will meet the surface dose rate limit.
4. A combination of 2 and 3 wherein waste loading for some drums would be constrained to stay within the ^{137}Cs limitation but others are loaded fully to the other limits.

Option 1 leads to no increase in the estimated number of drums compared to use of 55 gallon drums for all sludge. Option 1 also leads to the smallest fraction of drums that would qualify for handling as CH TRU waste. Based on the new sample data for KE EC and KW EC sludge and the reduced volume estimate for settler tank sludge, total drums are estimated at 1058 (see Section I3.4.2), or about 1200 if all the potential added sludge types are included (see Section I3.3). Fraction of the total drums that could be disposed as CH TRU will depend strongly on the loading of ^{137}Cs that is achievable within the 200 mR/hr limit. If it is on the high end of the preliminary estimates a large fraction of the drums should qualify as CH TRU. If it is on the low end of the preliminary estimates very few may qualify as CH TRU.

Option 2 leads to an estimated 83 % increase in the number of drums for the KE EC sludge and the potential added sludge types (I3.3), and no increase in estimated drums for KW EC and settler tank sludge types. Total drums based on the new sludge composition and quantity estimates increase from 1058 to 1255, a 19 % increase. Including the potential added sludge types increases the total to about 1510. The preliminary analysis suggests that the KE EC sludge shielded drums are likely to qualify as CH TRU waste. Fraction of the KW EC and settler tank sludge drums that could be disposed as CH TRU will depend strongly on the loading of ^{137}Cs that is achievable within the 200 mR/hr limit. If it is on the high end of the preliminary estimates a large fraction of the drums should qualify as CH TRU. If it is on the low end of the preliminary estimates very few may qualify as CH TRU.

Options 3 and 4 result in to an estimated 83 % increase in the number of drum for the KE EC sludge and the potential added sludge types (I3.3). For the other sludge types a small or large increase in the number of drums may result, depending strongly on the loading of ^{137}Cs that is achievable within the 200 mR/hr limit. If allowable ^{137}Cs is on the high end of the preliminary estimates the effect of drum count for the other waste types should be small. If allowable ^{137}Cs is on the low end of the preliminary estimates the effect on drum count for the other waste types could be very high.

I3.5.3 Conclusions-Shielded 30 Gallon Drum

1. Clear and reliable estimates for achievable ^{137}Cs are essential to estimating the fraction of waste disposable as CH TRU, drum count impacts, and for making decisions regarding implementation strategy. All options except loading volume limited waste in 55 gallon drums (Section 1.3.5.2 Option 1) result in increased drum count. Performance of ICV™ is most sensitive to changes in drum count. Sludge processing times for all alternatives are sensitive to drum count, however, with the exception of ICV™ the relative ranking of alternatives is not affected by changes in drum count (see Section I3.6). However, significantly increased drum count will push some options beyond the 60 month processing time criterion.
2. With the exception of drum count effects on processing schedule, use of shielded 30 gallon drums does not appear to significantly affect relative comparison of the currently defined alternatives, e.g. safety, operability, technical maturity, or cost. There will likely be significant impacts to the on-site storage and preparation for shipping functions, which are outside the scope of the current evaluation.

I3.6 Drum Count Related Impacts

There are a number of variables that could potentially affect the overall number of drums produced by the Immobilization and Packaging System. This section provides a summary of factors that could affect total drum count and estimates of the sensitivity of processing time to changes in drum count for each of the technologies currently being evaluated. The sensitivity analysis provides only a rough scoping evaluation, in that it does not fully evaluate all potential reasons for the changed drum count.

I3.6.1 Factors Affecting Drum Count

The base case drum count estimates are calculated using a number of bases and assumptions, several of which have significant uncertainty. The following factors were identified during the sludge treatment technology evaluation.

- Achievable ^{239}Pu FGE loading. Base case calculations assume and average 40 ^{239}Pu FGE loading per drum unless the volumetric waste loading limit is more restrictive. The WIPP WAC requires that measured value plus two times the measurement uncertainty be less than the applicable RH 72B loading limit [8]. The 40 ^{239}Pu FGE per drum is the assumed average operational loading that is achievable while assuring that a 325 ^{239}Pu FGE loading limit per RH-72B cask is met and assuming that 3 filled drums will normally be loaded in each RH-72B cask. The achievable loading value is lower than the limit based on consideration of TMU and operational allowances and inefficiencies. For example, due to normal process measurement and control fluctuations an operating facility cannot target loading each drum to the technical limit without having a substantial fraction of the drums end up over the limit. To assure all drums are within the limit, a lower operational target value or operating limit is required. Due to the number of parameters involved, limited definition of the assay and process controls systems, and the limited work to date to firm up estimates for the various parameters, the actual achievable ^{239}Pu FGE loadings could easily vary substantially from the assumed values.

  The relatively low 40 ^{239}Pu FGE average loading assumption is based in part on the assumption that fissile isotopes will be calculated using a dose to curie methodology based on gamma radiation measurements. Other methods could be considered to reduced total measurement uncertainty and thereby allow increased average 40 ^{239}Pu FGE loading. For example passive/active neutron analysis, or direct sampling and laboratory analysis of sludge samples could be considered. If reduced measurement uncertainty were sufficient to allow an increase from 40 ^{239}Pu FGE to 70 ^{239}Pu FGE average achievable drum loading, the estimated drum count drops by almost 43 %, (from 1513 to 864) using other base case assumptions [1].

- Achievable volumetric loading. Achievable volumetric waste loading for ICV™ has been estimated based on very limited test data and only partial information related to the dryer/melter interface, control of additions to the drum, and impact/recovery from drum overfilling. Consequently, there may be a substantial uncertainty in the actual average achievable waste loading per drum. For the Portland cement based immobilization processes there is relatively more test data on the technical limit for water loading to avoid free liquid in the drum. However, there is still significant uncertainty in the overall achievable waste loading which is a function of achievable solids concentration for slurry transfers, mixing uniformity, accuracy of process measurements, and overall performance of process instrumentation and control systems.

- Shielded 30 gallon drum. As discussed in Section I3.5 above use of shielded 30 gallon drums is expected to result in an increase in total drum count. However, the magnitude of the increase could vary substantially.

- Updated data on waste composition and quantity. As discussed in Section 3.4 more recent data on EC sludge properties and on settler tank sludge quantity are expected to reduce drum count by something on the order of 30 %. However, sample data on settler tank sludge and approved updated Databook values are not yet available.

- Additional waste added to scope. As discussed in Section I3.3 there are a number of additional wastes from 105 KW that may be added to the STP phase 2 scope. These added wastes are expected to add about 140 55-gallon drums or about 255 30-gallon drums. Other wastes from K Area sources or from other Hanford Site sources could conceivably be added to the STP Phase 2 processing scope. However, specifics have not currently been identified.

I3.6.2 Impact of Drum Count on Processing Duration

A large number of individual scenarios could be considered to evaluate the effect of changes in drum count. To allow a tractable scope for the current evaluation, simplified scoping analyses were developed that do not consider all reasons for the changed drum count. The base case number of drums required to package all K Basin sludge is 1,513 (323, 199, and 991 drums for the KE EC, KW EC, and settler tank sludges, respectively) based on the assumed average fissile loading of 40 ^{239}Pu FGE per drum. The sensitivity analyses consider minimum and maximum cases for the total number of drums based on 70 ^{239}Pu FGE and 20 ^{239}Pu FGE per drum, respectively, giving a minimum of 865 drums and maximum of 3,026 drums. It is assumed that there are no changes in the number of STSCs.

To estimate the effect of total drum count on overall processing duration, the average time to drum each KE EC, KW EC, and settler tank sludge batch with each processing method was calculated. This calculation is based on the assumed average number of drums expected per STSC batch (using base, minimum, or maximum drum count cases) and the base case drumming rate. The base case drum production rate for the Portland cement-based systems is 30 drums per week, and the base case immobilization rate for ICV^{TM} is 9.3 drums per week. Batch preparation time, which includes all steps required to receive an STSC batch and prepare it for transfer to the immobilization and packaging system, was calculated for each treatment method. A summary of average drumming and batch preparation times for each processing method and drum count is given in Table I-11. All Table I-11 values are based on 100% total operation efficiency (TOE).

Calculation of the overall processing time is performed as follows:

1. For each processing method and drum count combination, the estimated batch drumming time is compared to batch preparation time for each sludge type in order to determine the rate-limiting step.

2. Total processing times for each sludge type (KE EC, KW EC, and settler tank sludge) are then calculated using the limiting processing step and the base case number of STSC batches for each sludge type (11 KE EC, 5 KW EC, 8 settler).

3. Overall total processing time for each method is then calculated.

Elements of the calculation and the estimated total processing time as 100% and 70% TOE are shown in Table I-12.

Table I-11. Average Batch Preparation and Drumming Time Estimates

		Warm Water Oxidation (WWO)[1]	Peroxide Carbonate Oxidation (PCOP)	Fenton's Reagent Oxidation (FROP)	Size Reduction and Water Oxidation (SRWOP)	Nitrate Chemical Inhibitor (NCIP)	Joule Heated In-Container Vitrification (ICV™)
KE Batch Preparation Time (Days)[2]		124.8	50.2	14.3	8.9	6.4	N/A[6]
KE Batch Drumming Time (Days)	Min. drum count[3]	8.0	4.0	4.0	4.0	4.0	12.8
	Base case drum count[4]	14.0	7.0	7.0	7.0	7.0	22.6
	Max. drum count[5]	27.6	13.8	13.8	13.8	13.8	44.5
KW Batch Preparation Time (Days)[2]		124.8	50.2	14.3	8.9	6.4	N/A[6]
KW Batch Drumming Time (Days)	Min. drum count[3]	10.8	5.4	5.4	5.4	5.4	17.4
	Base case drum count[4]	18.8	9.4	9.4	9.4	9.4	30.2
	Max. drum count[5]	37.4	18.7	18.7	18.7	18.7	60.3
Settler Tank Sludge Batch Preparation Time (Days)[2]		10.8	15.0	14.3	8.9	6.4	N/A[6]
Settler Tank Sludge Batch Drumming Time (Days)	Min. drum count[3]	33.2	16.6	16.6	16.6	16.6	53.5
	Base case drum count[4]	58.0	29.0	29.0	29.0	29.0	93.4
	Max. drum count[5]	115.8	57.9	57.9	57.9	57.9	186.7

1. In the WWO base case, 2 STSCs are processed per batch; all others assume 1 STSC per batch.
2. Drum production rates are 9.3 drums per week for ICV™ and 30 drums per week for all other processes.
3. The minimum drum counts are 185, 114, and 566 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 70 FGE/drum loading value.
4. The base case drum counts are 323, 199, and 991 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 40 FGE/drum loading value.
5. The maximum drum counts are 646, 398, and 1,982 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 20 FGE/drum loading value.
6. The effective batch preparation time for ICV™ is considered to be negligible for all cases.

Table I-12. Total Processing Time for Drum Count Sensitivity Cases

	Drumming Rate Case	Warm Water Oxidation (WWO)[1]	Peroxide Carbonate Oxidation (PCOP)	Fenton's Reagent Oxidation (FROP)	Size Reduction and Water Oxidation (SRWOP)	Nitrate Chemical Inhibitor (NCIP)	Joule Heated In-Container Vitrification (ICV™)
Total KE EC Sludge Processing Time at 100% TOE (Months)[2]	Min. drum count[3]	16.4	18.2	5.2	3.2	2.3	4.6
	Base case drum count[4]	16.4	18.2	5.2	3.2	2.5	8.2
	Max. drum count[5]	16.4	18.2	5.2	5.0	5.0	16.1
Total KW EC Sludge Processing Time at 100% TOE (Months)[2]	Min. drum count[3]	16.4	8.3	2.4	1.5	1.1	2.9
	Base case drum count[4]	16.4	8.3	2.4	1.5	1.5	5.0
	Max. drum count[5]	16.4	8.3	2.4	3.1	3.1	9.9
Total Settler Tank Sludge Processing Time at 100% TOE (Months)[2]	Min. drum count[3]	4.4	4.4	4.4	4.4	4.4	14.1
	Base case drum count[4]	7.6	7.6	7.6	7.6	7.6	24.6
	Max. drum count[5]	15.2	15.2	15.2	15.2	15.2	49.1
Drumming Time of Last Batch at 100% TOE (Months)[2]	Min. drum count[3]	1.1	0.6	0.6	0.6	0.6	N/A
	Base case drum count[4]	1.9	1.0	1.0	1.0	1.0	N/A
	Max. drum count[5]	3.9	1.9	1.9	1.9	1.9	N/A
Total Processing Time (Months), at 100% TOE for all STSCs[2]	Min. drum count[3]	38.3	31.5	12.6	9.7	8.4	21.6
	Base case drum count[4]	42.3	35.1	16.2	13.3	12.6	37.8
	Max. drum count[5]	51.9	43.6	24.7	25.2	25.2	75.1
Total Processing Time (Months) at 70% TOE for all STSCs[2]	Min. drum count[3]	54.7	45.0	18.0	13.9	12.0	30.9
	Base case drum count[4]	60.4	50.1	23.1	19.0	18.0	54.0
	Max. drum count[5]	74.1	62.3	35.3	36.0	36.0	107.3

1. In the WWO base case, 2 STSCs are processed per batch; all others assume 1 STSC per batch.
2. Drum production rates are 9.3 drums per week for ICV™ and 30 drums per week for all other processes.
3. The minimum drum counts are 185, 114, and 566 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 70 FGE/drum loading value.
4. The base case drum counts are 323, 199, and 991 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 40 FGE/drum loading value.
5. The maximum drum counts are 646, 398, and 1,982 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 20 FGE/drum loading value.
6. The effective batch preparation time for ICV™ is considered to be negligible for all cases.

Table I-13 and Figure I-4 show the overall effects on processing time at 70% TOE from changes in drum count. As can be seen the drum count significantly affects processing time for all alternatives. The increase in processing time with increased drum count is largest for ICV™. With the exception of ICV™ there are no changes to the relative rankings of alternatives related to changes in drum count. However, for the WWO and ICV™ alternatives the maximum drum count case increases estimated processing time beyond the 60 month time criterion.

Table I-13. Total Processing Time versus Drum Count

	Total Processing Time (Months) At 70% TOE for all STSCs[2]		
	Minimum drum count[3]	**Base case drum count[4]**	**Maximum drum count[5]**
Warm Water Oxidation (WWO)[1]	54.7	60.4	74.1
Peroxide Carbonate Oxidation (PCOP)	45.0	50.1	62.3
Fenton's Reagent Oxidation (FROP)	18.0	23.1	35.3
Size Reduction and Water Oxidation (SRWOP)	13.9	19.0	36.0
Nitrate Chemical Inhibitor (NCIP)	12.0	18.0	36.0
Joule Heated In-Container Vitrification (ICV™)	30.9	54.0	107.3

1. In the WWO base case, 2 STSCs are processed per batch; all others assume 1 STSC per batch.
2. Drum production rates are 9.3 drums per week for ICV™ and 30 drums per week for all other processes.
3. The minimum drum counts are 185, 114, and 566 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 70 FGE/drum loading value.
4. The base case drum counts are 323, 199, and 991 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 40 FGE/drum loading value.
5. The maximum drum counts are 646, 398, and 1,982 drums of KE EC, KW EC, and settler sludge, respectively, and are based on a 20 FGE/drum loading value.

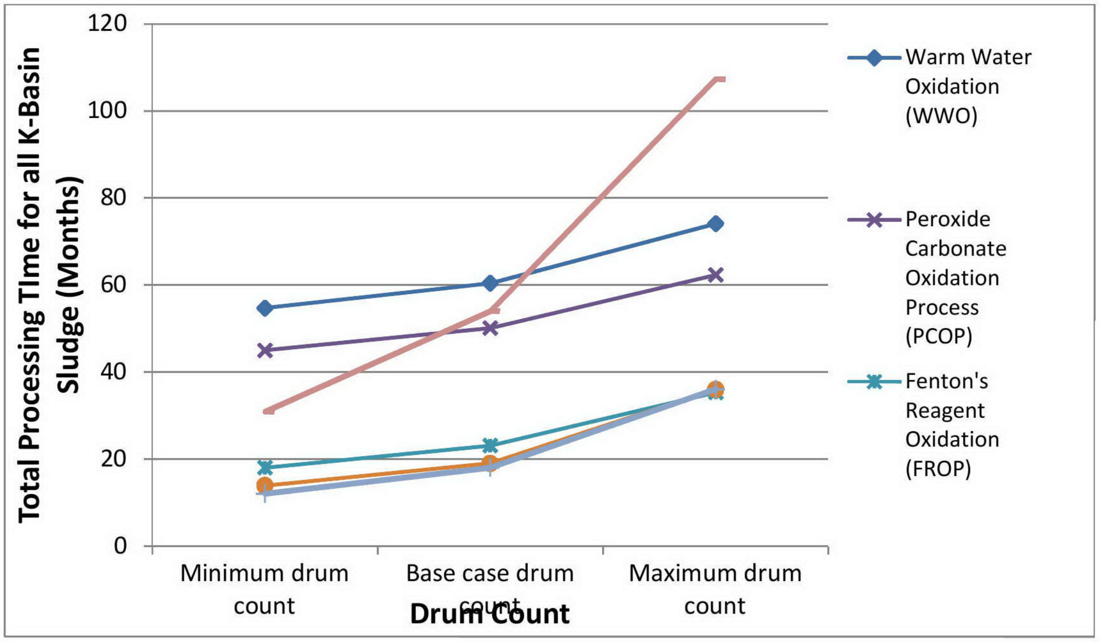

Figure I-4. Total Processing Time versus Drum Count

The total processing time for each method was calculating using the various estimated drum counts.

I3.6.3 Conclusions

The drum count significantly affects processing time for all alternatives. The increase/decrease in processing time with increased/reduced drum count is largest for the ICV™ alternative. With the exception of ICV™ there are no changes to the relative rankings of alternatives related to changes in drum count. However, for two of the alternatives (WWO and ICV™) the maximum drum count case increases estimated processing time beyond the 60 month processing time criterion.

There is significant uncertainty in a number of factors that affect drum count. Future project work should consider work to improve accuracy of the estimates, particularly in the following areas:

- Achievable ^{239}Pu FGE per drum. This includes better definition of the assay system technical approach and expected total measurement uncertainty; effects of batch mixing uniformity; process control including methods to reduce operational offset/contingency factors, rework of drums that exceed loading limits; use of two loaded drums per shipping cask versus three loaded drums; affect of 30 gallon drums on achievable ^{239}Pu FGE per drum; cost/benefit analysis of additional sampling and analysis of sludge batches. Evaluation of using active/passive neutron methods to reduce TMU. Evaluation of effect of waste form/configuration on TMU (grout formulation, mixing uniformity, vitrified waste forms, etc.).
- Effective ^{137}Cs limits in shielded 30 gallon drums. Identification and evaluation of methods to increase effective ^{137}Cs limits.
- More detailed topical study on achievable physical waste loading limits for remaining alternatives.
- Discussion with WIPP and/or review of WIPP safety documentation to determine applicability of specific limits, e.g. reduced ^{239}Pu FGE limit for high graphite waste, radiolytic hydrogen limit, chemically generated hydrogen limits, and effects of chemical hydrogen inhibitors.

- Programmatic determinations relative to additional waste streams to be processed. May include a review of potential wastes from other Hanford Site sources.
- Review and approval of updated baseline data for sludge composition and quantity for each sludge type.

I3.7 Total Operating Efficiency (TOE) and Process Performance

The actual achievable TOE is a complex function that includes factors such as equipment breakdown frequency, repair and recovery times, product failure and rework, and various operational inefficiencies. A reliable estimate of TOE is not feasible at the current very early preconceptual design stage. For the base case analyses an average total operating efficiency of 70 % was used as an enabling assumption (Appendix J). In addition, process rates were estimated using current best estimate information for process performance parameters.

Two different parameters were calculated to illustrate sensitivity to these parameters:

1. TOE-60, defined as the average TOE that would yield a total operating duration of 60 months, assuming this is the only change to the base case calculation.
2. Perf-60, defined as the performance degradation factor that would result in an estimated processing time of 60 months assuming all other base case parameters are fixed. This factor is simply the ratio of the base case estimated total processing time to 60 months.

Results are given in Table I-14 and illustrate the significant differences between alternatives. The three relatively "fast" alternatives (FROP, SRWOP, NCIP) show a TOE-60 value in the 21-27% range, while the three relatively "slow" alternatives (WWO, PCOP, ICV™) are grouped in the 59 to 69% range. Similarly the performance degradation factors are grouped in the 30-39% range and the 84 to 98% range for the relatively "fast" and "slow" alternatives respectively. Clearly the relatively fast alternatives are much less sensitive to uncertainties in achievable TOE and process performance when weighed against the 60 month completion criterion.

Table I-14. Required Performance Factors to Complete Processing in 60 Months

Required Performance Parameter	Warm Water Oxidation (WWO)[1]	Peroxide Carbonate Oxidation (PCOP)	Fenton's Reagent Oxidation (FROP)	Size Reduction and Water Oxidation (SRWOP)	Nitrate Chemical Inhibitor (NCIP)	Joule Heated In-Container Vitrification (ICV™)
TOE to complete in 60 months (TOE-60)	69%	59%	27%	22%	21%	68%
Performance degradation factor to complete in 60 months (Perf-60)	98%	84%	39%	32%	30%	97%

I4 References

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15. French, D. email to Mike Rivera. "Correction and Update," August 25, 2010, Los Alamos National Laboratory, Carlsbad, NM (See Attachment 1 to Appendix I).

16. French, D. email to Mike Rivera. "RE: Any luck with the Cs137 Shielded Drum Calc," August 25, 2010, Los Alamos National Laboratory, Carlsbad, NM (See Attachment 2 to Appendix I).

Appendix I, Attachment 1

From: David M. French [mailto:dmfrench@lanl.gov]
Sent: Wednesday, August 25, 2010 12:39 PM
To: Rivera, Michael A
Subject: FW: Correction and Update

Mike,

See correction below. dave

David M. French, J.D.
LANL Office 505.667.4565
LANL Cell   505.699.0967
Colo Cell   303.619.3455
email: dmfrench@lanl.gov
email: frenchesq@aol.com

From: Daniel P. Taggart [mailto:dpt@lanl.gov]
Sent: Wednesday, August 25, 2010 1:03 PM
To: David M. French
Cc: tahayes@lanl.gov
Subject: Correction and Update

Dave,

A uniformly contaminated cemented waste has a ~11.3 Ci Cs-137 activity limit when overpacked into a shielded drum (not 12.6 Ci).

In an extreme case of the Cs-137 concentration being 8x larger at the very bottom than at the very top of the cemented waste, the Cs-137 activity limit drops to ~6.8 Ci.

I'll run one more case at 2x (bottom:top concentration ratio). Then you should have a pretty good idea of what will work.

Thanks.

Dan

At 09:54 AM 8/24/2010, you wrote:
Dan,

Any good news yet? dave

David M. French, J.D.
LANL Office 505.667.4565
LANL Cell   505.699.0967
Colo Cell   303.619.3455

email: dmfrench@lanl.gov
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Daniel P. Taggart, Ph.D., CHP
Los Alamos National Laboratory
Carlsbad Operations
115 North Main Street
Carlsbad, NM 88220

Appendix I, Attachment 2

From: David M. French [mailto:dmfrench@lanl.gov]
Sent: Wednesday, August 25, 2010 10:39 AM
To: Rivera, Michael A
Subject: RE: Any luck with the Cs137 Shielded Drum Calc

Mike,

Yes, I confirmed the number with Dan – just to make sure. Also, he then reversed the calc to see what value he got if he "removed" the cement and he got 2 ci – same value he calc originally. dave

David M. French, J.D.
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Appendix J

Process Bases and Assumptions

J1 Document Purpose and Structure

In order to evaluate technology alternatives on a comparable basis, a uniform set of functions, requirements, bases, and assumptions were defined for use in developing process design concepts and for flowsheet analysis. Standardized simulant formulas were also defined for use in testing. Sections J2.0 through J3.0 below provide the bases and assumptions as they were included in the vendor contracts for use in engineering support tasks. Section J4 provides additional bases and assumptions used for development of normalized flowsheets. Section J5 provides a summary of simulants used for testing.

J2 Introduction and Scope

J2.1 Introduction

Candidate technologies and process alternatives for Sludge Treatment Project (STP) Phase 2 are currently being evaluated in three steps (referred to as "Round" 1, 2, and 3" or "Part" 1, 2, and 3).

Flowsheets, equipment sizing, facility layouts, hazards review, and cost estimates for integrated process concepts will be developed to support evaluation of candidate technologies. This document provides a set of process requirements, bases, and assumptions intended to provide consistent comparable bases for sizing and cost estimates in Round 3. The process functions and requirements herein are preliminary and are intended solely for comparing flowsheet alternatives on a consistent normalized basis. In some cases unverified enabling assumptions are defined for the purpose of preliminary evaluations. Verification of the enabling assumption and resolution of other uncertainties will be addressed during the normal course of future project development and design activities.

J2.2 Process Scope

The current evaluation considers only the treatment and packaging portion of the STP Phase 2. An enabling assumption is made that sludge will be retrieved from the STSCs as a water based slurry and delivered to the treatment system. Scope of the current evaluation ends after the sludge is placed in drums, solidified, and sealed to meet WIPP acceptance requirements. Interim on-site handling of finished drums and their storage, preparation for shipping, and shipping are not considered.

J3 Process Functions, Requirements, Bases and Enabling Assumptions

Primary process functions include: receipt of sludge slurry per STSC interface requirements, elimination of free liquid to meet WIPP WAC, control of flammable gas (primarily hydrogen) generation rate in finished packaged waste to meet transportation requirements, volume reduction of the dilute sludge slurry to minimize number of product drums, assay of waste radionuclide content to meet WIPP reporting requirements and to assure that radionuclide content limits are met, packaging of product waste to meet WIPP WAC, treatment/handling of process generated liquid and gaseous wastes to meet discharge requirements, and treatment and packaging of secondary solid wastes to meet requirements for onsite disposal.

The following sections outline key process requirements, bases, and enabling assumptions for the purpose of developing normalized Round 3 flowsheets and comparative engineering evaluations.

J3.1 Sludge Quantity and Properties

The proposed treatment and packaging technologies shall have the capability to stabilize and package the nominal quantities of Engineered Container (EC) and Settler Tank sludge provided in the Request for Technology Information #196456 Rev. 1 (RFI) and Tables 3-1, 3-2, and 3-3. This data was compiled in HNF-41051, (*Preliminary STP Container and Settler Sludge Process System Description and Material Balance*). Additional information on the characteristics of the Engineered Container and Settler Tank sludge streams is compiled in HNF-SD-SNF-TI-0 *15, Spent Nuclear Fuel Project Technical Databook,* Volume 2, *Sludge*, Rev. 14B.

J3.2 Processing Rate and Capacity

The minimum requirement provided in the RFI is that the process must have the ability to treat and/or package K Basin sludge inventory in 5-7 years.

For normalized Round 3 flowsheets, the processing period excluding hot commissioning and post processing cleanout shall be 5 years unless a shorter operating time is economically justified (reduced operating costs expected to more than offset increased capital cost).

J3.3 Product Requirements

The waste form that results from the proposed treatment and packaging technologies shall meet WIPP's waste acceptance criteria for transportation and final disposal as RH-TRU waste (DOE/WIPP-02-3122, *Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant*)), as well as the Hanford Site's waste acceptance criteria (HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*) for its interim storage. The packaged RH TRU waste form must also meeting shipping requirements as established in *Remote-Handled Transuranic Waste Authorized Methods for Payload Control*, (RH TRAMPAC).

The sludge shall be packaged in 30 or 55 gallon drums or dimensionally equivalent containers. Use of the RH-72B shipping cask is also assumed for non-shielded containers. The DOE is considering use of shielded 30 gallon containers within a 55-gallon overpack (1 inch lead shielding). This package has not yet been approved by the NRC. For the purpose of current flowsheet evaluations the RH-72B cask constraints are assumed to be bounding for gas generation, weight, and FGE requirements.

Hanford Site waste acceptance criteria for secondary waste streams that must be met include the latest revisions to, HNF-3172, *Liquid Waste Processing Facilities Waste Acceptance Criteria*, and WCH-191, *Environmental Restoration Disposal Facility Waste Acceptance Criteria*.

Table 3-1 Sludge Radionuclide Inventories[a]

Isotope[c]	KE Originating[b] Containers 240, 250, 260			KW Originating[b] Containers 210[e] and 220			Settler (Based on 50:50vol% KE:KW Canister)		
	Design	Safety	Shielding	Design	Safety	Shielding	Design	Safety	Shielding
	Ci/m^3	Ci/m^3	Ci/m^3	Ci/m^3	Ci/m^3	Ci/m^3	Ci/m^3	Ci/m^3	Ci/m^3
Am-241	1.9E+01	9.3E+01	1.9E+01	4.1E+01	2.2E+02	6.7E+01	1.87E+02	8.23E+02	2.95E+02
Np-237	4.5E-03	9.7E-03	4.5E-03	6.9E-03	2.0E-02	7.2E-03	2.20E-02	1.12E-01	2.20E-02
Pu-238	3.5E+00	1.4E+01	3.5E+00	8.8E+00	4.4E+01	1.2E+01	3.92E+01	1.89E+02	4.56E+01
Pu-239	1.4E+01	5.4E+01	1.4E+01	3.0E+01	1.2E+02	4.1E+01	1.40E+02	5.48E+02	1.88E+02
Pu-240	7.7E+00	3.0E+01	7.7E+00	1.6E+01	6.6E+01	2.5E+01	7.65E+01	3.00E+02	1.11E+02
Pu-241	4.1E+02	1.6E+03	4.1E+02	9.4E+02	3.8E+03	1.0E+03	4.38E+03	1.72E+04	4.28E+03
Pu-242	3.7E-03	1.4E-02	3.7E-03	7.3E-03	3.1E+02	1.0E-02	3.45E-02	1.35E-01	4.31E-02
Co-60	9.9E-01	3.8E+00	9.9E-01	3.1E+00	1.1E+01	1.1E+00	1.05E+01	3.97E+01	8.60E-01
Cs-134	--	--	7.6E-02	--	--	2.5E+00	--	--	1.57E+00
Cs-137	3.1E+02	2.7E+03	3.1E+02	7.7E+02	4.9E+03	1.3E+03	2.40E+03	1.23E+04	4.42E+03
Ba-137m[d]	2.9E+02	2.5E+03	2.9E+02	7.2E+02	4.6E+03	1.2E+03	2.3E+03	1.2E+04	4.2E+03
Eu-154	2.8E+00	1.2E+01	2.8E+00	8.1E+00	3.6E+01	9.4E+00	3.19E+01	1.43E+02	2.39E+01
Eu-155	1.4E+00	9.9E+00	1.4E+00	3.4E+00	1.7E+01	2.8E+00	1.51E+01	8.12E+01	9.86E+00
Sr-90	3.0E+02	3.6E+03	3.0E+02	9.3E+02	5.2E+03	1.3E+03	4.00E+03	1.56E+04	5.28E+03
Y-90[d]	3.0E+02	3.6E+03	3.0E+02	9.3E+02	5.2E+03	1.3E+03	4.00E+03	1.56E+04	5.28E+03
Tc-99	1.3E-01	7.5E-01	1.3E-01	3.2E-01	1.7E+00	3.3E-01	1.55E+00	7.79E+00	1.55E+00
U-234	4.7E-02	2.6E-01	--	9.7E-02	4.2E-01	--	5.02E-01	2.06E+00	0.00E+00
U-235	1.6E-03	8.8E-03	--	3.6E-03	1.6E-02	--	1.71E-02	6.98E-02	0.00E+00
U-236	4.8E-03	2.7E-02	--	1.2E-02	5.4E-02	--	5.67E-02	2.31E-01	0.00E+00
U-238	3.5E-02	2.0E-01	--	7.0E-02	3.1E-01	--	3.50E-01	1.44E+00	0.00E+00
Sm-151	--	--	7.6E-02	--	--	2.5E+00	--	--	1.57E+00

- From HNF-41051.
- These average values apply to the total inventory of this container sludge type. Due to the manner in which the containers were loaded, radionuclide concentration variability within and between containers is likely. Blank cells in the table indicate no values or incomplete data was reported for the radionuclide
- All radionuclides are decay corrected to May 31, 1998.
- Ba-137m = 0.944 x Cs-137; Y-90 = Sr-90
- Composition includes 1.3m^3 of KW Basin floor sludge planned to be added to container 210 in FY 2010.

Table 3-2 Properties for Container and Settler Sludge[a]

Property	KE Originating Containers 240, 250, 260		KW Originating Containers 210 and 220		Settler (Based on 50vol% KE: 50vol%KW Canister Sludge)		Units
	Design	Safety	Design	Safety	Design	Safety	
As Settled Density	1.4	1.6	1.6	1.8	2.45	3.25	gm/cm^3
Percent Water in Sludge	75%	75%	74%	74%	70%	70%	Volume %
Total Uranium	0.11	0.38	0.28	0.59	1.34	2.1	$g\ U/cm^3$
Uranium Metal Fraction in Settled Sludge - Non-Segregated	0.006	0.030	0.030	0.082	0.052	0.163	g/cm^3
Decay Heat	4.4	26	14	52	54.5	167	W/m^3
^{239}Pu Fissile Grams Equivalent (FGE)	702	3,480	1,560	7,280	7,340	29,600	FGE/m^3
Sludge Expansion Factors							
Uranium Metal Corrosion[b]	1.02	1.08	1.25	1.35	1.61	1.87	unit less
Gas Retention	1.41	1.54	1.41	1.58	1.41	1.63	unit less
Combined	1.43	1.66	1.76	2.13	2.26	3.04	unit less

a. From HNF-41051.
b. Sludge expansion results primarily from conversion of low oxidation state uranium (e.g. UO_2) to a higher oxidation state (e.g. UO_3). Expansion factors show apply to sludge oxidation in the presence of oxygen. Oxidation of uranium metal under anoxic conditions is expected to result in relatively little bulk sludge volume expansion.

Table 3-3. Estimated Chemical Composition of K Basin Sludge Streams[(a)]

Source		KE Engineered Containers	KW Engineered Containers[(b)]	Settler (Based on 50:50 KE Canister : KW Canister)
Settled Sludge Volume	m^3	18.4	5.1	5.4
Nominal Chemical Constituent				
Ag_2O	gm/cm^3	1.98E-05	2.59E-06	7.00E-05
$Al(OH)_3$	gm/cm^3	9.32E-03	1.61E-02	1.25E-01
Al_2O_3	gm/cm^3	7.17E-02	2.25E-02	0.00E+00
BaO	gm/cm^3	2.14E-04	1.68E-04	3.74E-04
CaO	gm/cm^3	8.09E-03	3.66E-03	9.65E-04
CdO	gm/cm^3	7.62E-05	5.16E-05	1.96E-05
Cr_2O_3	gm/cm^3	7.62E-04	3.24E-04	6.09E-04
FeO(OH)	gm/cm^3	2.80E-01	9.46E-02	1.25E-01
PbO	gm/cm^3	3.82E-04	1.29E-04	1.52E-04
Residual Solids	gm/cm^3	1.34E-01	7.41E-02	
CO_2 (Total Inorganic Carbon)	gm/cm^3	7.48E-03	1.53E-03	4.25E-03
Total Organic Carbon	gm/cm^3	1.91E-03	6.53E-04	2.02E-03
PCB	gm/cm^3	6.49E-05	7.55E-05	1.73E-06
OIER	gm/cm^3	3.55E-02	3.04E-05	5.60E-03
Zeolite	gm/cm^3	1.05E-02		
Zircalloy 2	gm/cm^3		1.79E-03	
graphoil	gm/cm^3		7.35E-03	2.76E-02

a. From HNF-41051.
b. Composition includes the estimated $1.3m^3$ of KW Basin floor sludge that is planned to be added to container number 210 in FY 2010.

Definitions:

OIER – Organic Ion Exchange Resin

PCB – Polychlorinated Biphenyl

Blank entry indicates no reported value is currently available

J3.4 Uranium Metal Reaction

The maximum uranium metal particle size is assumed to be 6350 microns (1/4 inch) diameter for EC sludge and 600 microns diameter for Settler Tank sludge.

The Spent Nuclear Fuel Project Technical Databook (Databook) includes a rate equation for reaction of uranium metal with oxygen free water (HNF-SD-SNF-TI-015, Vol. 2, Table 4-9). The Databook also defines an “enhancement factor,” which is multiplied by the calculated rate to obtain an adjusted rate or range of rates to compensate for uncertainty in the rate calculation. The Databook requires an enhancement factor range of 1/3 to 3.0 to be used for safety analyses and design. The most conservative value should generally be used unless there is sufficient technical justification to use a less conservative value.

Pending results of the planned PNNL testing, the study design sizing is based on uranium oxidation reaction using an enhancement factor of 1.0. This is the best estimate value based on available literature data for reaction of U metal with water without considering possible effects from other sludge components present or irradiation of the U metal. This will be updated as needed based on new test results when they become available. Flowsheet analyses should also include sensitivity estimates of the effect on operating duration if the actual enhancement factor varies by a factor of three from the base case value, i.e. between 3 and 1/3.

J3.5 STSC Interface Requirements.

Requirements and enabling assumptions are defined related to the interface with the STSC retrieval system as follows:

1. Maximum volume of as-settled sludge per STSC is estimated at 2.1, 1.6, and 0.86 cubic meters for KE EC, KW EC, and settler sludge respectively based on HNF-41051 Rev. 2.

2. A total of 24 STSCs are assumed to be processed. Breakdown is approximately 11, 5, and 8 STSCs each for KE EC, KW EC, and settler sludge respectively.

3. The treatment system must be sized to accept continuous batch transfers from STSCs as follows: Entire STSC batch is retrieved in a single pass with an average slurry discharge concentration of 5 volume % solids and nominal 70 gpm flow rate. In addition an allowance of 25 % of the slurry volume is assumed for flushing the pumps and transfer lines with water. Based on the maximum of 2.1 cubic meters of as-settled sludge per STSC, and a volumetric dilution factor of 5X for KE EC sludge these assumptions result in a maximum batch transfer volume of 13.1 cubic meters or 3500 gallons. It is also assumed that no water or other wastes are returned from the treatment system to STSC retrieval.

4. A 24 hour interval is assumed from the time the batch receipt tank is ready to accept a transfer from the STSC until the transfer is complete. If more than one STSC is to be transferred into a single processing batch it is assumed that there are no additional delays, i.e. 24 hours for the first STSC retrieval and 24 hours for each additional STSC per processing batch. Any additional retrieval delays are assumed to be captured by the total operational efficiency allowance.

J3.6 Fissile Material Content Limits

1. The RH TRU 72B cask (RH 72B) is the only shipment option for 55 gallon drums considered in the current analysis. Alternate shipping methods may be considered for the 30 gallon shielded drums.

2. Pending better information use the 325 ^{239}Pu Fissile Gram Equivalent (FGE) limit per RH 72B payload container as the base case. The base case assumes that the lower limit for high graphite waste does not apply.

3. Assume three filled drums per RH 72B payload container.

J3.7 Assay and Measurement Uncertainty

The sludge treatment and immobilization design concept must provide assay methods to determine content of reportable isotopes and to control ^{239}Pu FGE content of waste packages within acceptance levels. Total measurement uncertainty (TMU) must be considered in determining compliance with the loading limits. Currently WIPP prefers dose-to-curie assay methods, which typically have relatively high measurement uncertainty, e.g. TMU (two sigma) values on the order of 100 %.

Flowsheet basis: Use 40 ^{239}Pu FGE per drum average as the nominal or base case value for developing the flowsheets and sizing basis (unless the volumetric waste loading is more limiting). Two additional values may be considered for sensitivity calculations: a maximum value of 70 and a minimum value of 20 ^{239}Pu FGE per 55 gallon drum.

J3.8 Operating Schedule and Operating Efficiency

Assume that the treatment portion of the process will operate 24/7. The immobilization and packaging (drumming) processes and sludge retrieval from the STSCs may operate on fewer shifts as long as appropriate allowances for lag storage between the treatment and packaging processes are estimated and planned for.

Normalized flowsheets used for comparisons will assume two cases: 100 % total operating efficiency (TOE), and 70 % TOE. Total operating efficiency is defined as the average annual processed quantity of sludge divided by the sludge quantity that would be processed with the system as designed with no interruptions for equipment failures, process upsets, interface inefficiencies, and other operational inefficiencies within the treatment and packaging processes. Besides downtime for the treatment and packaging systems, the 70 % TOE value is assumed to also capture inefficiencies related to the retrieval interface, e.g. sludge transfers from retrieval not available when needed or interruptions in the retrieval/slurry transfer process that delay processing by the treatment and packaging system.

J3.9 Process Safety and Environmental Related Constraints

The following enabling assumptions are established for the current preliminary flowsheet development. Note that these assumptions must be verified in later design phases.

- Criticality controls: No limits on batch size or configuration are required to prevent potential criticalities.
- Runaway uranium reaction. No limits on batch size, configuration, or heat up rates are required to prevent runaway uranium reactions.
- Radioactive Air Emissions Control. Radioactive air emissions are expected to be controlled primarily by HEPA filtration and stack monitoring. All flowsheet alternatives will include HEPA filtration on the process offgas and cell exhausts. It is recognized that additional treatment to remove radioactive noble gasses (Xe, Kr), radioiodine, tritium and technetium may be required depending on the final facility configuration and permitting requirements. For purposes of this analysis the treatment system is assumed to be an "onsite" facility operating under the terms of the existing K Basin CERCLA Record of Decision. Determination of the final requirements is beyond the scope of the current analysis, and will be addressed in later design phases.
- PCBs in condensate. Liquid waste to be disposed at ETF shall meet all ETF waste acceptance requirements. An enabling assumption is made that water condensate produced by boiling K basins sludge slurries at < 100 °C will meet ETF acceptance limits for PCBs.

J3.10 Other Process, Interface and Programmatic Requirements

1. Current Phase 1 design concept and bases are assumed, including STSCs, storage and T Plant interface.

2. Facility assumptions. The treatment and packaging process system will be installed in a new facility or facility expansion, i.e. for the purpose of preliminary process design there are no constraints associated with fitting the process into an existing facility.
3. Other site wide RH TRU waste planning assumptions or bases. For the purpose of preliminary process technology evaluations it is assumed that the treatment and packaging processes are designed solely to process the K Basin sludge, i.e. no special design allowances or other considerations will be included solely to facilitate processing of other wastes.
4. The settler tank sludge has been segregated from the KE and KW floor sludge and must remain segregated during treatment and packaging operations. Unavoidable incidental mixing of small amounts of waste remaining in tank heels is acceptable.
5. For the current preliminary analyses no credit will be taken for U metal oxidation during storage prior to delivery to the Phase 2 treatment and packaging system.
6. It is assumed that there are no special nuclear material related safeguards or material accountability requirements that impact the process design. Special nuclear material accountability will be terminated when the sludge is removed from K Basins.

J3.11 Operating philosophy, maintenance philosophy, and operational risk acceptance

- Process vessels containing radioactive process streams should be maintained at a negative pressure during operations and most maintenance activities, in order to minimize the potential for spread of contamination.
- Up and down operations should generally be avoided, e.g. drumming shut down for several months followed by 24/7 operation for an interval followed by shut down again for extended period followed by 24/7 again.
- Remote maintenance, versus contact maintenance, versus non-maintenance (black cell) concepts, TBD. Proposed remote facility operating and maintenance concepts should be discussed with CHPRC early in the concept selection process to assure they are consistent with site operational expectations and ALARA considerations. To the extent possible, remote maintenance concepts should be based on successful vendor facility or other identified facility operational success.

J3.12 Technology Specific Bases and Assumptions

Technology specific bases and assumptions are provided in this section. These will be used primarily for internal development of flowsheets where external contractors have not provided the bases. For example, these may be used to develop an integrated flowsheet that incorporates the chemical hydrogen inhibitors being testing by PNNL.

J3.12.1 Waste Loading Using Grout Solidification

Individual contractors may develop and propose a basis for calculating waste loading using a grout solidification approach. In the absence of input from the contractors the estimated waste loading will be calculated based on the methods used for the warm water oxidation flowsheet.

For example, when using Portland cement based grout to eliminate free liquid loading of container average waste loading per drum is based on an average waste addition of 125 liters per 55 gallon drum, including sludge slurry and all dilution, flush, and adjustment water added to the drum. This value is based on the loading limit developed for North Loadout Pit sludge increased by 25 % to achieve 90% fill of a 55 gallon drum (46683-RPT01 "Control Measures to Assure 'No Liquid' in Grouted KE North Load Out Pit Sludge"). This value provides a conservative basis and includes allowances for control and measurement uncertainties.

J3.12.2 Sludge Concentration and Flush Volumes for Pipe Transfers.

The as-settled sludge must typically be diluted with water in order to facilitate transfer in a pipe/hose/pump system. Individual testing contractors may develop a proposed basis for calculating the maximum concentration. In the absence of such input the maximum concentration will be estimated based on slurry transfer in a pipe and the calculation methods used for the warm water oxidation flowsheet. A tentative working basis is discussed below, to be updated if needed when the warm water oxidation flowsheet is finalized.

The slurry dilution factor (SDF) is defined as the slurry volume divided by the bulk volume of as-settled sludge contained in the slurry. The reciprocal of the SDF is the volume fraction settled solids (VSS). VSS is the volume fraction (or percent) of the bulk settled solids if the slurry is allowed settle for an extended period.

For normalized flowsheet evaluations it is assumed the sludge concentration for short distance transfers is limited to a maximum VSS of 80 % or a minimum SDF 1.25. Based on the KE EC sludge data this is equivalent to 20 volume % solids.

For long distance transfers (hundreds of feet) CALC-5477-PR-G-0001 shows a lower value of 12 volume % solids, equivalent to an SDF of about 2 for relatively long distance transfers.

Transfer pumps and piping must be flushed with water after all slurry transfers. A minimum flush volume of 1.5 times the volume of the pump and piping is assumed.

Calculation of dilution from flushes requires information on piping and equipment size and configuration. In the absence of such data; dilution between the reaction tank and waste drum will estimated based on results in CALC-5477-PR-G-0001 as follows: The slurry leaves the reaction tank with 20 volume percent solids; and by the time all flush and dilution water is added the total stream transferred to the drum is reduced to 15.6 volume % solids. This indicates a volumetric dilution ratio of 20/15.6 or 1.28, i.e. water addition equal to 28% of the volume of slurry leaving the reaction tank. The following example is calculated for KE EC sludge using this dilution factor and other assumptions or bases discussed above.

Basis 1 liter (L) of as KE EC as-settled sludge (SS).

Volume of slurry transferred into the reaction tank

= 1 L SS*25 vol. % in SS/5 vol. % solids in dilute slurry = 5 L

Flush water related to slurry transfer into the reaction tank.

= .25*5 = 1.25 L

Total transfer into reaction tank= 5+1.25 = 6.25 L

Volume after concentration to 20 vol. % solids

= 1 L SS*25 vol. % solid in SS/20 vol. % solids in dilute slurry = 1.25 L

(Note that the volumetric expansion factor for oxidation is ignored)

Volume entering drum after all transfer dilutions

= 1 L SS*25 vol. % solid in SS/15.6 vol. % solids to drum = 1.60 L

Total SS transferred to average drum

= 125 L volume transferred/1.60 L transferred per L SS = 78 L SS.

The above represents the maximum physical limit for as-settled sludge loaded per drum based on assuring that the finished drum contains no residual liquids. If other limits are more restrictive (e.g. FGE) the amount of sludge loaded must be reduced accordingly. In this case a reduced quantity of total liquid and cement additives could be added to each drum. However, for the current preliminary analysis it is assumed that the reduced sludge volume is made up for with water such that the total liquid/slurry volume and cement additives are held constant for all drums.

J4 Bases and Assumptions for Normalized Flowsheets

Sections J2.0 through J3.0 above represent the process basis document provided to the contractors as an attachment to their contracts. In addition, the following were defined to provide a consistent basis for internally prepared normalized flowsheets.

J4.1 General Flowsheet Assumptions

The following are general assumptions used for base case process flowsheet calculations.

- The time required to boil down a batch of dilute sludge slurry from 4 volume % solids to the concentrated sludge end point is 3.4 days. This is based on the upper end of the range estimated in the EnergySolutions Task 3 report [12].
- A total of 24 hours is assumed to be required to cool the batch from near boiling to the temperature needed for the next step (either transfer or chemical reaction). This is based on the upper end of the range estimated in the EnergySolutions Task 3 report [12].
- An additional 24 hour allowance is made for transfer from the reaction/concentration tank to the lag storage tank. This provides for finalizing any documentation and approvals, valve line up, making the actual transfer, and any other activities required to secure the reaction/concentration tank and prepare it to receive the next incoming batch. Basis is engineering judgment.
- The WWO calculations assume uranium particles are oxidized to extinction using water at 95 to 98 °C. A spherical particle shape and anoxic water are also assumed. Multiple STSC batches may be accumulated during a single oxidation batch. For the WWO process 2 STSCs per oxidation batch are assumed as a base case; all other technologies assume 1 STSC per oxidation batch. Sensitivity cases may consider other combinations.
- For alternatives that assume transfer of more than one STSC into a single processing batch additional boil down and sludge transfer steps are required. The base case assumes 3.4 days for boil down and 24 hours for STSC batch retrieval and transfer, for each additional STSC per processing batch.
- The dilute slurry is concentrated by evaporation to about 20 volume % solids prior to transfer to the lag storage tank in order to minimize the amount of water transferred forward to the assay and drumming system. (See Section J3.12.2)
- The base case assumes a single receipt/reaction/mix/concentration tank plus a lag storage tank for the concentrated sludge slurry. Other sensitivity cases may be considered, e.g. two reaction/mix/concentration tanks with no lag storage tank, etc.
- Base case calculations assume that settler sludge is processed last.
- Sludge processing time cycle analyses do not consider ramp up at the start of hot operations or clean out after sludge processing is completed.
- An average achievable drum production rate of 30 drums per week at 100% TOE is assumed as a base case for the Portland cement based immobilization processes, i. e. all current alternatives except Impact In-container Vitrification (ICV™). Sensitivity cases of 10 drums per week and 49 drums per week are also considered [3]. These drum production rate assumptions do not apply to vitrification processes.

J4.2 Methods for Tank Sizing

The following methods are generally used for tank sizing. Adjustments or alternative methods are considered on a case by case basis, but should provide an equivalent level of conservatism and operational flexibility. These are not intended to be final design values, but are preliminary engineering judgment base values intended to provide a uniform basis for comparing alternatives.

- Reaction or Concentration/Mix Tank sizing basis.

    1. A nominal heel volume of 400 liters or 100 gallons is assumed for the Reaction or Mixing/Concentration Tank.
    2. The maximum volume slurry transfer from an STSC is assumed (13.2 m^3 or 3500 gallons)
    3. If multiple STSC batches are to be accumulated into a single oxidation batch, the concentrated volume of the additional batches is added.
    4. An operational allowance of about 15 % of (1)+(2)+(3) is added.
    5. The total of (1)+(2)+(3)+(4) is the estimated tank working volume, or maximum operational fill volume.
    6. A freeboard allowance of about 25 % of (5) is provided.
    7. Gross tank volume is estimated as the total of (5) and (6).

- Lag Storage Tank Sizing Basis

    1. A nominal heel allowance is assumed equal to ½ the maximum batch volume of concentrated sludge transferred in from the reaction or concentration tank.
    2. The maximum concentrated sludge volume is added assuming it will be transferred from the reaction/concentration tank as a single batch
    3. An operational allowance of about 15 % of (1)+(2) is added.
    4. The total of (1)+(2)+(3) is the estimated tank working volume, or maximum operational fill volume.
    5. A freeboard allowance of about 25 % of (4) is provided.
    6. Gross tank volume is estimated as the total of (4) and (5).

- Condensate Tank Sizing Basis

    For a single STSC processed in each oxidation or concentration batch, two condensate tanks will be used. The volume of each is calculated by the following method.

    1. A nominal heel allowance of 500 gallons or 2000 liters is assumed for each tank.
    2. With the exception of the EnergySolutions process the maximum condensate volume from a single STSC batch is added assuming 100 % steam condensation and no recycle for process use. For the EnergySolutions process the maximum condensate production during a one week operating time is added.

3. An operational allowance of about 15 % of (1)+(2) is added. The total of (1)+(2)+(3) is the estimated tank working volume, or maximum operational fill level.
4. A nominal 15% freeboard allowance is added to the working volume to give the gross tank volume

For the case of two or more STSCs processed in one oxidation or concentration batch the same method (steps 1-4) is used except that the total volume of condensate from all batches is include in step two and the required total tank volume is split evenly between the two tanks.

J5 Simulants Used for Testing

For the STP Phase 2 – Technology Alternatives Analysis, testing using actual K Basin sludge was not practical. Therefore, simulants were required. The sludge treatment project (STP) recently completed a review of simulants for K Basin sludge testing [14]. Based on review of this document a KW Origin Container Sludge simulant recipe was selected as the primary basis for proof-of-concept testing for the current evaluation. There are two versions of the base recipe:

- Physical Simulant. The simulant referred to as "physical simulant" contains no uranium. Cerium oxide and steel grit are substituted for uranium oxides. The physical simulant components are shown in Table 5-1. The first 7 components are referred to as the "base simulant" and are as defined in Reference 12. In addition, supplemental components that were identified as important were added to the base simulant for certain tests: graphoil, organic ion exchange resin (OIER), zeolite/mordenite, and flocculent. Where used, the nominal amounts for these additional components are also shown in Table 5-1. In some cases the base recipe was modified on a case by case basis to meet the needs of specific tests.
- Uranium Containing KW Container Simulant. The Uranium Containing KW Container Simulant was prepared by PNNL per reference [15] and supplied as needed for all tests that utilized uranium containing simulant. Nominal target composition (of the non-water components) is shown in Table 5-2. Note that simulants supplied by PNNL to the outside contractors did not include the U metal component. The U metal was obtained separately by the contractors to meet the needs of specific tests.

The recipes shown in Tables 5-1 and 5-2 were adjusted for certain tests based on testing needs, and characteristics of simulants supplied to the individual vendors are summarized in Table 5-3.

Table 5-1. Physical Simulant Recipe

Size dist. (μm)-mass basis			Base Simulant-Dry Components		
D 10% <	**D 50%**	**D 90% <**	**Component**		**Units**
6	13	19	FeOOH	21.9	g/100g base simulant (dry)
2	13	47	Al(OH)3	7.8	g/100g base simulant (dry)
1	4	19	CeO_2	30.9	g/100g base simulant (dry)
170	300	560	Sand	14.7	g/100g base simulant (dry)
1,300	2,200	3,700	Aggregate	16.9	g/100g base simulant (dry)
180	390	500	Steel grit,	4.2	g/100g base simulant (dry)
410	1,800	4,400	Tungsten or Densalloy™	3.6	g/100g base simulant (dry)
			Total	100	g/100g base simulant (dry)
Supplemental components added to base simulant on a case by case basis					
			Zeolite (Mordenite)	1.62	g/100g solids
			Organic Ion Exchange Resin	5.46	g/100g solids
		6,300	graphoil	0.85	g/100g solids
N/A	N/A	liquid	Flocculent	0.31	g/100g solids
			Total Supplemental	7.93	g/100g solids

Table 5-2. Uranium Containing KW Container Simulant Recipe[1]

Component	Quantity (g/100g solids)
FeOOH	21.9
$Al(OH)_3$	7.8
Sand	16.4
Organic Ion Exchange Resin	7.5
Zeolite (Mordenite)	7.7
UO_2	16.0[2]
$UO_3 \cdot 2H_2O$	19.1[2]
U metal	3.6[3]
Total Solids	100
Flocculent	0.31[1]

[1] Based on PNNL Test Instruction 53451-T121 Rev. 1
[2] Added as a slurry or water based suspension. Values listed do not include the liquid water.
[3] Nominal U metal quantity. U metal was typically not included in as-supplied simulant. The U metal form and quantity added varied for specific tests.

Table 5-3. Simulants Used for Specific Tests for the Current Technology Evaluation Activity

Test Performer, and Scope	Simulant Used
Impact Services, Joule Heated In-Can Vitrification (ICV™) Process (Dryer tests only)	Used physical simulant; base simulant plus all supplemental components (Table 5-1).
EnergySolutions, Peroxide Carbonate Oxidation Process (PCOP) laboratory testing	Tests used Uranium Containing KW Container Simulant (Table 5-2) plus ¼ inch U metal coupons
Ceradyne, Fenton's Reagent Oxidation Process (FROP) Testing	Two tests used the Uranium Containing KW Container Simulant plus ¼ inch U metal coupons, balance of the tests used only the FeO(OH) and $Al(OH)_3$ simulant components plus U metal coupons.
Ceradyne, Borobond™ Hydrogen Inhibition Tests	Some tests used 1.85 mm x 1.94 mm cylindrical U metal pellets either alone or with the FeO(OH) and $Al(OH)_3$ components of the physical simulant.
Ceradyne, Borobond™ Waste Loading Tests	Tests used physical simulant with all supplemental components except flocculent and Densalloy™
Ceradyne, Size Reduction Water Oxidation Process (SRWOP) Immersion Mill Size Reduction Tests	Test 1 used only the <100 µm components of the physical simulant, plus a tungsten alloy (Densalloy™) as a stand in for U metal. Test 2 used the physical simulant; including all base and supplemental simulant components with the exception of flocculent. Densalloy™ was used also in Test 2 as a stand in for U metal.
PNNL/AREVA, Warm Water Oxidation (WWO) Tests	Testing under the current effort used the Uranium Containing KW Container Simulant. In addition, parallel testing was conducted with a 50/50 U(IV)/U(VI) oxide mixture to represent KW Settler sludge. Earlier testing used a variety of simulants, actual K Basins sludge, and irradiated metallic uranium fuel.
PNNL, Nitrate Chemical Inhibitor Process (NCIP) Tests	Testing under the current effort used the Uranium Containing KW Container Simulant with U metal beads.

J6 References

1. 46683-RPT01, Delegard, C. H., S. I. Sinkov, and L. A. Snow, "Control Measures to Assure 'No Liquid' in Grouted KE North Load Out Pit Sludge," September 27, 2005.
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3. Clifford, J. R., "Drumming Count and Rate Estimation," Calculation Number: LEMS-STP-002, March 2011, Lucas Engineering and Management, Richland WA.
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Appendix K

Information on Garnet Filter Media

K1 Introduction

The Integrated Water Treatment System in the K West Basin includes three garnet filters for removal of suspended solids from basin water discharged from the settler tanks. Currently the garnet filters house approximately 6.9 m^3 (~2.3 m^3 per filter) of filter media along with an estimated 0.28 m^3 (0.092 m^3 per filter) of settler type sludge entrained in the media. The filter media was originally configured in three layers, a coarse sand, fine sand and garnet sand layer, within the annular filter vessels. This filter media and entrained settler type sludge material is termed Garnet Filter Media (GFM). The GFM is assumed to be RH-TRU waste based on initial calculations that estimate the volume of settler type sludge entrained in the filter media and dose measurements along the side of the filter vessels. The current baseline for the Garnet Filter Media Disposition Subproject of the Sludge Treatment Project is to retrieve the approximately 6.9 m^3 of GFM (along with the estimated 0.28 m^3 of sludge), package into Sludge Transport and Storage Containers (STSCs) and ship to T Plant for interim storage while a final treatment process is being developed. Once treated for long term storage, the GFM will be packaged and shipped to a national repository (WIPP) for ultimate disposal.

Further discussion on the planned Garnet Filter Media Disposition can be found in HNF-47664, Rev 0, *Sludge Treatment Project Retrieval, Transport, and Interim Storage of the KW Basin Garnet Filter Media Engineering Study.*

K2 Purpose and Scope

The purpose of this Appendix is to summarize the properties of the GFM and the entrained material for possible inclusion to Sludge Treatment Project Phase 2 technology evaluations.

The scope of this Appendix includes:

- Characteristics of the GFM
- Mass and volume of the GFM that will be loaded into STSCs and stored wet in T Plant
- The STSC configuration and expected loading characteristics (i.e., batch loading)

K3 Characteristics of the Garnet Filter Media from the IWTS

The IWTS garnet filter media is composed of two different types of silica sand, garnet sand and entrained setter type sludge with varying particle sizes and densities. Table K-1 provides a summary of the characteristics of GFM.

Table K-1. Characteristics of the Garnet Filter Media

	Coarse Silica Sand	Garnet Sand	Fine Silica Sand
Bags installed per filter[1]	25	38	25
Weight of a bag (lbs)[2]	100	100	100
Volume per filter (ft^3)	25	32.5	25
Density (lbs/ft^3)[2]	100	117	100
Specific Gravity [3]	2.6	4	2.6
Particle Size (µm)[3]	1680 -3360	177	250
Mass of Filter Media (kg)	1120	1700	1120
Estimated Volume of Settler Type sludge	0.092 m^3/filter (0.28 m^3 total)		
Total Mass of Filter Media	3940 kg		

The particulate material trapped within the inert sand layers came from the outflow of the IWTS settler tanks. Information regarding the sludge component of the GFM can be derived from the characteristics of the settler sludge, dose measurements for each filter vessel, and the differential pressures across the filters. The garnet filters were originally designed to have a 5µm nominal filtration capacity.

Settler sludge and the sludge captured in the garnet filter media were both generated from the same source and are stored wet. Therefore, with the exception of particle size distribution and the presumed low concentration of U metal[4], these materials are expected to have relatively consistent characteristics (e.g., radionuclide content and isotopic ratios) with respect to each other.

A calculation has been performed that estimates the volume of Settler Type sludge that is entrained in the GFM to be approximately 0.28 m^3. This calculation can be viewed in PRC-STP-00344, *Preliminary Hazard Categorization of the KW IWTS Garnet Filter Media* Appendix A.

The settler sludge was recently transferred from the ten settler tanks into a single engineered container in the KW Basin, where it has recently been sampled. Four cores from the engineered container were collected and sent to the laboratory for analysis per a DQO (HNF-36985) and sampling analysis plan (KBC-40467). The settling tests (i.e., suspended sludge segregation) that will be done as part of the settler sludge analysis will be used to verify the assumption that radiochemical and chemical characteristics remain relatively constant among the various particle size fractions of the settler sludge. Based on the results of the planned settler sludge analysis, the values for U metal and total uranium content in the sludge will be revised as necessary and incorporated into HNF-SD-SNF-TI-015, Revision 14B, *Spent Nuclear Fuel Project Technical Databook, Volume 2, Sludge*.

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1 Obtained from original work package.

2 Obtained from Telecom with original sand suppliers

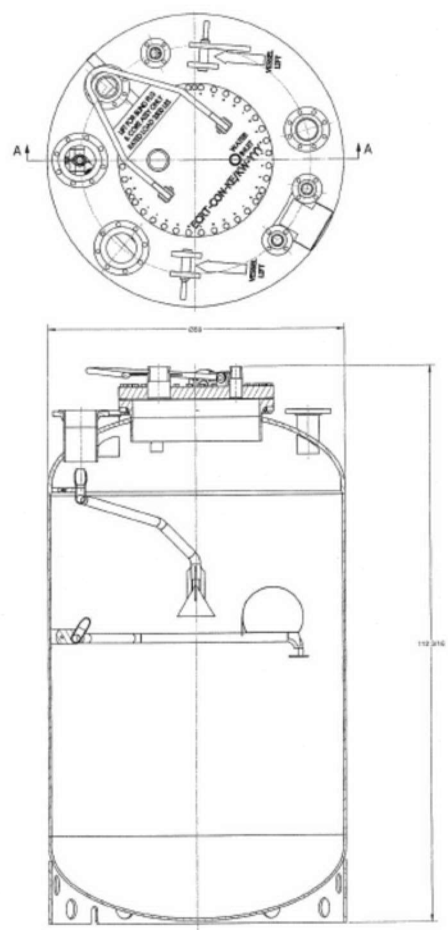
3 Obtained from Vendor Data

4 A preliminary (unpublished) calculation to determine the minimum particle size of uranium metal that theoretically could pass through the Settler Tanks and into the garnet filters indicates that a uranium metal particle of diameter > 8 µm would settle and be retained in the Settler Tanks. This calculation uses Stoke's Law for rigid, spherical particles and takes into account the geometry and operating conditions of the Settler Tank along with the properties of uranium metal (density) and the carrier fluid (water).

K4 STSC Loading Configuration

The GFM will be retrieved from the three annular garnet filter vessels into three STSCs with no inner core, batch wise in manner similar to sludge. Figure 5-1 shows a schematic of the KE/KW sludge STSC that the GFM Disposition subproject is planning to use for GFM transport and interim storage. For a more detailed drawing of the STSC planned for use by this project, please refer to drawing H-1-92550, Rev 13, *STP ECRTS Transport System STSC Assembly*. The current assumption for STSC loading limits is that one garnet filter volume (~2.4 m^3) of GFM will be loaded into one STSC. The STSCs loaded with GFM will be sent to T Plant and placed into dry storage cells with the KW Basin containerized sludge. The three GFM STSCs will occupy three out of the estimated 33 storage positions (7 storage cells in total) that will be used for both the GFM and the KW Basin containerized sludge.

Figure K-1. Simplified Sketch of KE/KW STSC



Depending on the flow characteristics and level of compaction of the GFM as it is being retrieved from the filter vessels, the media will be deposited into the STSCs in likely one of two scenarios. The first scenario assumes that the material will be retrieved in a manner that mixes all three layers during retrieval. This case would result in layers of material that settle depending on density and particle size (i.e., Stoke's Law for rigid, spherical particles) for each batch of GFM retrieved. This case would deposit the GFM in bands of material with all three types of sand present, segregated by their density and particle size. The second scenario assumes all of the coarse sand is removed first, followed by the garnet and the fine sand. This would result in a media configuration very much like the garnet filter vessels before they were retrieved with minimal mixing of sand layers. Testing is planned to identify which retrieval and STSC solids settling case is most likely to occur.

K5 References

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6. PRC-STP-00344, *Preliminary Hazard Categorization of the KW IWTS Garnet Filter Media*, CH2M HILL Plateau Remediation Company, Richland, Washington.

Appendix L

North Loadout Pit Sludge and KE Sand Filter Media

L1 KE Basin North Loadout Pit Sludge

The KE Basin North Loadout Pit (NLOP) was one of the locations where sludge had accumulated in the KE Basin and was isolated from the main basin pool. It was used to contain sand filter backwash material. The KE NLOP sludge consists of uranium metal and fuel oxide concentrations lower than the general basin floor or canister sludge.

The KE NLOP sludge (3.5 cubic meters) was packaged into four large diameter containers (LDCs) and shipped to T Plant for interim storage and treatment. The NLOP sludge has since been treated at T Plant by hydraulically retrieving (via suction wand) the sludge from the containers and combining with a grout mixture that ultimately produced a total of (332) 55-gallon drums of contact-handled transuranic waste to be shipped to WIPP. The consistency of the sludge was fairly light/fluffy and was relatively easy to mobilize with fluidizing jets when retrieving the sludge from the NLOP and from the LDCs prior to depositing the material into 55-gallon drums. However, the LDC design incorporated a series of internal filters within the top half of the vessel that made it difficult to decant supernatant resulting in less-than-desired sludge loading solids concentrations at the Basin. The filter assembly also made it difficult to physically position the suction wand into the sludge slurry at the bottom of the LDC during sludge retrieval at T Plant. Three of the four LDCs have been successfully cleaned out and disposed of at ERDF in the 200 Area. The fourth LDC still resides in the T Plant canyon within cell 10L because not enough of the sludge was able to be retrieved to allow for disposal of the container at ERDF. Although no heel of sludge exists in the bottom of the LDC, it is estimated that approximately 262 pounds of sludge is held up in the series of filters. The filters cannot be back-flushed and the material held up in the filters has been abandoned in place since mid-2006. The sludge in the filters is likely to have hardened by now as there has been no effort to keep the filter assembly wetted while in storage. The current storage configuration of the NLOP LDC at T Plant is shown in Figure L-1 (lower right side of storage cell).

A summary of the KE NLOP sludge payload characteristics is provided in Section 12.0 of SNF-10823, *Package Safety Analysis Assessment for Sludge Transportation System*. An excerpt from Section 12.0 of SNF-10823 is provided in Table L-1.

Figure L-1. Large Diameter Containers in Storage at T Plant

Table L-1. K East Basin North-Loadout-Pit Sludge Data (from SNF-10823 Rev 1A)

Isotope	Source term used in shielding analysis		Source term allowed in payload
	Characterization data (Ci/m^3)*	Activity used in shielding analysis (Ci)	Total activity allowed in payload (from Table 12-2) (Ci)
^{60}Co	5.01 E-01	1.50 E+00	6.00 E-01
^{90}Sr	9.83 E+00	2.95 E+01	1.57 E+01
^{90}Y	9.83 E+00	2.95 E+01	1.57 E+01
^{99}Tc	6.14 E-03	1.84 E-02	9.18 E-03
^{137}Cs	2.77 E+01	8.31 E+01	4.15 E+01
^{137m}Ba	2.49 E+01	7.47 E+01	3.93 E+01
^{154}Eu	6.30 E-01	1.89 E+00	8.68 E-01
^{155}Eu	2.57 E-01	7.71 E-01	3.03 E-01
^{234}U	9.62 E-03	2.89 E-02	1.37 E-02
^{235}U	3.64 E-04	1.09 E-03	5.18 E-04
^{236}U	1.36 E-03	4.08 E-03	1.95 E-03
^{238}U	7.84 E-03	2.35 E-02	1.12 E-02
^{237}Np	1.49 E-03	4.47 E-03	2.03 E-03
^{238}Pu	1.36 E+00	4.08 E+00	1.63 E+00
^{239}Pu	5.71 E+00	1.71 E+01	7.80 E+00
^{240}Pu	3.14 E+00	9.42 E+00	4.28 E+00
^{241}Pu	1.68 E+02	5.04 E+02	2.30 E+02
^{242}Pu	1.51 E-03	4.53 E-03	2.07 E-03
^{241}Am	7.01 E+00	2.10 E+01	1.03 E+01

*Based on the safety-basis case in 04-SNF-JPS-001, 2004, *Recommended Design and Safety Basis Values for Physical Properties, Radionuclides and Chemical Composition of Sludge in the KE Basin North Loadout Pit* (memo from J. P. Sloughter to A. L. Ramble, January 13), Fluor Hanford, Inc., Richland, Washington.

KE = K East.
NLOP = North Loadout Pit.

L2 KE Basin Sand Filter Media

The water cleaning system for the KE Basin was upgraded in 1978 by adding a sand filter and IXMs. Basin water containing finely divided, suspended solids was collected by three surface skimmers and pumped to the sand filter. The suspended solids accumulated in the sand filter media (sand) until the pressure drop across the filter reached established operating limits, at which time the sand filter was backwashed into the NLOP, also known as the sand filter backwash pit, where the solids settle as sludge. Following the final backwash, as much of the sand and hold-up components as possible (approximately 2.8 cubic meters) was removed from the sand filter vessel, placed into an LDC, and transported to T Plant for interim storage pending treatment. The sand filter media was relatively easy to mobilize and retrieve from the NLOP and transfer into the LDC.

The sand filter media LDC was shipped to T Plant in April 2008 for interim storage, but was never treated at T Plant due to funding shortfalls and competing priorities. The sand filter media LDC currently resides in T Plant canyon cell 10L (see Figure L-1 – sand filter media LDC is shown in the upper left side of storage cell photo). To date, there has been no appreciable loss of water cover to evaporation and as such the sand filter media is considered to be fully saturated.

A summary of the KE Basin Sand Filter Media payload characteristics is provided in Section 13.0 of SNF-10823, *Package Safety Analysis Assessment for Sludge Transportation System*. An excerpt from Section 13.0 of SNF-10823 is provided in Table L-2.

Table L-2. Sand Filter Media Radioisotope Content (From SNF-10823 Rev. 1E)

	Sand filter media source term (uCi/g)	Sand filter activity in 2.8 m^3 of sand (Ci)
^{60}Co	9.04 E-02	4.87 E-01
^{90}Sr	4.04 E-01	2.17 E+00
^{99}Tc	3.86 E-03	2.08 E-02
^{134}Cs	2.07 E-01	1.11 E+00
^{137}Cs	1.15 E+01	6.19 E+01
^{154}Eu	1.00 E-01	5.38 E-01
^{155}Eu	4.55 E-02	2.45 E-01
^{234}U	4.57 E-03	2.46 E-02
^{235}U	2.38 E-04	1.28 E-03
^{236}U	6.49 E-04	3.49 E-03
^{238}U	3.66 E-03	1.97 E-02
^{238}Pu	9.70 E-02	5.22 E-01
$^{239/240}Pu$	1.12 E-01	3.19 E+00
^{241}Pu	6.17 E-01	6.05 E-01
^{241}Am	5.92 E-01	3.32 E+00

L3 References

1. Romano, T., "Package Safety Analysis Assessment for Sludge Transportation System," SNF 10823, Rev. 0, March 2003, Duratek Federal Services, Inc.

Appendix M

Integration with Site-Wide RH-TRU Processing/Packaging, Schedule, and Approach

M1 Other Identified RH TRU Waste Types

One of the identified criteria for the evaluation of the technology options is the extent that a given technical approach would integrate with the planned processing and packaging for the balance of other RH-TRU waste streams on the Hanford Site.

As part of the evaluation of the technologies, a summary of identified RH-TRU streams was developed with input from the STP Project and CHPRC Waste and Fuels organization. Appendices L and K discuss the KW basin Garnet filter material that will be retrieved and stored in STSC's in T-Plant, along with KE NLOP already stored in LDC's in T-Plant. .This appendix includes an overview of those and other Hanford site RH TRU wastes that may share common functional requirements with the K-Basin sludge material. The identified RH-TRU waste types, the currently proposed treatment approach, and target schedule (if known) are summarized in Table 1 and include:

1. The baseline K-Basin Sludge Material
2. Estimated 9.9 m^3 of KW Basin Garnet filter media at K Basin.
3. Estimated 3 m^3 of KE NLOP and sand filter media in LDCs at T Plant.
4. Estimated 2 m^3 of crystallized salts and liquid inside steel tank D-10 at U Plant canyon.
5. Estimated 93 m^3 of $BiPO_4$ process waste inside concrete tank 241-T-361 settling tank.
6. Estimated 78 m^3 of $BiPO_4$ process waste inside concrete tank 241-B-361 settling tank.
7. Estimated > 1000m^3 of CH TRUM waste retrieved from low level burial grounds inside multiple containers.
8. Estimated > 100 m^3 of RH TRU waste retrieved from low level burial grounds inside multiple containers.
9. Estimated 35 m^3 of RH TRU in containers at CWC.
10. Estimated 24 m^3 of RH TRU waste from 324 Bldg. cleanout inside steel containers.
11. Estimated 70 m3 of RH TRU in containers at burial grounds.
12. Estimated 150 m^3 of RH TRU waste from 300 Area laboratories inside 55 gallon drums.
13. Estimated 300 m^3 of RH TRU waste from 300 Area inside 55 gallon drums.

Primary functional requirements for processing of K Basin sludge were identified and are discussed here. The primary K Basin sludge processing functions include

- Nuclear facility with confinement ventilation and hazard category 2 rating
- Receive waste in storage and transportation containers from interim storage
- Transfer waste from the container
- Process waste
- Characterize treated waste

- Waste package characterized
- Certify waste package
- Load WIPP acceptable waste package into shipping container

The primary functional requirements of the other identified RH-TRU waste streams were developed by representatives from the CHPRC Waste and Fuels organization and compared to those required to treat and package the K-Basin material. The results are shown in Table 2.

As illustrated in Table 2; the primary areas where the functional requirements overlap are the need for a qualified category 2 facility with a robust ventilation system ("Facility"), and the "Package Waste" and "Certify Waste" functions. There is limited overlap of the "Process Waste" and "Characterize Waste" functions, other than the KW Garnet filter media, the KE NLOP and sand filter media, and the U-Plant D-10 Tank waste streams

Since there is little overlap in the "Process Waste" function, there is little differentiation between the technical approaches evaluated; and this criteria was determined to be a non-discriminator for this technology evaluation.

The currently proposed schedule for treatment of most of these waste streams is slightly in advance or essentially concurrent with the projected K-Basin Sludge material processing; so consideration of sequential use of a shared facility may be problematic. Prior to start of conceptual design of any Phase 2 Sludge Treatment Approach, it will be important to select a specific facility strategy for both the K-Basin Sludge Material along with the balance of the RH-TRU streams. Typical facility strategies could include the following:

- Design a flexible facility that provides adequate shielding, floor space and remote handling capabilities to subsequently install processing and packaging capability for other RH-TRU streams. Initially install the equipment for the K-Basin sludge treatment and packaging mission; with the flexibility to remove tanks and/or processing modules to support packaging and certification of other waste streams (or vice versa) -- either sequential approach could impact the achievable treatment schedule
- Design a facility for treatment of K-Basin sludge with flexibility to add additional annex(es) to support packaging of the other RH-TRU in series with K-Basin sludge
- Design a facility which has the capability to process both the K-Basin sludge material and the remaining RH-TRU
- Requalify and upgrade an existing facility to permit the installation of equipment to remotely treat and package the K-Basin Material along with the other RH-TRU

Without clearly defining the specific facility strategy for Phase 2 Sludge Treatment and the balance of the Site RH-TRU and the attendant functions and requirements for all the waste treatment, it will be very difficult to complete the facility conceptual design, demonstrate TRL performance of the equipment selected; and establish an achievable Phase 2 baseline schedule.

Table M-1. Candidate Wastes for Processing in Phase 2 STP Facility

Waste Type	#	Waste	Waste Source	Container Type	Volume	Location	Comments	Proposed Treatment	Schedule	Reference
Sludge	**1**	**K Basin Sludge**	**K Basin particulate that can pass through a 0.25-inch screen**	**20 Sludge Transport Storage Containers**	**27 m^3**	**T Plant**	**Load STSCs with sludge and move to T Plant for interim storage by 9/30/2015.**	**Warm water oxidation and grouting of sludge into 30 and 55 gallon drums.**	**Complete treatment and packaging by 2028**	**HNF-41051, *Preliminary STP Container and Settler Sludge Process System Description and Material Balance*, Rev 7** **NOTE: ECRTS sand filter media disposition not yet established.**
	2	KW Basin Garnet Filter media	Filter media (sand and Garnet filter media)	≥3 STSCs 3 STSCs	3 m^3 Sand filter media 6.9 m^3 Garnet filter media	T Plant	Load STSCs with sand and Garnet filters and move to T Plant for interim storage by 9/30/2015.	Process with K Basin sludge	TBD	HNF-47664, Sludge Treatment Project Retrieval, Transport and Interim Storage of the KW Basin Garnet Filter Media Engineering Study, Rev 0 HNF-SD-WM-SAR-062, K Basins Safety Analysis Report, Rev 15 PRC-STP-00344, Preliminary Hazard Categorization of the KW IWTS Garnet Filter Media Appendix A
	3	KE NLOP and Sand Filter media	Filter media (sand) from 100 KE and residual KE NLOP sludge	Two - LDCs (4.2 m^3 metal cylinders)	0.2 m^3 KE NLOP 2.8 m^3 KE sand filter	T Plant	Two containers currently stored at T Plant, additional containers maybe generated.	Process with K Basin sludge	TBD	Solid Waste Information and Tracking System (SWITS) JCS work package, 2T-09-1177, 221 T 1 Yr Visual Inspection of LDC in Storage Cell NLOP
	4	Tank D-10, U Plant	Crystallized salts and liquids	7x7 tank in a 13x13x14 shipping container, 90,000 lbs	2 m^3	CWC	Stored at CWC until treatment capability available	Slucing, and solidification	Process at future RH large package facility	DOE/RL-2010-106, *90% Design Remedial Design Report Addendum for the Disposition of Tank D-10 from Cell 30 within the 221-U Plant Canyon Facility*, Rev. 0.
	5	241-T-361 Settling tank	T Plant	Underground concrete structure. 19 ft high by 20 ft diameter, 36 kgal capacity	93 m^3	Between 241-T Tank Farm and T Plant	Addressed by CERCLA cleanup	TBD	M-016-00, Complete remedial actions for all non-tank farm and non canyon OUs by 9/30/2024.	DOE/RL-2003-64, Feasibility Study for the 200-TW-1 Scavenged Waste Group, the 200-TW-2 Tank Waste Group and the 200-PW-5 Fission-Product Rich Waste Group Operable Unit, Draft A. DOE/RL-2007-02, *Supplemental Remedial Investigation/Feasibility Study Work Plan for the 200 Areas Central Plateau Operable Units*, Rev. 0. WHC-SD-EN-ES-040, *Engineering Study of 50 Miscellaneous Inactive Underground Radioactive Waste Tanks Located at the Hanford Site, Washington*, Rev 0
	6	241-B-361 Settling Tank	B Plant	Underground concrete structure. 19 ft high and 20 ft diameter. 36K gal capacity	78 m^3	West of B Plant, near 216-B-5	Addressed by CERCLA cleanup	TBD	M-016-00, Complete remedial actions for all non-tank farm and non canyon OUs by 9/30/2024.	DOE/RL-2003-64, *Feasibility Study for the 200-TW-1 Scavenged Waste Group, the 200-TW-2 Tank Waste Group and the 200-PW-5 Fission-Product Rich Waste Group Operable Unit*, Draft A. WHC-SD-EN-ES-040, *Engineering Study of 50 Miscellaneous Inactive Underground Radioactive Waste Tanks Located at the Hanford Site, Washington*, Rev 0 WMP-31915 Rev 0, Acceptable Knowledge Summary Report for 216-B Reverse Well Mixed Transuranic Debris
Debris	7	Large Boxes of CH-TRUM waste	Waste retrieved from LLBGs	FRP, concrete, metal. Max container 21'x13'x19' and 82,000 lbs	> 1,000 m^3	CWC outside storage Area A and B	CH waste that cannot be treated with available capabilities. Due to size or SNM content. (<1 wt % RH)	Size reduction, sort, remove prohibited items, repackage, verification, & assay.	M-091-44 Certify and Ship of all TRUM waste to WIPP by 12/31/2030	DOE/RL-2009-33, *Waste and Fuels Management Project Strategic Plan*, Rev. 1. HNF-19169, *M-91 Transuranic Mixed/Mixed Low-Level Waste Project Management Plan*, Rev. 8 CHPRC-00924, Rev 0, *Functions and Requirements for the Hanford RH/Large Package Processing Capability* SWITS
	8	RH-TRUM Waste	Waste retrieved from LLBGs, Cleanout of 324 building cells	Drums, casks, metal boxes, concrete vaults. Max 9.3'x9'x9' and 45,000 lbs including package overpack, 6,000 lbs individual waste item	> 100 m^3	CWC outside storage Area A and B	RH waste that cannot be treated with available capabilities.	Sorting to remove RH, size reduction remove prohibited items, repackage, verification, assay and loading.	M-091-44 Certify and Ship of all TRUM waste to WIPP by 12/31/2030	DOE/RL-2009-33, *Waste and Fuels Management Project Strategic Plan*, Rev. 1. HNF-19169, *M-91 Transuranic Mixed/Mixed Low-Level Waste Project Management Plan*, Rev. 8 CHPRC-00924, Rev 0, Functions and Requirements for the Hanford RH/Large Package Processing Capability SWITS
	9	RH-TRU Waste	Cleanout of 324 Building cells	Steel containers	35 m^3	CWC		Sorting to remove RH, size reduction remove prohibited items, repackage, verification, assay and loading.	TBD	CHPRC-00604, *No-Path-Forward Waste Stream Alternative Analysis*, Rev. 0 SWITS
	10	Alpha Caissons	325 and 327 hot cells	Four underground caissons.	24 m^3 RH-TRU	218-W-4B burial ground	TPA requires retrieval by 2018, may be relocated	Retrieve, repackage, verification, assay, loading	M-091-44 Certify and Ship of all TRUM waste to WIPP by 12/31/2030	CHPRC-00585, *218-W-4B Alpha Caissons Technical Information Report*, Rev. 0. HNF-19169, *M-91 Transuranic Mixed/Mixed Low-Level Waste Project Management Plan*, Rev. 8 SWITS
	11	618-10, 11 caissons	300 Area laboratories	1 gal containers (majority) in Galvanized corrugated metal pipe	70 m3 RH-TRU	CWC (proposed)	Likely to be stored in CWC after retrieval.		M-016-00, Complete remedial actions for all non-tank farm and non canyon OUs by 9/30/2024.	WCH-125, *600 Area remediation Design Solution Waste Volume and Inventory*, Rev. 0. HNF-19169 Rev 8, M-91 Transuranic Mixed/Mixed Low-Level Waste Project Management Plan
	12	618-10/11 Vertical Pipe units 94 in 618-10 50 in 618-11	300 Area laboratories	Aluminum milk pails in vertical pipe units that are metal 55 gal drums welded together	150 m^3 RH-TRU	CWC (proposed)	Likely to be stored in CWC after retrieval. Addressed by CERCLA cleanup		M-016-00, Complete remedial actions for all non-tank farm and non canyon OUs by 9/30/2024.	WCH-125, *600 Area remediation Design Solution Waste Volume and Inventory*, Rev. 0. HNF-19169, *M-91 Transuranic Mixed/Mixed Low-Level Waste Project Management Plan*, Rev. 8
	13	618-10/11 Trench RH-TRU Waste	300 Area laboratories	Waste in 55-gal concreted drums	300 m^3 RH-TRU	CWC (proposed)	Likely to be stored in CWC after retrieval. Addressed by CERCLA cleanup		M-016-00, Complete remedial actions for all non-tank farm and non canyon OUs by 9/30/2024.	WCH-125, *600 Area remediation Design Solution Waste Volume and Inventory*, Rev. 0. HNF-19169, *M-91 Transuranic Mixed/Mixed Low-Level Waste Project Management Plan*, Rev. 8

Table M-2. Waste Types and Process Functional Requirements for Phase 2 STP Facility

Process Function Description		Waste Type/Process Function										
		1	2	3	4	5	6	7, 8, 9	10	11	12	13
		Phase 2 K Basin Sludge Treatment	KW Basin Garnet Filter media	KE NLOP and Sand Filter media	U Plant D-10 Tank	241-T-361 Settling Tank	241-B-361 Settling Tank	RH TRU and CH-TRU Large Package	RH TRU Alpha Caisson Waste Package Retrieval Project	618-10,11 Caissons	618-10,11 Vertical Pipe Units	618-10,11 Trench Waste
Waste Type	Sludge	X	X	X	X	X	X					
	Debris (in large package)							X			X	X
	Debris (in small package)								X	X		X
Facility	AG-1 HVAC System	X	X	X	X	X	X	X	X	X	X	X
	Category 2 Nuclear Facility	X	X	X	X	X	X	X	X	X	X	X
Receive Waste Package	Receive Sludge STSCs, Tanks, etc.	X	X	X	X	X	X					
	Receive large package waste containers (debris) from interim storage							X			X	X
	Receive small packages of debris waste								X	X		X
Transfer Waste from Package	Remotely open and retrieve sludge using water spray retrieval tool and transfer pump.	X	X	X	X							
	Remotely open and retrieve debris from large package waste containers.							X			X	
	Remotely open and retrieve debris from small package waste containers.								X	X		X
Process Waste	Transfer sludge slurry to reactor tank for treatment and water evaporation to desired solids concentration. Add chemicals (Fenton Reagent) as required to enhance treatment.	X	X	X	X	X	X					
	Condense and collect process condensate and truck trailer transport excess condensate to ETF for disposal.	X	X	X	X	X	X					
	Remotely extract and sort material/debris							X	X	X	X	X
	Remove WIPP unacceptable debris and transfer to appropriate area for processing or packaging							X	X	X	X	X
	Remotely size reduce/compact large items (STSC water filled annulus, flange, etc) to fit into drums.	X	X	X				X			X	
Characterize Waste	Lag storage tank for storing treated sludge before immobilization	X	X	X	X	X	X					
	Lag storage tank recirculation system with sensor for radio isotope estimation	X	X	X	X	X	X					
Package Waste	Assay and meter sludge for immobilization	X	X	X	X	X	X					
	Assay debris for packaging							X	X	X	X	X
	Add drums or other containers for packaging waste materials	X	X	X	X	X	X	X	X	X	X	X
	Add cement mix/absorbent to drums and retrieved STSCs and tanks	X	X	X	X	X	X					
	Package sludge, debris and size reduced solid waste into drums	X	X	X	X	X	X	X	X	X	X	X
	Decontaminate exterior surface of waste drums and retrieved STSC/ tanks and measure dose rate	X	X	X	X	X	X	X	X	X	X	X
	Insert RH waste drums into shielded containers or overpacks	X	X	X	X	X	X	X	X	X	X	X
	Transport waste packages to interim storage	X	X	X	X	X	X	X	X	X	X	X
Certify Waste	Certify waste drums for WIPP acceptance	X	X	X	X	X	X	X	X	X	X	X
	Certify non TRU waste drums, containers and/or equipment for disposal as ERDF waste	X	X	X	X	X	X	X	X	X	X	X
Load WIPP Acceptable Waste into Shipping Container (i.e., HALFPACT, RH-72B)	Transport shielded waste packages from interim storage to shipping container loading.	X	X	X	X	X	X	X	X	X	X	X
	Load waste drums into shipping containers	X	X	X	X	X	X	X	X	X	X	X
	Transport waste to WIPP	X	X	X	X	X	X	X	X	X	X	X

Appendix N

Regulatory and Stakeholder Acceptance

N1 Regulatory Background

The overall purpose of the K Basins interim remedial action is to mitigate the potential to release hazardous substances from the K Basins by removing the spent nuclear fuel, debris, sludge, and water from the K Basins, deactivate the basins, and transfer the SNF and waste to facilities that will manage them in a manner that protects human health and the environment. The K Basins Amended Record of Decision[1] (the Amended ROD) specifies that the transuranic portion of the radioactive sludge will be treated prior to disposal at a national repository[2] and states that the modified remedy for sludge could use a combination of the treatment technologies (physical, chemical, thermal, and/or solidification) that meet treatment performance criteria and were evaluated in the original feasibility study.

The Amended ROD indicates that, in addition to requiring treatment for disposal, the sludge will require treatment to place it in a safer state for interim storage prior to disposal. The Amended ROD further specifies that the treatment will address the national repository's acceptance criteria for reactive metal, free liquids, hydrogen gas, and radiological dose (for contact-handled waste).

The two predominant waste treatment criteria that must be achieved to prepare the waste for disposal and to place the sludge in a safer state are: (1) the waste must contain "no drainable liquids" and (2) the waste must not generate hydrogen to the extent of requiring stringent engineering and administrative controls. The treatment will be designed will be consistent with the remedial action objectives of the ROD. Specifically, treatment will be designed and performed in a manner that addresses sludge management concerns identified in the ROD such as high surface dose, high fissile concentrations, and the presence of potentially pyrophoric metal fines and metal hydrides.

Transuranic sludge will be dispositioned in two phases. Phase 1 will focus on retrieval of sludge from the KW Basin into Sludge Transport and Storage Containers and transport to T-Plant for lag storage. Phase 2 will include removal of the sludge from lag storage and transport to a facility where it will be treated, immobilized, and packaged in preparation for transport to the national repository.

To support the Phase 2 decision criteria, goals, and measures consistent with the modified sludge remedy in the Amended ROD, a technology alternative analysis process was applied to a variety of proposed technologies which resulted in the selection of eight candidate processes for evaluation and bench-top feasibility testing. From these candidate processes, six alternatives were evaluated by the Decision Support Board (DSB), which selected an integrated set of technologies that could be used for pre-conceptual design of a facility to meet project objectives, including the achievement of regulatory and stakeholder acceptance.

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[1] 100 K Area K Basins, Hanford Site – 100 Area, Benton County, Washington Amended Record of Decision, Decisions Summary and Responsiveness Summary, U.S. Department of Energy

[2] DOE anticipates disposing of the treated transuranic sludge at the Waste Isolation Pilot Plant in New Mexico.

N2 Discussion

Regulatory and stakeholder acceptance for Phase 2 will be achieved by ensuring work is performed in accordance with environmental laws and regulations (and applicable DOE Orders) and by addressing the sludge management concerns identified above. Each of the technology alternatives evaluated by the DSB could conceivably satisfy the criterion for regulatory and stakeholder acceptance.

All the water-based technologies (with one exception) are sufficiently similar to each other such that the basic uranium treatment objectives could be similarly met for each. These technologies include the Warm Water Oxidation Process (WWOP), the Fenton's Reagent Oxidation Process (FROP), the Peroxide and Carbonate Oxidation Process (PCOP), and Size Reduction and Water Oxidation Process (SRWOP). Each of these processes would be anticipated to successfully oxidize uranium metal to uranium oxide. Another water-based process, the Nitrate Chemical Inhibitor Process (NCIP), would differ from the other water-based processes because instead of direct uranium oxidation, nitrate would react with hydrogen radicals to significantly reduce evolution of hydrogen gas from the oxidation reaction of uranium with water. This approach would therefore require additional evaluation to ensure that retention of metallic uranium within the final waste form would meet the receiving facility's acceptance criterion regarding hydrogen generation. Variations in time necessary to achieve end state for the sludge treatment step resulted in slight differences related to potential stakeholder acceptance.

All alternatives appear to be equally capable of ensuring that "no drainable liquids" are present in the waste through addition of cement mix or other absorbent. This would be unnecessary for the vitrification process, which would drive off residual water through the application of high heat energy.

All alternatives (with the potential exception of vitrification) appear to be equally satisfactory with respect to the PCB component of the sludge because the PCBs in the final waste form can readily meet the waste acceptance criteria for the national repository. This is based on the fact that the waste acceptance criteria for PCBs can be met at the candidate disposal facility (the Waste Isolation Pilot Plant) without specific PCB treatment, and the facility meets the substantive standards for disposal of PCB remediation waste. Because large amounts of heat energy would be applied to the sludge in the vitrification process, further evaluation would be necessary to confirm that such thermal treatment would not be deemed unacceptable under the Toxic Substances Control Act due to potential emissions of dioxins and furans during vitrification.

Appendix O

Life-Cycle Cost and Schedule

Contents

O1 Introduction

CHPRC is performing a Technology Evaluation and Alternatives Analysis (TEAA) to support development of recommendations for technology alternatives to be used for Sludge Treatment Project (STP) Phase 2 treatment and packaging of K Basin Sludge. As part of the TEAA effort, comparative cost and schedule estimates were prepared for the 6 alternatives currently being evaluated. A project life-cycle schedule was prepared at the same time and utilizes the same work breakdown structure (WBS), activities, and durations as the cost estimates. This appendix provides a summary of the cost and schedule estimate results, together with a description of the scope, assumptions and methodology used in preparing the estimates.

One of the primary Decision Plan evaluation criteria requires a comparison of life-cycle cost and schedule for the development, design, deployment and operation of each technology approach under evaluation [1].

The cost and schedule estimates were generated to meet one of the objectives of the Decision Plan, consistent with and supportive of a key principle of DOEs project management approach (as outlined in DOE 0 413.3B, Program and Project Management for the Acquisition of Capital Assets)"... to ensure (that) appropriate supporting analyses and risk evaluations are available when making a critical decision" (DNFSB, 2008, "DNFSB Quarterly Report to Congress"). The Decision Plan also incorporates the principles and guidance provided in DOE STD 1189, Integration of Safety in to Design Process, into its activities, evaluations and documentation. As a result the cost estimates are also framed and structured to comply with DOE 0 413.3B.

The purpose of this appendix is to:

- Provide cost data to allow comparisons of pre-conceptual life-cycle cost (LCC) estimates of the 6 identified technical alternatives.
- Provide the basis and support information utilized to generate the pre-conceptual cost data.
- Present a Present Worth Analysis (PW) of the alternatives.

The six alternatives are presented in Table O-1.

Table O-1. Evaluated Alternatives

Alternative Number	Alternative Title
Alternative 1	WWO -Warm Water Oxidation
Alternative 2	PCOP – Peroxide Carbonate Oxidation Process
Alternative 3	FROP – Fenton's Reagent and Water Oxidation Process
Alternative 4	SRWOP – Size Reduction and Water Oxidation Process
Alternative 5	NCIP – Nitrate Chemical Inhibitor Process
Alternative 6	ICV™ – Joule Heated In-Container Vitrification

O2 Scope and Assumptions

Flowsheets, equipment sizing, facility layouts, and hazards reviews, for integrated process concepts were developed to support the cost estimates for candidate technologies. The cost and schedule estimates herein are preliminary and are intended solely for comparing flowsheet alternatives on a consistent normalized basis. In some cases unverified enabling assumptions are defined for the purpose of conducting preliminary evaluations. Verification of the enabling assumption and resolution of other uncertainties will be addressed during the normal course of future conceptual design development, project baseline development and ongoing testing and design activities.

The elements that make up the life-cycle scope are based on the data developed and found in the following reference documents:

- Appendix A – Pre-conceptual design information for the WWO alternative for treatment of K-Basin Sludge (Sketches and process flow diagram used to represent identical scope found in the different process alternatives).
- Appendices B-H – provide process descriptions for the other processes under evaluation. Facility size and layouts are assumed to be similar to that presented in appendix A for the WWO alternative.
- Appendix J –Process Bases and Assumptions
- DOE 0 413.3B defines the balance of the scope and activities found in a typical program/project life cycle.

O2.1 Program/Project Scope

Volume 1 discusses and appendices A-H describe the basic technical approaches needed to receive, treat, and immobilize the sludge. While these discussions address the similarities and differences between the technical approaches, the cost estimate includes a definition of the entire project life cycle in the WBS structure found in Table O-2 below. The estimate includes the common elements needed for a complete life cycle description required to implement the technical approaches. For this estimate, life cycle is defined as starting with retrieval of the STSCs from T-Plant, transfer to the "Treatment and Packaging" facility, operations to treat and package the waste in a package suitable for shipment to WIPP, interim storage on a pad near this facility, and finally, deactivation of the systems in the facility to clean out the equipment and place it in a safe state pending other future use. Once the waste drums are produced and placed on the storage pad, surveillance and maintenance will be performed by others until the drums are transferred to a central site packaging and shipping facility. Since the facility is assumed to be utilized for other site activities after it completes the Sludge Treatment and Packaging Mission; final decommissioning costs were excluded from this lifecycle estimate.

Enabling assumptions that are related to scope, schedule and pricing include:

- Project will be managed following DOE O 413.3B, STD 1189 and Technology Readiness Assessment guidance
- The base case assumption is that after an undefined interim storage period the product drums will be loaded into RH-72B casks for shipment to WIPP. However, the RH-72B loading and shipping facilities, operations, and shipping costs are planned to be provided by central site organizations and are excluded from these cost and schedule estimates.
- Estimate includes building a lag storage facility to house drums between the packaging process and the shipping process to facilitate the production operations. The storage cost (operations, maintenance and surveillance) for the packaged drums will be borne by others once the treatment and packaging is completed.

- As a placeholder for a location for the full scale integrated testing system, the estimate assumes that a portion of the Fuels and Materials Examination Facility (FMEF) is made available for treatment and packaging system testing and qualification (including use of depleted uranium metal and oxides) with appropriate fire protection and ventilation systems (or that no more than $3M is required to upgrade the facility, and $1M to reconnect utilities).
- Project will competitively outsource the Preliminary and Final design efforts, with CHPRC oversight and engineering reviews.
- Facility operating cost estimates assume the base case operating durations as discussed in Appendix I.
- An onsite laboratory will be available during waste processing operations to analyze samples, when required.
- Deactivation of process systems at completion of the project is included; however other facility use is expected. Therefore, decontamination and decommissioning of the facility and systems is not included in the cost and schedule estimates.
- Empty STSCs will be grouted and disposed of at ERDF.
- Early procurement and construction authorization by DOE will be required to meet current schedules (i.e. a tailored approach to the Critical Decision (CD) process).
- The design phases for this project will be a continuous process, with DOE reviews and approvals of the CD documents in parallel with the next design phase (no delays in funding authorization awaiting CD decisions).
- The critical path schedules assume a common start point (October 1, 2012) for all options for comparison. The common start date is an assumption and should not be taken as a DOE commitment for overall project completion at this early preconceptual stage.

O2.2 Work Breakdown Structure (WBS)

Cost estimates for each alternative approach utilized the typical WBS Structure and Description provided by DOE 0 413.3B, "Program and Project Management for the Acquisition of Capital Assets." The WBS includes typical project definition and decisions activities as well as Technology Readiness Assessments and Testing required for meeting the Critical Decision requirements at each phase of the development.

The programmatic scope of the cost and schedule are included in Table O-2.

Table O-2. WBS Structure and Description

WBS	Description
100	Project Management
110	Project Startup
120	Submit CD-0
130	Mission Validation Independent Review (MVIR)
140	DOE Approval Of CD-0
150	Conceptual Design (Including DOE CD-1 Approval)
160	Testing For TRL-4
170	Test Article Procurements
180	Preliminary Design (Including DOE CD-2 Approval)
190	Testing For TRL-6 / Reconnect And Upgrade FMEF
200	Final Design (Including DOE CD-3 Approval)
210	Process Optimization Testing
220	Procurements
230	Prepare, Award, And Perform Construction (Including CAT)
240	Cold Commissioning
250	Operational Readiness Reviews
260	DOE Approval CD-4
270	Operations
280	Laboratory Characterization
290	Deactivation (Secondary Waste Disposal)
300	Project Closeout

O3 Basis of Estimate

As discussed in Appendix A, a more complete preconceptual definition was documented for the Warm Water Oxidation alternative. The Warm Water Oxidation concept described in Appendix A was used as a starting basis for the cost and schedule for the "Treatment and Packaging" facility, equipment, and operations production rate basis. Other technical approaches were then estimated by making adjustments to this base estimate based on the addition or removal of some required process and supporting functions, and by adjustment of the assumed operating durations. For the Warm Water Oxidation process the estimate was based on:

- Utilization of existing Labor mix of STP Phase 1 ECRTS project profiles.
- Actual labor and subcontract staff & rates from the current STP project.
- The "Project Management" WBS element cost is based on existing STP Management staff (funded through 12/31/14). The estimate accounts for the shift from shared management to a standalone project management function as the ECRTS project is completed in 2014
- Engineering is based on the current ECRTS existing staff and rates utilized for the ongoing ECRTS Conceptual design. Subsequent engineering phases assume that preliminary and final designs will be subcontracted with capable Architect-Engineering firms, with oversight from the STP Engineering organization.
- The "Testing" WBS elements are based on using the Maintenance And Storage Facility (MASF) testing model used for the ECRTS sub-project conceptual design phase, then moving to a different facility that could utilize uranium for full scale testing. As a placeholder, the estimate assumed that the project would utilize a portion of the inactive Fuels and Materials Examination Facility (FMEF) for remainder of testing and qualification, since MASF is not currently permitted for reactive chemicals and the required quantities of depleted uranium metal and oxides. The estimate includes allowances to re-establish FMEF services(currently cold & dark), based on the STP project experience with significant MASF upgrades to support ECRTS, KOP and K Basin sludge characterization development, ECRTS TRL-4 component testing and qualification, and TRL-6 full scale integrated testing and qualification to support conceptual and preliminary design.
- Overall building construction costs are estimated using a parametric approach based on facility square footage as provided in WWO studies, modified using the more detailed cost estimates developed to support an earlier STP alternatives analysis [2]. Where differences in scope or facility functional requirements were identified, adjustments were made as needed.
- Operation durations are based on the Sensitivity Analysis base case presented in Appendix I and a staffing profile estimate to include "A, B, C, and D" shifts (24/7 operations).
- Laboratory analysis cost estimate is based on 222-S analytical laboratory estimate assuming 5 samples per stream.
- WIPP Certification cost estimate is based WRAP Operations estimate for WIPP certification packaging.
- Deactivation is based on a model provided by Central Estimating D&D projects.

Work scope that is included:

- Design, Testing, Construction Startup and Operation of the Phase 2 facility
- Movement of the Loaded STSC's from T Plant to the Phase 2 Treatment and Packaging Facility

- Receipt and Staging of the STSC at the head end of the Phase 2 Treatment and Packaging Facility
- Assay of the loaded drums and certification to WIPP requirements
- Lag storage of the loaded drums in a shielded container until treatment and packaging operations is completed.
- Deactivation/removal of Phase 2 equipment in preparation for reuse by another program

Work scope excluded in this estimate is identified in Table O-3.

Table O-3. Excluded Work Scope

Work scope Excluded	Basis for Exclusion
Transport of the shield boxes containing filled drums to RH-72B loading and shipping facility	Central site program function on an indefinite schedule
Design/Construction of Central RH-72B loading and shipping facility (including any lag storage/staging pad required)	Central site program function on an indefinite schedule
Loading operations to place the drums in the RH-72B (or HalfPack, if shielded drums)	Central site program function on an indefinite schedule
Transportation to WIPP	RH-TRU transportation is a WIPP directed and funded activity
Surveillance and Maintenance of the stored loaded containers until RH-72B loading facility in operations	Central site program function on an indefinite schedule
Final Decommissioning and Demolition of the facilities	Final D&D will be completed by subsequent utilizing organization

Method of Contract

The “method of contract” to complete the various phases of the project was established for pricing purposes as follows:

- Construction labor and support is all “new process line.” New or greenfield work shall be performed by “fixed-price” construction.
- Engineering/Design, Engineering and Inspection during Construction, and bid package preparation will be by the onsite contractor.
- Project and Construction Management will be by the onsite contractor.

Direct Costs

For the purpose of developing direct costs, fixed price construction craft labor rates are those listed in Appendix A of the current Hanford Site Stabilization Agreement.

Miscellaneous Inputs

The following is an overview of miscellaneous inputs to the facility cost estimate:

- Infrastructure upgrades were identified from generalized data on power and other utility requirements
- Fully burdened current labor rates and site mark-ups are utilized

- Standard Fluor Government Group (FGG) and CHPRC planning rates, adders, taxes, indirects, and escalation are used
- On site disposal costs for the projected contaminated materials generated during operations and deactivation are included

Construction Labor, Material and Equipment Units

Construction labor, material and equipment units have been estimated based upon the cost data from HNF-39744, *Sludge Treatment Project Alternatives Analysis Summary Report, Vol.* 1, Rev. 1, 2009, CHPRC, Richland, Washington.

The units may have been factored and/or adjusted by the estimator as appropriate to reflect differences in the proposed scope, contract, work site, safety significance factors or other identified project or special conditions.

OPC/Expense Basis

Engineering and support costs were derived from actual costs currently being experienced on the ECRTS design subproject. The scope for OPC activities used for this estimate includes:

- Engineering Design/Testing
- Start-up/Readiness
- Operations and support

Escalation

U. S. Department of Energy (DOE) escalation rate guidelines were used for lifecycle and present worth analyses. Average escalation is at 2.0 % annually compounded for fiscal years (FY) 2011 through FY 2026

Costs in the supporting estimate details are shown in 2011 dollars with escalation applied when a specific scenario is evaluated.

The estimate escalation factors are determined from the time phased logic schedule. The calendar date of the activity midpoint is calculated, converted to fiscal year and then found on the escalation rate by fiscal year table. The standard annual DOE approved/directed escalation applied to each summary element in the estimate, which is critical for the life cycle cost comparison basis.

Contingency

The contingency[1] incorporated in the estimate numbers are based on the maturity of design and process included in the current and future pricing.

Contingency allowance includes -50%/+100% accuracy range on capital costs, consistent with an Association of the Advancement of Cost Engineering (AACE) International Class 5 estimate.

Cost Estimate Detail Backup

A file share area on HLAN prepared by CHPRC Estimating includes the detailed supporting cost data used to generate the six alternative/option estimates. In addition, detailed supporting documents being retained in the STP Project offices includes:

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[1] "Contingency covers costs that may result from incomplete design, unforeseen and unpredictable conditions, or uncertainties within the defined project scope. The amount of contingency will depend on the status of design, procurement, and construction; and the complexity and uncertainties of the component parts of the project. Contingency is not to be used to avoid making an accurate assessment of expected cost."

1. Historical costs (Design, Testing, Startup, Readiness, and Operations)
2. Scope and costs used from Appendices A-H and J, and HNF-39744, *Sludge Treatment Project Alternatives Analysis Summary Report, Vol.* 1, Rev. 1, 2009, CHPRC, Richland, Washington[2]
    i. Equipment List (WWO)
    ii. Estimate Process (Site Facilities And Process Equipment)
    iii. Prorated Calculation Basis (Design, CM/PM, E&I & CD)
    iv. Cost Estimate – Detailed Reference (Similar & Unique)
    v. New Facility (square foot)
    vi. New Facilities (volume)
    vii. D&D Backup
    viii. Common Process Description
    ix. Unique Process Description (ICV™)
    x. FY Date Midpoint of Estimate Activities
    xi. Process Equipment Cost Estimates
    xii. Pro-Rate Treatment/Packaging Facility
    xiii. Unique Cost - Site Civil Utilities
    xiv. Unique Cost – ISC Storage
    xv. Unique Cost – Control Room

[2] Costs found in HNF-39744, *Sludge Treatment Project Alternatives Analysis Summary Report, Vol.* 1, Rev. 1, 2009, CHPRC, Richland, Washington, reflect FY2009 values and have been escalated to FY2011 costs as a starting point for this estimate.

O4 Estimate Methodology

The estimate methodology generally consists of common or "building block" estimates pro-rated from pre-conceptual estimates or actual costs. In general, construction costs were obtained using parameters for equivalent facilities derived from square footage. The balance of life cycle activities were pro-rated from actual or equivalent labor and subcontractor costs, including project management, design, testing, start-up, technical readiness, operations, characterization and deactivation.

Each alternative has multiple common elements with the other alternatives with similar bases, which facilitates this building block estimate approach. Alternatives vary in process/treatment and execution durations; however, the resulting cost differences were considered minor and within the tolerance of the intent of the alternative analysis. Table O-4 lists the activities with common costs used in the "building block" approach. Project Management and Operations are different for the alternatives because of the range of actual operating times for the various approaches.

Table O-4. Life-cycle Activities (Common costs)

WBS	**Life-Cycle Project Activities**	**Common Activities between Alternatives**
100	Project Management	No
110	Project Startup	Yes
120	Submit CD-0	Yes
130	Mission Validation Independent Review (MVIR)	Yes
140	DOE Approval Of CD-0	Yes
150	Conceptual Design (Including DOE CD-1 Approval)	Yes
160	Testing For TRL-4	Yes
170	Test Article Procurements	Yes
180	Preliminary Design (Including DOE CD-2 Approval)	Yes
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	Yes
200	Final Design (Including DOE CD-3 Approval)	Yes
210	Process Optimization Testing	Yes
220	Procurements	Yes
230	Prepare, Award, And Perform Construction (Including CAT)	Yes
240	Cold Commissioning	Yes
250	Operational Readiness Reviews	Yes
260	DOE Approval CD-4	Yes
270	Operations	No
280	Laboratory Characterization	Yes
290	Deactivation (Secondary Waste Disposal)	Yes
300	Project Closeout	Yes

O4.1 Estimating Process

Scope:

- Align each alternative cost estimate WBS with the alternative time-phased schedule.
- Select similar and unique scope of work elements for each of the six (6) alternatives.
- Generate cost estimates for similar and unique scope.

- Use a level of detail commensurate with the detail provided.
- Includes -50%/+100% accuracy range on capital costs, consistent with an American Association of Cost Engineers (AACE) Class 5 estimates.
- Flag (group) the estimate components into capital and expense fund types.

Approach:

- Reuse to the extent possible recent existing estimates to form the building blocks of Alternative 1 (WWO).
- Generate unique cost estimates for operations and the program account (to align completion dates)
- Generate similar (common), estimates for:
  - Project Startup
  - Submit CD-0
  - Mission Validation Independent Review (MVIR)
  - DOE Approval Of CD-0
  - Conceptual Design (Including DOE CD-1 Approval)
  - Testing For TRL-4
  - Test Article Procurements
  - Preliminary Design (Including DOE CD-2 Approval)
  - Testing For TRL-6 / Reconnect And Upgrade FMEF
  - Final Design (Including DOE CD-3 Approval)
  - Process Optimization Testing
  - Procurements
  - Prepare, Award, And Perform Construction (Including CAT)
  - Cold Commissioning
  - Operational Readiness Reviews
  - DOE Approval CD-4
  - Laboratory Characterization
  - Deactivation (Secondary Waste Disposal)
  - Project Closeout

Technique – Various:

- Reuse/update from previous cost estimates with adjustments for scope, size, and schedule differences
- Parametric/factored – buildings $\$/ft^2$; factored from recent STP estimates
- Take-offs– Architectural/Structural (hot cells), process equipment

- Since the definitions of the alternatives in this study are preconceptual at this early stage -- all LCC estimate scope was not fully developed or available. Therefore, some cost allowances for TEC & OPC were generated.
- The major scope and costs for the baseline WWO Alternative were priced and then used to prorate similar scope in the other five (5) alternatives. (Reference Table 4-1 Life-cycle Activities (Common costs)
- Estimates are planning/feasibility (study) level estimates.

O5 Schedule Development

The reference critical path schedule was built using previous STP experience for design and expected construction durations for similar facilities, operations support requirements and the DOE Order 413.3B approval schedule requirements. The critical path schedules assume a common start point (October 1, 2012) for all options for comparison and are driven by start to finish times to establish the overall project elements duration. The common start date is an assumption and should not be taken as a DOE commitment for overall project completion at this early preconceptual stage.

The individual alternative overall life cycle schedule duration begins with the design, mobilization, and preparation of environmental documentation, and ends at the point of the receipt of the last container in the interim storage container pad located at Hanford.

The schedule was not resource loaded nor resource leveled due to the pre-conceptual nature of the design. See Attachment A for summary life-cycle schedules.

Schedule basis include:

- Estimate based on a 24/7 operations schedule (A-B-C-D shifts) at the treatment and packaging facility.
- Total treatment and packaging drum production time depends on immobilization system drum production capacity as noted in Table O-5, which were described in appendices A-H and the sensitivity analysis (Appendix I). Cost and schedule estimates herein assume the base case processing durations for each alternative.

Table O-5. Total Processing Time versus Drum Production Capacity (from Appendix I)

	Total Processing Time (Months) At 70% TOE for all STSCs with Various Drum Production Capacities		
	Minimum rate[2]	**Base case rate[2]**	**Maximum rate[2]**
Warm Water Oxidation (WWO)[1]	88	59	55
Peroxide Carbonate Oxidation (PCOP)	75	50	45
Fenton's Reagent Oxidation (FROP)	54	23	18.4
Size Reduction and Water Oxidation (SRWOP)	54	19	14.3
Nitrate Chemical Inhibitor (NCIP)	54	18	12.4
Joule Heated In-Container Vitrification (ICV™)	100	54	36

1. In the WWO base case, 2 STSCs are processed per batch; all others assume 1 STSC per batch.
2. Minimum, base case, and maximum drum production capacity for ICV™ are 5, 9.3, and 14 drums per week, all others are 10, 30, and 49 drums per week respectively.

The selected general durations for the common schedule activities Operations duration for Alternatives 1-6 are shown in Table O-6.

Table O-6. Schedule activity durations

WBS	WBS Description	Durations (days)
100	Project Management	*
110	Project Startup	21
120	Submit CD-0	72
130	Mission Validation Independent Review (MVIR)	18
140	DOE Approval Of CD-0	20
150	Conceptual Design (Including DOE CD-1 Approval)	566
160	Testing For TRL-4	566
170	Test Article Procurements	133
180	Preliminary Design (Including DOE CD-2 Approval)	701
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	701
200	Final Design (Including DOE CD-3 Approval)	372
210	Process Optimization Testing	372
220	Procurements	378
230	Prepare, Award, And Perform Construction (Including CAT)	1153
240	Cold Commissioning	125
250	Operational Readiness Reviews	125
260	DOE Approval CD-4	21
270	Operations	*
280	Laboratory Characterization	*
290	Deactivation (Secondary Waste Disposal)	251
300	Project Closeout	83

*Activities vary depending on alternative technology

O6 Cost Reports

The cost reports below present the estimated cost of each alternative/option:

- Table O-7. Summary Cost Report
- Table O-8. Level 2 Cost Report (includes escalation and G&A)
- Table O-9. Detailed Cost Report

Table O-7. PHASE 2 ALTERNATIVE - Estimated Life-Cycle Cost Summary ($000)

Alternative Number	Alternatives	-50%	Base Estimate	+100%
1	WWO	$354,848	$709,696	$1,419,393
2	PCOP	$322,158	$644,316	$1,288,632
3	FROP	$258,145	$516,289	$1,032,579
4	SRWOP	$242,511	$485,021	$970,043
5	NCIP	$242,511	$485,021	$970,043
6	ICV™	$354,848	$709,696	$1,419,393

Table O-8. PHASE 2 ALTERNATIVE COST REPORT - SUMMARY LEVEL 2 COSTS ($000)

Number	Alternative	-50%	BASE CASE	+100%	Cost Types
1	**WWO**	$257,289	$514,579	$1,029,158	Total Project Cost
		$68,409	$136,818	$273,635	Escalation
		$29,150	$58,300	$116,600	CHPRC G&A
		$354,848	**$709,696**	**$1,419,393**	**Total Life-Cycle Cost**
2	**PCOP**	$236,096	$472,192	$944,383	Total Project Cost
		$59,598	$119,195	$238,390	Escalation
		$26,465	$52,929	$105,858	CHPRC G&A
		$322,158	**$644,316**	**$1,288,632**	**Total Life-Cycle Cost**
3	**FROP**	$193,834	$387,667	$775,334	Total Project Cost
		$43,105	$86,210	$172,420	Escalation
		$21,206	$42,412	$84,824	CHPRC G&A
		$258,145	**$516,289**	**$1,032,579**	**Total Life-Cycle Cost**
4	**SRWOP**	$183,268	$366,536	$733,072	Total Project Cost
		$39,321	$78,642	$157,284	Escalation
		$19,922	$39,843	$79,687	CHPRC G&A
		$242,511	**$485,021**	**$970,043**	**Total Life-Cycle Cost**
5	**NCIP**	$183,268	$366,536	$733,072	Total Project Cost
		$39,321	$78,642	$157,284	Escalation
		$19,922	$39,843	$79,687	CHPRC G&A
		$242,511	**$485,021**	**$970,043**	**Total Life-Cycle Cost**
6	**ICV™**	$257,289	$514,579	$1,029,158	Total Project Cost
		$68,409	$136,818	$273,635	Escalation
		$29,150	$58,300	$116,600	CHPRC G&A
		$354,848	**$709,696**	**$1,419,393**	**Total Life-Cycle Cost**

Table O-9. PHASE 2 ALTERNATIVE DETAILED COST REPORT ($000) Page 1 of 2

Alternative		1 WWO			2 PCOP			3 FROP		
P6 ID	Activity Description	-50%	BASE CASE	+100%	-50%	BASE CASE	+100%	-50%	BASE CASE	+100%
100	Project Management	$37,013	$74,025	$148,050	$34,600	$69,200	$138,400	$29,900	$59,800	$119,600
110	Project Startup	$66	$132	$263	$66	$132	$263	$66	$132	$263
120	Submit CD-0	$292	$585	$1,170	$292	$585	$1,170	$292	$585	$1,170
130	Mission Validation Independent Review (MVIR)	$82	$165	$329	$82	$165	$329	$82	$165	$329
140	DOE Approval Of CD-0	$67	$135	$269	$67	$135	$269	$67	$135	$269
150	Conceptual Design (Including DOE CD-1 Approval)	$7,341	$14,681	$29,363	$7,341	$14,681	$29,363	$7,341	$14,681	$29,363
160	Testing For TRL-4	$5,000	$10,000	$20,000	$5,000	$10,000	$20,000	$5,000	$10,000	$20,000
170	Test Article Procurements	$3,000	$6,000	$12,000	$3,000	$6,000	$12,000	$3,000	$6,000	$12,000
180	Preliminary Design (Including DOE CD-2 Approval)	$13,088	$26,176	$52,352	$13,088	$26,176	$52,352	$13,088	$26,176	$52,352
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	$9,500	$19,000	$38,000	$9,500	$19,000	$38,000	$9,500	$19,000	$38,000
200	Final Design (Including DOE CD-3 Approval)	$6,999	$13,999	$27,997	$6,999	$13,999	$27,997	$6,999	$13,999	$27,997
210	Process Optimization Testing	$3,750	$7,500	$15,000	$3,750	$7,500	$15,000	$3,750	$7,500	$15,000
220	Procurements	$23,000	$46,000	$92,000	$23,000	$46,000	$92,000	$23,000	$46,000	$92,000
230	Prepare, Award, And Perform Construction (Including CAT)	$36,300	$72,600	$145,200	$36,300	$72,600	$145,200	$36,300	$72,600	$145,200
240	Cold Commissioning	$3,141	$6,282	$12,563	$3,141	$6,282	$12,563	$3,141	$6,282	$12,563
250	Operational Readines Reviews	$1,047	$2,094	$4,188	$1,047	$2,094	$4,188	$1,047	$2,094	$4,188
260	DOE Approval CD-4	$73	$146	$291	$73	$146	$291	$73	$146	$291
270	Operations	$93,906	$187,811	$375,622	$75,124	$150,249	$300,498	$37,562	$75,124	$150,249
280	Laboratory Characterization	$8,375	$16,750	$33,500	$8,375	$16,750	$33,500	$8,375	$16,750	$33,500
290	Deactivation (2nd Waste Disposal)	$2,750	$5,500	$11,000	$2,750	$5,500	$11,000	$2,750	$5,500	$11,000
300	Project Closeout	$2,500	$5,000	$10,000	$2,500	$5,000	$10,000	$2,500	$5,000	$10,000
	SUBTOTAL	$257,289	**$514,579**	$1,029,158	$236,096	**$472,192**	$944,383	$193,834	**$387,667**	$775,334
	Escalation	$68,409	$136,818	$273,635	$59,598	$119,195	$238,390	$43,105	$86,210	$172,420
	CHPRC G&A	$29,150	$58,300	$116,600	$26,465	$52,929	$105,858	$21,206	$42,412	$84,824
	TOTAL LIFE-CYCLE COST	$354,848	**$709,696**	$1,419,393	$322,158	**$644,316**	$1,288,632	$258,145	**$516,289**	$1,032,579

Table O-9. PHASE 2 ALTERNATIVE DETAILED COST REPORT ($000) Page 2 of 2

O6.1 Alternative		O6.2 4SRWOP			5 NCIP			6 ICV™		
P6 ID	Activity Description	-50%	BASE CASE	+100%	-50%	BASE CASE	+100%	-50%	BASE CASE	+100%
100	Project Management	$28,725	$57,450	$114,900	$28,725	$57,450	$114,900	$37,013	$74,025	$148,050
110	Project Startup	$66	$132	$263	$66	$132	$263	$66	$132	$263
120	Submit CD-0	$292	$585	$1,170	$292	$585	$1,170	$292	$585	$1,170
130	Mission Validation Independent Review (MVIR)	$82	$165	$329	$82	$165	$329	$82	$165	$329
140	DOE Approval Of CD-0	$67	$135	$269	$67	$135	$269	$67	$135	$269
150	Conceptual Design (Including DOE CD-1 Approval)	$7,341	$14,681	$29,363	$7,341	$14,681	$29,363	$7,341	$14,681	$29,363
160	Testing For TRL-4	$5,000	$10,000	$20,000	$5,000	$10,000	$20,000	$5,000	$10,000	$20,000
170	Test Article Procurements	$3,000	$6,000	$12,000	$3,000	$6,000	$12,000	$3,000	$6,000	$12,000
180	Preliminary Design (Including DOE CD-2 Approval)	$13,088	$26,176	$52,352	$13,088	$26,176	$52,352	$13,088	$26,176	$52,352
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	$9,500	$19,000	$38,000	$9,500	$19,000	$38,000	$9,500	$19,000	$38,000
200	Final Design (Including DOE CD-3 Approval)	$6,999	$13,999	$27,997	$6,999	$13,999	$27,997	$6,999	$13,999	$27,997
210	Process Optimization Testing	$3,750	$7,500	$15,000	$3,750	$7,500	$15,000	$3,750	$7,500	$15,000
220	Procurements	$23,000	$46,000	$92,000	$23,000	$46,000	$92,000	$23,000	$46,000	$92,000
230	Prepare, Award, And Perform Construction (Including CAT)	$36,300	$72,600	$145,200	$36,300	$72,600	$145,200	$36,300	$72,600	$145,200
240	Cold Commissioning	$3,141	$6,282	$12,563	$3,141	$6,282	$12,563	$3,141	$6,282	$12,563
250	Operational Readines Reviews	$1,047	$2,094	$4,188	$1,047	$2,094	$4,188	$1,047	$2,094	$4,188
260	DOE Approval CD-4	$73	$146	$291	$73	$146	$291	$73	$146	$291
270	Operations	$28,172	$56,343	$112,687	$28,172	$56,343	$112,687	$93,906	$187,811	$375,622
280	Laboratory Characterization	$8,375	$16,750	$33,500	$8,375	$16,750	$33,500	$8,375	$16,750	$33,500
290	Deactivation (2nd Waste Disposal)	$2,750	$5,500	$11,000	$2,750	$5,500	$11,000	$2,750	$5,500	$11,000
300	Project Closeout	$2,500	$5,000	$10,000	$2,500	$5,000	$10,000	$2,500	$5,000	$10,000
	SUBTOTAL	$183,268	**$366,536**	$733,072	$183,268	**$366,536**	$733,072	$257,289	**$514,579**	$1,029,158
	Escalation	$39,321	$78,642	$157,284	$39,321	$78,642	$157,284	$68,409	$136,818	$273,635
	CHPRC G&A	$19,922	$39,843	$79,687	$19,922	$39,843	$79,687	$29,150	$58,300	$116,600
	TOTAL LIFE-CYCLE COST	$242,511	**$485,021**	$970,043	$242,511	**$485,021**	$970,043	$354,848	**$709,696**	$1,419,393

O7 Present Worth Analysis

Due to the pre-conceptual nature of the project definition the present worth calculations were developed in accordance with guidance specified in EPA/540/R-00/002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, OSWER 9355.0-75. The cost data level of detail for the alternative analysis is considered at a similar level for feasibility Studies.

The costs are presented as present-net-worth values. The present-net-worth value method is used to evaluate costs that occur during different time periods and allows for cost comparisons of alternatives based on a single cost number, (base case) for each alternative. The present-net-worth value represents the dollars that would need to be set aside today to ensure that funds would be available in the future as they are needed to execute the project.

Present-net-worth costs are estimated using the real discount rate published in Appendix C of OMB Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, effective through January 2011.

The STP Present Worth (PW) estimates consist of two funding types. The first part represents the Total Estimate Cost (TEC) which also defines the capital funding type. The second part is the periodic and or annual costs. These costs may also be defined as the Other Project Costs (OPC) or balance of the life-cycle activities, which also defines the expense funding type. For the purpose of this estimate the capital and expense funding types are defined and shown in Table O-10. However, they may change as the design and construction details mature.

Table O-10. Capital and Expense Funds

WBS	Description	Capital (TEC)	Expense (OPC)
100	Project Management		X
110	Project Startup		X
120	Submit CD-0		X
130	Mission Validation Independent Review (MVIR)		X
140	DOE Approval Of CD-0		X
150	Conceptual Design (Including DOE CD-1 Approval)		X
160	Testing For TRL-4		X
170	Test Article Procurements		X
180	Preliminary Design (Including DOE CD-2 Approval)	X	
190	Testing For TRL-6 / Reconnect And Upgrade FMEF		X
200	Final Design (Including DOE CD-3 Approval)	X	
210	Process Optimization Testing		X
220	Procurements	X	
230	Prepare, Award, And Perform Construction (Including CAT)	X	
240	Cold Commissioning		X
250	Operational Readiness Reviews		X
260	DOE Approval CD-4		X
270	Operations		X
280	Laboratory Characterization		X
290	Deactivation (Secondary Waste Disposal)		X
300	Project Closeout	X	

EPA/540/R-00/002 recommends including the non-discounted costs in the analysis. Non-discounted constant dollar costs demonstrate the impact of a discount rate on the total present-value cost. The non-discounted costs are calculated for the project life-cycle duration and are presented for comparison purposes only. Figure O-1, shows the discounted (or PW) and non-discounted costs for Alternatives 1-6.

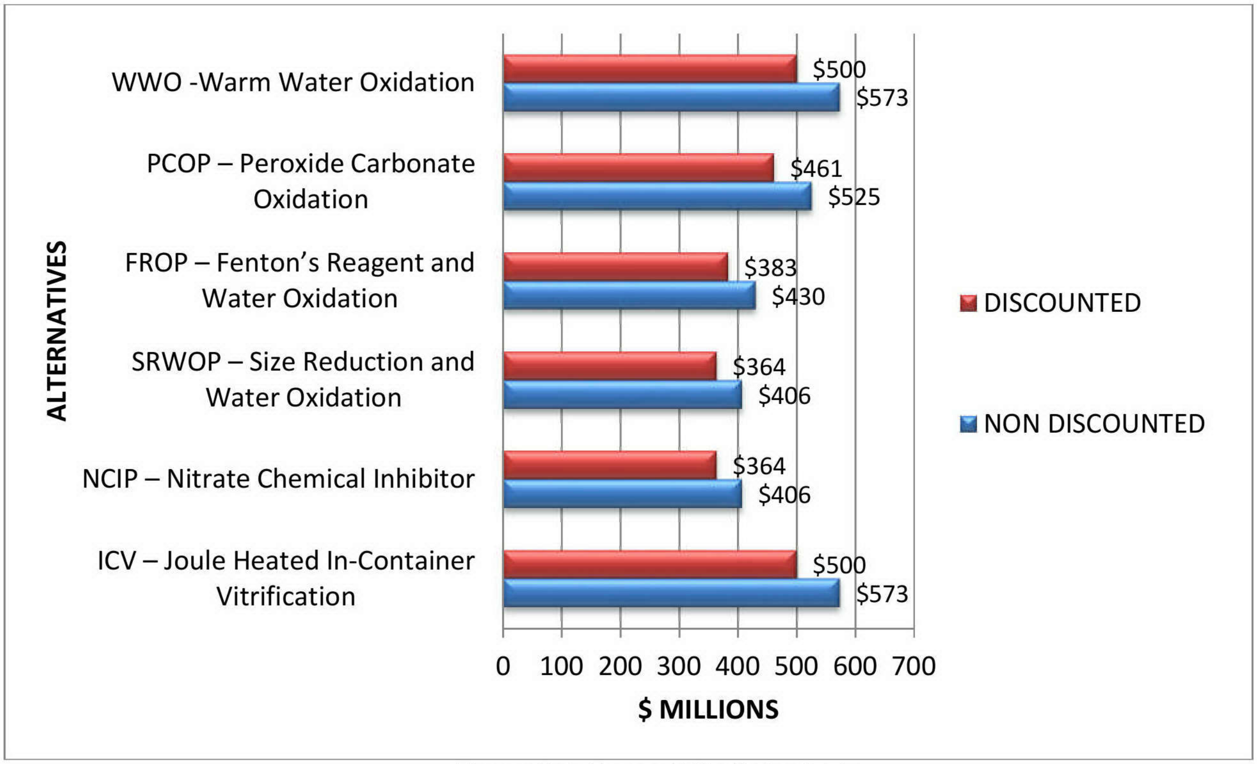


Figure O-1. Present Worth Analysis

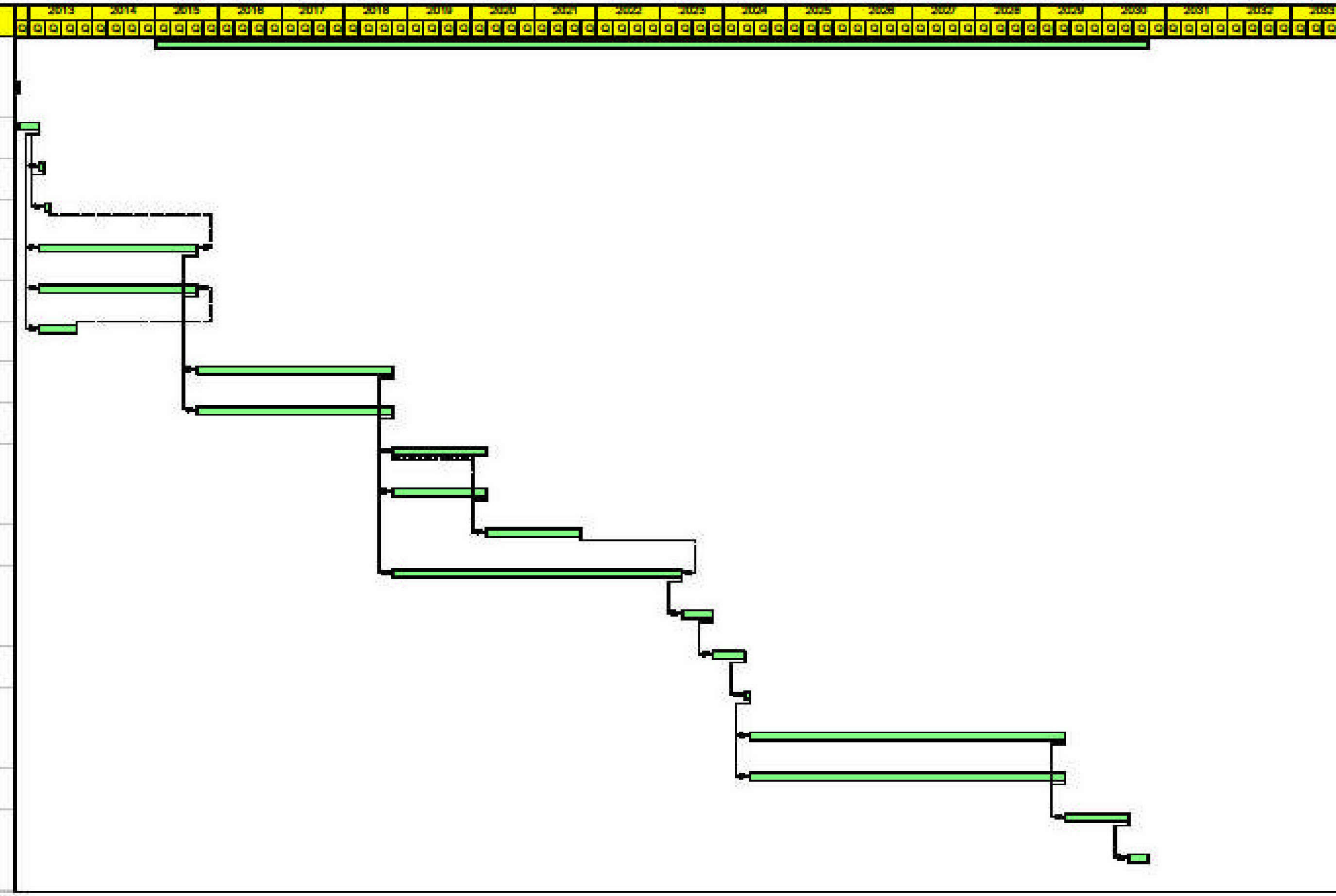
Note: The operations (and associated Project Management), duration and cost are the leading activities affecting the Present Worth calculations for each alternative. A single point number referred to as the base-case is calculated by adding the direct labor and non-labor costs and the General and Administrative (G&A) indirect cost rate.

O8 References

1. Honeyman, J. O. and P. Shaus, "Decision Plan: Alternatives Analysis and Selection for Treatment and Packaging of K Basin Sludge," PRC-STP-00065, CHPRC, October 7, 2009.
2. HNF-39744, *Sludge Treatment Project Alternatives Analysis Summary Report, Vol.* 1, Rev. 1, 2009, CHPRC, Richland, Washington.

Attachment A – Summary life cycle schedules

Activity ID	Activity Name	Remaining Duration	Start	Finish
100	Project Management	3870	05-Jan-15*	30-Sep-30
110	Project Startup	21	01-Oct-12*	31-Oct-12
120	Submit CD-0	72	01-Nov-12	28-Feb-13
130	Mission Validation Independent Review (MVIR)	18	04-Mar-13	28-Mar-13
140	DOE Approval Of CD-0	20	01-Apr-13	30-Apr-13
150	Conceptual Design (Including DOE CD-1 Approval)	566	04-Mar-13	31-Aug-15
160	Testing For TRL-4	566	04-Mar-13	31-Aug-15
170	Test Article Procurements	133	04-Mar-13	30-Sep-13
180	Preliminary Design (Including DOE CD-2 Approval)	701	01-Sep-15	05-Oct-18
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	701	01-Sep-15	05-Oct-18
200	Final Design (Including DOE CD-3 Approval)	372	08-Oct-18	31-Mar-20
210	Process Optimization Testing	372	08-Oct-18	31-Mar-20
220	Procurements	378	01-Apr-20	28-Sep-21
230	Prepare, Award, And Perform Construction (Including CAT)	1153	08-Oct-18	05-May-23
240	Cold Commissioning	125	08-May-23	01-Nov-23
250	ORR	125	02-Nov-23	02-May-24
260	CD-4 Approval	21	03-May-24	03-Jun-24
270	Operations	1259	04-Jun-24	01-Jun-29
280	Characterization	1259	04-Jun-24	01-Jun-29
290	Deactivation Of Process Systems	251	04-Jun-29	31-May-30
300	Project Closeout	84	03-Jun-30	30-Sep-30



Actual Work
Remaining Work
Critical Remaining Work
Milestone

STP Project

AREVA Warm Water Oxidation

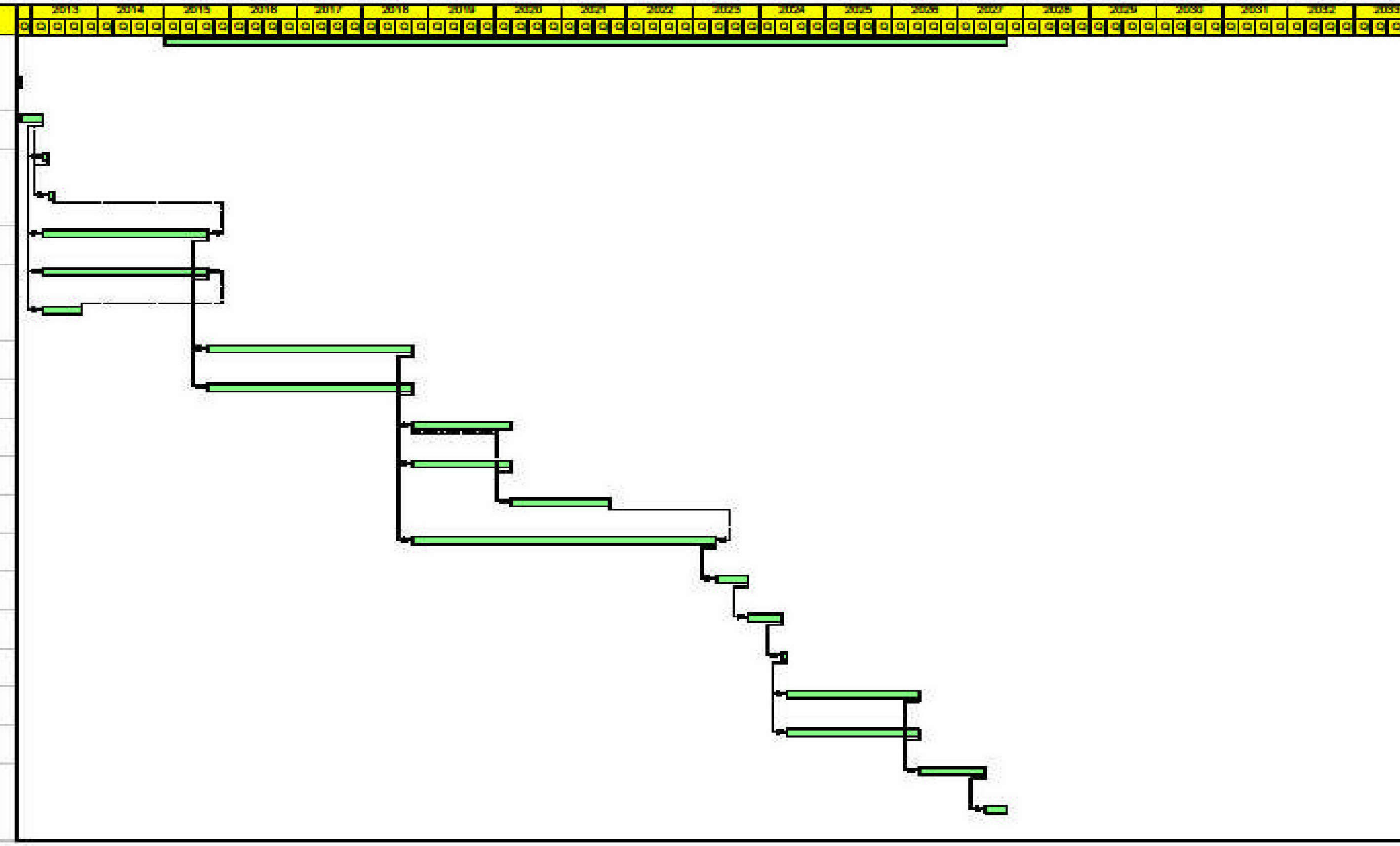
Project name: AREVA Warm Water Oxidation

Layout: AREVA Warm Water Oxidation

TASK filter: All Activities

Figure O-2. Schedule for Warm Water Oxidation Alternative

Activity ID	Activity Name	Remaining Duration	Start	Finish
100	Project Management	3115	05-Jan-15*	30-Sep-27
110	Project Startup	21	01-Oct-12*	31-Oct-12
120	Submit CD-0	72	01-Nov-12	28-Feb-13
130	Mission Validation Independent Review (MVIR)	18	04-Mar-13	28-Mar-13
140	DOE Approval Of CD-0	20	01-Apr-13	30-Apr-13
150	Conceptual Design (Including DOE CD-1 Approval)	566	04-Mar-13	31-Aug-15
160	Testing For TRL-4	566	04-Mar-13	31-Aug-15
170	Test Article Procurements	133	04-Mar-13	30-Sep-13
180	Preliminary Design (Including DOE CD-2 Approval)	701	01-Sep-15	05-Oct-18
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	701	01-Sep-15	05-Oct-18
200	Final Design (Including DOE CD-3 Approval)	372	08-Oct-18	31-Mar-20
210	Process Optimization Testing	372	08-Oct-18	31-Mar-20
220	Procurements	378	01-Apr-20	28-Sep-21
230	Prepare, Award, And Perform Construction (Including CAT)	1153	08-Oct-18	05-May-23
240	Cold Commissioning	125	08-May-23	01-Nov-23
250	ORR	125	02-Nov-23	02-May-24
260	CD-4 Approval	21	03-May-24	03-Jun-24
270	Operations	505	04-Jun-24	04-Jun-26
280	Characterization	505	04-Jun-24	04-Jun-26
290	Deactivation Of Process Systems	251	05-Jun-26	03-Jun-27
300	Project Closeout	83	04-Jun-27	30-Sep-27



Actual Work
Remaining Work
Critical Remaining Work
◆ Milestone

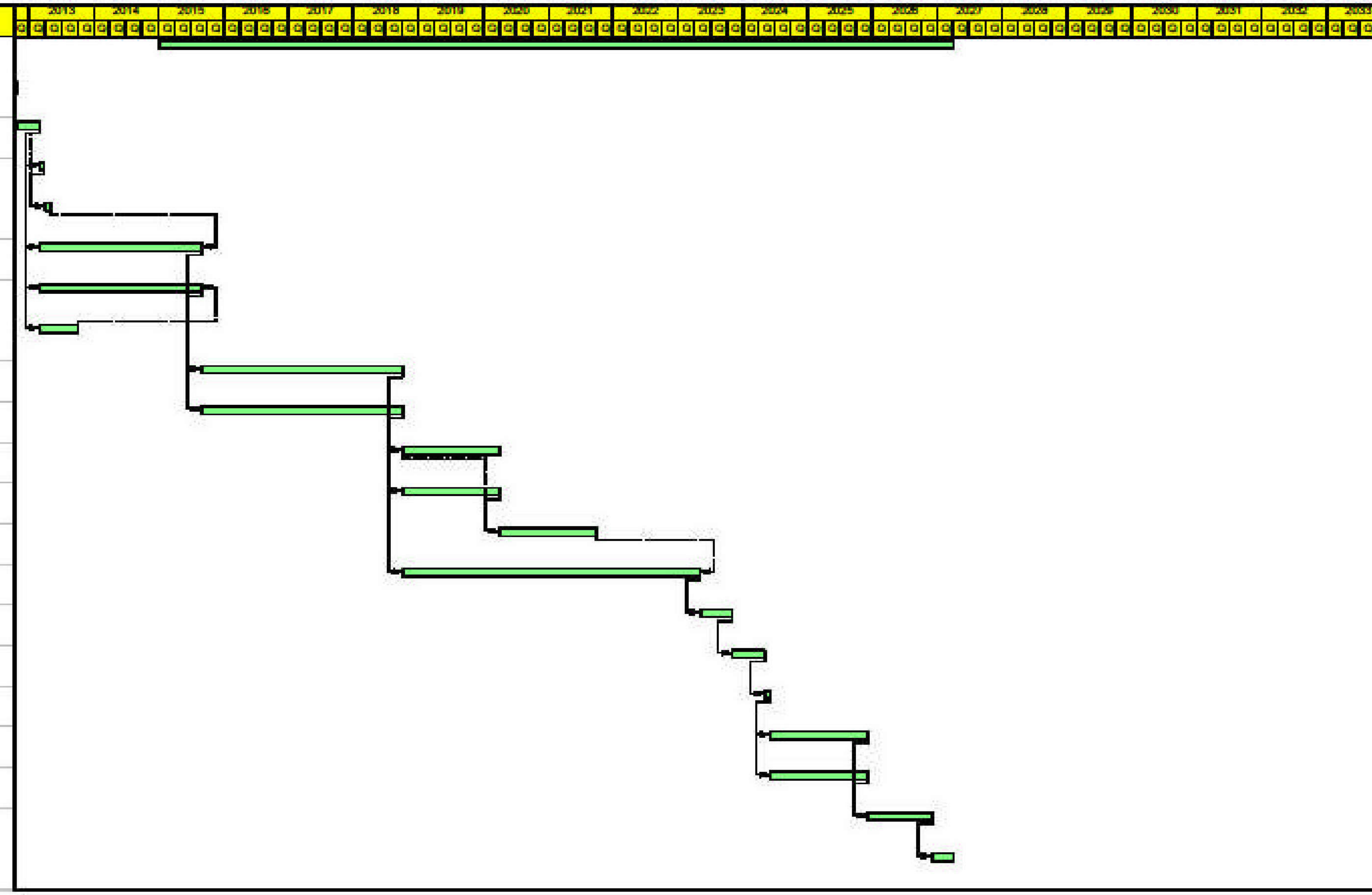
STP Project

Ceradyne Fenton's Reagent Oxidation

Project name: Ceradyne Fenton's Reagent Oxidation
Layout: Ceradyne Fenton's Reagent Oxidation
TASK filter: All Activities

Figure O-3. Schedule for Ceradyne Fenton's Reagent Oxidation

Activity ID	Activity Name	Remaining Duration	Start	Finish
100	Project Management	2990	05-Jan-15*	05-Apr-27
110	Project Startup	21	01-Oct-12*	31-Oct-12
120	Submit CD-0	72	01-Nov-12	28-Feb-13
130	Mission Validation Independent Review (MVIR)	18	04-Mar-13	28-Mar-13
140	DOE Approval Of CD-0	20	01-Apr-13	30-Apr-13
150	Conceptual Design (Including DOE CD-1 Approval)	566	04-Mar-13	31-Aug-15
160	Testing For TRL-4	566	04-Mar-13	31-Aug-15
170	Test Article Procurements	133	04-Mar-13	30-Sep-13
180	Preliminary Design (Including DOE CD-2 Approval)	701	01-Sep-15	05-Oct-18
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	701	01-Sep-15	05-Oct-18
200	Final Design (Including DOE CD-3 Approval)	372	08-Oct-18	31-Mar-20
210	Process Optimization Testing	372	08-Oct-18	31-Mar-20
220	Procurements	378	01-Apr-20	28-Sep-21
230	Prepare, Award, And Perform Construction (Including CAT)	1153	08-Oct-18	05-May-23
240	Cold Commissioning	125	08-May-23	01-Nov-23
250	ORR	125	02-Nov-23	02-May-24
260	CD-4 Approval	21	03-May-24	03-Jun-24
270	Operations	380	04-Jun-24	04-Dec-25
280	Characterization	380	04-Jun-24	04-Dec-25
290	Deactivation Of Process Systems	251	05-Dec-25	03-Dec-26
300	Project Closeout	83	04-Dec-26	05-Apr-27



Actual Work ◆ ◆ Milestone
Remaining Work
Critical Remaining Work

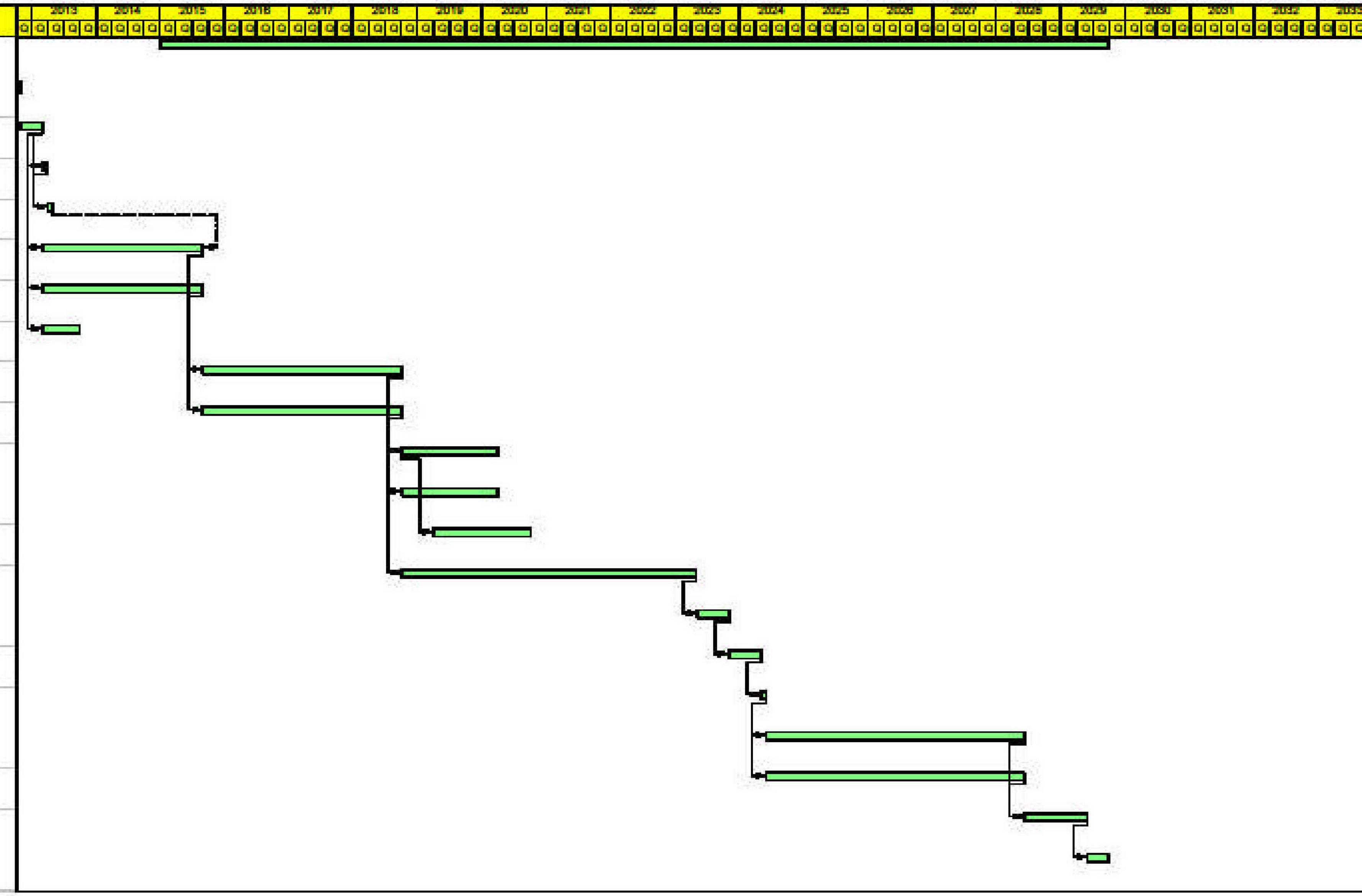
STP Project

Ceradyne Size Reduction And Warm Water Oxidation

Project name: Ceradyne Size Reduction And Water Oxidation
Layout: Ceradyne Size Reduction And Water Oxidat
TASK filter: All Activities

Figure O-4. Schedule for Ceradyne Size Reduction and Warm Water Oxidation Process

Activity ID	Activity Name	Remaining Duration	Start	Finish
100	Project Management	3618	05-Jan-15*	28-Sep-29
110	Project Startup	21	01-Oct-12*	31-Oct-12
120	Submit CD-0	72	01-Nov-12	28-Feb-13
130	Mission Validation Independent Review (MVIR)	18	04-Mar-13	28-Mar-13
140	DOE Approval Of CD-0	20	01-Apr-13	30-Apr-13
150	Conceptual Design (Including DOE CD-1 Approval)	566	04-Mar-13	31-Aug-15
160	Testing For TRL-4	566	04-Mar-13	31-Aug-15
170	Test Article Procurements	133	04-Mar-13	30-Sep-13
180	Preliminary Design (Including DOE CD-2 Approval)	701	01-Sep-15	05-Oct-18
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	701	01-Sep-15	05-Oct-18
200	Final Design (Including DOE CD-3 Approval)	372	08-Oct-18	31-Mar-20
210	Process Optimization Testing	372	08-Oct-18	31-Mar-20
220	Procurements	378	04-Apr-19	30-Sep-20
230	Prepare, Award, And Perform Construction (Including CAT)	1153	08-Oct-18	05-May-23
240	Cold Commissioning	125	08-May-23	01-Nov-23
250	ORR	125	02-Nov-23	02-May-24
260	CD-4 Approval	21	03-May-24	03-Jun-24
270	Operations	1008	04-Jun-24	02-Jun-28
280	Characterization	1008	04-Jun-24	02-Jun-28
290	Deactivation Of Process Systems	251	05-Jun-28	01-Jun-29
300	Project Closeout	83	04-Jun-29	28-Sep-29



Actual Work
Remaining Work
Critical Remaining Work
Milestone

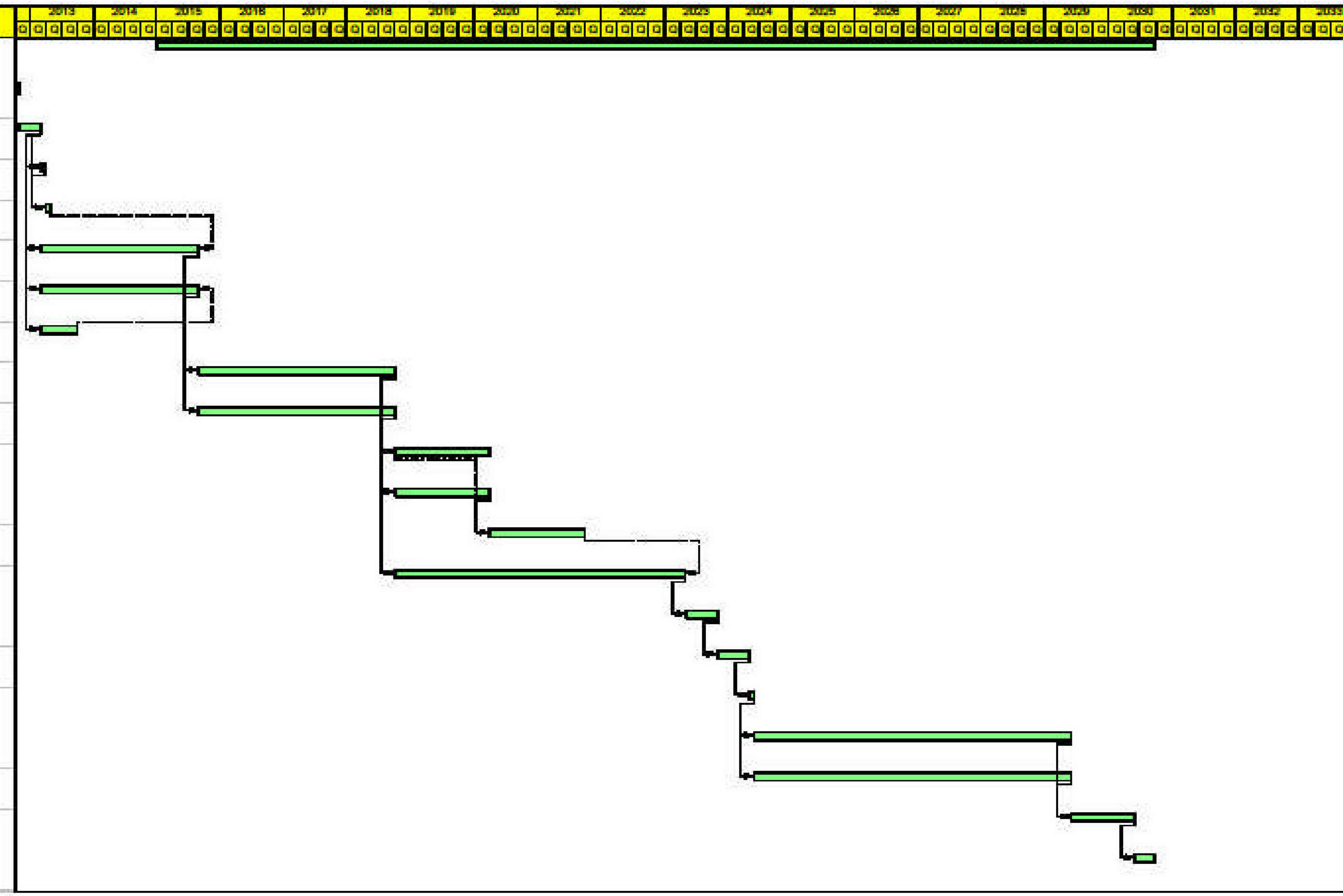
STP Project

Energy Solutions Carbonate Peroxide Oxidation

Project name: Energy Solutions Carbonate Peroxide Oxidation
Layout: Energy Solutions Carbonate Peroxide Oxidation
TASK filter: All Activities

Figure O-5. Schedule for Energy Solutions Carbonate Peroxide Oxidation Process

Activity ID	Activity Name	Remaining Duration	Start	Finish
100	Project Management	3870	05-Jan-15*	30-Sep-30
110	Project Startup	21	01-Oct-12*	31-Oct-12
120	Submit CD-0	72	01-Nov-12	28-Feb-13
130	Mission Validation Independent Review (MVIR)	18	04-Mar-13	28-Mar-13
140	DOE Approval Of CD-0	20	01-Apr-13	30-Apr-13
150	Conceptual Design (Including DOE CD-1 Approval)	566	04-Mar-13	31-Aug-15
160	Testing For TRL-4	566	04-Mar-13	31-Aug-15
170	Test Article Procurements	133	04-Mar-13	30-Sep-13
180	Preliminary Design (Including DOE CD-2 Approval)	701	01-Sep-15	05-Oct-18
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	701	01-Sep-15	05-Oct-18
200	Final Design (Including DOE CD-3 Approval)	372	08-Oct-18	31-Mar-20
210	Process Optimization Testing	372	08-Oct-18	31-Mar-20
220	Procurements	378	01-Apr-20	28-Sep-21
230	Prepare, Award, And Perform Construction (Including CAT)	1153	08-Oct-18	05-May-23
240	Cold Commissioning	125	08-May-23	01-Nov-23
250	ORR	125	02-Nov-23	02-May-24
260	CD-4 Approval	21	03-May-24	03-Jun-24
270	Operations	1259	04-Jun-24	01-Jun-29
280	Characterization	1259	04-Jun-24	01-Jun-29
290	Deactivation Of Process Systems	251	04-Jun-29	31-May-30
300	Project Closeout	84	03-Jun-30	30-Sep-30



Actual Work
Remaining Work
Critical Remaining Work
Milestone

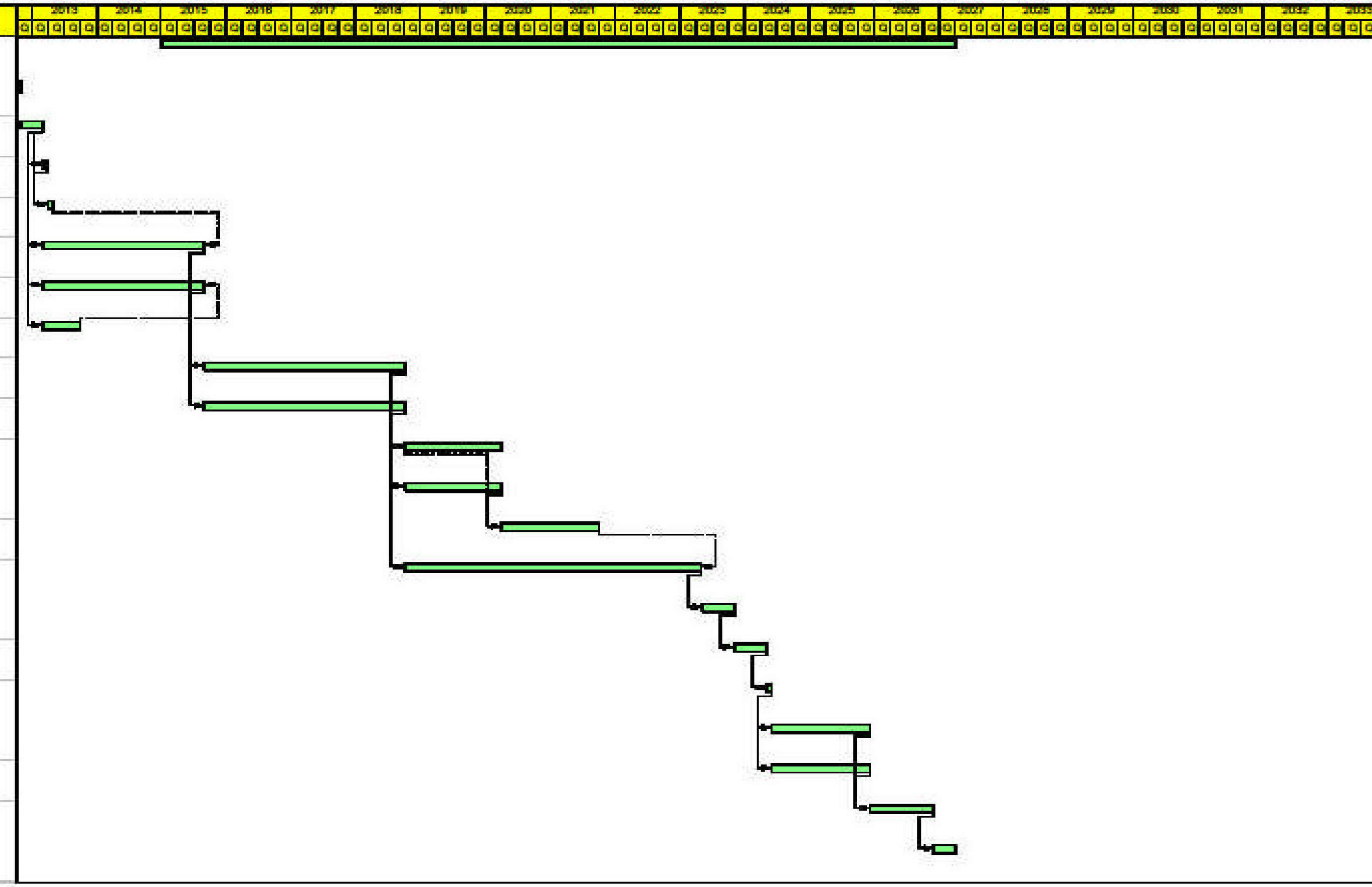
STP Project

IMPACT Services Joule Heated In-Vitrification

Project name: IMPACT Services Joule Heated In-Vitrification
Layout: IMPACT Services Joule Heated In-Vitrific
TASK filter: All Activities

Figure O-6. Schedule for IMPACT Services Joule Heated In-Container Vitrification Process

Activity ID	Activity Name	Remaining Duration	Start	Finish
100	Project Management	2990	05-Jan-15*	05-Apr-27
110	Project Startup	21	01-Oct-12*	31-Oct-12
120	Submit CD-0	72	01-Nov-12	28-Feb-13
130	Mission Validation Independent Review (MVIR)	18	04-Mar-13	28-Mar-13
140	DOE Approval Of CD-0	20	01-Apr-13	30-Apr-13
150	Conceptual Design (Including DOE CD-1 Approval)	566	04-Mar-13	31-Aug-15
160	Testing For TRL-4	566	04-Mar-13	31-Aug-15
170	Test Article Procurements	133	04-Mar-13	30-Sep-13
180	Preliminary Design (Including DOE CD-2 Approval)	701	01-Sep-15	05-Oct-18
190	Testing For TRL-6 / Reconnect And Upgrade FMEF	701	01-Sep-15	05-Oct-18
200	Final Design (Including DOE CD-3 Approval)	372	08-Oct-18	31-Mar-20
210	Process Optimization Testing	372	08-Oct-18	31-Mar-20
220	Procurements	378	01-Apr-20	28-Sep-21
230	Prepare, Award, And Perform Construction (Including CAT)	1153	08-Oct-18	05-May-23
240	Cold Commissioning	125	08-May-23	01-Nov-23
250	ORR	125	02-Nov-23	02-May-24
260	CD-4 Approval	21	03-May-24	03-Jun-24
270	Operations	380	04-Jun-24	04-Dec-25
280	Characterization	380	04-Jun-24	04-Dec-25
290	Deactivation Of Process Systems	251	05-Dec-25	03-Dec-26
300	Project Closeout	83	04-Dec-26	05-Apr-27



Actual Work
Remaining Work
Critical Remaining Work
Milestone

STP Project

PNNL Nitrate Chemical Inhibitor

Project name: PNNL Nitrate Chemical Inhibitor
Layout: PNNL Nitrate Chemical Inhibitor
TASK filter: All Activities

Figure O-7. Schedule for PNNL Nitrate Chemical Inhibitor Process

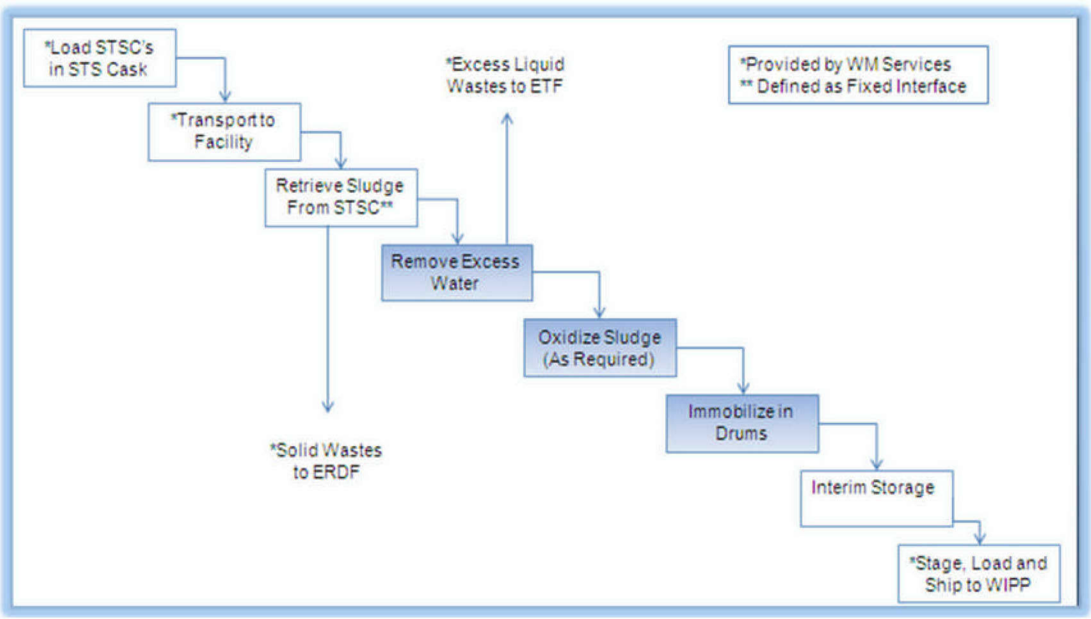
Appendix P

PRC-STP-00460, Rev. 0, Sludge Treatment Project Decision Support Board Phase 2 Treatment and Packaging Alternative Workshop

This appendix provides a copy of the report originally issued as: PRC-STP-00460, Rev. 0, Sludge Treatment Project Decision Support Board Phase 2 Treatment and Packaging Alternative Workshop. It is identical to the original document with the exception of addition of the header and revised pagination for the current document.

Sludge Treatment Project Decision Support Board Phase 2 Treatment and Packaging Alternative Workshop

May 9-12, 2011



Requested by: James Honeyman, Technology Project Manager
Sludge Treatment Project, Phase 2
CH2M HILL Plateau Remediation Company
Richland, Washington

Facilitated by: Richard Harrington, CVS-Life
Mary Day, Project Specialist
CH2M HILL Plateau Remediation Company
Richland, Washington

CH2MHILL
Plateau Remediation Company

Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop

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**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Acronym List

CD	Critical Decision
CHPRC	CH2M Hill Plateau Remediation Company
CH-TRU	Contact-Handled Transuranic
CTE	Critical Technology Element
DNFSB	Defense Nuclear Facility Safety Board
DOE-HQ	U. S. Department of Energy Headquarters
DOE-CBFO	U. S. Department of Energy Carlsbad Field Office
DOE-RL	U. S. Department of Energy Richland Operations Office
DSB	Decision Support Board
ECRTS	Engineered Container Retrieval and Transfer System
EPA	Environmental Protection Agency
EPC	Engineering, Procurement, and Construction
ERDF	Environmental Restoration Disposal Facility
ETF	Effluent Treatment Facility
ISC	Interim Storage Container
KOP	Knock-out Pot
NRC	U.S. Nuclear Regulatory Commission
O&M	Operability and Maintainability
RH-TRU	Remote-Handled Transuranic
SME	Subject Matter Experts
STP	Sludge Treatment Project
STS	Sludge Transfer System
STSC	Sludge Transfer and Storage Container
TMP	Technology Maturation Plan
TOE	Total Operating Efficiency
TRAMPAC	TRUPACT II Authorized Methods For Payload Control
TRL	Technology Readiness Level
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant
WM	Waste Management

Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop

Executive Summary

The overall objective of the Sludge Treatment Project (STP) Phase 2 is to treat and package K Basin sludge so that it can be certified for transport to and disposal at the Waste Isolation Pilot Plant (WIPP) as Remote-Handled Transuranic (RH-TRU) waste. This project is managed by the CH2M HILL Plateau Remediation Company (CHPRC) on behalf of the U.S. Department of Energy Richland Operations Office (DOE-RL).

As described in the STP Phase 2 Design Plan, PRC-STP-00065, a Decision Support Board (DSB) will convene and deliberate to *select an integrated set of technologies that can be used for pre-conceptual design of a process and facility that will treat and package K Basin sludge for acceptable transport to and disposal at the Waste Isolation Pilot Plant (WIPP) as RH-TRU.* A facilitated STP Phase 2 DSB alternatives workshop was determined as the best approach to complete this critical step to support beginning conceptual design.

Mr. J.O. (Jim) Honeyman, CHPRC STP Technology Project Manager, requested the workshop and Richard Harrington provided facilitation services. The workshop was conducted at the Clarion Conference Center, Whitman Room, Richland Washington, May 9-12, 2011. The multidisciplinary DSB members consisted of representatives from the STP operations, engineering, regulatory, nuclear safety, and radiological protection, including WIPP and external private sector Subject Matter Experts (SME). Additional attendees and observers included representatives from the DOE-RL, Environmental Protection Agency (EPA), Defense Nuclear Facility Board (DNFSB), Department of Energy Headquarters (DOE-HQ) and Carlsbad Field Office (DOE-CBFO), and various STP SME support personnel. The purpose of the workshop was to develop recommendations for the preferred Phase 2 Treatment and Packaging Approach which provides a predictable, low risk path forward to begin conceptual design. Appendix A contains the workshop agenda, and the list of attendees throughout the four-day workshop.

Workshop Results

The DSB team, with input and support from the observers and various STP SME's, was successful in developing recommendations for the preferred technology approach, including recommendations to address areas of risk/vulnerabilities, and an overall path forward implementation approach to proceed with conceptual design. The recommended technology approach is to use *Warm Water Oxidation* as a technical baseline, and develop *Size Reductio*n and *Fenton's Reagen*t to enhance the baseline during conceptual design. If implemented, these recommendations would result in development and demonstration of these three technologies during conceptual design for STP Phase 2 to achieve Technical Readiness Level 4 (TRL-4) in support of Critical Decision 1 (CD-1) submittal point. In addition, the DSB recommended maintaining a flexible conceptual design for space considerations in the functions and requirements to facilitate other site RH-TRU waste, which was specifically called out in the overall path forward.

The DSB risk/vulnerabilities and mitigation recommendations centered on technology development, maintaining remote operating systems, and an aggressive RH-TRU drum production. Technology development risk/vulnerabilities and mitigation recommendations focused on in-process sludge assay instrument testing to confirm the ability to accurately assay sludge and remove part of the final waste form from a drum and/or mix and match drums in order to meet fissile gram equivalent limits. Additional technology development risks and mitigation recommendations were identified for determining completion of the uranium metal oxidation reaction and sludge missing/suspension. Primary needs for the remote operating systems were to incorporate lessons learned from across the DOE complex, and Sellafield and LaHague, including maintenance expertise and confirmation of the appropriate spare parts required to minimize downtime. The aggressive drum production risk mitigation needs are to incorporate lessons learned while improving assay accuracy to lower the drum production rate, and consider the potential for parallel lines.

In summary, the DSB recommended Overall Path Forward implementation plan calls for proceeding into conceptual design with the recommended technology approach; risk/vulnerability and mitigation actions, including completion of an implementation decision schedule; priority technology bench scale demonstrations; a siting study; evaluations on advanced assay methodologies and the potential to mix waste streams. The path forward also called for a joint DOE-RL, DOE-CBFO, CHPRC, and WIPP meeting in July of 2011 to determine potential options to pursue regarding transport and disposal of RH-TRU in the WIPP.

The DSB recommended technology approach, risk/vulnerability and mitigation actions, and the overall path forward were presented in a management presentation out-brief on Thursday afternoon, May 12, 2011. Following the presentation, feedback was obtained from the management attendees and observers via several questions/answers and input. The presentation out-brief concluded with management's endorsement of the DSB recommendations to proceed. Appendix B contains the management presentation agenda, the presentations, questions/answers and inputs, and attendee list.

Workshop Process

Jim Honeyman and the facilitator opened the workshop with the purpose, safety topic, introductions, agenda review, and opening remarks. M.W. Johnson, STP Project Manager, and T.K. Teynor, DOE-RL Director, delivered opening remarks which began with thanking all personnel for their time commitment for this important step, and emphasized the need to maintain an integrated approach with Phase 1, address the considerable number of project opportunities and challenges, and to solicit all observer inputs and challenges in order to make the right technology decision. Following the opening remarks, several STP SMEs delivered 14 presentations that ranged from sludge characterization, Phase 2 technology evaluations and alternative analysis, primary treatment and packaging requirements, to the baseline project assumptions, six technology alternatives, other technologies considered but not evaluated, and the project sensitivity analysis.

Throughout the workshop, inputs/comments, observations, and recommendations were encouraged by all attendees and documented accordingly. Inputs such as observations, memories (i.e., ideas/concepts), enabling assumptions, and/or needed actions identified were recorded on flipcharts (a.k.a., parking-lot sheets) for recall. The flipcharts of information, including the

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

parking-lot sheets, were tabulated and stored on the room walls for reference and recall as the workshop progressed. In addition, any items of significant importance were denoted by a "flag-note" symbol ( ) for quick visual reference. Appendix C, Session Flipcharts, contains the typed flipchart information recorded throughout the workshop.

Following the first 14 presentations, the seven evaluation criterion presentations were delivered. After each criterion presentation and respective observations and inputs, the facilitator led the DSB to evaluate and rate each alternative against each criterion. During this step all DSB evaluation results and conclusions were recorded on the evaluation matrix or parking-lot information sheets as required (Appendix C). Upon completion of the alternatives criteria evaluation matrix, the DSB reviewed the results using the pre-workshop draft weighted criteria and conducted a sensitivity analysis.

During the sensitivity analysis the DSB adjusted the weighted criteria by lowering the safety weighting due to the hazards being well understood, controls were previously deployed, and development was essentially the same for the alternatives. In addition, the team omitted the sixth criterion, Potential Integration with Phase 1, as this criterion was a non discriminator and applied this weight across the remaining criteria. Upon review of the second alternatives criteria evaluation matrix, the DSB concluded these weight changes did not change the score or ranking.

Following the sensitivity analysis, the facilitator led the team into developing their draft technology approach conclusions, a listing of opportunities and challenges, and definition of the top areas of risk/vulnerabilities. At this point, the DSB was divided into four sub-teams and tasked with developing draft DSB recommendations into management out-brief presentations. The four sub-teams were: 1) Alternative Ranking, 2) Recommended Technology Approach, 3) Areas of Risk/Vulnerabilities, and 4) Overall Path Forward Recommendations.

The dry-run presentations involved four DSB members presenting to the entire DSB team and STP project members. Following each presentation, any enhancements were incorporated to finalize the final management presentation out-brief. Appendix B contains the team's final product presented during the management presentation that was conducted from 2:45 p.m. to 4:30 p.m. on Thursday, May 12, 2011. The purpose of the presentation was to solicit management's review, enhancements, and endorsement of the DSB's preferred technology approach and recommendations to proceed. In summary, management endorsed the DSB's recommendations during closing remarks, and joined the facilitator in a round of applause for the DSB and STP SME's who provided invaluable support prior to and throughout this workshop.

Facilitators Comments

The team did an excellent job of maintaining focus on the purpose throughout the workshop. Moreover, the multidisciplinary team members were successful in building off the project SME's completed work, and EPA, DNFSB, DOE-RL, DOE-CBFO, and DOE-HQ input and observations. This team was dedicated, proactive and synergistic in their approach to developing the best recommendations to proceed.

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Special thanks to the entire project SME's who worked diligently to prepare, present, and support the DSB throughout this important pre-conceptual process step.

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Appendix A – Agenda, Purpose, Attendee List, and Opening Remarks

Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop

Sludge Treatment Project: Decision Support Board (DSB) Phase 2 Treatment and Packaging Clarion Conference Center, Whitman Room, Richland, Washington May 9-12, 2011

Purpose: ***Select the preferred Phase 2 Treatment and Packaging Approach which provides a predictable, low risk path forward to begin conceptual design***

AGENDA

Day 1, Monday, May 9, 2011

7:30-8:00	- Meet and Congregate (Beverages and morning snacks)	All
8:00-8:15	- Welcome/Purpose, Safety Topic, and Introductions	Jim Honeyman
8:15-8:45	- Opening Remarks and Overview	MW Johnson
8:45-9:15	- Review DSB Purpose, Agenda, and Decision Criteria, Rating and Ranking Process	Richard Harrington

Background

9:15-10:00	- Sludge Characterization	Wally Rutherford
10:00-10:15	- **BREAK**	
10:15-11:00	- Phase 2 Technology Evaluations & Alternatives Analysis	Jim Honeyman
11:00-12:00	- Primary Technical Requirements –	
	Sludge Treatment and Packaging Requirements	Mike Rivera
	Basis and Assumptions for All Alternatives	Tom Fogwell
12:00-12:45	- **LUNCH** (Provided)	

Describe the Alternatives

12:45-1:45	- a) Warm Water Oxidation (base case)	Tom Fogwell
1:45-2:00	- Baseline Facility Pre-conceptual Study	Tom Fogwell
2:00-2:45	- b) Fenton's Reagent – Chemical Oxidation	Tom Fogwell
2:45-3:00	- **BREAK** (Refreshments)	
3:00-3:45	- c) Ammonium Carbonate/Peroxide – Chemical Oxidation	Tom Fogwell
3:45-4:30	- d) Size Red. and Water Oxidation – Chemical Oxidation	Tom Fogwell
4:30	- Finish Day 1 with Review of Status and Day 2 Agenda	

Sludge Treatment Project Decision Support Board Phase 2 Treatment and Packaging Alternative Workshop

Sludge Treatment Project: Decision Support Board (DSB) Phase 2 Treatment and Packaging Clarion Conference Center, Whitman Room, Richland, Washington May 9-12, 2011

Purpose: ***Select the preferred Phase 2 Treatment and Packaging Approach which provides a predictable, low risk path forward to begin conceptual design***

Day 2, Tuesday, May 10, 2011

7:30-8:15	- e) Nitrate Inhibitor Process	Tom Fogwell
8:15-9:00	- f) In-Container Vitrification^{TM}	Al Pajunen
9:00-9:45	- Remote Solidification (Grout/Borobond^{TM}/Clay)	Tom Fogwell
9:45-10:00	- **BREAK**	
10:15-11:00	- Other Technologies considered but not evaluated	Kim Auclair Jim Honeyman
11:00-11:45	- Sensitivity Analysis	Tom Fogwell
11:45-12:45	- **LUNCH** (Provided)	

Comparison of Alternatives

12:45-1:30	- Hazards Considerations (Nuclear Safety)	Gary Franz
1:30-2:15	- Evaluate and Rate Alternatives on Safety Criteria	DSB
2:15-3:00	- Technical Maturity	Kim Auclair
3:00-3:15	- **BREAK** (Refreshments)	
3:15-4:00	- Evaluate and Rate Alternatives on Technical Maturity	DSB
4:00-4:30	- Operability/Maintainability Criteria	Chris Lucas
4:30	- Finish Day 2 with Review of Status and Day 3 Agenda	

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Sludge Treatment Project: Decision Support Board (DSB) Phase 2 Treatment and Packaging Alternative Workshop May 9-12, 2011

Purpose: ***Select the preferred Phase 2 Treatment and Packaging Approach which provides a predictable, low risk path forward to begin conceptual design.***

AGENDA

<u>Day 3, Wednesday, May 11, 2011</u>

7:30-8:30	- Evaluate and Rank Alternatives on O&M Criteria	DSB
8:30-9:15	- Regulatory/Stakeholder Considerations	Dave Watson/Eric D'Amico
9:15-10:00	- Evaluate and Rate Alternatives on Regulatory/ Stakeholder Acceptance	DSB
10:00-10:15	**BREAK**	
10:15-11:00	- Lifecycle Costs and Schedule	Doug Bragg
11:00-12:00	- Evaluate Alternatives with Lifecycle Costs and Schedule	DSB
12:00-1:00	- **LUNCH** (Provided)	
1:00-1:45	- Potential for Beneficial Integration with Phase 1	Jim Honeyman
1:45-2:45	- Evaluate and Rate Alternatives regarding Beneficial Int.	DSB
2:45-3:00	**BREAK** (Refreshments)	
3:00-3:45	- Potential for Integration with Site wide RH-TRU treatment & Packaging	Don Flyckt
3:45-4:45	- Evaluation of Potential for Integration with Site wide RH-TRU	DSB
4:45	- Finish Day 3 with Review of Status and Day 4 Agenda	

Sludge Treatment Project Decision Support Board Phase 2 Treatment and Packaging Alternative Workshop

Sludge Treatment Project: Decision Support Board (DSB) Phase 2 Treatment and Packaging Alternative Workshop May 9-12, 2011

Purpose: ***Select the preferred Phase 2 Treatment and Packaging Approach which provides a predictable, low risk path forward to begin conceptual design.***

AGENDA

Day 4, Thursday, May 12, 2011

7:30-10:00	- Review Alternative Rating Results & Finalize ranking	DSB
10:00-10:15	**BREAK**	
10:15-12:00	- Conduct Sensitivity Analysis, as required	DSB
12:00-1:00	- **LUNCH** (Provided)	
1:00-2:30	- Develop path forward recommendations and actions required to proceed • Pros/Cons, areas to mitigate risk, and/or additional information • Finalize management summary format and logistics	
2:30-2:45	- **BREAK** (Refreshments)	
2:45-4:30	- Conduct Management Summary Out-brief	DSB
4:30	- Finish Workshop with a Round Robin Closeout • Last minute items • Meeting utility/closing remarks	

Sludge Treatment Project Decision Support Board Phase 2 Treatment and Packaging Alternative Workshop

Sludge Treatment Project Alternative Workshop Attendees Clarion Hotel, Richland, Washington May 9 - 12, 2011					
Name	**Organization**	**5/9**	**5/10**	**5/11**	**5/12**
[1] ***Rick Raymond****	CHPRC Sludge Treatment Project	X	X	X	X
Jim Mathews*	CHPRC Sludge Treatment Project	X	X	X	X
Jim Sloughter*	CHPRC Sludge Treatment Project	X	X	X	X
John Williams*	CHPRC Safety Analysis	X	X	X	X
Wayne Toebe*	CHPRC Environmental Protection	X	X	X	X
Don Flyckt *	CHPRC Environmental & Strategy Planning	X		X	X
Kristi Lueck*	CHPRC Environmental & Strategy Planning		X		
Michael E. Johnson*	CHPRC Sludge Treatment Project	X	X	X	X
Calvin Slotemaker*	CHPRC Worker Protection Program	X	X	X	X
Chris Lucas*	Lucas EMS	X	X	X	X
Eric D'Amico*	Washington TRU Solutions	X	X	X	X
Phil Loscoe*	Quadrant One	X	X	X	X
Barry Naft*	Environmental International	X	X	X	X
Mike W. Johnson	CHPRC Project Manager	X	X	X	X
Jim Honeyman	CHPRC Sludge Treatment Project	X	X	X	X
Mike Jennings	CHPRC EPC	X		X	X
Mike Klem	CHPRC Sludge Treatment Project	X	X	X	X
Doug Bragg	CHPRC Sludge Treatment Project	X	X	X	X
Al Pajunen	Lucas EMS	X	X		
Mike Rivera	CHPRC Sludge Treatment Project	X		X	
Kim Auclair	Lucas EMS	X	X	X	X
Andy Schmidt	PNL	X		X	X
Tom Fogwell	Lucas EMS	X	X	X	X
Mary Cunningham	Lucas EMS	X	X	X	X
Harry Humphreys	Lucas EMS	X			
David French	WIPP Contractor	X		X	X
Blake Spilman	CHPRC Sludge Treatment Project	X	X	X	
Jim Clifford	Lucas EMS	X	X	X	
Mitch Vitulli	CHPRC DNFSB Liaison	X	X	X	X
Wally Rutherford	CHPRC Sludge Treatment Project	X			
Robert Tai	CHPRC Sludge Treatment Project	X	X	X	X
Jennifer Braley	PNNL	X	X		
Calvin Delegard	PNNL	X	X	X	X
Gary Franz	CHPRC STP Sludge Treatment Project		X		
Mike Davis	CHPRC Sludge Treatment Project			X	
David Watson	CHPRC Sludge Treatment Project			X	
Scott Van Camp	Lucas EMS				X

[1] ***(*) and (**) denotes Decision Support Board Members and Decision Support Board Chairman, respectively.***

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Sludge Treatment Project Alternative Workshop Attendees
Clarion Hotel, Richland, Washington
May 9 - 12, 2011

Name	Organization	5/9	5/10	5/11	5/12
Tom Teynor	DOE-RL	X	X	X	X
Howard Budweg	DOE-CBFO	X	X	X	
Roger Quintero	DOE-RL	X	X	X	X
James Crocker	DOE-RL	X	X		X
Sahid Smith	DOE-RL	X	X	X	X
Greg Morgan	DOE-RL	X			
Alex Teimouri	DOE-HQ (Richland)	X	X		X
Jim Davis	DOE-HQ (Richland)			X	
Gary Pyles	DOE-RL				X
Bob Quirk	DNFSB	X			
Monique Helfrich	DNFSB	X	X	X	X
Dennis Faulk	EPA	X			
Mary Cole	CHPRC Sludge Treatment Project	X	X	X	X
Katherine Jones	CHPRC Sludge Treatment Project	X	X	X	X
Richard Harrington	CHPRC Value Management	X	X	X	X
Mary Day	CHPRC Value Management	X	X	X	X

OPENING REMARKS

- Thank you for your support of this project going forward
- Project has two phases:
  - Phase 1: moving forward to retrieve and transport STSCs from KW to T Plant; testing of KOPs is ongoing through June, 2011
  - Phase 2: DSB and observers
    - Considerable opportunities and challenges
    - This is the foundation
- Observers need/want your comments
  - This is the project's/DSB workshop
  - No pre-conceived decisions
  - Please challenge
- Challenge is to make a decision
  - Need a technology that works

Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop

Appendix B – Management Out-brief Agenda, Presentations, Attendee List, and Questions & Answers

Agenda

2:45-4:30 - Conduct Management Summary Out-brief DSB

- Welcome/Purpose, Safety Topic, Introductions
- Opening Remarks
  - Results
  - Brief Process Overview – Jim Honeyman
- *Alternatives Ranking* - Phil Loscoe
- *Recommended Technology Approach* - Barry Naft
- *Areas of Risk/Vulnerability and Recommendations* – Mike E. Johnson
- *Overall Recommended Path Forward Implementation* – Rick Raymond
- Summary
  - Questions and Answers
  - Closing Remarks

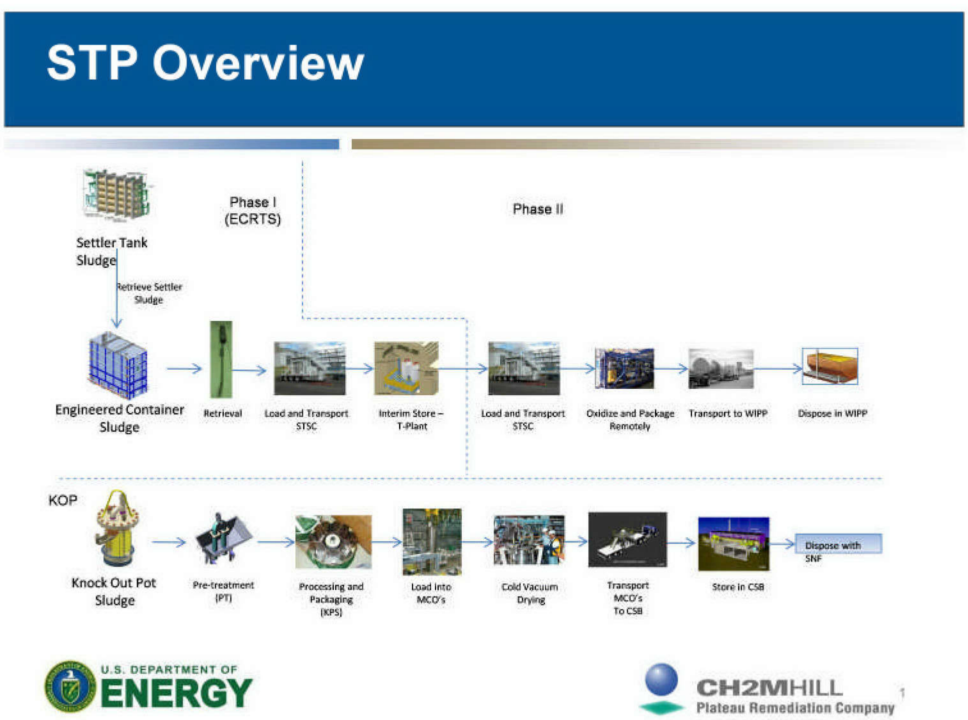
4:30 - Finish Workshop with a Round Robin Closeout

- Last minute items
- Meeting utility/closing remarks

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Slide 1

Slide 2



**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

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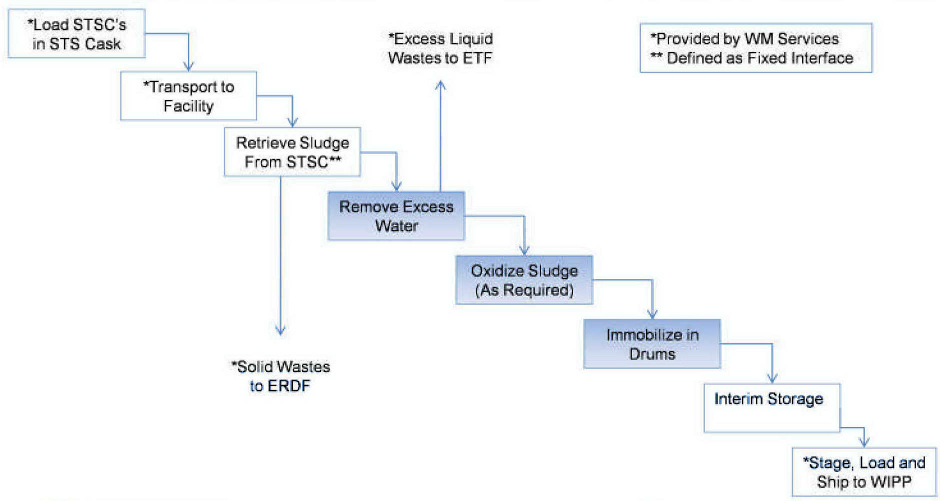
Scope for Phase 2 Treatment System



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Alternative Ranking

Presented by: Phil Loscoe

May 12, 2011

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Treatment and Packaging Alternative Workshop**

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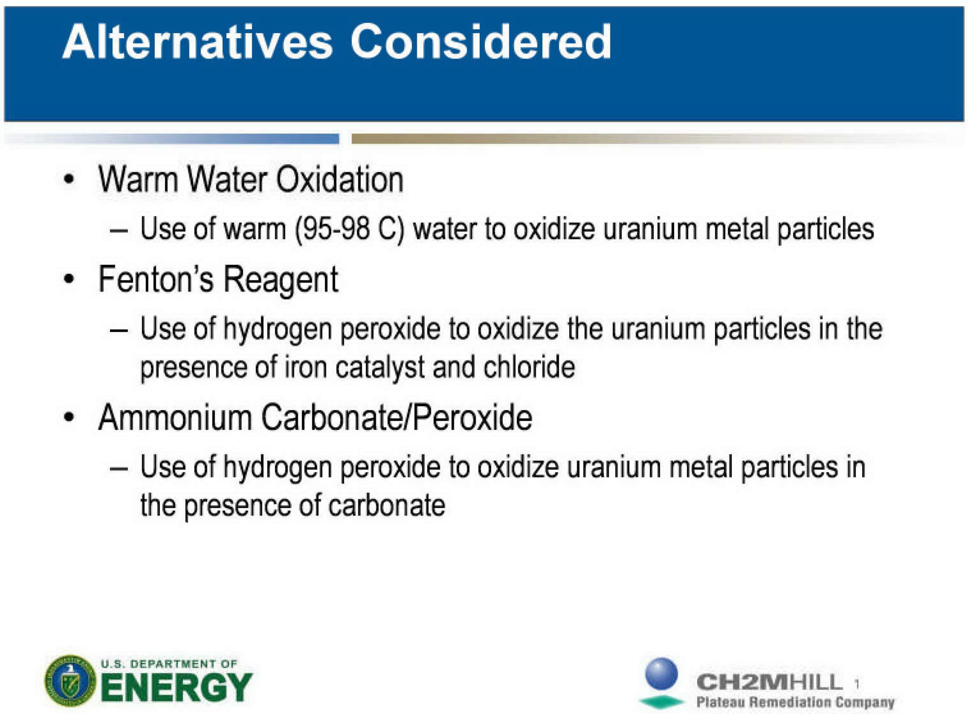

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**Sludge Treatment Project Decision Support Board Phase 2
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Alternatives Considered, cont'd

- Warm Water Oxidation with Size Reduction
  - Use of immersion mill to size reduce uranium metal particles; followed by oxidization of metal particles in warm water
- Nitrate Inhibitor Process
  - Use of nitrate to decrease production of hydrogen from the uranium metal/water reaction
- In-Container Vitrification
  - Immobilization of sludge into a glass matrix

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**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

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Evaluation Criteria

- Ease of Making the Safety Case
- Technical Maturity
- Operability/Maintainability
- Regulator/Stakeholder Acceptance
- Lifecycle Costs and Schedule
- Beneficial Integration with Phase I
- Integration with Sitewide RH-TRU

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Results of Evaluation – Weighting 1

Technology Alternatives	Weighted Evaluation Criteria: Safety	Technical Maturity	Operability/Maintainability	Regulatory/Stakeholder Acceptance	Lifecycle Costs and Schedule	Beneficial Integration with Phase I	Integration with Sitewide RH-TRU		
Rating Score / Rating Score x Raw Score	A	B	C	D	E	F	G		
	0.25	0.15	0.15	0.1	0.15	0.1	0.1	Total Points	New Rank
1 - Warm Water Oxidation	5 / 1.25	5 / 0.75	5 / 0.75	4 / 0.4	2 / 0.3	3 / 0.3	3 / 0.3	4.05	
2 - Fenton's Reagent	3 / 0.75	3 / 0.45	3 / 0.45	4 / 0.4	4 / 0.6	3 / 0.3	3 / 0.3	3.25	
3 - Ammonium Carbonate/Peroxide	2 / 0.5	2 / 0.3	2 / 0.3	3 / 0.3	3 / 0.45	3 / 0.3	3 / 0.3	2.45	
4 - Size Red, and Water Oxidation	4 / 1	4 / 0.6	4 / 0.6	5 / 0.5	5 / 0.75	3 / 0.3	3 / 0.3	4.05	
5 - Nitrate Inhibitor Process	4.5 / 1.125	3 / 0.45	4 / 0.6	1.5 / 0.15	5 / 0.75	3 / 0.3	3 / 0.3	3.675	
6 - In-Container Vitrification	3 / 0.75	4 / 0.6	2 / 0.3	4 / 0.4	2 / 0.3	3 / 0.3	1 / 0.1	2.75	

Excellent - 5 Very Good - 4 Good - 3 Fair - 2 Poor - 1

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Treatment and Packaging Alternative Workshop**

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Evaluation Criteria – Weighting 2

Technology Alternatives (Rating Score / Rating Score x Raw Score)	A – Safety	B – Technical Maturity	C – Operability/Maintainability	D – Regulatory/Stakeholder Acceptance	E – Lifecycle Costs and Schedule	F – Beneficial Integration with Phase I	G – Integration with Sitewide RH-TRU	Total Points	New Rank
Weighted Evaluation Criteria	0.15	0.25	0.25	0.15	0.15	0	0.05		
1 - Warm Water Oxidation	5 / 0.75	5 / 1.25	5 / 1.25	4 / 0.6	2 / 0.3	3 / 0	3 / 0.15	4.3	1
2 - Fenton's Reagent	3 / 0.45	3 / 0.75	3 / 0.75	4 / 0.6	4 / 0.6	3 / 0	3 / 0.15	3.3	4
3 - Ammonium Carbonate/Peroxide	2 / 0.3	2 / 0.5	2 / 0.5	3 / 0.45	3 / 0.45	3 / 0	3 / 0.15	2.35	6
4 - Size Red, and Water Oxidation	4 / 0.6	4 / 1	4 / 1	5 / 0.75	5 / 0.75	3 / 0	3 / 0.15	4.25	2
5 - Nitrate Inhibitor Process	4.5 / 0.675	3 / 0.75	4 / 1	1.5 / 0.225	5 / 0.75	3 / 0	3 / 0.15	3.55	3
6 - In-Container Vitrification	3 / 0.45	4 / 1	2 / 0.5	4 / 0.6	2 / 0.3	3 / 0	1 / 0.05	2.9	5

Excellent - 5 Very Good - 4 Good - 3 Fair - 2 Poor -1

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Summary

Independent of weighting factors the top scoring alternatives were:

- –Warm Water Oxidation
- –Warm Water Oxidation With Size Reduction

Somewhat lower scoring, were the Nitrate Inhibitor and Fenton's Reagent.

Lowest scoring alternatives were In-Container Vitrification and the Ammonium Carbonate/Peroxide Processes.

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Recommended Technical Approach

Presented by: Barry Naft

May 12, 2011

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Recommended Technical Approach

- Proceed into conceptual design using Warm Water Oxidation as the technical baseline.
- Develop the Size Reduction and Fenton's Reagent during conceptual design with goal of TRL-4 as an enhancement to the baseline.
- The conceptual design should make provision for Size Reduction or Fenton’s Reagent in case they are at TRL-4 when CD-1 is submitted.

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Treatment and Packaging Alternative Workshop

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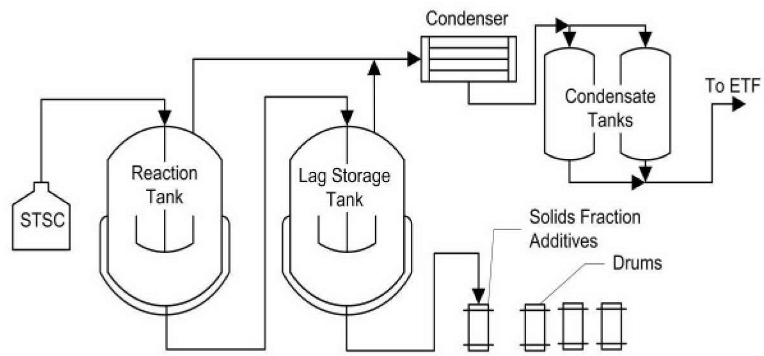
Warm Water Oxidation – Process Flowsheet



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Areas of Risk / Vulnerabilities & Recommendations

Management Out-Brief

Presented by: Mike E. Johnson

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Treatment and Packaging Alternative Workshop

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Areas of Risk / Vulnerabilities & Recommendations

- Technology Development
  - In process sludge assay
  - Determining when Uranium metal oxidation reaction is complete
  - Sludge mixing / suspension
- Maintaining remote operating systems
- Aggressive RH-TRU drum production rate of 3 drums/day of final waste form – ~70% TOE over 2 years

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Technology Development

- In process sludge assay
  - Vendor survey and test candidate instrument
  - Ability to remove part of final waste form from drum / mix and match drums
- Determine when Uranium metal reaction is complete
  - Qualify process on time and temperature controls
- Sludge mixing / suspension
  - Develop appropriate simulants and conduct full-scale testing of mixing and transfer systems

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Maintaining remote operating systems

- Apply lessons learned in design from other DOE and remote handled waste processing sites (e.g. Sellafield, LaHague)
- Acquire expertise in remote handled maintenance
- Maintain adequate spare parts to minimize downtime

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Aggressive RH-TRU Drum Production

- Apply lessons learned in design from other DOE and remote handled waste processing sites (e.g. Sellafield, LaHague)
- Improving in process sludge assay accuracy will reduce drum count; therefore lower drum production rate / TOE acceptable
- Consider parallel lines

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**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

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Overall Recommended Path Forward Implementation Approach

Presented by: Rick Raymond

May 12, 2011

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Overall Recommended Path Forward Implementation Approach

1. Proceed to conceptual design using the recommended technical approach.
2. Establish the set of decisions and the schedule for completing these decisions to enable timely implementation of Sludge Treatment Project Phase II.
3. Initiate technology development and bench scale demonstrations on the following (in priority order):
   - Size reduction,
   - Fenton's Reagent, and
   - Nitrate/Drying options that reduce hydrogen release.

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Treatment and Packaging Alternative Workshop**

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Overall Recommended Path Forward Implementation Approach (cont.)

4. Refine requirement set, scope, and interfaces applicable to the Phase II Sludge Treatment Project, including consideration of other Hanford waste management projects.
   – Develop integration strategy.
5. Implement a flexible Conceptual Design that includes space for existing functions and requirements associated with other site RH-TRU wastes. These may include:
   – Second drum packaging line,
   – Receipt and remote sorting of solid waste, and
   – Ability to easily remove process tanks to convert cells to other activities.

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Overall Recommended Path Forward Implementation Approach (cont.)

6. Complete a siting study.
7. Select and demonstrate drumming and immobilization technology.
8. Evaluate advanced assay methodologies to enable optimized waste loading.
9. Evaluate potential for mixing sludge waste streams to enable optimizing facility utilization schedule.
10. Set-up July meeting with RL, CBFO, and Contractors to refine and document requirements for transport and disposal in WIPP as RH-TRU.

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Overall Recommended Path Forward Implementation Approach (cont.)

11. Define the maximum uranium particle size to provide better estimates of treatment time requirements.

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**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Management Out-brief Attendees

Name	Organization
[2] ***Rick Raymond*****	CHPRC Sludge Treatment Project
Jim Mathews*	CHPRC Sludge Treatment Project
Jim Sloughter*	CHPRC Sludge Treatment Project
John Williams*	CHPRC Safety Analysis
Wayne Toebe*	CHPRC Environmental Protection
Don Flyckt *	CHPRC Environmental & Strategy Planning
Michael E. Johnson*	CHPRC Sludge Treatment Project
Calvin Slotemaker*	CHPRC Worker Protection Program
Chris Lucas*	CHPRC D&D
Eric D'Amico*	Washington TRU Solutions
Phil Loscoe*	Quadrant One
Barry Naft*	Environmental International
Jim Honeyman	CHPRC Sludge Treatment Project
Mike W. Johnson	CHPRC Project Manager
Tom Teynor	DOE-RL
Roger Quintero	DOE-RL
Sahid Smith	DOE-RL
James Crocker	DOE-RL
Alex Teimouri	DOE-HQ (Richland)
Gary Pyles	DOE-RL
Monique Helfrich	DNFSB
Scott Van Camp	Lucas EMS
Mary Cunningham	Lucas EMS
Tom Fogwell	Lucas EMS
Mike Jennings	CHPRC EPC
Doug Bragg	CHPRC Sludge Treatment Project
Mike Klem	CHPRC Sludge Treatment Project
Blake Spilman	CHPRC Sludge Treatment Project
Andy Schmidt	PNNL

[2] ***(*) and (**) denotes Decision Support Board Members and Decision Support Board Chairman, respectively.***

Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop

Management Out-brief Questions and Answers

Q: De-watering In *Warm Water Oxidation*?
A: Retrieve Sludge, remove water via evaporation, and maintain sludge at about 95°C. Initial feed slurry is ~ 5 volume % → Concentrated to ~20 volume%

- Slurry is mixed with an agitator

Q: Vacuum drying?
A: Not directly considered – Drying was demonstrated with a physical simulant as part of the In-Container Vitrification™ testing.

Input – Drying and put it in a drum is a follow-on action

Q: Nitrate Inhibitor?
A: Nitrate eliminates release of Hydrogen gas. U metal reactions continue

- If one molar nitrate then it keeps hydrogen gas release in check
- Since the metal continues to react, it is not clear if it meets WIPP's "non-reactive/Chemically Stable" criterion
- Use of nitrate inhibitors may be treated similarly to hydrogen getters. NRC approval may be required to modify transportation safety documentation of RH-72B
- The option to pursue with WIPP remains open, it just won't be easy

Q: Why wouldn't you use nitrate with *Size Reduction*?
A: The primary purpose of *Size Reduction* is to cause acceleration of the U-Metal oxidation; while the nitrate reduces the evolution of hydrogen gas. *Size Reduction* should be coupled with a U-Metal oxidation technique; while the nitrate addition would be in lieu of an oxidation prior to immobilization and packaging. Nitrate could be added as a "defense in depth" measure if uncertainty regarding the residual levels of u-metal remaining after oxidation requires additional measures.

Q: Safety concerns with corrosion using *Fenton's Reagent*
A: If *Fenton's Reagent* is selected, materials for the processing equipment will be selected for their corrosion resistance. Any issues for potential corrosion in the immobilized waste drum would need to be addressed via testing and engineering evaluation prior to final selection of this approach

.

Sludge Treatment Project Decision Support Board Phase 2 Treatment and Packaging Alternative Workshop

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Appendix C – Session Flipcharts

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Presentation Observations

<u>Project Background</u>*:*

Sludge Characterization – Wally Rutherford

<u>Summary</u>:

- Wide range of physical properties
  - Contains U metal
  - Contains Polychlorinated Biphenyls (PCBs)
  - Contains IX beads and graphoil fragments
  - High TRU content
  - High radiation dose

<u>Observations</u>:

- KE data is at 90% completion; should be complete over the next few weeks

STP Phase 2 Technology Evaluations and Alternatives Analysis – Jim Honeyman

<u>Summary</u>: Several approaches appear feasible based on bench top or larger testing with uranium bearing and physical simulants

- Alternative development is in process (process descriptions, safety, cost and schedule with alternative performance data)
- Formal DSB
- CHPRC recommendation in June-July, 2011

<u>Observations</u>:

- Would like to see this project complete as soon as possible within the technology limitations

<u>Primary Technical Requirements</u>:

Sludge Treatment and Packaging Requirements – Mike Rivera

<u>Summary:</u>

- All sludge is limited by Fissile Gram Equivalent (FGE), based on current assumptions
- Sensitivity analysis of 30 gallon versus 50 gallon drums
- Potential improvements
  - FGE and waste loading
    - ➢ Characterization data
    - ➢ Assay versus dose-to-Curie
    - ➢ Fissile Equivalent Mass (FEM) versus FGE (< 0.96% Uranium-235)
    - ➢ Volume: grout absorbent or dry
    - ➢ Acceptable residual uranium
    - ➢ Mitigate hydrogen and/or reduce relapse

<u>Observations:</u>

- Uncertainties in Dose-to-Curie measurement will result in more waste drums, which in turn will impact will affect space available in WIPP.
  - Space is filling up at WIPP; RH-TRU shipped in RH-72Bs may not fit with space available (remaining side-wall disposal locations)
  - Total hydrogen gas lessons and precedence from Rocky Flats and now Idaho

Process Bases and Assumptions – Kim Auclair/Tom Fogwell

**Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop**

Summary: see presentation
Observations: none, only clarifications

Sludge Treatment Project Decision Support Board Phase 2
Treatment and Packaging Alternative Workshop

Presentation Observations: The Alternatives

a) ***Warm Water Oxidation*** – Tom Fogwell

Summary:

- Appears technically feasible; has relatively well understood performance requirements
- Could be developed, designed, and deployed to meet mission goals
- Conforms to WIPP and transportation requirements
- Laboratory testing is required to develop the basis for better flow sheet definition and to provide the basis for final process selection and optimization in conceptual design

Observations:

- "Significant" testing is/or should be clarified
- Consider testing to determine the residual un-reacted U-Metal remain in the reaction vessel

Baseline Facility Pre-conceptual Study – Tom Fogwell

Summary: Two layouts considered – 1) Stand-Alone; 2) Existing facility

Observations: Liquidated questions and answers

b) ***Fenton's Reagent – Chemical Oxidation*** **–** Tom Fogwell

Summary: Process appears technically feasible and has favorable performance characteristics

- Short reaction time near ambient temperature
- Could be developed, designed, and deployed to meet the mission goals
- Expected to meet WIPP and transportation requirements

Observations:

- Need to fully understand the reaction mechanisms beyond U-Metal corrosion
- Look at hydrogen release rates during reaction (important for purge system design)
- Look at and consider effects of chlorides

c) ***Ammonium Carbonate/Peroxide – Chemical Oxidation*** **–** Tom Fogwell

Summary: Process appears technically feasible and has favorable performance characteristics

- Moderate reaction time near ambient temperature
- Could be developed, designed, and deployed to meet the mission goals
- Expected to meet WIPP and transportation requirements

Observations:

- Safety criteria: look at actinides in solution – may impact safety considerations
- Off-gas system is different from the other alternatives
  - Consider flammability as well! (NH_3)

d) ***Size Reduction and Water Oxidation – Chemical Oxidation*** **–** Tom Fogwell

Summary: Process appears technically feasible and has favorable performance characteristics

- Short reaction time near ambient temperature
- Could be developed, designed, and deployed to meet the mission goals
- Expected to meet WIPP and transportation requirements

Observations:

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- Failure of size reduction reverts to warm water oxidation process
  - However, further information is required for operating in bypass mode

Presentation Observations: The Alternatives (continued):

e) ***Nitrate Inhibitor Process*** **–** Tom Fogwell

Summary: Process appears technically feasible with favorable performance → short reaction times at near ambient temperature; can be developed, designed, and deployed to meet mission goals

- Whether final product will meet WIPP and transportation requirements is uncertain
  - Note: acceptance of presence of U metal in final waste form by WIPP is uncertain

Observations:

- Consumption rate is on the order of 3%

f) ***In-Container Vitrification™*** – Al Pajunen

Summary: Process appears technically feasible; demonstrated at full-scale

- Could be developed, designed, and deployed to meet mission goals
- Expected to conform with WIPP and transportation requirements

Observations:

- Need to address Cesium at some point
  - Consider dose-to-Curie
- What about the volatiles and organics?
  - Consider evaluation of known work/lessons already done

Remote Solidification (Grout/BoroBond™/Clay) and Information on Immobilization Approaches – Tom Fogwell/Kim Auclair

Conclusions:

- BoroBond™ does not show the necessary hydrogen inhibition for direct immobilization, a candidate for immobilization
- Updated MOSS system
  - No standard design, equipment is adapted for each application
- Operating AREVA immobilization line uses robots no longer manufactured
- Ceradyne → no specific system design for STP – only described standard industrial equipment
- Immobilization Agent Formulations:
  - Grout, clay and BoroBond™ testing completed

Summary:

- No agent selected; needs to be integrated with WIPP disposal and transportation

Observations:

- All options need it, no discriminators across options
- Discuss off-shore lessons
- Add 0413.3b , 0420, and STD-1189
- Consider Nochar absorbent

Other Technologies considered but not evaluated – Kim Auclair/Jim Honeyman

- Liquidated questions and answers

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Base Case and Sensitivity Analysis – Tom Fogwell

- Assay effects number of drums required

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Presentation Observations: The Criteria

Hazards Considerations (Safety) – Gary Franz

- A potential that c) *Ammonium Carbonate/Peroxide* - would have safety class controls (i.e. integrated accident consequence may be higher than other alternatives)
- Maintenance will be the dose driver (maintenance and time)
- May be some discrimination between a) *Warm Water Oxidation* and c) *Ammonium Carbonate/Peroxide* – due to demands on the ventilation system
- Industrial safety: alternatives - b) *Fenton's Reagent*, c) *Ammonium Carbonate/Peroxide*, e) *Nitrate Inhibitor Process*, and f) I*n-Container Vitrification*™, will have chemical management
  - This may be a discriminator
- Not sufficient information to make a decision on active versus passive controls

Technical Maturity – Kim Auclair

- ~~Critical Technology Elements (CTE) as it relates to TRL process versus~~
- **Judgment to determine taking all CTEs to a Level 4 at CD-1**
  (DSB decision to go this route)

Operability/Maintainability – Chris Lucas

- Evaluate **relative** to each other
- This is a remote-handling activity and will be difficult in all cases

Regulatory/Stakeholder Considerations – Dave Watson

Summary: No apparent discriminators with the exception of time to treat and package and the potential need to remove/destroy PCBs

Observations: There are stakeholders with a cost effectiveness view point

WIPP Perspective – Eric D'Amico

- Compliance with requirements, including supporting methodology requirements, which are negotiable
- Philosophy: do the minimum to achieve compliance
- ⚑ WIPP is willing to work with you
- WIPP's key goal is to fill the site
- ⚑ Reactive chemicals open questions, including compatibility
- ⚑ Identify the biggest bang for the money and let waste be delivered to WIPP
- Variability and drum count are not discriminators
- WIPP might prefer a 30 gallon shielded drum for any waste that can meet the requirements (e.g. KE waste)
- ⚑ There is also a preference for CH-waste in shielded drums rather than RH-72Bs
- ⚑ Number of shipments into mine effects a cost effective operating strategy
- Ten day versus sixty day shipping authorization: may be considered

Lifecycle Costs and Schedule – Doug Bragg

- Key difference between alternatives is the basis of operation
  - Time

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  - Dollar estimate is -50%/+100%
- Cost per unit volume appears to be high

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Presentation Observations: The Criteria

Potential for Beneficial Integration with ECRTS (Phase 1) - Jim Honeyman

Summary: ECRTS has design features and technology to support integration with Phase 2

- Interim storage in T-Plant will result in little oxidation
- Enhancements to increase U metal oxidation during storage are likely not cost effective

Observations:

- Design features in Phase 1 are appropriate for all Phase 2 alternatives
- Phase 1 test results will be available for Phase 2
- No discriminator across the alternatives
- Excellent plan to mitigate any integration problems/issues from Phase 1 to Phase 2

Potential for Integration with Site wide RH-TRU Treatment – Don Flyckt

Summary: No need for sludge treatment; maybe solidification and packaging

- Potential integration with head-end treatment and some elements in final design
- Potential integration with some tank (e.g., D10 and/or settling tanks) wastes and possibly some Alpha Caisson waste, if the design can facilitate "plug and play" type work

Observations:

- Question is: do we have a slurry and/or non-slurry to consider as potential?
  - A small facility footprint may limit additional use
  - May anticipate unknowns, such as vitrification needs, but this may have no merit
- Rate technologies a through e a 3; technology f) *In-Container Vitrification™* is a 1 due to a lower through-put and is not needed for balance of site waste

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Evaluation Results and Conclusions

Sensitivity Analysis:

- Project Viewpoint
  - Thought b) *Fenton's Reagent* and d) *Size Reduction and Water Oxidation* would have ranked in the top two
  - Consider an approach to combine two to four technologies
    - Considering a five-year span
    - Need to understand what to consider; rules to apply, etc.
  - Key is to have a predictable pathway with low risk

- Decision Support Board
  - Weight changes do not appear to change the score or ranking
  - We can meet the timeline
  - Regulatory, specifically meeting NRC, may be the largest risk
    - Alternative e) *Nitrate Inhibitor Process*, may not meet the requirements
  - Remaining four (top four rankings) have commonalities
    - Water based
    - Rely on same fundamental equipment
    - Minimum modifications to switch from one alternative to another
      Note: Could design tank (system of tanks) to do any alternative
    - All these options are add-ons that remove schedule risk
      - You can carry these alternatives in parallel
      - One way has a significant regulatory risk
  - Single step drying? The project looked at part of this but not in total
    - Consider/Evaluate single-step drying or define why this approach is not viable
    - Need a gas generation test of the dried waste product
    - Previous project evidence suggests this approach is not viable
      Note: drums will have moisture and some condensation build-up due to hygroscopic nature of dried solids
  - Two basic approaches:
    - 1) Oxide to extinction with or without enhancements, **or**
    - 2) Transport U metals with additional controls

- Thoughts/Observations
  - Particle size of U metal is < ¼ inch; this may change the ranking and make #1, a) *Warm Water Oxidation,* more attractive
  - Integration site-wide is critical and may be a top risk to successful project delivery
    - Need to build in flexibility
  - Engineered features will make safety a non-discriminator
    - Relative to other Hazard Category 2 facilities

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Evaluation Results and Conclusions (continued)

Sensitivity Analysis:

- Thoughts/Observations (continued)
  - Based on the weight changes alternatives #s 1and 2, a) *Warm Water Oxidation* and d) S*ize Reduction and Water Oxidation,* came together, a group;
  - b) *Fenton's Reagent* and e) *Nitrate Inhibitor Process* are a group;
  - c) *Ammonium Carbonate/Peroxide* and f) *In-Container Vitrification*™, are a group
  - c) *Ammonium Carbonate/Peroxide* and f) *In-Container Vitrification*™ drop out

In the second weighting, the safety criterion was lowered to 15%. The basis for this decision was to avoid over-weighting differences created when the options were relatively ranked in the technology evaluation process. In all cases the hazards are reasonably well understood, the necessary hazard controls have been previously deployed, and the safety design basis development efforts are essentially the same for all options.

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Evaluation Results and Conclusions (continued)

Technology Approach

- Proceed into conceptual design using *Warm Water Oxidation* as the technical baseline
- Develop *Size Reduction* and *Fenton's Reagent* during conceptual design with goal of TRL-4 as an enhancement to the baseline
- The conceptual design should make provisions for *Size Reduction* or *Fenton's Reagent* in case they are at TRL-4 when CD-1 is submitted
- Proceed with a flexible conceptual design that includes existing functions and requirements for other site RH-TRU wastes. These may include:
  1) Space for a second drum packaging line
  2) Space for receipt and remote sorting of solid waste
  3) Ability to easily remove process tanks to convert cells to other activities

#	OPPORTUNITIES	#	CHALLENGES
1 (circled)	Most predictable • Technically mature • Strongest technical basis	1	Expensive • Requires a Category 2 facility
2	Deliberate speed • Less potential for upsets	2	Time
3 (circled)	Manageable safety risk	3 (circled)	Defining and controlling scope and requirements definition • Regulatory acceptance
4	Potential accelerated mission delivery • Flexible • Accommodate enhancement		
5 (circled)	Reliable • Robust • Less complex		
All	Least project risk		
All	Just do it - *Get'er done*		

(circle) = Most significant impact

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Evaluation Results and Conclusions (continued)

Areas of Risk/Vulnerabilities

1 Three drums per day
(2) Sludge assay
3 Uranium reaction
   - How do you know you are done?
4 Delivering Hazard Category 2 facility
5 Stability of final waste form (i.e. keeping it dry)
- ~~Limited scope~~
6 Mission schedule compliance
(7) Technology development
   - Timely completion
(8) Revisiting decisions
   - (8a) Requirement definition
9 Maintaining remote operations system
10 Sludge mixing

◯ = Most significant impact

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Parking Lot Information

Memories

- 1 Sensitivity Analysis: Evaluate the outliers (e.g. U metal in 220)
- ~~Graphite limitation on the 72B **may** be negotiable~~
- ✓ Dose rate to Curie uncertainty measurement
  - Consider commercially available survey instruments
  - Effect on technology differential (could be a discriminating factor between technologies)
- ~~✓ Check volume estimate math on a) *Warm Water Oxidation*~~
- ✓ b) *Fenton's Reagent*: Possible chemical incompatibility with waste packaging and transportation
- ✓ b) *Fenton's Reagent*: take a look at zirconium metal as a part of this process
- ✓ b) *Fenton's Reagent*: operating parameters need clarification (e.g. how much Uranium)
- ~~c) *Ammonium Carbonate/Peroxide*: may be a difference between the safety associated with spray accidents in solutions and criticality of fissile material in solution~~
- ✓ d) *Size Reduction and Water Oxidation*: define amount of dense alloys used/tested on size reduction and water oxidation
  - 100g used in the mill
  - Ball bearings were chrome steel
- ✓ Remote Solidification has no discriminators across the options
- ✓ Consider different particle size and its effect on operating schedule
- ✓Consider more sophisticated technologies that are not dependent on dose-to-Curie
- ✓ Sample lag storage tank
  - Reference: dose-to-Curie
- ✓ Consider multiple processing trains in conceptual
- ✓ Operating efficiency starts low then should get to 70%, maybe 80%
  - Equipment and various administrative controls will impact efficiency
  - Small crews work well
- ✓ Solidification point in the process may be of the most concern for Operations/Maintenance
- ✓ Sampling during Operations/Maintenance can be difficult
- Operations/Maintenance lessons from Idaho and Savannah River Site
  - Hanford annex, DWPF, AMWTF, etc.
- ~~Addressing PCBs and interface with EPA~~
- ✓ A trade-off for capital costs versus operational costs
- ✓ ⚐ Potential Phase 2 connect point would be design of STSC connections to facilitate remote operations
- ✓ Need an integrated function analysis
- ✓ Potentially 1,000 drums per year of RH-TRU may meet site-wide mission needs
  - May need up to 5,000 total drums and consideration of more than one train

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✓ = Valid memory

Parking Lot Information (continued)

Areas of Risk

- ✓ Simulants used
- Acceptability of U metal is currently outside TRAMPAC requirements – will require NRC review/endorsement
  - Also, WIPP performance 191 assessment

  Note: we are outside of WAC compliance

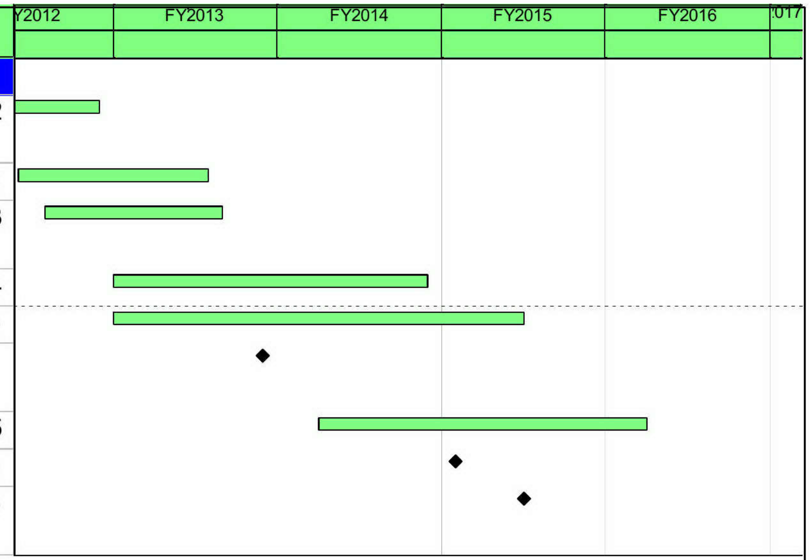
Assumptions

- This will be a Hazard Category 2 facility

Path Forward Actions

#	WHAT	WHO/WHEN
1	Define potential for mixing engineered contained sludge streams	In management out-brief
2	Define potential bounds of shipping ability	In management out-brief
3	Schedule meeting – mid-June or early July - to develop decision points and path forward between DOE-RL and contractor	Tom Teynor Michael W. Johnson

Activity Name	Target Start	Target Finish
Milestones and Target Dates		
Phase 2 Sludge Treatment and Packaging Facility Baseline Flowsheet	23-Jan-12	31-Aug-12
Phase 2 Sludge Treatment and Packaging Facility Siting Study	05-Mar-12	30-Apr-13
Engineering Scoping Studies and Bench Scale and Technology Screening Testing	01-May-12	31-May-13
Engineering Evaluations, Testing, and Concept Definitions	01-Oct-12	29-Aug-14
Preparation of the Interim Design Report	01-Oct-12	31-Mar-15
Initiate Laboratory Testing Necessary to Design the Warm Water Oxidation Process for K-Basin Sludge Treatment	30-Aug-13	
System Integration Testing Needed to Demonstrate TRL-4	31-Dec-13	31-Dec-15
Complete Warm Water Oxidation Process Testing		31-Oct-14
Final K Basin Sludge Treatment Packaging Technology and proposed interim milestones (TPA M-016-173)		31-Mar-15



Actual Work
Remaining Work
Critical Remaining Work
◆ Milestone

K-Basins Sludge Treatment and Packaging Technolog

Summary Schedule

CH2MHILL Plateau Remediation Company