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Department of Energy

Richland Operations Office

# memorandum

DATE: **NOV 20 2003**

REPLY TO  
ATTN OF: 03-WEC-056 WEC:WFH

SUBJECT: TRANSMITTAL OF DESIGN OVERSIGHT ASSESSMENT, D-03-DESIGN-004, ENTITLED "AN ASSESSMENT OF THE FACTORS AFFECTING THE ABILITY TO INCREASE THE Na<sub>2</sub>O LOADING IN THE WASTE TREATMENT AND IMMOBILIZATION PLANT (WTP) LOW-ACTIVITY WASTE (LAW) GLASS," DATED OCTOBER 30, 2003

TO: John R. Eschenberg, Manager  
Waste Treatment Plant Project

This memo transmits the subject Design Oversight report conducted by the U.S. Department of Energy, Office of River Protection (ORP) WTP Engineering Division to evaluate:

- Factors that affect the LAW loading (weight percent Na<sub>2</sub>O) in WTP LAW glass;
- Provide a basis to select LAW to be treated in the WTP and that to be processed by supplemental treatment; and
- Provide a potential treatment and disposal strategy to reduce the treatment schedule for the LAW.

This evaluation was completed to provide a clear definition of the current technical performance baseline for the WTP Immobilized LAW glass and identify specific areas where the performance of the WTP LAW vitrification system can be improved.

This study has concluded that:

1. There is a technical basis for a 20 wt% Na<sub>2</sub>O loading in the WTP LAW glass as postulated by ORP's Stretch Case.
2. The 20 wt% Na<sub>2</sub>O waste-loading in WTP LAW glass can be achieved for 60 percent of the Hanford tank waste inventory of Na using an appropriate waste feed selection strategy between WTP and supplemental treatment, and LAW glass development. A potential waste feed selection strategy has the higher sulfate containing wastes immobilized in supplemental treatment and would result in an increase in the average waste-loading in WTP LAW glass from 14 wt% to 17 wt%. Glass development can provide further improvement in the WTP LAW average waste loading from 17 wt% to 20 wt%.
3. The LAW treatment mission can potentially be shortened by three years through the combined strategies of feed selection and LAW glass development.

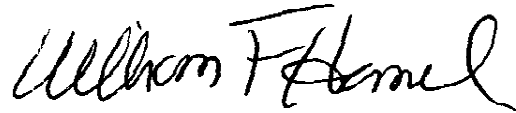
Mr. John R. Eschenberg  
03-WEC-056

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**NOV 20 2003**

4. Near term benefits can be realized in feed selection between WTP and supplemental treatment equivalent to an additional 4,300 to 6,800 MT Na treated during the period 2011 to 2018. This is equivalent to creating three to five additional double-shell tank volumes, which can greatly improve the potential to meet single-shell tank retrieval milestones.

Please contact me if you have any questions on the content of this report.



William F. Hamel, Director  
WTP Engineering Division

Attachment

cc:

L. E. Demick, PAC  
L. K. Holton, PNL

U.S. Department of Energy, Office of River Protection

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**An Assessment of the Factors  
Affecting the Ability to Increase the Na<sub>2</sub>O Loading in the  
Waste Treatment and Immobilization Plant (WTP)  
Low-Activity Waste (LAW) Glass**

**D-03-DESIGN-004**

**October 30, 2003**

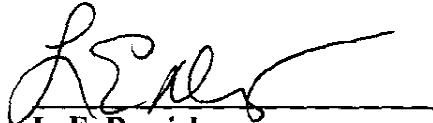
**Prepared by:**



**W. F. Hamel**

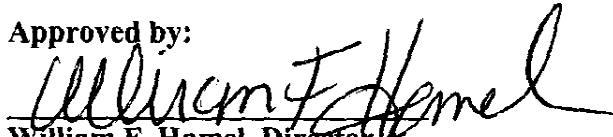


**L. K. Holton**



**L. E. Demick**

**Approved by:**



**William F. Hamel, Director  
WTP Engineering Division**

## Executive Summary

The U.S. Department of Energy (DOE), Office of River Protection (ORP) Waste Treatment and Immobilization Plant (WTP) Engineering Division (WEC) has conducted a study to evaluate:

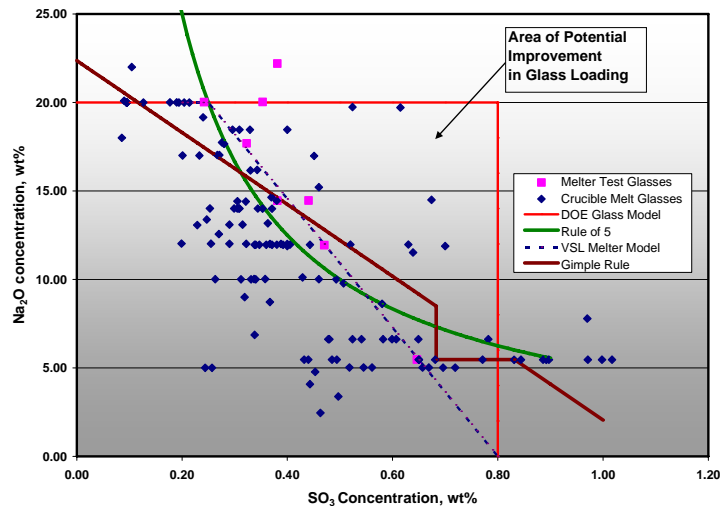
- Factors that affect the low-activity waste (LAW) loading (weight percent Na<sub>2</sub>O) in WTP LAW glass;
- Provide a basis to select LAW waste to be treated in the WTP and that to be processed by supplemental treatment; and
- Provide a potential treatment and disposal strategy to reduce the treatment schedule for the LAW.

This evaluation was completed to provide a clear definition of the current technical performance baseline for the WTP Immobilized Low-Activity Waste (ILAW) glass and identify specific areas where the performance of the WTP LAW vitrification system can be improved.

The figure to the right compares several glass models used to project acceptable LAW glass waste-loading, expressed in terms of the Na<sub>2</sub>O and SO<sub>3</sub> concentration in the glass. The presence of sulfur, as sulfate, has been found to dictate the concentration of Na in the LAW glass. The Gimpel Glass Model is currently used by Bechtel National, Inc. (BNI) in the design

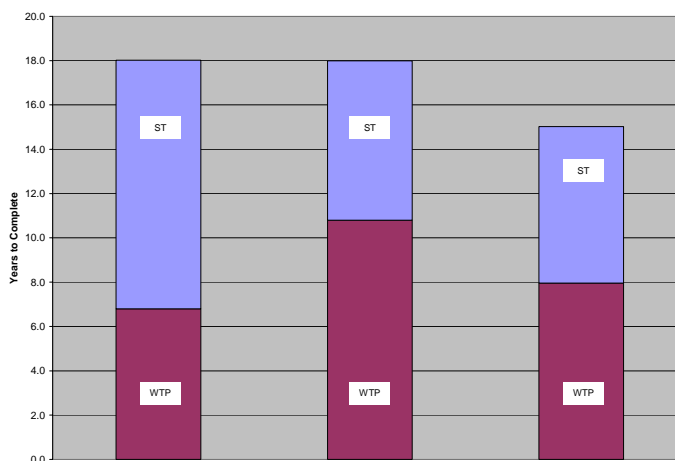
process for the WTP. The Gimpel Model is based on a limited set of glass development work sponsored by BNI at Duratek and Vitreous State Laboratory (VSL). The Rule of 5 and VSL Melter models are also derived from experimental work sponsored by BNI targeted at demonstrating WTP contract requirements. The DOE Model is based on a broader scope of DOE glass development work and indicates that the LAW glass has the potential to incorporate higher concentrations of Na. Operation of the LAW Vitrification Facility more consistently with the DOE Model than the Gimpel Model would result in less glass production to complete the River Protection Project (RPP) mission; thereby, reducing mission time and life-cycle cost.

Completion of the RPP mission within the current accelerated schedule requires immobilization of LAW in both the two-line WTP LAW Vitrification Facility and by supplemental treatment. DOE has defined two cases in the "River Protection Project System Plan," Revision 2 (Target



and Stretch Case) that apportion the LAW immobilization mission between WTP and supplemental treatment. Prior studies have indicated that LAW waste could be immobilized using bulk vitrification (or steam reforming process) at an average of 20 wt% for the range of sulfate concentrations in Hanford waste. Accordingly, it is possible to improve the RPP mission completion time by (1) increasing the LAW glass waste-loading and also (2) using sulfate concentration as one of the principal factors in selecting whether a specific tank waste is immobilized in WTP LAW vitrification or supplemental treatment.

The figure to the right illustrates the potential schedule improvement by comparing the DOE Target and Stretch goals using the Gimpel Model for glass production in the WTP LAW facility with application of the DOE glass model in the WTP combined with a process selection logic that maximizes the glass-loading in WTP by sending high sulfate wastes to supplemental treatment. This figure shows that these factors could reduce the overall RPP mission completion time by up to 3 years.



Item	DOE Target Case	DOE Stretch Case	Application of Selection Logic
<b>Glass Model</b>	<b>Gimpel</b>	<b>Gimpel</b>	<b>DOE</b>
<b>Na Treated in WTP, %</b>	<b>40 %</b>	<b>60 %</b>	<b>53 %</b>
<b>Average Na<sub>2</sub>O weight %</b>	<b>14.0</b>	<b>18.9</b>	<b>20.0</b>
<b>LAW Annual average capacity, MTG/day</b>	<b>28.8</b>	<b>34.0</b>	<b>34.0</b>
<b>Feed Selection Applied</b>	<b>No</b>	<b>No</b>	<b>Yes</b>
<b>Supplemental Treatment Rate, Na/year</b>	<b>1,800</b>	<b>1,160</b>	<b>1,635</b>
<b>Years to Complete</b>	<b>18.0</b>	<b>18.0</b>	<b>15.0</b>

This study has concluded the following:

1. There is a technical basis for a 20 wt% Na<sub>2</sub>O loading in the LAW glass as postulated by ORP's Stretch Case.
2. The 20 wt% Na<sub>2</sub>O waste-loading in the LAW glass can be achieved for 60% of the Hanford tank waste inventory of Na. Using appropriate waste feed selection between WTP and supplemental treatment, in which the higher sulfate containing wastes are immobilized in

supplemental treatment, the average waste-loading in the WTP LAW can be increased from 14 wt% to 17 wt%. Glass development should provide the basis for further improvement in the waste-loading from 17 wt% to 20 wt%.

3. The LAW treatment mission can potentially be shortened by three years through the combined strategies of feed selection and LAW glass development.
4. Near-term benefits can be realized in feed selection between WTP and supplemental treatment equivalent to an additional 4,300 to 6,800 MT Na treated during the period 2011 to 2018. This is equivalent to 3 to 5 additional double-shell tank (DST) volumes created, which can greatly improve the potential to meet single-shell tank (SST) retrieval milestones.

This evaluation demonstrates the potential benefits to be gained in developing a more robust LAW glass performance baseline for WTP LAW glass production and a logic for selecting the immobilization process (WTP versus supplemental treatment) for a specific tank to maximize the waste-loading in WTP LAW glass. Accordingly, the following ORP actions are recommended:

1. ORP should pursue separate funding in the near term through the Office of Science and Technology to support a LAW glass development program to increase the Na oxide loading over current WTP contract requirements to take advantage of technical information that indicates 20% Na<sub>2</sub>O at up to 0.8% SO<sub>3</sub> loading is possible. In the longer term, glass formulation and testing should be part of the future WTP Maintenance and Operations (M&O) contract.
2. The LAW melter condensate originating from the Submerged Bed Scrubbers (SBSs) in the LAW Vitrification Facility should be recycled within the WTP Pretreatment Facility, because with improved glass formulations, purging to the ETF or Tank Farms is not needed to achieve 20% Na<sub>2</sub>O waste-loadings in LAW product.
3. The near term LAW immobilization plan should consider transferring to the extent practical pretreated AZ-101 and AZ-102 supernatant to the supplemental treatment technology to improve system performance and reduce life-cycle costs. This is because both the Bulk Vitrification and Steam Reforming technologies have the ability to immobilize these tank waste compositions more efficiently compared to the WTP LAW Vitrification Facility.
4. A strategy for feed selection that exploits the relative capabilities of the WTP and supplemental treatment technologies and preferentially transfers higher sulfate containing feeds to the supplemental technology should be studied further. This strategy, if effectively implemented, can significantly reduce the life-cycle cost of the RPP.

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## 1.0 Introduction

### 1.1 Background

The Waste Treatment and Immobilization Plant (WTP) two-melter Low-Activity Waste (LAW) Facility does not have sufficient waste vitrification capacity to complete the River Protection Project (RPP) LAW treatment mission by the U.S. Department of Energy (DOE) target date of 2028. Accordingly, DOE is investigating opportunities to enhance the production capability of the LAW Vitrification facility and the use of other technologies, (e.g., steam reforming, cast stone and bulk vitrification) to supplement the WTP LAW facility to complete the treatment mission [1]. Prior evaluations [2] have shown that bulk vitrification combined with the WTP LAW facility is a cost-effective approach to treating all LAW waste within the target date.

A summary of the Target and Stretch Cases from the DOE Office of River Protection (ORP) System Plan for treatment and disposal of the LAW in WTP is summarized in the table below. The Target Case demonstrates how ORP will use the WTP to meet the 2018 Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) Milestone M-62-00A for processing 10% of the tank waste mass (6000 MT Na LAW and 600 MT solids for high-level waste [HLW]) and 25% of the radioactivity by 2018, and together with supplemental treatment will complete the processing of tank wastes by 2028 (TPA M-62-00).

The Stretch Case shows ORP's vision of how waste treatment might unfold if sufficient breakthroughs in the performance of the WTP are realized. By identification of those areas where breakthroughs are required, ORP can set performance goals that drive the contractors toward that vision.

Parameter	ORP Target Case System Plan, Revision 2	ORP Stretch Case System Plan, Revision 2
Na to Pretreatment, MT	44,600	39,700
Na for Sludge Leaching, MT	6,100	5,600
Na for Processing, MT	1,800	1,600
Na to LAW Vitrification	19,800 (~40%)	31,100 (~60%)
LAW Waste Loading, %Na20	14%	20%
LAW Vitrification Treatment Capacity, MTG/d (net annual average)	28.8	34
Na directly to Supplemental Treatment, MT	3,100	8,000
Na from Pretreatment to Supplemental Treatment, MT (without pretreatment)	31,000	14,000
Total Na to Supplemental Treatment, MT	34,100	22,000
Waste Treatment Period	2011-2028	2011-2028
Operating Time, years	18	18

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The principal factor that governs the waste-loading (in terms of wt% Na<sub>2</sub>O) in WTP LAW glass is the relative concentration of sodium oxide (Na<sub>2</sub>O) and sulfate (as SO<sub>3</sub>) in the LAW glass formulation. In general, the sodium oxide concentration is limited by sulfate concentration in the waste; that is, wastes that have a higher sulfate concentration have a lower sodium oxide concentration. When specific concentration values are exceeded, sodium sulfate salts may form on the surface of the glass melt in the LAW melter. These salt layers may increase melter component (refractory and metallic component) corrosion rates, make melter operations unstable and reduce the LAW glass durability by the presence of secondary and less durable glass phases. In the current Bechtel National, Inc. (BNI) design process, the LAW melter glass formulations are defined using a conservative glass formulation basis to minimize these impacts. Current glass formulations are based on WTP LAW pilot melter testing and work at the Vitreous State Laboratory (VSL). These glass formulations are targeted to meet WTP contract requirements (e.g, Envelope A LAW-14 wt% Na<sub>2</sub>O, Envelope B LAW-5 wt% Na<sub>2</sub>O and Envelope C LAW-10 wt% Na<sub>2</sub>O). There is no clear performance incentive in the WTP contract for BNI to prepare glasses that have higher waste-loadings.

There is, however, a body of prior DOE work, and laboratory-scale testing at VSL that is relevant to achieving increased Na waste-loading in the LAW glass compared to the WTP contract limits and the current BNI planning basis (see Appendix A and B for further discussion.) This work is of interest because increased Na<sub>2</sub>O loading in LAW glass can be achieved with acceptable melter lifetime and glass waste-form durability. In addition, the higher permissible waste-loading will reduce the glass volume that must be produced, thereby increasing the efficiency of WTP melter operations and shortening the time required to complete the RPP Mission. In this regard, ORP has set Target and Stretch goals for achieving an average minimum of 14 wt% (Target) to 20 wt% (Stretch) loading in WTP LAW glass.

As part of the decision to reduce the number of LAW melters from 3 to 2, ORP committed to treating a percentage of the LAW by supplemental processes other than in the WTP LAW facility. The ORP Target and Stretch goals would treat between 40% (Target) and 60% (Stretch) of the LAW in the WTP LAW facility.

This evaluation:

- Examines the effect of applying different correlations (models) of permissible glass sulfate concentration versus soda (Na<sub>2</sub>O) concentration on the ability to achieve 20 weight % sodium oxide loading in WTP LAW;
- evaluates the trade off between increased sodium oxide concentration and melter lifetime on the time required to complete mission treatment requirements; and
- establishes and investigates feed strategies for WTP LAW and for supplemental treatment to maximize glass waste-loading and minimize mission completion time.

## 1.2 Objectives

The objectives of this evaluation are to:

- Assess the feasibility to achieve 20wt% Na<sub>2</sub>O waste-loading in the WTP LAW glass product and complete greater than 60% of the LAW treatment mission by the WTP. (This requires an identification and evaluation of the methods to achieve a 20% Na<sub>2</sub>O waste-loading in the WTP LAW product, including: Glass Development, LAW SBS Recycle Management, and Feed Staging Decisions.)
- Identify near term actions, if any, to improve system performance. Identify longer term mission level changes, if any, to improve system performance.
- Determine if early completion of the LAW mission is possible
- Establish criteria to identify which tank wastes should be targeted for WTP versus supplemental treatment

## 1.3 Methodology

The following methodology was used to complete this evaluation:

- Identification of LAW Glass Capability: Identify and assess the capability of LAW glasses to incorporate sodium oxide and sulfate into the LAW glass product. Specify a LAW glass-loading model to support subsequent analysis.
- Determine Glass Production Requirements for Specific Glass Compositions: Using the Glass Models, evaluate the tank waste compositions on a tank-by-tank basis to estimate:
  - The ratio of sulfate to sodium oxide concentration in the tank wastes as a function of the cumulative LAW waste to be processed
  - The percentage of the tank wastes that can be processed in WTP at a minimum of 20 wt % and 14 wt% sodium oxide for the identified glass models
  - The effect of LAW SBS condensate recycle, or purge, on the sodium oxide waste-loading in the LAW glass.
- Assess Current Tank Waste Feed Staging Plan: Evaluate the current feed staging logic, (e.g., selection of WTP or supplemental treatment) to determine the following:
  - Strategy to increase the average sodium oxide-loading in the LAW glass.
  - Opportunities to reduce the treatment schedule for mission completion.

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## 2.0 Summary of Conclusions and Recommendations

### 2.1 Conclusions

The following conclusions have been made based upon this evaluation.

1. A technical basis exists for achieving the ORP Stretch Goal of 20 wt% sodium oxide ( $\text{Na}_2\text{O}$ ) loading in WTP LAW glass. The existing work in this area is applicable to the WTP LAW and is projected to exhibit acceptable performance at this waste-loading. The DOE glass model developed from this data results in higher acceptable sulfate and sodium oxide loadings in the glass compared to the Gimpel and VSL Models used by the WTP contractor to project LAW glass capability. These latter models, which are used by BNI in the design of the LAW facility are conservative, and consistent with contract requirements, but result in much lower glass sodium oxide loadings. Adherence to these waste-loading levels throughout the mission would reduce the effective production capacity of the LAW vitrification facility adding to life-cycle waste treatment costs and increasing the risk of not completing the mission on an accelerated schedule.
2. The  $\text{Na}_2\text{O}$  loading in WTP LAW glass can be increased from the estimated 14 wt% to ~17 wt% by the appropriate selection of waste feeds to be immobilized in the WTP versus supplemental treatment. Additional improvement in the LAW glass-loading to 20 wt%  $\text{Na}_2\text{O}$  will require additional glass testing and development to validate preliminary studies that have already been conducted by DOE technology programs.
3. One of the factors in limiting sulfate concentration in LAW glass is to minimize the sulfate corrosion of melter components (principally the melter bubblers glass contact refractory), thereby increasing melter life. However, the evaluation performed in this study shows that the decrease in plant availability due to the increased downtime required to replace a melter more frequently (3-year melter life as compared to 5-year melter life) that fails earlier is more than offset by the reduction in the amount of glass that would be produced at the higher waste-loadings.
4. The amount of high sulfate waste that has to be processed through WTP LAW can be significantly reduced by directing that waste to supplemental treatment. The majority of the high sulfate tank wastes contain low levels of radioactivity and require minimal pretreatment ( e.g., filtering of solids) to meet the Nuclear Regulatory Commission's (NRC) Class C LAW limits as defined by 10 CFR 61. The waste from these tanks could, therefore, be sent directly to supplemental treatment for treatment and immobilization. These tanks contain approximately 33% of the total tank waste Na and are relatively evenly distributed in the current schedule for tank retrieval; facilitating parallel operation of WTP LAW and the supplemental treatment technology.

5. There is a small fraction of waste (~14%) that has high sulfate and high activity levels. If treated by WTP, the resulting glass-loading would be less than 20 wt% Na<sub>2</sub>O even using the DOE Glass model. This waste can be sent to supplemental treatment from the WTP Pretreatment facility and immobilized at ~20 wt%.
6. A feed strategy that directs to supplemental treatment all low-level waste and low-curie LAW (directly if possible without pretreatment) and any LAW that cannot be immobilized at a waste-loading of 20 wt% Na<sub>2</sub>O in WTP results in 53% of the waste being treated by WTP LAW in a period of 15 to 18 years, depending on the annual average glass production rate assumed for that facility. Further reductions in completion period to less than 12 years may be possible by limiting the amount of Na treated in WTP to 40% of the total, as defined in the DOE Target case. These outcomes are consistent with the ORP Target and Stretch case goals and meet the accelerated schedule for completion on or before 2028. This strategy assumes that the DOE Model is used for glass formulations in WTP. This strategy also requires commissioning of the supplemental treatment facility by 2011 at sufficient capacity.
7. Using this feed strategy in the initial phase of treatment from 2011-2018 results in processing an additional 4,300 to 6,800 MT Na. This is equivalent to 3 to 5 additional DST volumes created, which can greatly improve the potential to meet SST retrieval milestones, and reduce the current concerns raised by the Tank Farm contractor on meeting the Tri-Party Agreement milestone for tank retrieval.
8. The amount of sulfate that has to be managed in WTP LAW depends on whether the condensate from the LAW melter off-gas SBS is recycled to pretreatment or purged from the plant and treated elsewhere. Based upon the results of this evaluation, there does not appear to be an overall life-cycle benefit to the RPP for the purging of LAW melter condensate to either the Tank Farms or ETF. If the majority of the high sulfate tank waste is treated in supplemental treatment and the DOE glass model is applied, then the Na<sub>2</sub>O glass-loading in WTP is not significantly changed whether the SBS condensate is recycled or not. Purging of the SBS condensate to other facilities would: 1) impact the waste retrieval and tank closure program in the near term, and 2) require upgrades or additions to the Tank Farms or ETF at significant costs to DOE. In addition, the SBS condensate will contain Tc-99. The disposal of this radionuclide through the ETF would unfavorably impact the LAW wastes form disposal assessments.

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## 2.2 Recommendations

### Recommendation #1

ORP should pursue separate funding in the near term through the Office of Science and Technology to support a LAW glass development program to increase the Na oxide loading over current contract requirements to take advantage of technical information that indicates 20% Na<sub>2</sub>O at up to 0.8% SO<sub>3</sub> loading is possible. In the longer term glass formulation and testing should be part of the future WTP M&O contract.

#### **Benefit:**

This action will allow DOE to substantially reduce life-cycle costs by:

- Reducing the amount of glass produced in WTP;
- Processing waste at a faster rate in WTP by more effective waste incorporation; thus
- Resulting in a shorter time period required to complete the RPP mission.

### Recommendation #2

The SBS condensate from the LAW Vitrification facility should be managed within WTP because with improved glass formulations, purging to the ETF or Tank Farms is not needed to achieve 20% Na<sub>2</sub>O waste-loadings in LAW product.

**Benefit:** This action will prevent impacts to other parts of the RPP system and help to reduce Life-Cycle Costs. Other considerations in this assessment include:

- WTP is designed to manage the LAW SBS recycle stream.
- This allows ORP to shut down the 242A Evaporator in 2018 as planned. This could not be done, or another new evaporator would be required, if the Tank Farm is to be the purge point for LAW SBS condensate.
- This avoids the complication with DST space management and the retrieval program. Conflicts with near term retrieval and tank closure milestones will also be avoided for the case in which the Tank Farm is the purge point for the LAW SBS condensate.
- This recommendation avoids the need for significant upgrades (and cost) to the ETF to handle solids and Tc-99 from the LAW SBS condensate in cases where the ETF is the purge point.

### Recommendation #3

The near term feed immobilization plan should consider transferring, to the extent practical, pretreated AZ-101 and AZ-102 supernatant to the supplemental treatment technology to improve system performance and reduce life-cycle costs

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**Benefit:** This action allows ORP to:

- Treat a greater quantity of waste because the supplemental treatment technology has a greater waste-loading capability for the chemistry of AZ-101 and AZ-102 compared to the WTP LAW glass, even with improved glass formulations;
- Provide additional DST space (~3 to 5 tanks equivalent) in the 2011 to 2018 time frame because waste is treated faster and improves availability of tank space to support retrieval; and
- Results in greater quantity of Na immobilized (>40% or 4,300 to 6,800 MT Na) in the early treatment phase.

#### **Recommendation #4**

A strategy similar to that discussed in this report should be developed for selection of whether a specific tank waste needs to be pretreated, and whether it should be treated by WTP or supplemental treatment. This strategy would consider, for example:

- The tank waste classification, e.g., LLW or HLW;
- The level of activity in the tank, and whether the tank has already been treated to remove critical nuclides and the waste could meet LAW 10 CFR 61 Class C limits for near surface burial with solids removal by filtering alone; and
- The sulfate level in the waste, and the ability to achieve 20 wt% Na<sub>2</sub>O loading in WTP.

**Benefit:** The analyses in this report show:

- A large fraction of the waste could be sent to supplemental treatment without passing through WTP pretreatment if solids are removed by filtration. This reduces the load on pretreatment and also reduces the total amount of waste Na treated since the amount added in pretreatment would be eliminated.
- All the waste sent to WTP could be treated at 20 wt% Na<sub>2</sub>O.
- The mission could be completed three to seven years sooner than the current Target and Stretch goals define, reducing mission life-cycle costs.

### 3.0 Low-Activity Waste Glass-Loading Models and Tank Waste Chemistry

This section summarizes the LAW glass models that were considered as technical bases for this assessment. A detailed discussion of the LAW glass models is presented in Appendix A. This section also summarizes the effect of the variations in the waste chemistry between tanks on the glass Na<sub>2</sub>O loading for each glass model. As shown below, it is the relative concentrations of Na and sulfate in the tank waste that establish permissible Na<sub>2</sub>O loading in the glass.

#### 3.1 LAW Glass-Loading Models

Four glass models are identified and used as a basis for analysis in this assessment. Each of these models establishes a different relationship between the amounts of Na that can be incorporated into the glass waste form as a function of the sulfate concentration in the glass. It is believed that all of these glass models produce glass forms that are acceptable with respect to the current performance assessment for WTP LAW and obtain acceptable melter corrosion rates. A summary of actual glass performance, including their relative Na and sulfate concentration and durability as measured by the Product Consistent Test (PCT) and Vapor Hydration Test (VHT), is summarized in Appendix B.

Figure 1 shows the relationship between sodium oxide (Na<sub>2</sub>O) in the glass and the sulfur trioxide (SO<sub>3</sub>) in the WTP LAW glass for the models considered in this study. The technical bases for the models and their derivations are summarized in Appendix A and Appendix B. Referring to Figure 1:

- The **Gimpel Model** is a mathematical correlation based upon glass testing completed by VSL. This model is used by BNI in the WTP design and modeling processes to estimate glass-loadings and production rates.
- The **“Rule of 5”** is an anecdotal model that has been used to project waste-loading. It is not used in the current design process. However, this model has been used in the past to project glass volumes to be produced by the WTP LAW vitrification facility based upon specific tank waste chemistries.
- The **VSL Model** is an empirical model based on LAW Pilot Melter runs designed to meet WTP contract requirements, (e.g., Envelope A = 14 wt%, Envelope B = 5 wt% and Envelope C = 3 wt%) and thus is conservative relative to the true capability of the glass waste form. This model was derived from an examination of the experimental data developed by the WTP LAW Vitrification Research and Technology Program.
- The **DOE Model** is a correlation based upon glass testing for the WTP, Idaho Sodium Bearing Wastes (SBW) and laboratory-scale testing using the Sodium Boro-Silicate (SBS) formulation approach to Hanford waste chemistry.



As shown in the figure, the DOE Model provides a much higher sodium oxide waste-loading estimate than the other models for sulfate concentrations greater than ~0.25 %. Thus, if the assumptions for the DOE glass model hold true, there is a significant potential to increase the overall waste-loading in WTP LAW glass.

The following analyses examine the improvement in glass sodium oxide waste-loading and the resultant reduction in total glass production that could be realized by applying the DOE Model compared with the Gimpel and VSL Models.

### 3.2 Sulfate Concentrations in Hanford Waste

Figure 2 summarizes the sulfate concentrations in the tank waste at Hanford; presenting the sulfate to sodium ( $\text{SO}_4/\text{Na}$ ) ratio for each tank in ascending order as a function of the cumulative mass of sodium requiring treatment.[4] This figure illustrates the effect of limiting the sulfate concentration on the glass Na waste-loading and the differences in the results for the Gimpel and DOE Models. Using the Gimpel Model, about 7% of the waste can be incorporated into the glass at 20 wt%  $\text{Na}_2\text{O}$  because that model limits the sulfate concentration at 20 wt%  $\text{Na}_2\text{O}$  to 0.25 wt%  $\text{SO}_3$  (equivalent to a feed  $\text{SO}_4/\text{Na}$  ratio of 0.02). For the DOE Model, a little more than 60% of the waste can be incorporated into the glass at 20 wt%  $\text{Na}_2\text{O}$  because that model permits the  $\text{Na}_2\text{O}$  loading up to a sulfate concentration of 0.8 wt% in the glass (equivalent to a feed  $\text{SO}_4/\text{Na}$  ratio of 0.065).

*(Note: In the following analyses the cumulative amount of Na treated includes the Na in the tanks plus the amount added in WTP pretreatment.)*

### 3.3 Submerged Bed Scrubber (SBS) Condensate Recycle or Purge

The correlations shown in Figure 1 establish a permissible  $\text{Na}_2\text{O}$  loading for the residual sulfate concentration in the glass. During the glass melting process, a certain percentage of the sulfate entering the melter is either evolved as  $\text{SO}_x$  ( $\text{SO}_2 + \text{SO}_3$ ) or entrained and leaves the melter in the off-gas. This sulfate stream is collected as a constituent in the SBS condensate. Figure 3 shows the relationship between the amounts of sulfate that are retained in the glass as a function of the concentration of the sulfate in the entering waste stream [5]. For this analysis it is assumed that at target  $\text{SO}_3$  concentrations above 0.8%, the residual percentage does not drop below the value for a 0.8% target concentration; (i.e., 68.9%). The target concentration is defined as the concentration of  $\text{SO}_3$  in the glass if none of the feed sulfate is evaporated, but is fully incorporated in the glass.

The current plant design assumes that the SBS condensate is recycled and eventually is processed in the LAW glass. The WTP project has been considering purging the SBS condensate from the cycle to be treated elsewhere in the Hanford complex. In the following

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analyses, the effect of recycling or purging the SBS condensate on LAW glass waste-loading is examined.

Comparisons of the tank waste that can be processed at 20wt% Na<sub>2</sub>O shown in Figure 2 are based on the recycle condition, (e.g., the entire tank sulfate fed to WTP LAW is eventually incorporated in the glass). Comparing Figures 1 and 3, it is noted that for the Gimpel Model there is 100% sulfate retention at 20wt% Na<sub>2</sub>O (SO<sub>3</sub> at 0.25%). Accordingly, recycling or purging of SBS condensate has no effect on the results at this Na<sub>2</sub>O loading for that model. There is, however, an effect when applying the DOE Model or at 14wt% Na<sub>2</sub>O. This effect is explored in further analysis below.

#### **4.0 WTP LAW Glass Waste-Loadings**

##### **4.1 Impact of the Sulfate Model and SBS Condensate Recycle or Purge**

Figures 4 and 5 compare the percent of Na present in the Hanford tanks that can be treated at a minimum of 20 wt % Na<sub>2</sub>O and 14 wt % Na<sub>2</sub>O for the three different models. The figures also show the effect of recycling or purging the SBS condensate. Based on these figures:

- Glass formulations using the DOE Model are required to approach the ORP Stretch goal of treating 60% of the tank waste Na at a minimum 20 wt % soda glass-loading. The Gimpel and VSL Models would permit 20 wt% Na<sub>2</sub>O loading in only 6.5% and 18% of the waste, respectively.
- Purging of the SBS condensate from the stream is not required to meet the target goal of 60% of the total Na treated at 20 wt% when applying the DOE Model. This is the only model that is significantly affected by recycling or purging SBS condensate.
- Significantly higher percentages of the waste can be processed at a minimum of 14 wt% Na<sub>2</sub>O glass-loading using all three models. The Gimpel and VSL Models show that greater than 50% of the waste can be processed at an average Na<sub>2</sub>O loading of about 17 wt%. Using the DOE Model with SBS condensate recycled, over 90% of the waste can be processed at an average Na<sub>2</sub>O loading of 19.5 wt%. Accordingly, all three models produce results that satisfy the ORP Target objective of treating 40% of the LAW waste at a minimum of 14 wt% Na<sub>2</sub>O.

These available processing percentages must be resolved, however, against the glass production rate of the WTP facility and the total time available to process glass in the accelerated schedule to complete by 2028. This and other factors affecting glass waste-loading and schedule are addressed below.

## 4.2 Impact of Glass Production Rate

Figure 6 compares the percent of total tank waste Na treated in 18 years of production for the ORP Target case and Stretch case WTP LAW facility annual average glass production rates of 28.8 and 34.0 MTG/day, respectively. These figures assume the tanks are treated in increasing levels of sulfate and are, therefore, idealized. This figure shows that only if the higher production rate is maintained, and the DOE Model is applied, can the goal of treating 60% of the total tank waste be approached and complete the mission by 2028. About 50% of the Na can be treated at the lower rate if the Gimpel or VSL Model is applied. Only the DOE Model meets the 20 wt% Na<sub>2</sub>O loading target. The other models achieve about 17 wt% loadings on average.

Comparing Figures 5 and 6 shows that the annual average production rate for the LAW facility is a constraint on the percentage of the waste that can be treated at 20 wt% Na<sub>2</sub>O when applying the DOE sulfate model. It is not a constraint on processing at a minimum of 14 wt% Na<sub>2</sub>O when applying the Gimpel and VSL Models.

Figure 7 shows the separate and combined effects of the glass model assumption, feed selection and glass production rate on the amount of Na that can be treated in the WTP LAW Vitrification facility. This figure illustrates that the increase in Na<sub>2</sub>O loading in the glass and increased LAW glass production rate have comparable impacts on the overall amount of Na that can be treated in the 18 years of the accelerated schedule. The feed selection strategy used to develop this figure is discussed below.

## 5.0 Effect of Melter Replacement on Life-Cycle Treatment Rate

Figure 8 compares the total amount of waste treated over the mission for different LAW facility peak productions rates, glass Na<sub>2</sub>O loading and melter replacement frequency. In all the cases shown, it is assumed that when the melters need replacement, the plant is shutdown for six months to replace both melters, but that the facility has 100% availability at the peak production rate when the melters are operating. The "Contract case", (i.e., 14 wt% Na<sub>2</sub>O and 30 MTG/day peak facility production rate), is shown for comparison with the Target case of 45 MTG/day peak production rate at 14 wt% Na<sub>2</sub>O and 20 wt% Na<sub>2</sub>O. This figure shows that operating with higher Na<sub>2</sub>O loading has more impact on total waste treatment than the frequency at which the melter has to be replaced. For example, if operating at 20 wt% Na<sub>2</sub>O instead of 14 wt% Na<sub>2</sub>O decreases melter life from 5 years to 3 years, the total amount of waste processed over the 19-year period is about 38% higher at the higher loading. Accordingly, melter lifetime should not be the principal factor limiting Na<sub>2</sub>O loading in the glass.

## 6.0 Tanks Containing Low Curie Waste

There are a number of tanks with LAW that may not require WTP pretreatment prior to immobilization and disposal as Class C low-level waste. Prior estimates show that

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approximately 33% (~17,000 MT Na) of the total waste Na to be immobilized falls into this category [6]. A large number of the high sulfate tanks also fall into this category (e.g., the B Farm tanks). Figure 9 compares the sulfate to sodium ratio for the tanks that would remain after removal of these tanks from the inventory with that ratio for all tanks. It is possible that the waste from these tanks could be sent directly to the supplemental treatment facility for immobilization. This has several advantages:

- The pretreatment production capacity is reduced.
- The Na added in pretreatment that must be immobilized (~8% of the entering Na) is reduced the total amount of Na that must be treated.
- Supplemental treatment can be operated in parallel with pretreatment and WTP LAW reduced and therefore reducing the total time required to treat all waste.
- A large fraction of the high sulfate waste is sent to supplemental treatment (1) reducing the potential for accelerated LAW melter corrosion and (2) increasing the average Na<sub>2</sub>O loading in the LAW glass

A small number of these tanks contain low-level waste that can be treated with no pretreatment. There are 6 tanks totaling 104 MT Na that fall into this category.

There are 35 tanks potentially containing waste compositions that have already had some treatment. Accordingly, sending the waste from these tanks through WTP pretreatment would constitute a second treatment and may not provide any appreciable environmental benefit. Appendix D summarizes the relevant nuclide concentrations of these tanks LLW and Low-Curie LAW (LCLAW) tanks) and the as-found classification of the wastes in accordance with 10 CFR 61. As shown, the tanks will require some filtering to remove solids, principally transuranic (TRU) and <sup>90</sup>Sr to meet Class C limits for near-surface burial. The tables show that a filter with DF as low as 10 would obtain Class C limits in 98% of the waste in these tanks. These tables in Appendix D also show that the <sup>137</sup>Cs and possibly the <sup>99</sup>Tc concentrations may be high enough to require engineered shielding in the supplemental treatment facility. It is recommended that cost benefit and “As Low as Reasonably Achievable” (ALARA) analyses be completed to determine which tank wastes should be treated in WTP versus direct treatment in supplemental treatment.

## **7.0 Criteria for Selection of whether a specific tank waste is treated in WTP or Supplemental Treatment**

The results of the preceding evaluations suggest applying the following criteria for selecting whether a specific tank waste should be treated in WTP or in supplemental treatment to support ORP's goals in treating LAW. See Figure 10.

- Waste should be treated in WTP if the sulfate concentration permits a 20 wt% or higher soda concentration.
- Waste should be treated in supplemental treatment: (1) if the waste does not require full WTP pretreatment, (i.e., LLW or LCLAW); or (2) the sulfate concentration restricts soda concentration to less than 20 wt% in WTP glass.

In both cases, the DOE glass model should be applied to establish the acceptable soda concentration in the WTP glass.

Application of this selection logic will: (1) achieve the ORP Target goal of a minimum 20 wt% Na<sub>2</sub>O loading in all WTP glass; and (2) complete all LAW waste treatment on or before 2028 at achievable WTP LAW glass production rates comparable to the ORP Target and Stretch rates. The following analyses support this conclusion.

## **8.0 Assessment of Tank Wastes and Treatment Preference, WTP versus Supplemental Treatment**

The proposed selection logic of Figure 10 was applied to the sequence of tanks used in the October 2002 Hanford Tank Waste Operations Simulator Case 1 study and the Best Basis Inventory 2002 for tank waste composition. This evaluation was performed assuming that the SBS condensate is recycled to pretreatment so all sulfate fed to WTP LAW is ultimately treated in WTP LAW glass. It was also assumed that all tank waste must pass through pretreatment prior to immobilization either in the WTP LAW facility or in supplemental treatment.

### **8.1 Tanks Treated in WTP versus Supplemental Treatment**

Figure 11 shows the destination for each tank over the total mission sequence by applying this logic. Table 1 lists the tanks by destination and type. Even though the sequence has not been optimized for the selection logic, the distribution of destinations is fairly uniform after treatment of the first series of waste in the DSTs. The split between treatment in WTP and supplemental treatment is about equal; 53% is ultimately treated by WTP LAW.

### **8.2 Mission Completion Time versus Selection of Treatment**

Depending on the average annual glass production rate achieved in the WTP LAW facility, the sequence of waste treatment shown in Figure 11 meets or improves the objective of completing the mission in 18 years; 17.8 years at 28.8 MTG/day and 15.0 years at 34.0 MTG/day. The supplemental treatment rate required for these periods ranges from 1,373 MT Na/year

(17.8 years) to 1,622 MT Na/year (15.0 years). These are well within the treatment rates projected for supplemental treatment in prior studies [3].

Future efforts to optimize the selection logic and the sequence of tank retrieval would take into account that some tank waste will not require pretreatment in WTP and could, therefore, potentially bypass transfer to the WTP. As noted on Figure 10, it is recommended that at-tank treatment be considered for those tanks. That approach to supplemental treatment would free up space in the DSTs. It is recommended that additional studies be completed to develop and optimize selection logic and tank retrieval sequence.

Figure 12 compares the results of applying the selection logic using the DOE sulfate model with similar results using the Gimpel Model and the DOE Model for the Stretch Case in which 60% of the waste is treated in WTP. As shown, the total mission time is reduced by about 10 years if the DOE Model and selection logic are applied versus treating 60 percent of the waste in WTP and using the Gimpel Model. The selection logic reduces the mission time by three years if the DOE Model is used in treating 60 percent of the waste in WTP. The advantage of the selection logic applied with the DOE sulfate model is that all the waste is treated at 20 percent Na<sub>2</sub>O loading and supplemental treatment and WTP are operated in parallel. The time is reduced for this case because only 53 percent of the waste is treated in WTP LAW at 34 MTG/day. The rest is treated by supplemental treatment at 1,635 MT Na/year. Based on prior analyses, only two lines of bulk vitrification would be required to support this treatment rate. Figure 13 shows the treatment by tank and treatment facility in time for this case. The projected 15-year completion time betters the accelerated schedule by three years.

Figure 4 shows the results of applying the selection logic for the Target Case in which 40 percent of the waste is treated in WTP at an annual average rate of 34.0 MTG/day. The supplemental treatment rate for this case is 2,765 MT Na/year which is equivalent to a three-line bulk vitrification plant. This figure shows that the mission can be completed in 11 years for this case or seven years earlier than required to meet the accelerated schedule.

Figure 15 summarizes the results of all of these cases, illustrating the full potential of developing a more robust LAW glass capability and devising an effective selection logic for specific tank wastes on reducing RPP mission completion time.

### **8.3 Near Term Decisions on Treatment Selection**

Figure 16 compares application of the selection logic and the DOE Model with the results of the Gimpel Model in the first eight years of processing; 2011 through 2018. Current projections using the Gimpel Model show that about 10,000 MT Na can be treated over this eight-year period at an average annual production rate of 28.8 MTG/day and an average glass waste-loading of 15.3 wt% Na<sub>2</sub>O. Applying the DOE Model, the amount of waste processed at this glass

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production rate increases to about 11,500 MT Na and the average glass-loading increases to 18.3 wt% Na<sub>2</sub>O. If the selection logic is applied so that both WTP LAW and supplemental treatment are used over this period, the amount of waste treated increases to approximately 14,000 MT Na and the average waste-loading is 20 wt% Na<sub>2</sub>O.

Assuming that each DST contains about 800 to 1000 MT Na, the increase of 4,000 MT Na treated by using the selection logic when compared with treating all waste in WTP using the Gimpel Model, would clear space in an additional three to five DSTs over this initial processing period. This could address concerns raised recently by the Tank Farm contractor on being able to meet Tri-Party Agreement milestones for tank retrieval.

One of the principal factors that lead to the significant difference in the results for the selection logic versus the Gimpel Model is the treatment of the high sulfate wastes in the AZ-101 and 102 tanks. Using the Gimpel Model, the glass-loading is limited to 5 wt% to 8 wt% Na<sub>2</sub>O for these tanks significantly increasing the amount of glass required to immobilize these wastes and increasing the time for treatment. It is recommended that the near term feed immobilization plan consider transferring, to the extent practical, pretreated AZ-101 and A101-102 supernatant to the supplemental treatment technology to improve system performance and reduce life-cycle costs. This action allows ORP to:

- Treat a greater quantity of waste because the supplemental treatment technology has a greater waste-loading capability for the chemistry of AZ-101 and AZ-102 compared to the WTP LAW glass even with improved glass formulations;
- Provide additional DST space (~three to five tanks equivalent) in the 2012 to 2016 time frame because waste is treated faster and improves availability of tank space to support retrieval; and
- Results in greater quantity of Na immobilized (>40% ) in the early treatment phase

#### **8.4 SBS Condensate Recycle or Purge**

As discussed above, the amount of sulfate that has to be managed in WTP LAW depends on whether the condensate from the LAW melter off-gas SBS is recycled to pretreatment or purged from the plant and treated elsewhere. Based upon the results discussed above, there does not appear to be an overall life-cycle benefit to the RPP for the purging of LAW Melter condensate to either the Tank Farms or ETF. If the majority of the high sulfate tank waste is treated in supplemental treatment and the DOE glass model is applied, the Na<sub>2</sub>O glass-loading in WTP is not changed whether the sulfate is recycled or not. Purging of the condensate to other facilities would require upgrade or additions to these facilities at significant cost to DOE for no benefit to the project. Accordingly, it is recommended that SBS Condensate from the LAW Vitrification facility be managed within WTP because with improved glass formulations, purging to the ETF or Tank Farms is not needed to achieve 20% Na<sub>2</sub>O waste-loadings in LAW product.

## 9.0 References

1. DOE-ORP Commitment to Supplemental Treatment – 2 LAW Melter Facility.
2. ORP-11242, Rev 2.0, “River Protection Project System Plan,” September 2003, Office of River Protection, Richland, Washington.
3. “Assessment of Low Activity Waste (LAW) Treatment and Disposal Scenarios for the River Protection Project (RPP),” April 14, 2003.
4. Best Basis Inventory 2002.
5. 24590-WTP-MCR-PT-02351, Rev. 0, Attachment A1 [Correlation of SO<sub>3</sub> Retention in the glass versus sulfate concentration in the waste].
6. RPP-13678, March 2003, Integrated Mission Acceleration Plan, Office of River Protection, Richland, Washington.
7. HNF-SD-WM-SP-012, Rev. 4A, Tank Farm Contractor Operation and Utilization Plan, October 30, 2002.



**Table 1 Summary of Waste Type by Tank**

TRU <sup>1</sup> Packaging	Supplemental Treatment			WTP LAW	
	LLW	LCLAW <sup>2</sup>	WTP < 20wt% Na <sub>2</sub> O <sup>3</sup>	WTP LAW ≥ 20 wt% Na <sub>2</sub> O <sup>3</sup>	
1,218 MT	104 MT	16,839 MT	7,467 MT	27,880 MT	
AW-103	C-204	B-101	A-101	A-104	SX-102
AW-105	U-201	B-103	A-102	A-106	SX-103
B-201	U-202	B-104	A-103	AN-101	SX-104
B-202	U-203	B-105	A-105	AN-103	SX-105
B-203	U-204	B-106	AN-102	AN-104	SX-106
B-204	T-110(tentative, may be TRU)	B-107	AW-104	AN-105	SX-107
SY-102		B-109	AX-101	AN-106	SX-108
T-111		BX-110	AX-103	AN-107	SX-109
T-201		BX-111	AX-104	AP-101	SX-110
T-202		BY-102	AZ-101	AP-102	SX-111
T-203		BY-103	AZ-102	AP-103	SX-112
T-204		BY-105	B-102	AP-104	SX-113
		BY-108	B-108	AP-105	SX-114
		BY-109	B-110	AP-106	SY-101
		BY-110	B-111	AP-107	SY-103
		BY-111	B-112	AP-108	T-102
		BY-112	BX-101	AW-101	T-103
		S-109	BX-103	AW-102	T-104
		S-110	BX-105	AW-106	T-108
		S-112	BX-107	AX-102	TX-101
		T-109	BX-108	AY-101	TX-104
		TX-103	BX-109	AY-102	TY-101
		TX-105	BX-112	BX-102	TY-104
		TX-106	BY-104	BX-104	U-101
		TX-108	C-101	BX-106	U-102
		TX-110	C-103	BY-101	U-103
		TX-111	C-105	BY-106	U-104
		TX-112	C-107	BY-107	U-106
		TX-113	C-109	C-102	U-107
		TX-114	C-110	C-104	U-108
		TX-115	C-111	C-106	U-109
		TX-116	C-112	C-108	U-110
		TX-117	SX-115	C-201	U-111
		TX-118	T-101	C-202	U-112
		TY-102	T-105	C-203	
			T-106	S-101	
			T-107	S-102	
			T-112	S-103	
			TX-102	S-104	
			TX-107	S-105	
			TX-109	S-106	
			TY-103	S-107	
			TY-105	S-108	
			TY-106	S-111	
			U-105	SX-101	

<sup>1</sup> TRU tanks are not included in the Total Waste Na to be treated

<sup>2</sup> Low Curie Low Activity Waste tanks that may be able to go directly to Supplemental Treatment without pretreatment

<sup>3</sup> It is assumed that SBS Condensate will be recycled to pretreatment

## 10.0 Figures

1. WTP LAW Glass Models
2. SO<sub>4</sub>/Na in Ascending Order by Tank and Accumulated Waste Na
3. Retention of SO<sub>3</sub> in the LAW Glass
4. Percent of Na Treatable at 20% Na<sub>2</sub>O Waste Loading versus Glass Sulfate Model (with and without recycle of LAW Condensate within WTP)
5. Percent of Na Treatable at 14% Na<sub>2</sub>O Waste Loading versus Glass Sulfate Model (with and without recycle of LAW Condensate within WTP)
6. Comparison of Percent of Total Na Treated in 18 years of production (2011-2018) at Base and Target Production Rates using Different Glass Sulfate Models
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9. Comparison of SO<sub>4</sub>/Na with and without the Tanks that may not require Pretreatment
10. Logic for Selection of LAW Treatment Process
11. Example Application of Selection Logic for Treatment Destination
12. Effect of Sulfate Model and Application of Selection Logic on Mission Completion Time
13. Example of Application of Selection Logic for Treatment Destination (Target Production Rate of 34.0 MTG/day)
14. Example Application of Selection Logic for Treatment Destination, Base Case – 39% Total Na Treated in WTP, 28.8 MTG/day in WTP LAW
15. Potential Optimization of RPP Mission Completion
16. Comparison of the Amount of Waste Processed in the Period 2011-2018 for the Different Sulfate Models and Application of the Selection

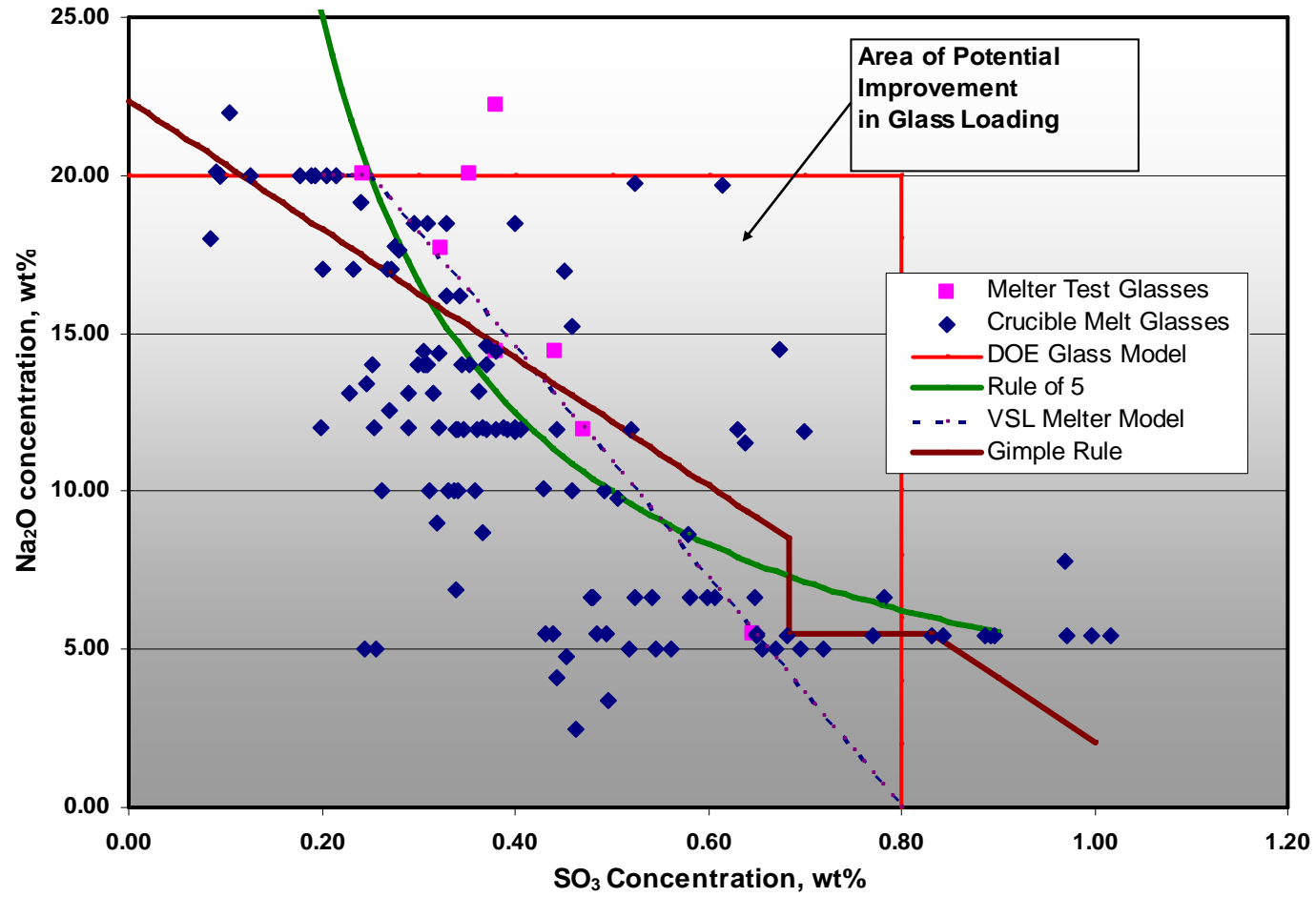
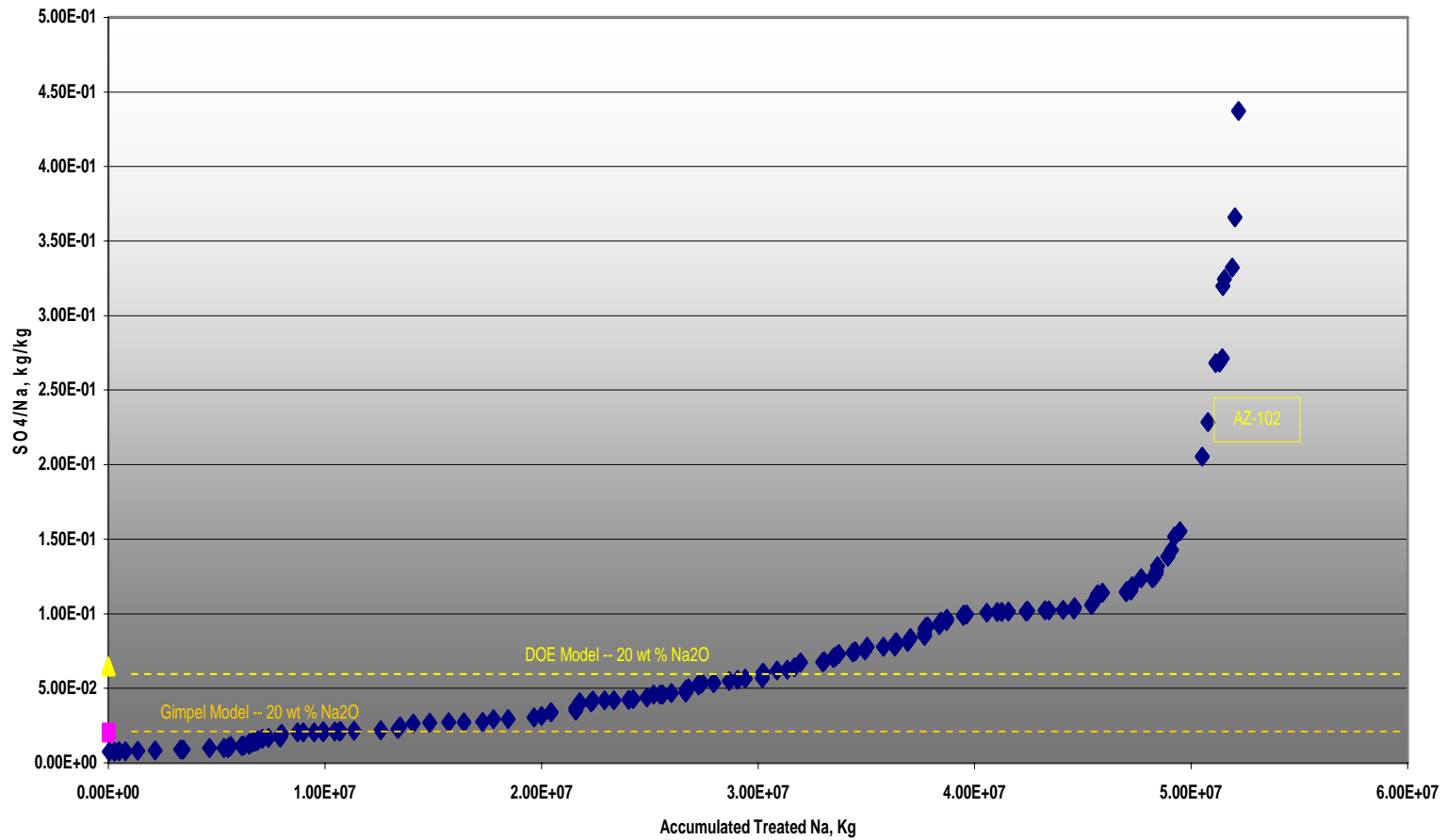
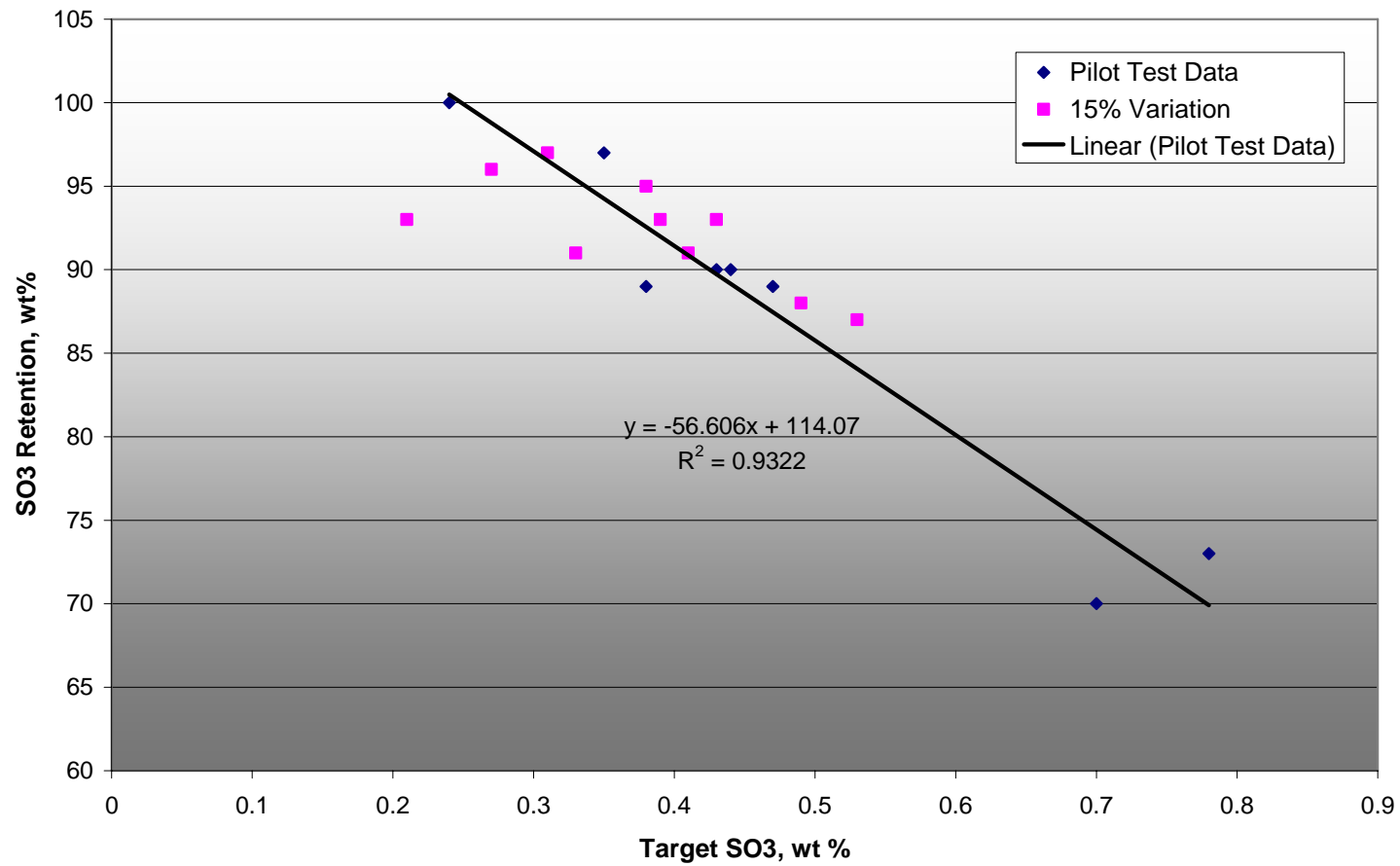


Figure 1 WTP LAW Glass Models

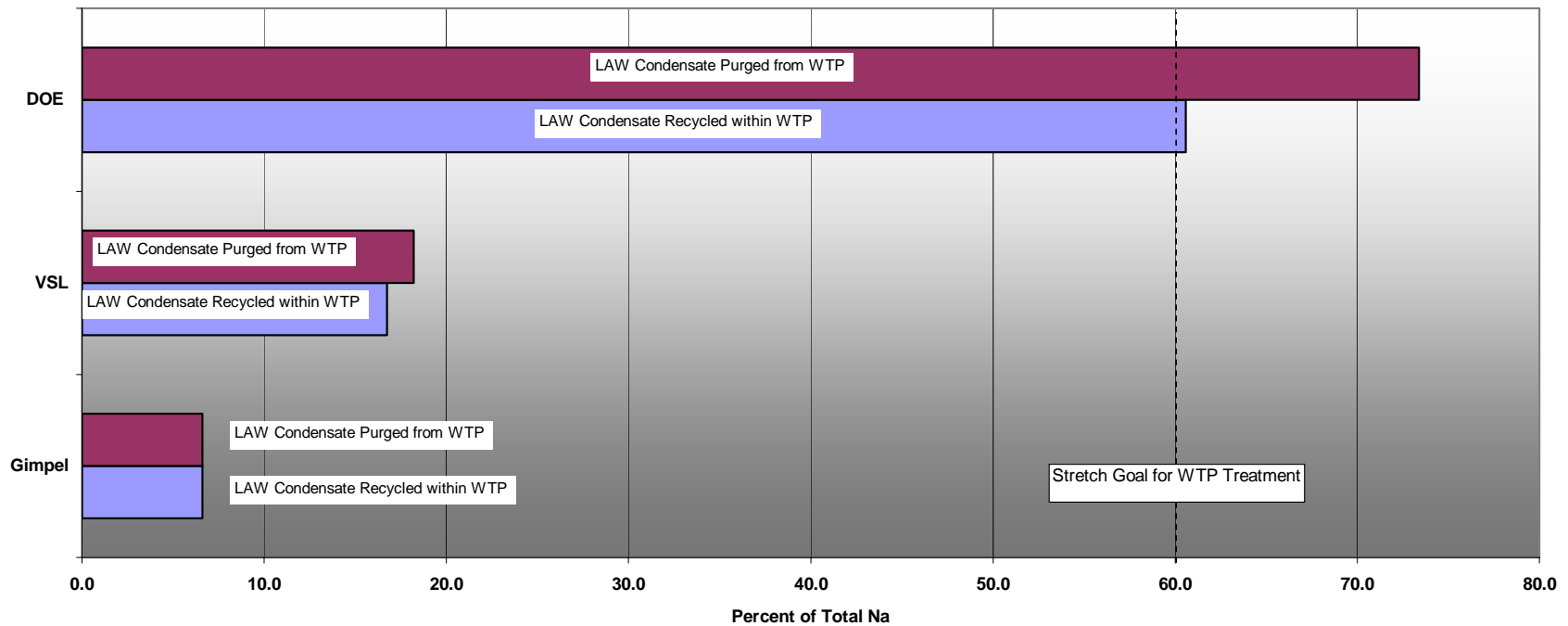


**Figure 2**  $SO_4/Na$  in Ascending Order by Tank and Accumulated Waste Na



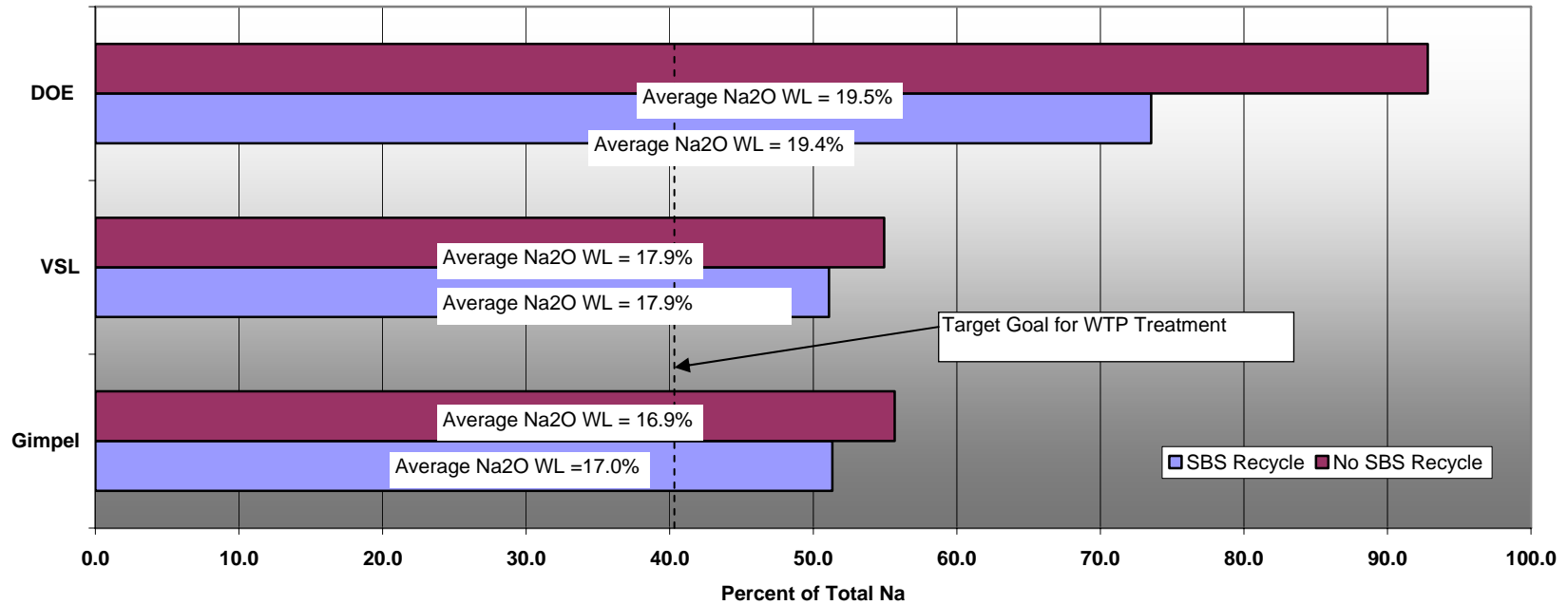
- Retention of SO3 in the Glass decreases in proportion to the concentration of SO3 in the LAW Feed

**Figure 3 Retention of SO<sub>3</sub> in the LAW Glass**



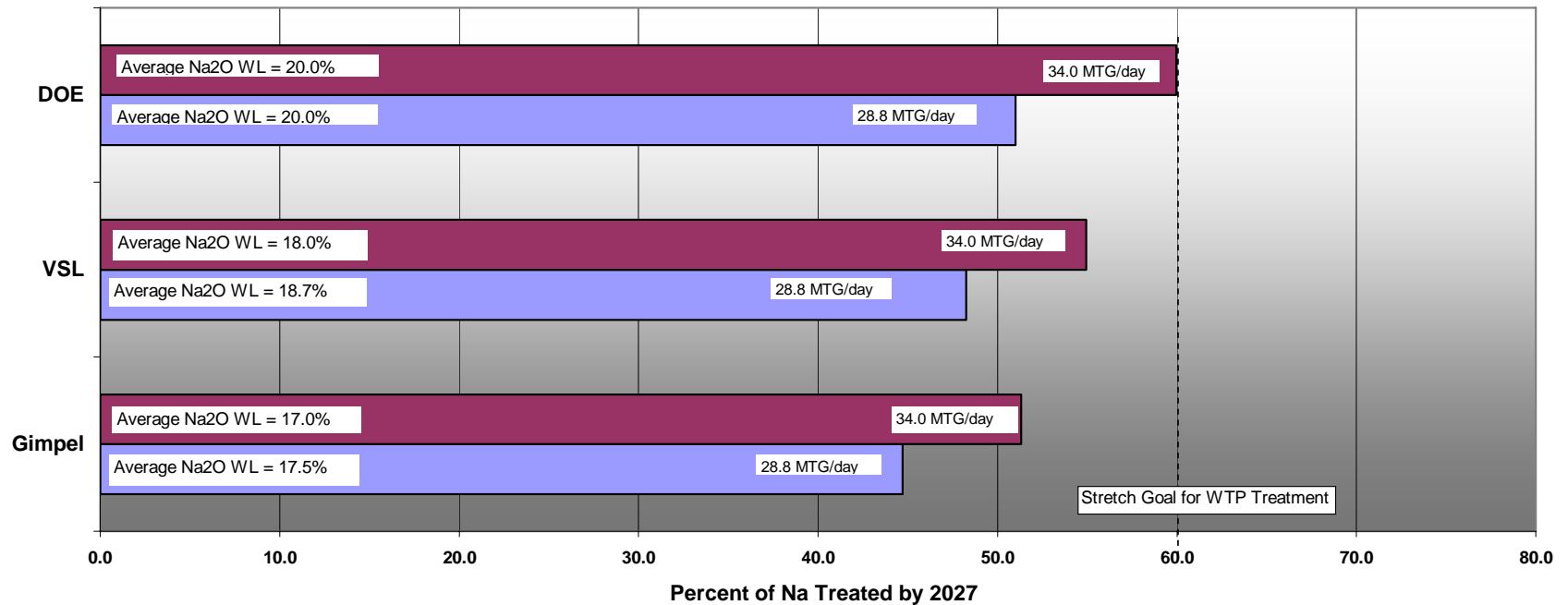
- Target goal of treating 60% of total Na in WTP at 20 wt% glass can only be met with DOE Model
- Purging of LAW Condensate containing sulfate increases amount of Na that can be immobilized at 20 wt% Na<sub>2</sub>O for DOE glass model only

**Figure 4** Percent of Na Treatable at 20% Na<sub>2</sub>O Waste Loading versus Glass Sulfate Model (with and without recycle of LAW Condensate within WTP)



- Target (Base) goal of treating 40% of Na in WTP at a minimum of 14 wt% Na<sub>2</sub>O can be met with all three models
- Purging of LAW Condensate containing sulfate increases amount of Na that can be immobilized at 14 wt% Na<sub>2</sub>O. Improvement is greatest for DOE glass model.

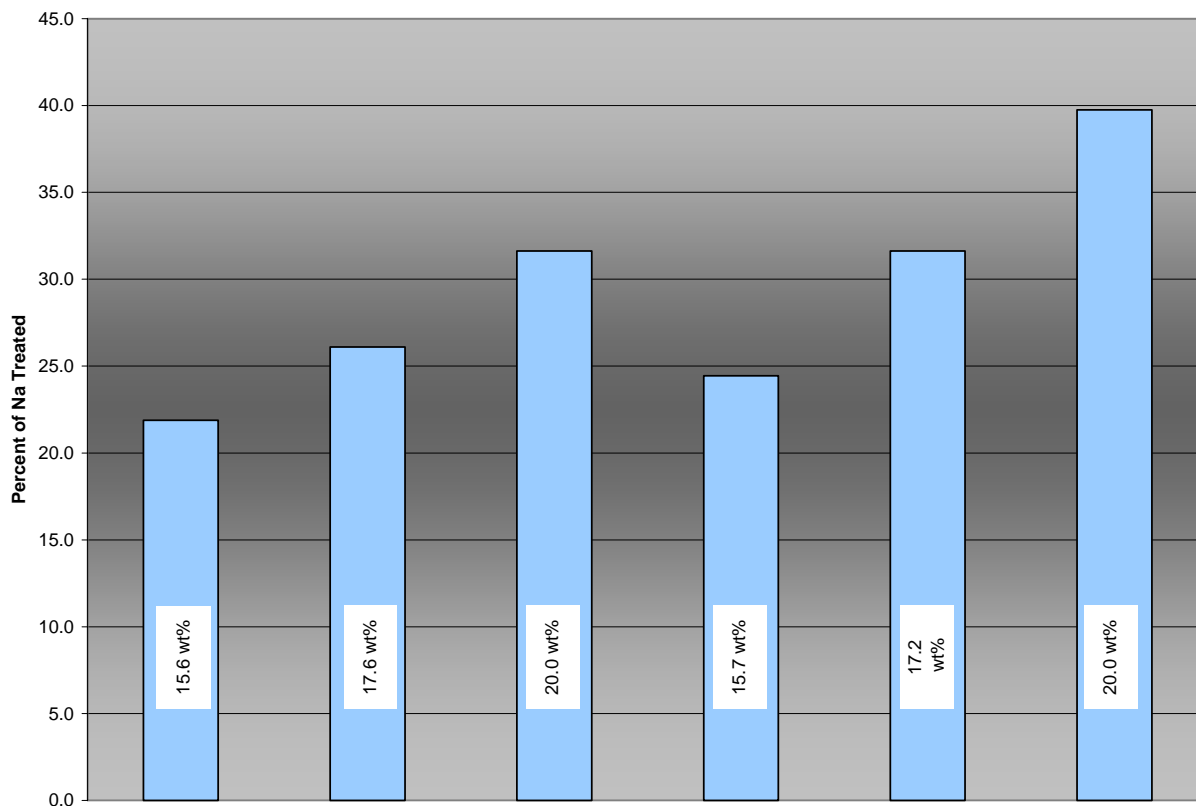
**Figure 5 Percent of Na Treatable at 14% Na<sub>2</sub>O Waste Loading versus Glass Sulfate Model (with and without recycle of LAW Condensate within WTP)**



- The Target goal of treating 60% of the total Na at 20 wt% Na<sub>2</sub>O by 2028 can be approached only for the DOE Model and for a WTP LAW facility annual average production rate of 34.0 MTG/day
- The increase from Base to Target LAW glass production rate has a slightly greater impact to overall amount of Na treated compared to improvement in waste-loading

**Figure 6 Comparison of Percent of Total Na Treated in 18 years of production (2011-2018) at Target and Stretch Production Rates using Different Glass Sulfate Models**

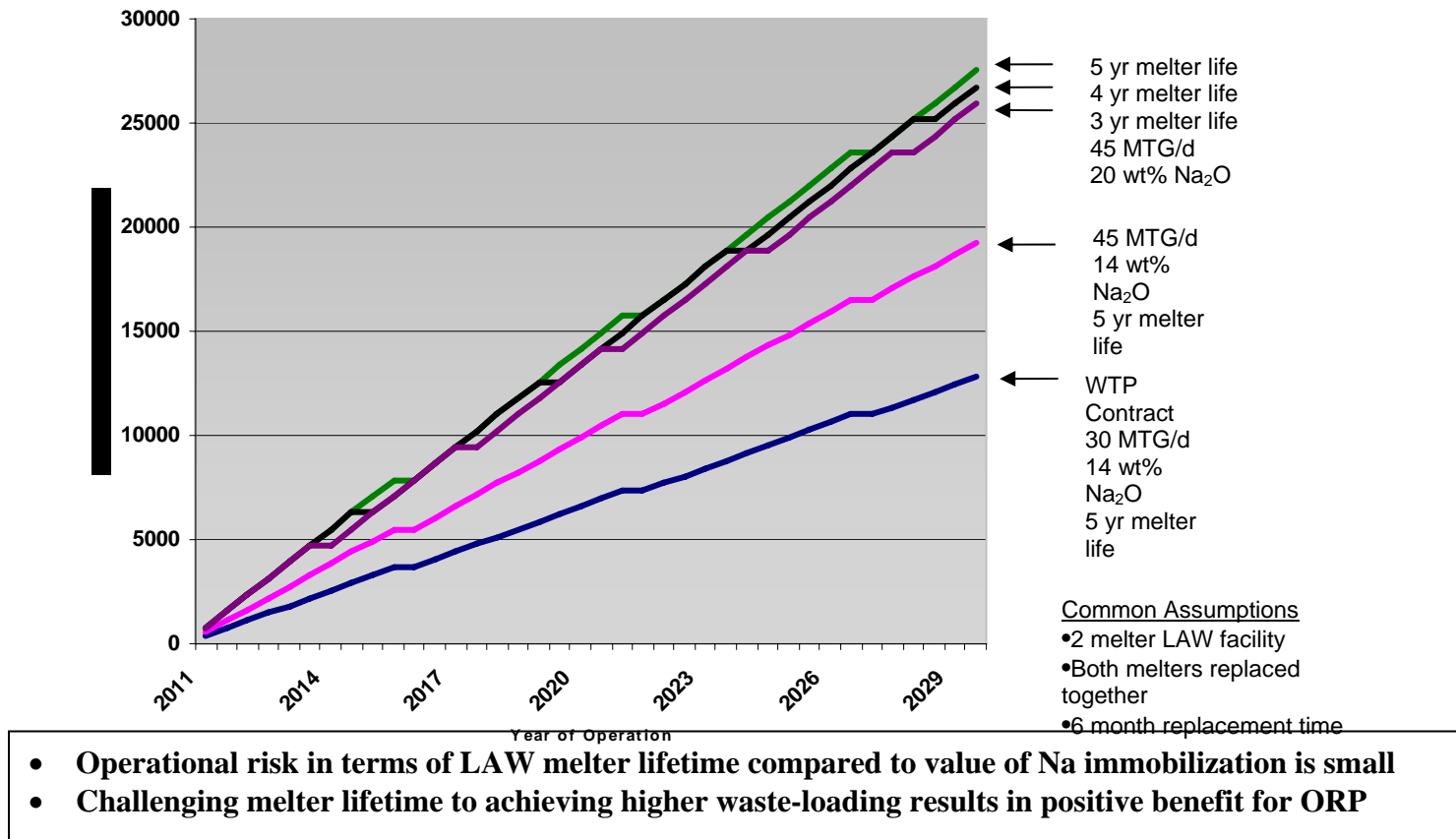




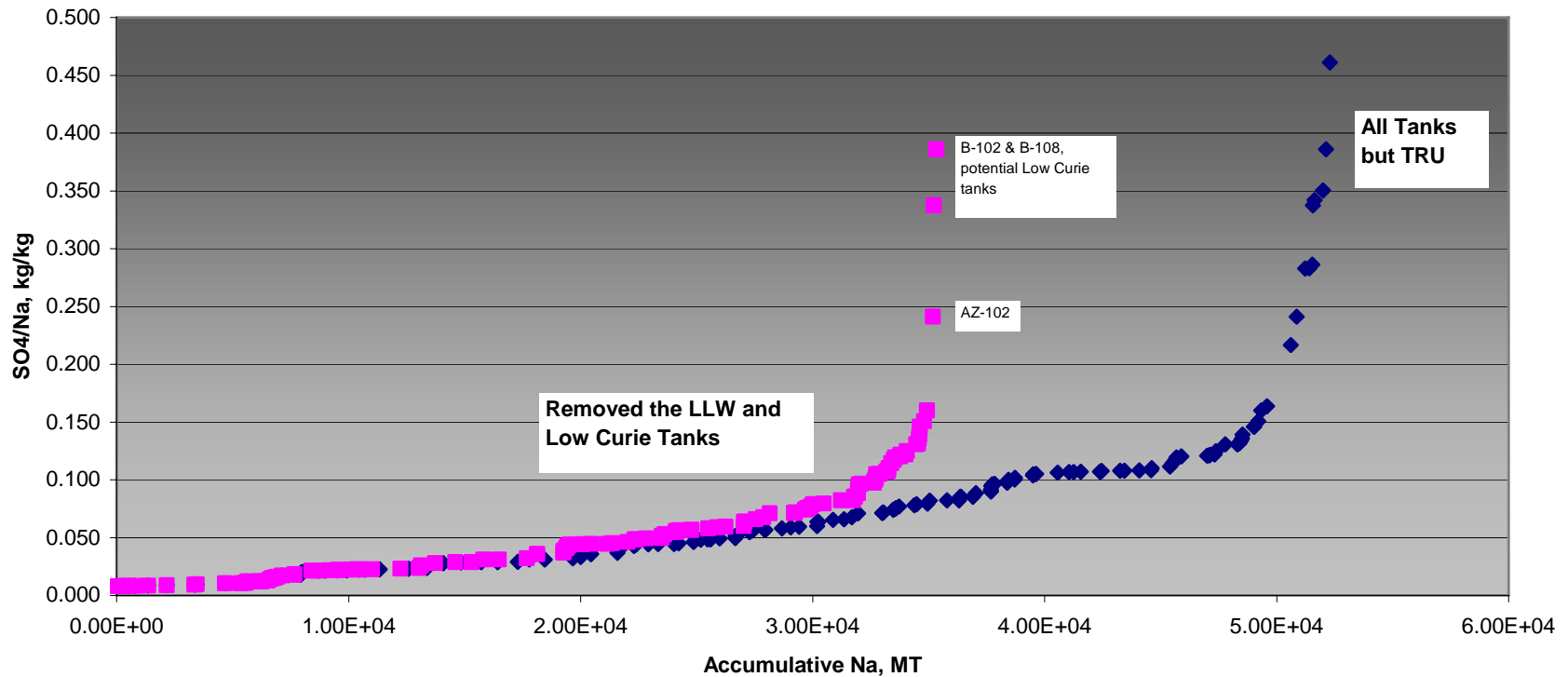
Target Case Annual Average Production Rate 28.8 MTG/day			Stretch Case Annual Average Production Rate -- 34.0 MTG/day		
Gimpel Glass Model			Gimpel Glass Model		DOE Glass Model
No Feed Selection	Feed Selection	Feed Selection	No Feed Selection	Feed Selection	Feed Selection
15.7 wt% Na <sub>2</sub> O	17.6 wt% Na <sub>2</sub> O	20.0 wt% Na <sub>2</sub> O	15.7 wt% Na <sub>2</sub> O	17.2 wt% Na <sub>2</sub> O	20.0 wt% Na <sub>2</sub> O
9,750 MT Na	11,600 MT Na	14,069 MT Na	10,874 MT Na	14,069 MT Na	17,682 MT Na

- The amount of Na treated in the near term (2011-2018) can be increased significantly by use of a more robust glass model and feed selection logic
- The increase in production rate from the Target to the Stretch Case has a significant impact on the total amount of Na treated in the 2011-2018 time frame

**Figure 7 Effects of Glass Model, Feed Selection and WTP LAW Facility Production Rate on Percent Na Treated in the 2011 – 2018 Time Frame**

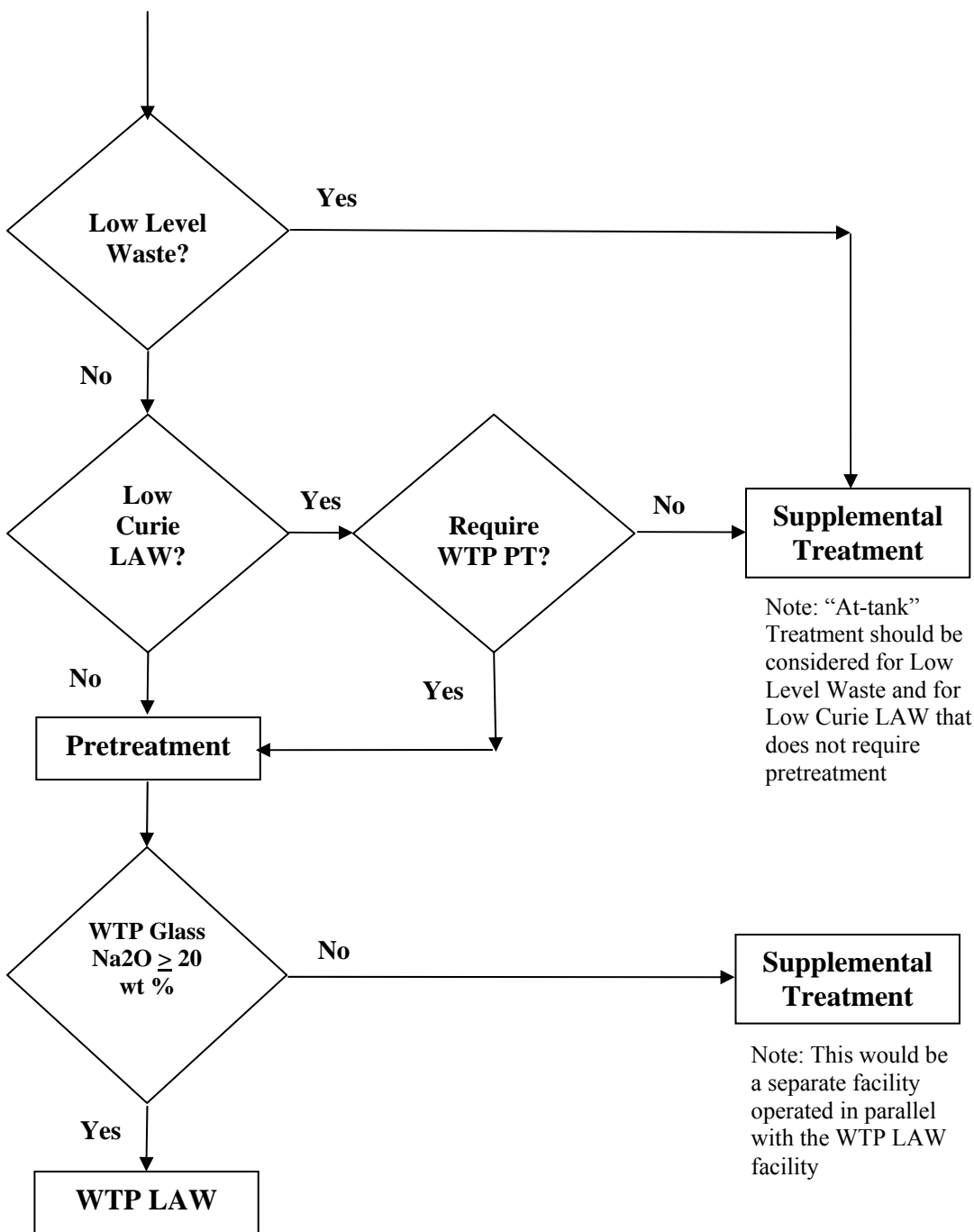


**Figure 8 Comparison of Na Immobilized as a Function of LAW Vitrification Capacity, Waste Loading and Melter Life**

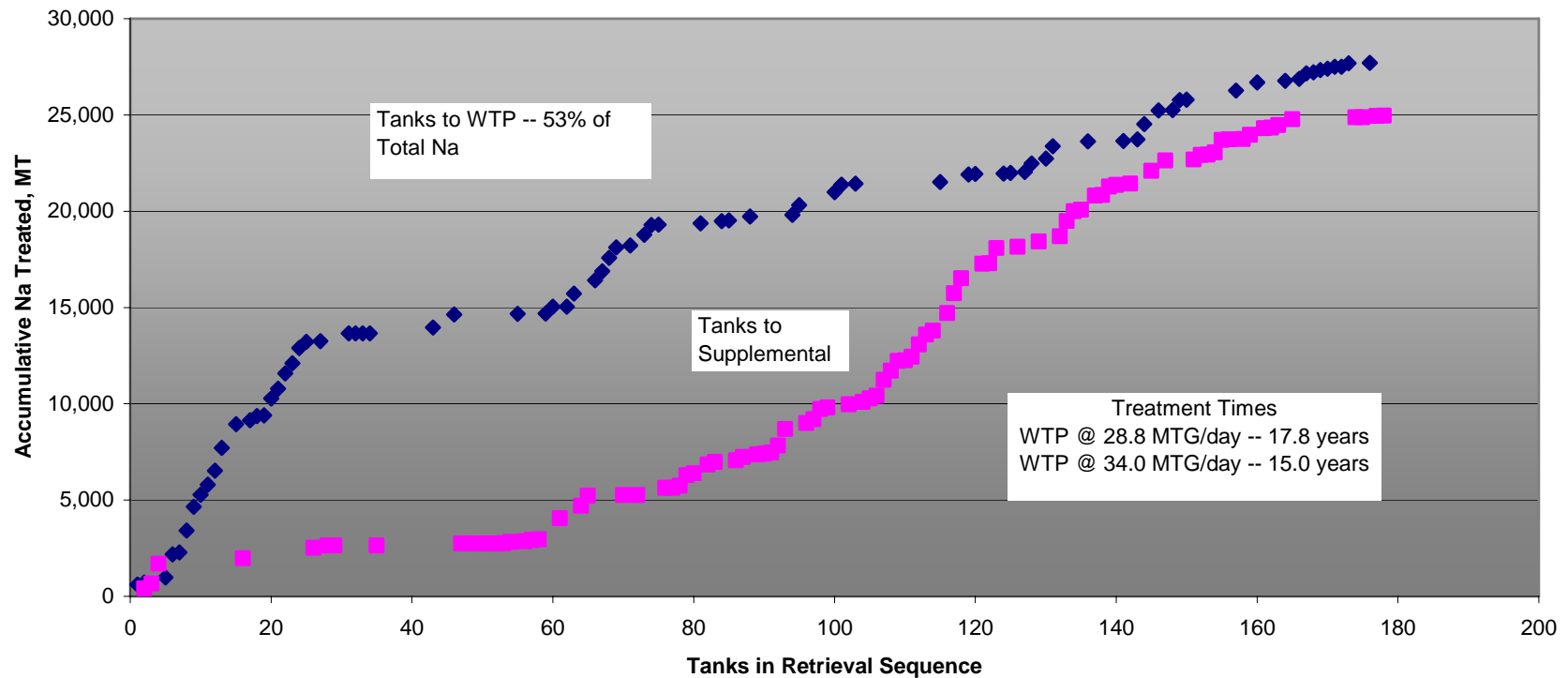


- **Approximately 1/3 of the total waste to be treated is low-level waste or low curie LAW that has already been treated**
- **Tanks containing these categories of waste may not require pretreatment and could be sent directly to Supplemental treatment**

**Figure 9 Comparison of SO<sub>4</sub>/Na with and without the Tanks that may not require Pretreatment**

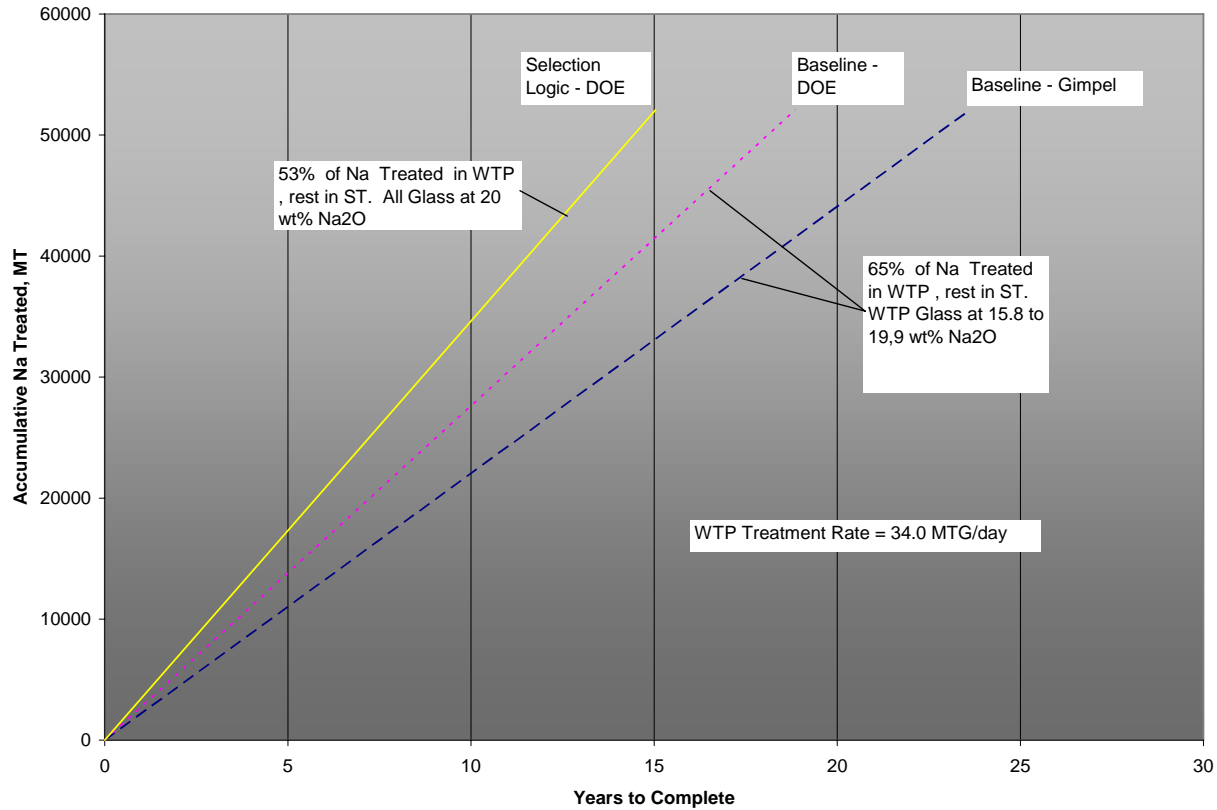


**Figure 10 Logic for Selection of LAW Treatment Process**



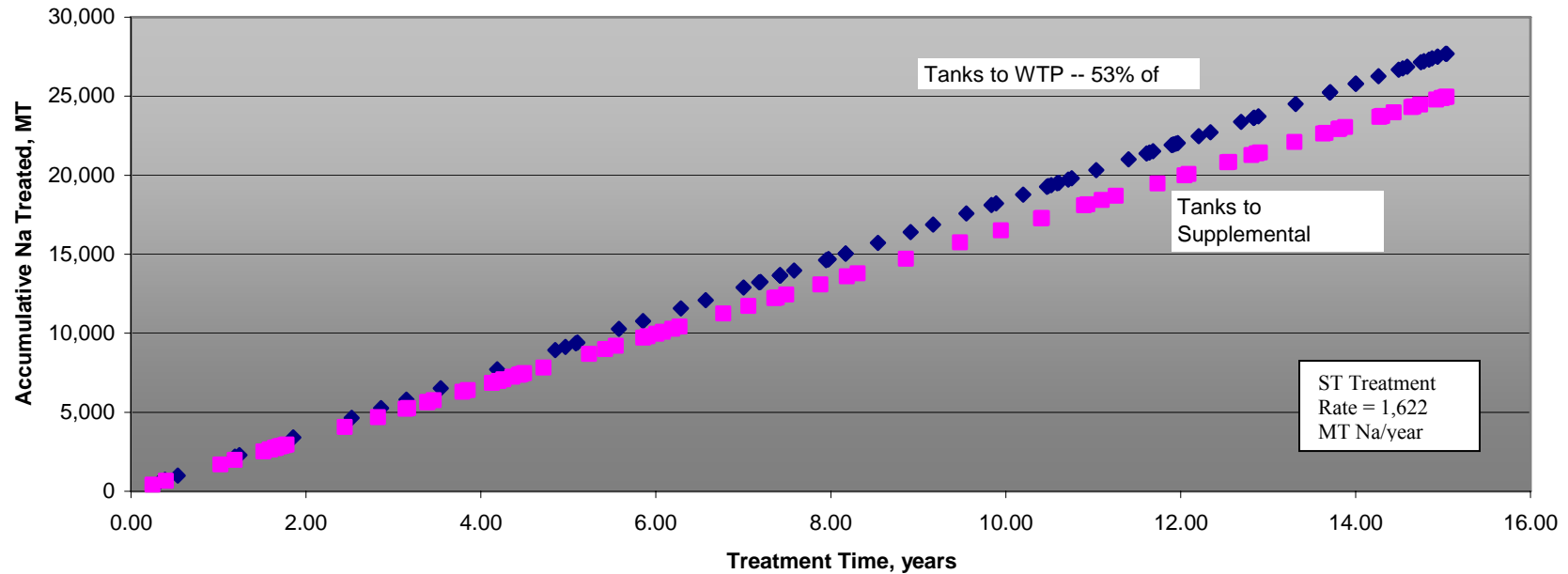
- The selection logic of Figure 9 was used to determine the treatment destination
- Application of this logic results in about an equal split between WTP LAW and supplemental treatment
- The goal of completing all treatment in 18 years is met for both the Base and Target WTP annual average glass production rates.

**Figure 11 Example Application of Selection Logic for Treatment Destination**



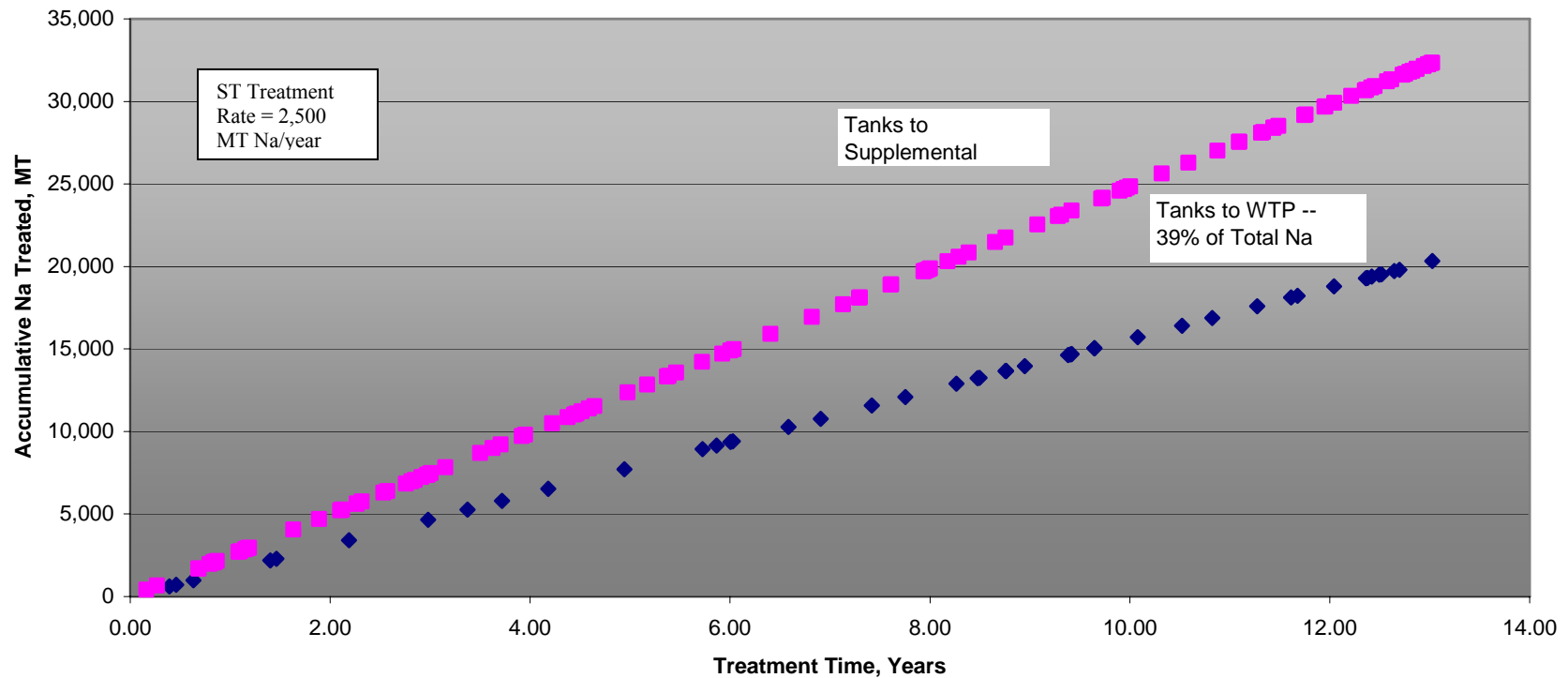
- Applying the DOE Model for the glass formulation reduces the mission completion time by 10 years compared with the Gimpel Model, if 65% of the waste is to be treated in WTP LAW
- Applying the DOE Model and the selection logic reduces the mission completion time by another 3 years with about an equal split of treatment between WTP LAW and supplemental treatment

**Figure 12 Effect of Sulfate Model and Application of Selection Logic on Mission Completion Time**



- **The tank sequence is based on Case 1 of the HTWOS of October 2002**
- **Application of the selection logic results in a 15 year mission completion time, about an equal split in waste treated and a fairly uniform distribution in time for the assumed retrieval sequence**
- **Additional study is required to optimize the retrieval sequence and selection logic**

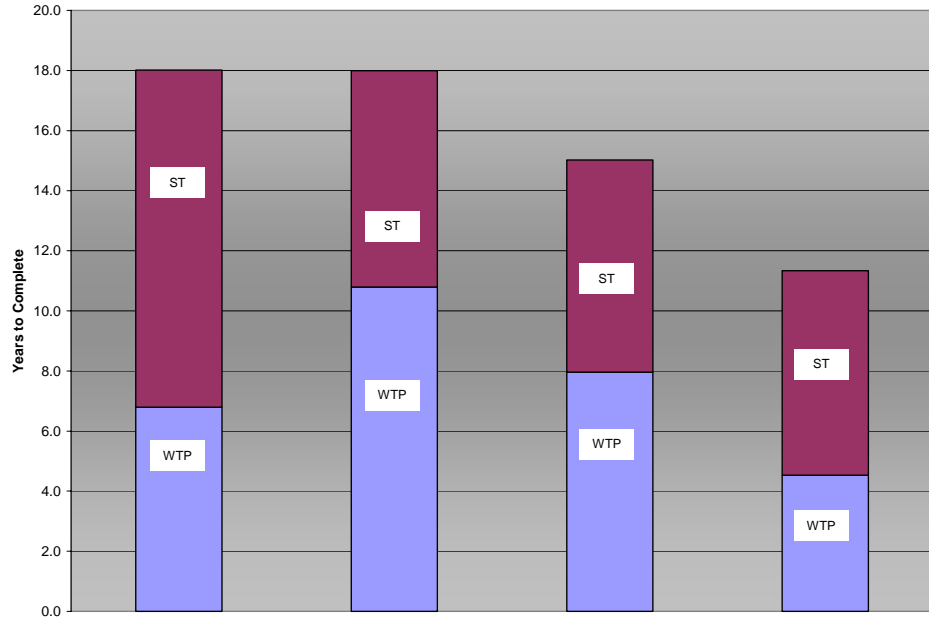
**Figure 13 Example of Application of Selection Logic for Treatment Destination  
(Stretch Production Rate of 34.0 MTG/day)**



- Reducing the percentage of waste treated in WTP LAW reduces the time for mission completion to 13 years compared with the higher percentage case shown in the preceding figure
- The retrieval sequence is the same as shown in the preceding figure. Additional study is required to optimize the sequence and the selection logic.

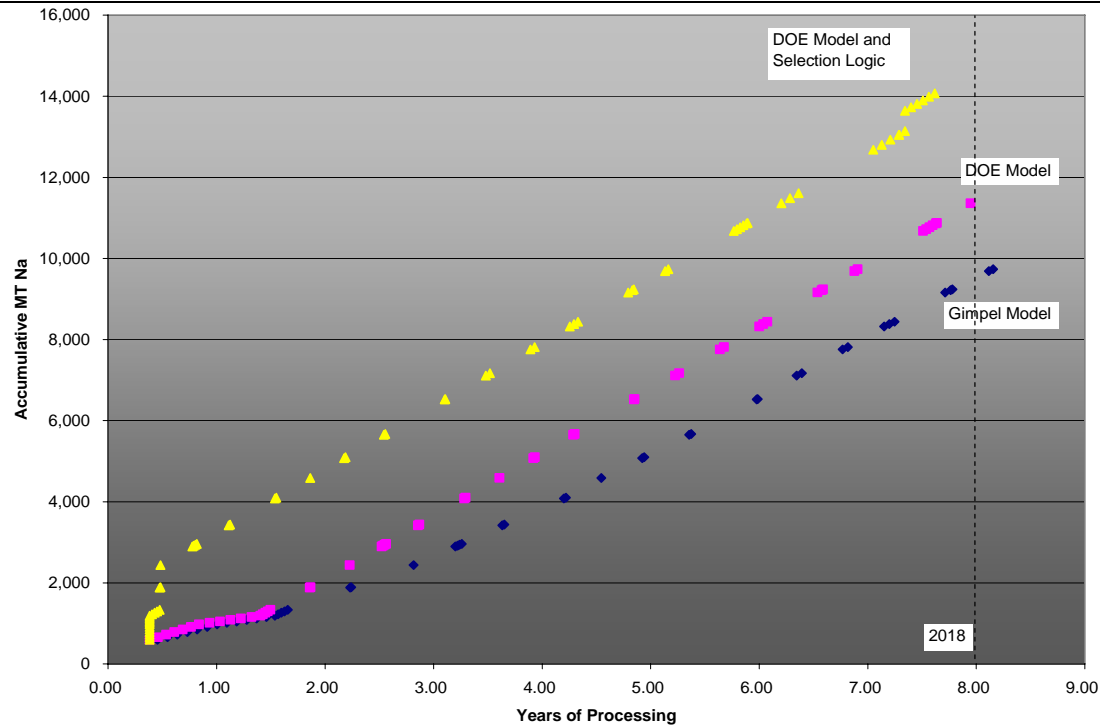
**Figure 14 Example Application of Selection Logic for Treatment Destination, Target Case – 39% Total Na Treated in WTP, 28.8 MTG/day in WTP LAW**





Item	DOE Target Case	DOE Stretch Case	Application of Selection Logic	Potential Optimization Case
<b>Glass Model</b>	<b>Gimpel</b>	<b>Gimpel</b>	<b>DOE</b>	<b>DOE</b>
<b>Na Treated in WTP, %</b>	<b>40 %</b>	<b>60 %</b>	<b>53 %</b>	<b>40 %</b>
<b>Average Na<sub>2</sub>O weight %</b>	<b>14.0</b>	<b>19.0</b>	<b>20.0</b>	<b>20.0</b>
<b>LAW Annual average capacity, MTG/day</b>	<b>28.8</b>	<b>34.0</b>	<b>34.0</b>	<b>34.0</b>
<b>Feed Selection Applied</b>	<b>No</b>	<b>No</b>	<b>Yes</b>	<b>Yes</b>
<b>Supplemental Treatment Rate, Na/year</b>	<b>1,800</b>	<b>1,160</b>	<b>1,635</b>	<b>2,765</b>
<b>Years to Complete</b>	<b>18.0</b>	<b>18.0</b>	<b>15.0</b>	<b>11.3</b>

**Figure 15 Potential Optimization of RPP Mission Completion**



- The batch sequence is based on Case 1 of October 2002 HTWOS
- Use of the DOE Model for glass formulation and the selection logic increases the amount of waste treated by ~4000 MT Na over the Gimpel Model.
- The additional treatment would free up ~2 to 5 DSTs over this period; addressing TFC concerns with being able to meet the Tri-Party Agreement milestones for tank retrieval

**Figure 16 Comparison of the Amount of Waste Processed in the Period 2011-2018 for the Different Glass Models and Application of the Selection Logic**

## Appendix A

### LAW Glass Loading Models and Basis for DOE Glass Loading Model

*Note: Descriptive information on the LAW Glass Properties models was derived from information prepared for the WTP Contractor and authors of this Design Oversight.*

This appendix describes the four LAW glass models that have been evaluated in this assessment. These models are the:

- “Rule of Five”
- Gimpel Model
- VSL Model, and
- DOE Model

#### A.1 The “Rule-of-Five”

Loading of Hanford LAW in glass to be produced at the Waste Treatment and Immobilization Plant (WTP) is determined by two primary factors:

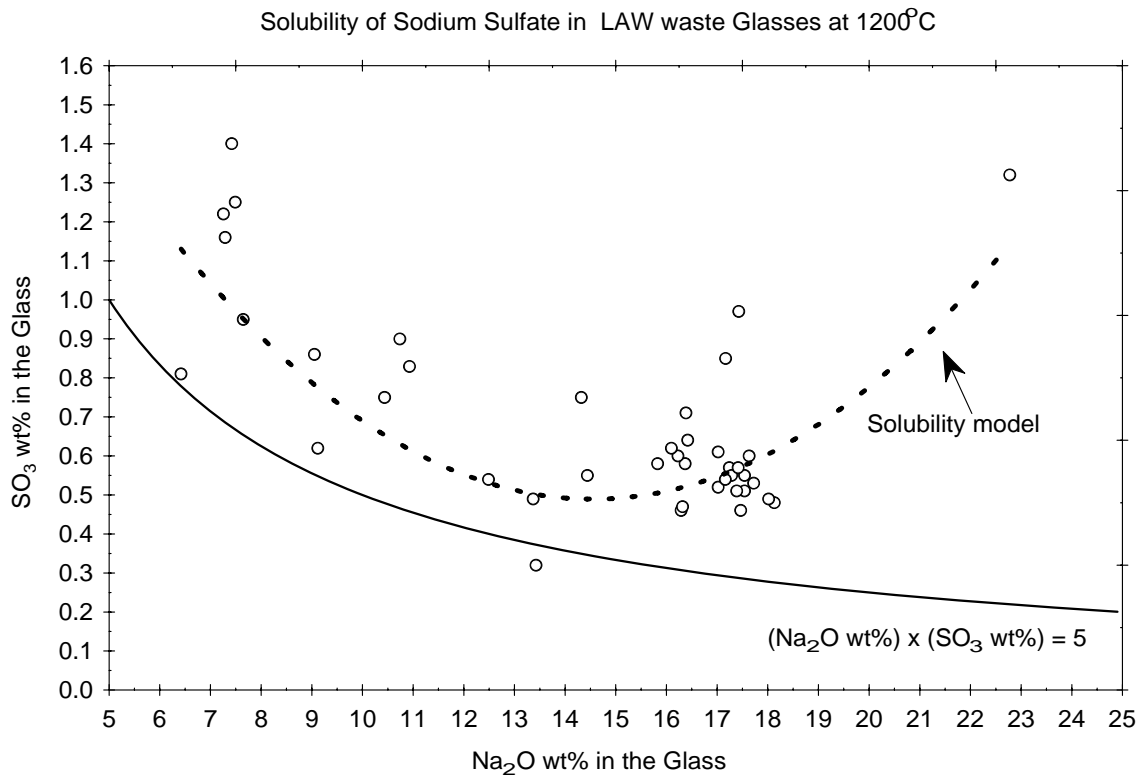
- 1) Allowable sulfur content in the melter and
- 2) Chemical durability of resultant glass.

The allowable sulfur content is that concentration of sulfur in the melter feed that can be incorporated into the glass melt without the accumulation of an alkali-sulfate-based molten salt phase at the melt surface. The allowable sulfur concentration is significantly lower than the thermodynamic solubility of sulfur in the glass melt at nominal melt composition and temperature. Since, sulfur has been found to segregate during the cold-cap process at nominal melter operating rates at lower concentrations. To account for this kinetic effect of sulfur segregation, the *rule-of-five* was proposed by researchers at the Vitreous State Laboratory (VSL, Pegg et al. 2000). In the development of the *rule-of-five*, it was suggested that the solubility of sulfur in the melt initially decreased and then increased with increasing soda ( $\text{Na}_2\text{O}$ ) concentration in the melt and that the kinetics of sulfur incorporation into the melt decreased with increasing soda concentration as shown in Figure A.1. Stated simply, the *rule-of-five* is the product of  $\text{Na}_2\text{O}$  concentration in glass ( $g_{\text{Na}_2\text{O}}$ , in mass %) times the concentration of  $\text{SO}_3$  in the glass ( $g_{\text{SO}_3}$ , in mass %) must be below 5:

$$g_{\text{Na}_2\text{O}} \times g_{\text{SO}_3} \leq 5.$$

Although there has been considerable debate about this approach to limiting the loading of LAW in glass, the *rule-of-five* forms the starting point of glass formulations developed by VSL for WTP and forms the basis for the waste-loading limits in the contract (BNI 2003). It should also be noted that in the original development of the rule-of-five,

extrapolation to very low and high sulfur concentrations was not acceptable. Therefore, the range of applicability should be considered from roughly  $0.25 < g_{SO_3} < 1$  mass%.

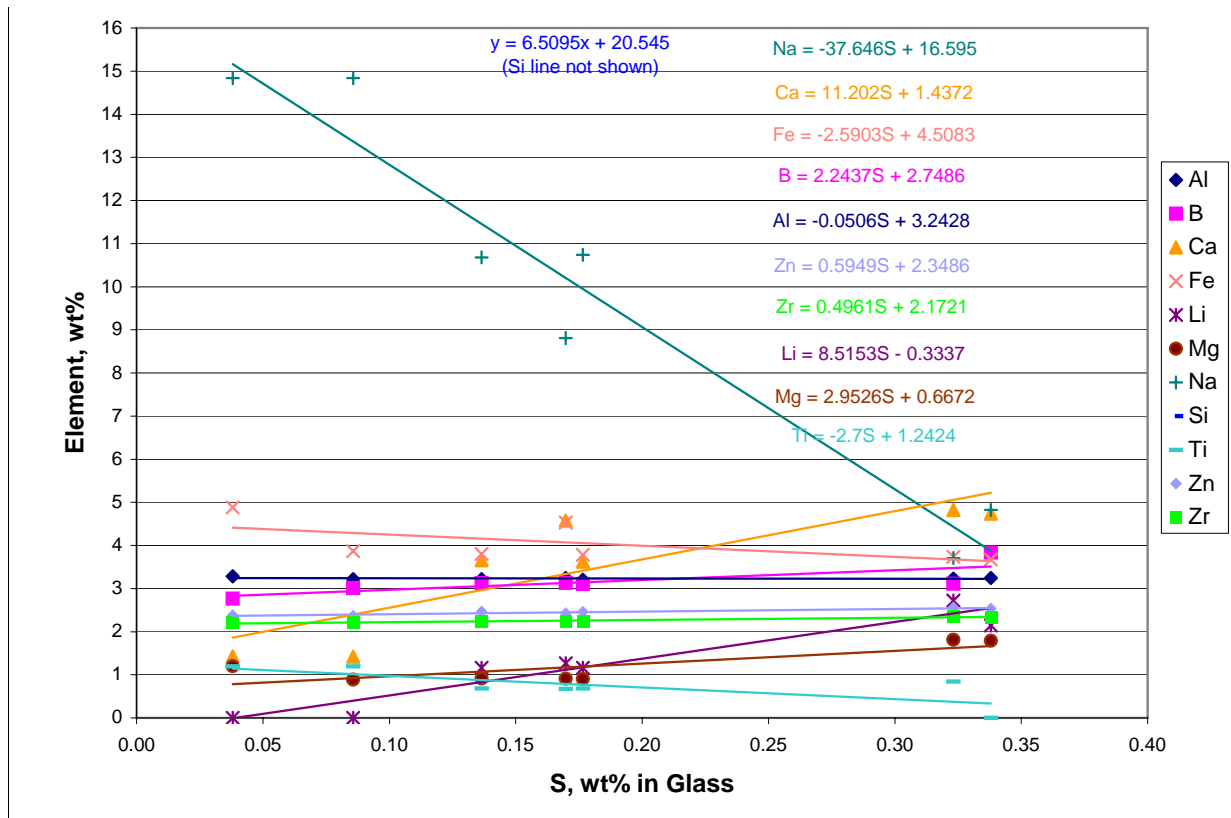


**Figure A.1 SO<sub>3</sub> Solubility as a Function of Melt Na<sub>2</sub>O Concentration (From Pegg et al. 2000)**

## A.2 The Gimpel Model

VSL has formulated a number of LAW glasses for use in melter demonstrations, baseline glass definitions, and radioactive glass testing (see Muller et al. 2001 for example). The compositions of these glasses were evaluated by Gimpel (2002a) for the purpose of modeling the glass composition as a function of waste composition. As shown in Figure A.22, the composition of glass was found to be a linear function of sulfur content. This allows for a preliminary estimate of glass composition and waste-loading using Na and S concentrations in the waste. Quantitatively, the relationship between  $g_{Na_2O}$  and  $g_{SO_3}$  was found to be:

$$g_{Na_2O} = 22.369 - 20.321g_{SO_3} .$$



**Figure A.2 Glass Component Concentrations as vs. Sulfur Concentration in LAW Glass (from Gimpel 2002).**

However, it became apparent that the  $Li_2O$  concentration in glasses with high  $g_{SO_3}$  (e.g., 0.683 mass%) was causing excessive melter refractory corrosion (Muller et al., 2002). Therefore, an adjustment was made to the original *Gimpel-rule* to account for this effect (Gimpel 2002b). The modified rule lowered the loading at  $0.683 \leq g_{SO_3} \leq 0.832$  mass% to that associated with  $g_{Na_2O}=5.47$  mass%.

### ***Comparison***

With the loading of LAW determined primarily by  $g_{Na_2O}$  and  $g_{SO_3}$ , it's possible to compare the influence of different constraints or rules on the acceptable glass composition region in two dimensions ( $g_{Na_2O}$  and  $g_{SO_3}$ ). The acceptable glass composition region defined by the *Gimpel-rule* is compared to that estimated by the *rule-of-five* in Figure 17. Also included in the figure are the “nominal” glass compositions successfully processed at pilot scale, the current project baseline glasses tested at crucible scale (Muller and Pegg 2003), and a line fit to the pilot scale melter glasses – called the *Morrey-rule*:

$$g_{Na_2O} = 32.45 - 41.51 \times g_{SO_3},$$

valid over the range  $0.3 < g_{SO_3} < 0.65$ .

All three estimates (given by lines in the figure) give similar response over much of the range. For each of these rules glass compositions should fall on or below the lines (lower left portion of the plot) and not above the line.

The formulations developed by VSL, shown in Figure 17, and used in the development of the various rules are developed to tolerate expected process variations and uncertainties. To test the robustness of these formulations, the loading of LAW in glass was varied by  $\pm 15\%$  (relative) and key glass compositions transitions were tested at pilot scale. The nominal transition point glasses are also shown in Figure 17 for comparison. This level of robustness is necessary to successfully process LAW in WTP. In other words, it isn't possible to increase the target loading of LAW by 15% because when actual uncertainties and variations occur in the plant, the sulfur and/or soda concentration in glass is likely to exceed the processing and product quality constraints discussed above.

### **A.3 The Morrey Rule of VSL Empirical Data Rule**

The *Morrey-rule*, (or as noted in this assessment the VSL Empirical Model ) was developed to help interpolate LAW loadings between pilot melter variation tests. This rule give the best current indication of loading that can be expected based on pilot melter demonstrated compositions. In all these models, the allowable  $g_{SO_3}$  decreases with increasing  $g_{Na_2O}$ . It is worth noting that these trends are not generally accepted in the waste glass industry (see Vienna et al. 2003 for example).

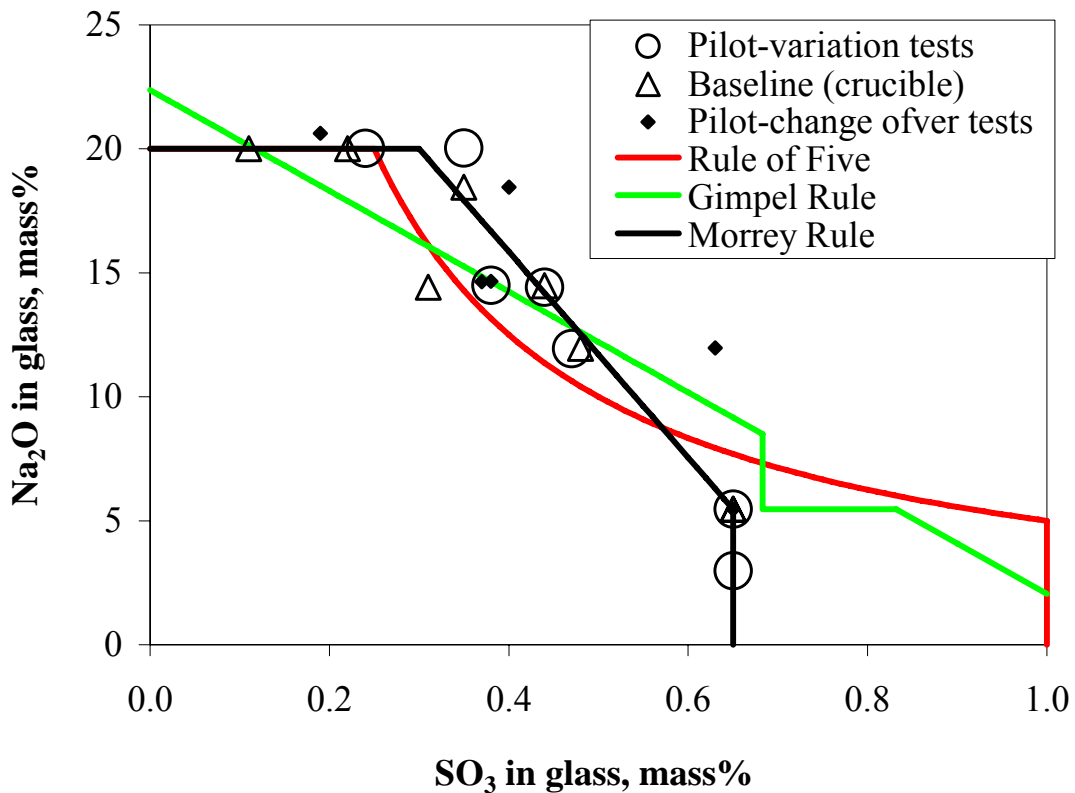


Figure 17. Comparison of  $g_{Na_2O}$ - $g_{SO_3}$  Boundaries from *Rule-of-Five*, *Gimpel-Rule*, and *Morrey-Rule* with Pilot and Baseline Glass Formulations

#### A.4 The DOE Glass-Loading Model

The DOE Glass Model was derived from empirical studies associated with immobilization of the Sodium Bearing Wastes at Idaho. The glass formulation methodology for this model has been recently extended to the WTP.

##### *Background*

Sodium-bearing waste (SBW) is a high soda, acidic, high-activity waste stored at the Idaho National Engineering and Environmental Laboratory (INEEL). Table A.2 lists the compositions of SBW composition estimates on a glass oxide basis. The composition of SBW falls within the region of expected Hanford LAWs with the exception of  $Al_2O_3$  concentration which is roughly 28% in SBW and up to roughly 20% in LAW. This difference may not be significant since  $Al_2O_3$  is added as a glass former in many LAW glasses.

Studies were performed to optimize the loading of SBW in glass to be produced in a liquid-fed, ceramic-lined, Joule-heated melter similar to those used at the Defense Waste Processing Facility (DWPF) and West Valley Demonstration Project (WVDP). These

studies began in 1999 and continued through 2002 with evolving waste composition estimates and flowsheet assumptions. In the first phase, a glass was formulated to demonstrate the feasibility of direct vitrification of SBW using current melter technologies (Vienna et al. 1999). The second phase was aimed at developing a glass to demonstrate the direct vitrification process and determine the range of expected waste-loadings, assuming sulfur lost to the off-gas would be grouted (Peeler et al. 2001). The third phase of the study was aimed at formulation of a baseline glass composition to be used in development of engineering data for vitrification plant design. The overriding assumption during the third phase was that salt accumulation in the melter would not be tolerated, and that nearly all of the sulfur lost to the off-gas would be recycled back to the melter feed. Different SBW compositions were assumed for each phase of the study – 1998 SBW, 2000 WM-180, and 2001 WM-180 in phases 1, 2, and 3, respectively (shown in Table A.2).

### ***Glass Formulation Strategy***

The basis of the formulation work performed by Vienna, Peeler, and colleagues was based primarily on years of research and production experience in commercial glass melts where sulfur was used as a melting and fining aid. The literature is full of data suggesting that the thermodynamic solubility of sulfate in glass melts is increased with increasing concentrations of alkali and alkaline earth components and decreasing silica and alumina (see for example Papadopoulos 1973). This relationship between sulfate solubility and composition was shown to hold true for waste glasses by Li et al. (2001). To increase waste-loading, it is necessary but insufficient to formulate a glass to have relatively high sulfate solubility. Since, many examples from studies with SBW, WVDP, and WTP glasses have shown that sulfate may segregate as a mixed alkali/alkaline earth oxyanionic salt during melter processing at concentrations below the equilibrium solubility of sulfate in the bulk melt at the nominal operating temperature. Therefore, tests were performed to determine the mechanism of sulfate segregation during melter processing and to mimic cold-cap processing conditions in the laboratory (Darab et al. 2001). These tests led to several key outcomes including the determination of the primary mechanism for salt segregation at seemingly sub-saturated conditions, composition influences on sulfur retention kinetics, and optimized glass formulations for treatment of SBW. It was found, as is intuitively logical, that the higher the solubility, the more that is incorporated into the melt before salt segregation. This led to formulations with increase alkali and alkaline earth concentrations. It was also shown that no one alkali or alkali earth component was as effective as a mix of many alkali and alkali earth components. Finally, the addition of  $V_2O_5$  in the melt allowed for higher concentrations of sulfur in the feed prior to salt segregation. In addition to these simple rules,  $ZrO_2$  was added to increase the chemical durability and viscosity of the waste glass/melt that was lowered by high alkali and alkaline earth component concentrations. The overall blend of glass components was largely dictated by the need to meet a range of glass property constraints.



**Table A.2 Various SBW Composition Estimates (Vienna et al. 2002)**

<b>Component</b>	<b>1998 SBW</b>	<b>2000 WM-180</b>	<b>2001 WM-180</b>
<i>Oxides (mass% non-volatile oxides)</i>			
Al <sub>2</sub> O <sub>3</sub>	27.34	27.96	27.52
As <sub>2</sub> O <sub>3</sub>	0	0	0.04
B <sub>2</sub> O <sub>3</sub>	0.65	0.35	0.35
BaO	0	0.01	0.01
CaO	2.23	2.22	2.15
CdO	0	0.08	0.08
Ce <sub>2</sub> O <sub>3</sub>	0	0.01	0.01
CoO	0	0.21	0
Cr <sub>2</sub> O <sub>3</sub>	0.25	0	0.21
CuO	0	0.05	0.05
Fe <sub>2</sub> O <sub>3</sub>	1.55	1.43	1.41
Gd <sub>2</sub> O <sub>3</sub>	0	0.03	0.03
K <sub>2</sub> O	7.92	7.62	7.53
MgO	0.05	0.4	0.39
MnO	0.78	0.82	0.81
MoO <sub>3</sub>	0.13	0.02	0.02
Na <sub>2</sub> O	50.05	52.54	51.91
NiO	0.55	0.09	0.09
P <sub>2</sub> O <sub>5</sub>	1.19	0.8	0.79
PbO	0.31	0.24	0.24
RuO <sub>2</sub>	0.04	0.01	0.01
<b>SO<sub>3</sub></b>	<b>3.73</b>	<b>3.57</b>	<b>4.55</b>
Sb <sub>2</sub> O <sub>5</sub>	0	0	0.01
SeO <sub>2</sub>	0	0	0.01
SiO <sub>2</sub>	0.18	0	0
SnO	0.02	0	0
SrO	0	0	0.01
V <sub>2</sub> O <sub>5</sub>	0	0	0.07
ZnO	0	0.07	0.07
ZrO <sub>2</sub>	1	0.01	0.01
<i>Halogens (mass% of non-volatile oxides)</i>			
Cl	1.04	0.88	0.87
F	0.98	0.57	0.73
I	0.02	0.01	0.01
<i>Volatiles (moles/L)</i>			
H <sup>+</sup>	1.94	1.08	1.01
NO <sub>3</sub> <sup>-</sup>	6.96	5.11	5.27
<i>Oxide and Halogen Loading (g/L)</i>			
Solids	145.26	114.55	122.62

The various additive compositions tested during this period of development are listed in Table A.3. Testing of these additive compositions in a laboratory scale melter showed a consistent trend in that increased alkali (R<sub>2</sub>O) and alkaline earth (AO) component concentrations, along with V<sub>2</sub>O<sub>5</sub> allowed for higher sulfur incorporation. For example, a series of tests with SBW-22 through -27 with fixed waste-loading at 20% and excess

SO<sub>3</sub><sup>4</sup> showed salt formation in all samples with R<sub>2</sub>O + AO < 20 mole% of frit and R<sub>2</sub>O/(R<sub>2</sub>O+AO) < 40 mole% of frit, while other samples showed no salt formation. One exception was SBW-24 which showed salt formation even with R<sub>2</sub>O+AO=21% and R<sub>2</sub>O/(R<sub>2</sub>O+AO)=64%. The major difference in this formulation is the lack of V<sub>2</sub>O<sub>5</sub>. Similar results were found with crucible melts as reported by Vienna et al. (2001).

**Table A.3 Additive Compositions Tested with SBW (in mass% glass oxides)**

Mix ID	B <sub>2</sub> O <sub>3</sub>	CaO	Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Li <sub>2</sub> O	MgO	Na <sub>2</sub> O	SiO <sub>2</sub>	V <sub>2</sub> O <sub>5</sub>	ZrO <sub>2</sub>
SBW-1*	14.26		11.31		2.67			68.69		
SBW-2*	12.00		11.31		4.00			69.61		
SBW-3*	15.00		11.31		4.50			66.11		
SBW-4	12.00	2.00	12.00		4.00			70.00		
SBW-5	15.00	4.00	12.00		4.00			65.00		
SBW-6	15.00	2.00	12.00		4.00			67.00		
SBW-7	10.00	4.00	15.00		5.00			66.00		
SBW-8	15.00	2.00	15.00		5.00			63.00		
SBW-9	15.00	5.00	10.00		5.00			65.00		
SBW-10*	12.00		12.00		4.00			70.00		
SBW-11	12.15	5.02	1.52		6.11	1.75	1.90	64.23	4.88	2.44
SBW-12	6.03	5.02	1.52		6.11	1.75	6.98	65.27	4.88	2.44
SBW-13	12.15		1.52	8.15	6.11		1.90	62.85	4.88	2.44
SBW-14	14.45	5.02	1.52		6.11	1.75	1.90	66.81		2.44
SBW-15	7.00	8.00	8.00		6.00		7.00	64.00		
SBW-16	14.00	7.00			6.00		2.00	71.00		
SBW-17	12.00	2.00	12.00		4.00			70.00		
SBW-18	12.00	2.00	12.00		3.00		4.00	64.00	2.00	1.00
SBW-19	12.00	2.00	12.00		3.00		4.00	62.00	4.00	1.00
SBW-20	12.00	4.00	12.00		3.00		4.00	60.00	4.00	1.00
SBW-21	10.00	4.00	12.00		3.00		4.00	62.00	4.00	1.00
SBW-22	6.03	5.02	1.52		6.11	1.75	4.29	67.95	4.88	2.44
SBW-23	12.15		1.52	4.32	6.11		1.90	66.68	4.88	2.44
SBW-24	11.10	5.02	1.52		6.11	1.75	1.90	70.16		2.44
SBW-25	12.15	5.02	12.00		3.44	1.75		58.32	4.88	2.44
SBW-26	6.03	14.19	1.52		3.52	1.75	1.90	63.77	4.88	2.44
SBW-27	6.03	11.75	1.52		4.08	1.75	1.90	63.21	7.32	2.44

\* SBW-1 through -3 contain 3.08 mass% TiO<sub>2</sub> and SBW-10 contains 2 mass% BaO

### *Melter Testing*

Melter testing was performed with:

- SBW-1 and 1998 SBW at a 35% waste-loading in the first phase

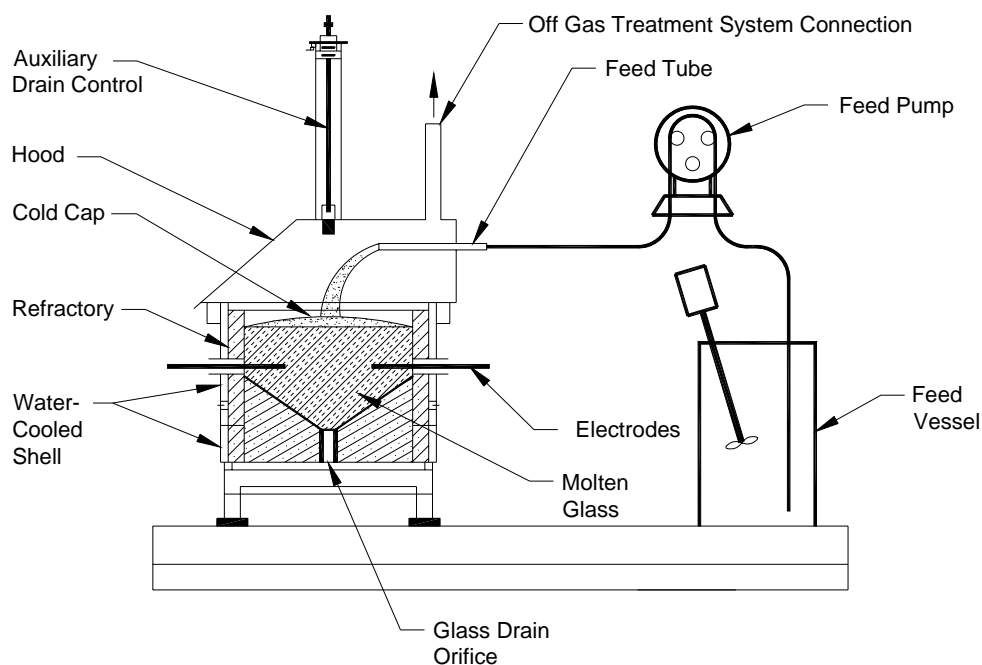
<sup>4</sup> All other parameters in these tests were fixed, e.g., feed rate, reductant concentration, etc.

- SBW-9 and 2000 WM-180 at loadings ranging from 20 to 35% in the second phase
- SBW-22 and 2001 WM-180 at 20% loading in the third phase

on either/or the EV-16 melter at Clemson University and the research scale melter (RSM) at PNNL. In addition, a number of tests were performed using a slurry-fed melt-rate furnace operated by Savannah River Technology Center at Clemson University. Key points of these tests and their results are described below.

#### *EV16-1999-1 Test*

The initial formulation SBW-1-35 (SBW-1 used to define the additive mix and -35 the waste-loading used) was tested in a pilot scale melter (EV-16). The EV-16 melter at Clemson University has a  $45.7 \times 45.7$  cm melt chamber, with a design depth of 40.6 cm and retrofit with a sloped bottom. A diagram of the melter (with the sloped bottom installed) is provided in Figure . The off-gas treatment system for the EV-16 is a multi-stage wet scrubber, designed to handle particulate matter and acid gases. The off-gas system is constructed of 304 stainless steel and PVC and consists of a quench chamber, steam/air atomizing scrubber, cyclonic separator, scrubbing column, demister, and rotary blower.



**Figure A.4** Schematic of the EV-16 Melter (after Musick et al. 2000)

The EV-16-1999-1 test was performed in April 1999 using the 1998 SBW simulant composition with glass-forming additives of SBW-1 and a target waste-loading of 35 mass% based on crucible test results described in Vienna et al. 1999. Carbon in the form

of powdered activated carbon was added to the feed at 87.4 g/L to ensure adequate reduction of transition elements to avoid undue corrosion of the melter electrodes and ensure nitrate destruction for less problematic melting. The test was performed over a period of just less than 3 days with a time-average feeding rate of 135 mL/min. Over the duration of the test, 450 L of feed were fed to the melter, producing 155 kg of glass. The target melt-pool temperature was 1150°C. However, temperature excursions of up to 1350°C occurred throughout the test due to a faulty temperature control device.

Analyses of the resulting glass by X-ray fluorescence spectroscopy (XRF) and by inductively couple plasma (ICP) atomic emission spectroscopy (AES) showed a SO<sub>3</sub> concentration of 0.49 mass% and 0.58 mass%, respectively. The target concentration of SO<sub>3</sub> in glass was 1.3 mass%, and ICP analyses of the melter feed suggests an *as-batched* SO<sub>3</sub> concentration of 1.07 mass%. This suggests that 54% of the S fed to the melter was in the glass (based on ICP measured results of the feed and the glass). No evidence of a salt layer was seen at the melt surface during or after the test.<sup>(5)</sup> Insufficient data were collected to determine the amount and speciation of S in the off gas. However, it is likely that the remaining fraction of the S fed to the melter partitioned to the off gas.

#### *RSM-01-1 Test*

The second formulation SBW-9 with 30, 32, and 35% waste-loading were tested in a research scale melter (RSM). The testing to support this formulation were reported by Peeler et al. (2001) The RSM is a 15.24-cm (6-in.) diameter, joule-heated melter capable of continuous feeding and pouring that was specifically designed and built to evaluate various aspects of the vitrification process. The RSM consists of a 26-cm (10.25 in.) outside diameter × 44.45-cm (17.5 in.) high Inconel 601 shell, lined with ceramic paper and Alfrac 66. A crucible of Monofrax K-3 high Cr<sub>2</sub>O<sub>3</sub> refractory provided a melt cavity that measures 15.24 cm (6 in.) in diameter. The operating glass height of the RSM is nominally 7.6 cm (3 in.) resulting in a glass volume of 1.4 L. A view port in the lid allowed observations of the cold cap, observations of salt-layer formation, and sampling from the melt surface. The off gas-system included a film cooler, venturi scrubber, high-efficiency mist eliminator, and scrub-solution tank. Characterization of process off-gas effluent emission rates and equipment abatement efficiencies were accomplished using gaseous and particulate samplers operated according to applicable U.S. Environmental Protection Agency (EPA) protocols. In addition, an online quadrupole MS allowed real time analysis to be conducted for volatile and semivolatile effluents having mass numbers between 2 and 300 AMU. Figure shows a schematic of the RSM.

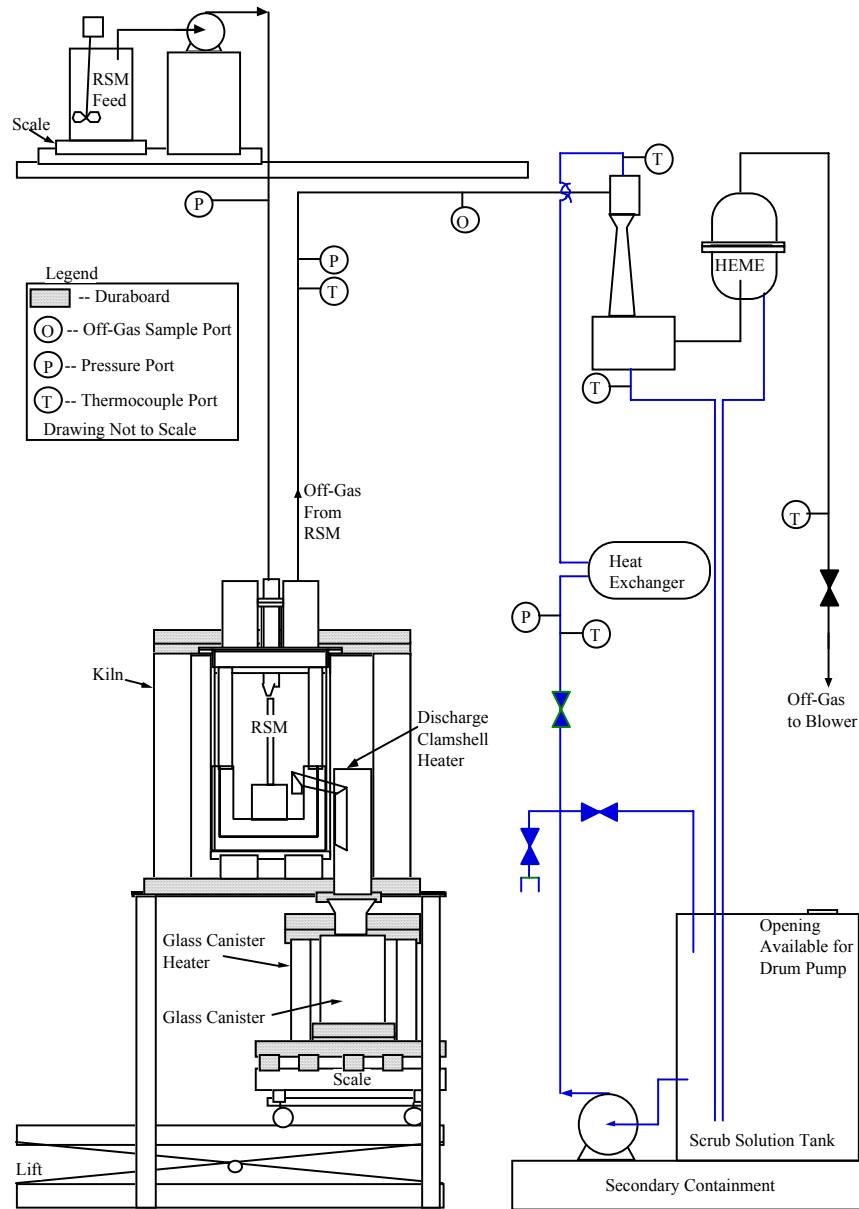
The RSM-01-1 test was performed in January 2001 using the 2000 WM-180 simulant composition with glass-forming additives of SBW-9. The target waste-loadings were increased from 30 to 35 mass% during the eight test segments to determine the loading at which a salt layer would accumulate (see Table A.5). The amount of S was increased by 40% during the final segment to intentionally form a salt layer. Sugar was added as a

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<sup>(5)</sup> The absence of a salt phase during this test may have been influenced by the temperature excursions.

reductant at concentrations ranging from 135 to 197 g/L of SBW to get an initial assessment of the impacts of reductant concentration on S loss and glass redox. The test was performed over a period of 120 h with a feeding rate of 2.1 to 3.3 L/h and a glass pour rate of 35 to 54 Kg/h/m<sup>2</sup>. The average oxide loading of the feed was 292 g/L. The melt-pool temperature was maintained between 1147 and 1162°C with a target nominal melt temperature of 1150°C.

Goles et al. (2001) thoroughly described the results of the RSM-01-1 test. Table compares the ICP analyses of SO<sub>3</sub> in glass with target values. Roughly, 50 to 60% of the S fed to the melter partitioned to the glass and is apparently relatively independent of waste-loading in the range of 30 to 35 mass%. A mass balance over the entire 120-h test found that roughly 25% of the S fed to the melter partitioned to the off-gas system, roughly 80% of which was found in the drainage from the high-efficiency mist eliminator (HEME), and the remaining were in the scrub solution. More of the S could have been in the HEME since the entire HEME was not flushed after the test. Alternatively, if the remaining 15 to 25% of the S left the melter as SO<sub>2</sub>, the concentration of SO<sub>2</sub> would have been below the detection limit of the MS used to monitor off-gas composition. Very small spots of molten salt could be found on the melt surface during nearly the entire test. Typically, the salt disappeared after feeding was stopped for some period. Salt accumulation was not seen until the waste-loading was increased to 35%. Although no accurate data were taken to quantify the amount of salt accumulation, visual observations suggested that the amount of salt on the melt surface decreased when the amount of sugar increased during the last test segment.



**Figure A.5** Schematic of the Research-Scale Melter System (after Goles et al. 2001)

**Table A.5** Summary of RSM-01-1 Segments

Segment	Waste Loading (mass%)	Target SO <sub>3</sub> Concentration	Sugar Concentration (g/L of SBW)	Average Feed Rate (L/h)
A	30	1.07	135	2.1
B	30	1.07	135	2.3
C	32	1.14	135	3.0
D	32	1.14	135	2.8
E	35	1.25	135	2.5
F	35	1.25	150	2.6
G	35	1.25	155	3.2
H	35	1.75	178	3.3

**Table A.6** Summary of S Content in RSM-01-1 Glass

Waste Loading (mass%)	Target SO <sub>3</sub> in Glass (mass%)	Measured SO <sub>3</sub> in Glass (mass%)	% of S in Glass
30	1.07	0.68	63
32	1.14	0.66	56
35	1.25	0.70	56
35 (1.40×S)	1.75	0.89	51

*EV-16-2001-1 Test*

A second melter test was performed in the EV-16 pilot-scale melter in April of 2001 (Perry et al. 2001). Prior to the test, the melter plenum was rebuilt, and other melter modifications were made to simulate more closely the planned INEEL process. This test, EV-16-2001-1, processed a glass using the 2000 WM-180 waste simulant at 30 mass% loading with the SBW-9 additive mix (SBW-9-30). Sugar was added as a reductant to the feed at concentration of 160 g/L of SBW. With the exception of the sugar concentration, the target feed composition was the same as that processed in the RSM-01-1 test during the first two segments. This test was performed over 175 h with active feeding for approximately 120 h. The average nominal feeding rate was 14.7 L/h. Approximately 1790 L of feed was fed during the test, and 538 kg of glass were produced. The empirical oxide loading of the feed was 21.9%. The melt pool temperature was maintained between 1100°C and 1175°C with a nominal target of 1150°C. Normalizing the feed rate to the melter surface area, the average RSM-01-1 feed rate was 120 L/h/m<sup>2</sup> and that for the EV-16-2001-1 was 70 L/h/m<sup>2</sup>.<sup>(6)</sup> With slower feeding, there is more opportunity for the melt to approach the equilibrium concentration of SO<sub>3</sub>, which is estimated to be roughly 1 mass% for this melt composition in air.

<sup>(6)</sup> The complexity of melter feed to glass conversion processes does not allow the scaling of melter feed rates between different melters; the feed rate per unit melt pool surface area is often used as a very rough estimate for comparison purposes.

A molten salt was found to form and possibly accumulate during the EV-16-2001-1 test, unlike the EV-16-1999-1 and RSM-01-1 tests. A method to measure the amount of salt at the melt pool surface during the test was not available, but qualitative observations were made by probing the melt surface with an alumina tube. The amount of salt that remained on the glass surface when the melter was cooled after the test was estimated. This salt layer, which was found primarily on the melter refractory-glass interface, was estimated to contain 7.7% of the S fed to the melter.<sup>(7)</sup> After completion of the test, melter feed samples, that had been systematically taken during feeding were analyzed using ICP-AES to find that a significantly higher sulfur content was in the feed than targeted in glass. Table compares the concentrations of SO<sub>3</sub> in feed and in glass with the target values (all on a glass oxide composition basis). Therefore, these results correspond well with the result of RSM-01-1 test.

**Table A.7** Summary of S Content in EV-16-2001-1 Glass

Sample	Target SO <sub>3</sub> (Mass%)	ICP SO <sub>3</sub> in Feed on a Mass% in Glass Basis	XRF SO <sub>3</sub> in Glass (mass%)	ICP SO <sub>3</sub> in Glass (mass%)
Melter Bottom	1.07	1.35	0.74	0.79
General Melter Glass	1.07	1.35	0.75	0.77
Melter Top	1.07	1.35	0.76	0.76

*RSM-01-2 Test*

The third composition to be tested at melter scale was SBW-22 at 20% loading of the 2001 WM-180 simulant (SBW-22-20). This formulation differed from SBW-9 since the concentration of sulfur in the waste increased and the planned INEEL flowsheet changed from one in which the sulfur leaving the melter would be grouted to one in which a majority of sulfur leaving the melter would return as recycle. Vienna et al. 2001 describe the formulation and testing activities for this feed.

This test was performed in much the same manner as RSM-01-1. The test was performed over a period of 120 h with a feeding rate of 1.24 to 1.9 L/h and a glass pour rate of 6.2 to 9.4 lb/h/ft<sup>2</sup>. The melt-pool temperature was maintained at roughly 1150°C throughout the test. Details of this test are reported by Goles et al. (2001b).

<sup>(7)</sup> The amount of salt on the melter surface after the test was roughly 575 g, and a total of 2594 g of S was fed to the melter. Assuming the salt was composed of 34.77 mass% S, 7.7% of the S fed to the melter would be in the salt.



**Table A.8. Summary of Test Segments for RSM-01-2**

<b>Segment</b>	<b>Feeding Time, h</b>	<b>Type</b>	<b>Reductant Conc g/L-SBW</b>	<b>Feed Rate,</b>	<b>Glass ProductionRate, lbs/h/Ft2</b>
A1	16.0	sugar	200	1.89	9.42
A2	4.9	sugar	180	1.54	7.67
A3	4.7	sugar	46	1.34	6.65
A4	9.0	sugar	170	1.9	9.43
A5	1.5	sugar	175	1.61	8.03
B1	6.5	glycolic acid	280	1.76	8.77
B2	2.1	glycolic acid	280	1.77	8.82
B3	1.3	glycolic acid	340	1.46	7.28
B4	3.8	glycolic acid	392	1.4	6.95
C1	5.1	sugar	160	1.85	9.18
C2	3.5	sugar	160	1.83	9.08
D1	2.0	none	n/a	1.35	6.73
D2	1.0	none	n/a	1.39	6.89
D3	1.6	none	n/a	1.45	7.2
D4	1.7	none	n/a	1.24	6.16
E	0.8	sugar	250	1.78	8.85

Analyses of the feed and glass suggest that the target SO<sub>3</sub> concentration was obtained in the feed and that 94.2% of the sulfur fed to the melter remained in the glass with 3.4% found in the off-gas scrub solution. The additional 2.4% of sulfur couldn't be accounted for by the mass balance, but no sign of salt formation existed. The sulfur retention in glass would likely be higher if not for the wide variations in reductant concentrations.

#### *EV16-2001-2 Test*

A final EV-16 test with SBW simulant (2001 WM-180) was performed in September of 2001. This test was performed with the same feed composition of RSM-01-2 test (SBW-22-20). The test was conducted over a three day period, stopped short by unrelated difficulties occurring on September 11, 2001. The result of the three day test was that no salt phase was identified during the test. Analyses of the feed and glass suggest that the target SO<sub>3</sub> concentration was obtained in the feed and that 97.1% of the sulfur fed to the melter remained in the glass with 2.4% found in the off-gas scrub solution. The additional 0.5% of sulfur couldn't be accounted for by the mass balance.

#### *Summary of SBW Formulation and Testing*

Formulations were performed to develop high loaded SBW glasses that would avoid salt formation during pilot scale melter testing at prototypic plant operating conditions. Initial formulations showed concentrations of  $\text{SO}_3$  in feed of  $> 1$  mass% (on a glass oxide basis) could be processed without salt formation/accumulation in the melter. A baseline glass, developed as a conservative formulation contained 0.91 mass% of  $\text{SO}_3$  (on a glass oxide basis). The latter formulation was shown to incorporate nearly completely to the glass phases during pilot testing (97.1%) at prototypic processing rates. These formulations were based on increased alkali, alkaline earth, and vanadium.  $\text{Na}_2\text{O}$  concentrations in melter tests ranged from 14 to 17.5% in glass. These correspond to  $\text{Na}_2\text{O} \times \text{SO}_3$  products between 12.6 to 19.2. As the testing was performed on single point compositions without accounting for variation in waste composition, waste-loading, and process uncertainty; it was recommended that INEEL reduce the anticipated sulfate loading in the incoming feed to 0.8 mass% on a glass oxide basis. This limit was to be combined with a limit of 20 mass%  $\text{Na}_2\text{O}$  for the purposes of durability control. These limits were independent of each other. In other words, the glass could contain up to 20%  $\text{Na}_2\text{O}$  and/or 0.8%  $\text{SO}_3$ , but neither should be higher than the limits.

### ***Application to Hanford LAW***

It's difficult to say how directly applicable the results from SBW formulation work are toward Hanford LAW glass. Clearly the compositions of the two waste streams are very similar. The SBW is slightly higher in nitrates and aluminum, while the LAW is basic. These differences are considered to be minor so long as sugar concentration is adjusted for the nitrate concentration.

Other differences in the process may be more significant. For example, the concentration of water in SBW is significantly higher with a sodium molarity of 2 M rather than the molarity range from 1.15 to 10 that are currently planned for Hanford LAW. The planned INEEL flowsheet didn't include the use of bubblers in their melter to increase processing rate. The combined differences between the sodium concentration and lack of bubbling gives a reduced normalized processing rate for SBW (ranged between 0.38 and 1.3  $\text{MTg/d/m}^2$ ). A final difference between the INEEL SBW and Hanford LAW glasses is the glass property constraints imposed on the glasses and thus on the formulations. For SBW glass the entire melter operating time was planned to be less than 3 years while for Hanford LAW glass melter life was due to be significantly longer, plus, SBW melter was not planned to use bubblers. This translates to a difference in constraints on the corrosivity of the melt to glass contact materials. The SBW glass was to be disposed of in the Federal Geologic Repository, and so, was required to meet durability constraints based on the product consistency test (PCT) and the toxicity characteristic leaching procedure (TCLP) much like Hanford LAW glasses. However, Hanford LAW glass must also meet constraints based on the vapor hydration test (VHT) which was not required for the SBW glasses.

With these similarities and differences in mind, a small task was performed by PNNL and SRTC under the funding and guidance of the Tanks Focus Area (TFA) to evaluate the

possibility of expanding the experience from glass formulation and testing for SBW to Hanford LAW. To perform the study, a typical Hanford LAW was selected so that the current Waste Treatment and Immobilization Plant (WTP) formulation would give significantly lower waste-loading than would a formulation based on the loading limits developed for INEEL (e.g., Na<sub>2</sub>O<20% and SO<sub>3</sub><0.8%). The baseline formulations assumed in this comparison were those reported by Muller et al. (2001), listed in Table A.8. As sub-envelopes A1 and A2 were limited by 20% Na<sub>2</sub>O and sub-envelope B2 was limited by 1% SO<sub>3</sub>, only sub-envelopes A3, C1, and C2 would have a substantially increased loading if the INEEL limits were used. Sub-envelope C1 (AN-107) was found to have the greatest loading increase, so, was used in the TFA study.

**Table A.8 Formulation Summary for Hanford LAW (From Muller et al. 2001)**

Current Envelope Designation	Envelope A			Envelope B*		Envelope C	
Sub-Envelope	A1	A2	A3	B1	B2	C1	C2
Tanks applicable to this subset	AN-105 SY-101 AN-103	AP-101 AW-101	AN-104 possibly AP-108	Blended AZ-101 & AZ-102	AZ-102	AN-107	AN-102 possibly S-102
Na <sub>2</sub> O wt%	20%		14.8 % (recycled SO <sub>3</sub> added)	6.5 %	5 %	~ 14%	11.2% (recycled SO <sub>3</sub> added)
K <sub>2</sub> O wt%	0.3 to 0.7%	~ 2%	~ 0.3%	~0.2%	~0.2%	~0.3%	~ 0.2%
SO <sub>3</sub> wt%	0.1 to 0.2%	0.1 to 0.2%	~ 0.35 %	0.75 %	~1 %	~ 0.35 %	~ 0.45%
Formulation Selected	LAWA44	LAWA88	LAWA102S	LAWB45*	LAWB53S*	LAWC22	LAWC21 S

\*Current selection of glasses for envelope B may not apply to individual tank waste as most of the present study was based on blending of AZ-101 and AZ-102 now abandoned.

A simulant of AN-107 was prepared according to the procedures used in pilot melter testing of AN-107 with glass LAWC22 by the WTP. A new formulation was developed for the waste using the approach described above for INEEL SBW. This new formulation is known as LAW-New-1 or LAWN-1. The waste, additives, and resulting glasses are compared in Table . The LAWN-1 composition was designed to meet the property constraints for the Hanford LAW melter while allowing for higher sulfur incorporation. The predicted VHT response of LAWN-1 is comparable to that of LAWC22 using models developed by WTP. The ZnO added to LAWC22 for corrosion resistance of glass contact materials was not added to LAWN-1.

The two formulations were tested in the same laboratory scale melter with all conditions held constant (e.g., feed rate, temperature, sweep gas, reductant type and concentration) at those values expected for the WTP LAW melter. A series of test were performed with increasing SO<sub>3</sub> concentrations in the simulant to determine the maximum concentration of SO<sub>3</sub> that could be added to the feed without the formation of an accumulated salt phase. The results (given in Table A.10) clearly demonstrate that in the laboratory scale melter (described in detail by Darab et al. 2001), the LAWN-1 glass can tolerate almost twice the SO<sub>3</sub> loading as the LAWC22 formulation prior to the formation of a salt. In addition, these results show that the allowable SO<sub>3</sub> concentration was higher in a glass with 20% Na<sub>2</sub>O than one with 14% Na<sub>2</sub>O. It should be noted that the laboratory scale melter was found to show higher allowable sulfur concentrations prior to a salt formation than did the pilot melter. However, there was a consistent shift in allowable sulfur concentrations so the laboratory scale melter gives an excellent qualitative comparison between formulations.

**Table A.9 Comparison of LAWC22 and LAWN-1 Formulations (mass% glass oxides)**

Oxide	AN-107	C22 Add	LAWC22	New Add	LAWN-1
Al <sub>2</sub> O <sub>3</sub>	3.52%	6.58%	6.09%	2.85%	3.00%
B <sub>2</sub> O <sub>3</sub>		11.99%	10.05%	7.71%	6.00%
CaO	0.22%	6.04%	5.10%	5.07%	4.00%
Cl	0.50%		0.08%		0.11%
Cr <sub>2</sub> O <sub>3</sub>	0.12%		0.02%		0.03%
F	0.91%		0.15%		0.20%
Fe <sub>2</sub> O <sub>3</sub>	1.08%	6.43%	5.57%	1.62%	1.50%
K <sub>2</sub> O			0.00%	0.96%	0.75%
Li <sub>2</sub> O		2.98%	2.50%	3.21%	2.50%
MgO		1.80%	1.51%	2.57%	2.00%
Na <sub>2</sub> O	90.19%		14.58%		20.00%
NiO	0.17%		0.03%		0.04%
P <sub>2</sub> O <sub>5</sub>	0.74%		0.12%	1.46%	1.30%
PbO	0.11%		0.02%		0.02%
SO <sub>3</sub>	2.35%		0.38%		0.52%
SiO <sub>2</sub>		55.58%	46.60%	67.48%	52.53%
TiO <sub>2</sub>		1.36%	1.14%		0.00%
V <sub>2</sub> O <sub>5</sub>			0.00%	4.50%	3.50%
ZnO		3.65%	3.06%		0.00%
ZrO <sub>2</sub>		3.59%	3.01%	2.57%	2.00%
SUM	99.91%	100.00%	100.00%	100.00%	100.00%
Loading		83.85%	16.15%	77.85%	22.15%

**Table A.10 Observations from Laboratory Scale Melter Tests with AN-107 Waste Simulant**

Test ID	Additive	Target	Measured SO <sub>3</sub> (mass%)	Salts Observation
S6-1-1	C22	0.6	0.46	No salt visible
M6-1-1	C22	0.6	0.49	No salt visible
L6-1-2	C22	0.6	0.66	No salt visible
S9-1-1	C22	0.9	0.63	No salt visible
M9-1-1	C22	0.9	0.55	No salt visible
L9-1-2	C22	0.9	0.73	No salt visible
S12-1-1	C22	1.2	0.70	Trace salts
M12-1-1	C22	1.2	0.82	Specks of salt seen in broken glass sample
L12-1-2	C22	1.2	0.74	Salts observed at meniscus
NS12-2-1	New-1	1.2	0.85	No salt visible
NS15-1-1	New-1	1.5	1.15	No salt visible
NS18-1-1	New-1	1.8	1.26	No salt visible
NS21-1-1	New-1	2.1	1.26	No salt visible

### *Summary and Conclusion*

These results show promise for the use of the formulation approach developed by Vienna and colleagues (Vienna et al. 1999, Peeler et al. 2001, Vienna et al. 2002, and Vienna et al. 2003) for maximizing Hanford LAW loading in glass. There is also a clear need for follow-on work including:

- testing and optimization for those properties key to Hanford LAW glasses that were not considered for INEEL SBW (VHT response, melter component corrosion)
- scale-up testing to demonstrate the ability to incorporate higher LAW loadings while meeting required processing rate constraints
- variation studies to ensure the robustness of the compositions to process uncertainties and waste composition variations
- additional waste-form qualification activities (to expand current LAW composition region to include these compositions)

The possible benefit of adopting this approach would be to lower the amount of LAW glass produced at the WTP and allow for higher sulfur tolerances. These benefits may outweigh the cost and effort required to perform the necessary testing.

### **A.5 Glass Performance Criteria and Constraints**

For low sulfur wastes, the loading of LAW is primarily determined by chemical durability of the final waste form. Ultimately, the release of radionuclides and hazardous components from the Hanford site near surface burial facility must meet regulatory requirements. To project the possible concentrations of radionuclides and hazardous components in ground water at various locations and times a performance assessment (PA) is performed (Mann et al. 2001). The release of these components from the waste package is calculated based on estimate of glass reaction rates with two concurrent processes – leaching and dissolution – each with assumed rate laws (McGrail et al. 2002). Extensive testing and modeling is required to estimate these waste form releases (e.g., populate the rate law equations and model releases), which is not practical to perform on many glasses or on short time frames. Thus, two performance based criteria were specified in the contract to limit the glass compositions produced by the WTP to within ranges expected to pass the regulatory requirements as projected by the PA. The detailed testing and source term modeling is performed under CH2M Hill Hanford Group (CHG) on a small number of glasses within this range of compositions (as defined by test responses) (McGrail et al. 2002). The contract limit on responses to the vapor hydration test (VHT) and product consistency test (PCT) were obtained by comparison with responses to the small number of glasses for which the detailed source term testing and calculations were performed. Figure A.10 compares the responses of two series of glasses (TFA from Vienna et al. 2001, and BWG from Muller et al. 2001) to the PCT and VHT to the contract limits. The releases of radioactive and hazardous components from those glasses significantly above either of the contract limits (A23, 27, 52, 2, 63, 67, 31, 64, and 41) are expected to fail the PA requirements. This was shown by detailed testing of A23, 52, and 31). The glasses near the contract limits (29, 47, A33, 48, and 39) are expected to barely pass the PA requirements as shown by detailed testing of A33, 48, and 39.

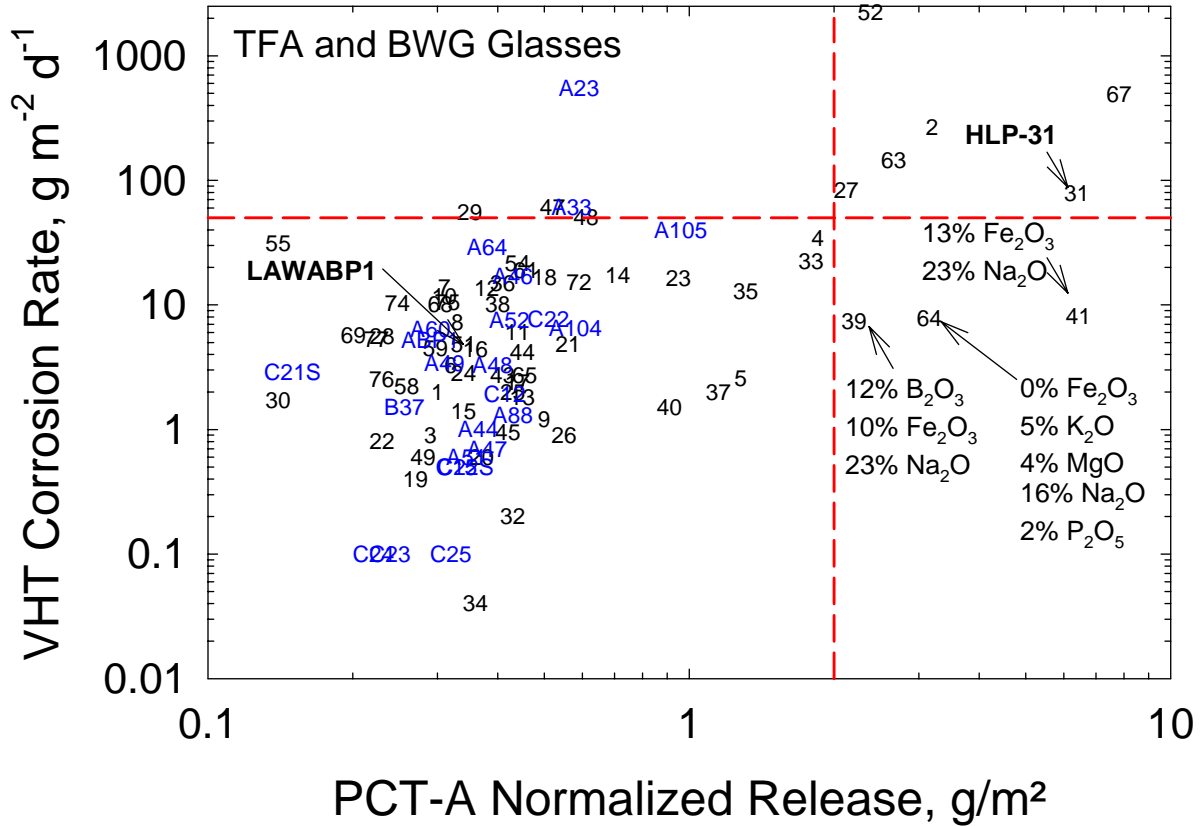


Figure A.10 VHT and PCT-A Responses of Typical LAW Glasses (from McGrail et al. 2001)

**PCT and VHT Responses as Functions of Composition**

The responses of LAW glasses to both VHT and PCT are strong functions of composition. Most notably, as the concentration of alkali ( $g_{R2O}$ ) increases, the test responses increase (with other composition variables held constant). However, the exact  $g_{R2O}$  that can be incorporated in LAW glasses and still meet the contract limits for PCT and VHT responses is a function of the remaining glass composition. Glasses with  $g_{Na2O}$  as high as 23 mass% have been found to meet both contract requirements (Vienna et al. 2001). However, normal plant operation requires some tolerance to process variations and uncertainties. It has been recognized that Hanford LAW glasses with  $g_{Na2O} \leq 20$  mass% (and currently anticipated LAW compositions) can be reliably made. Therefore,  $g_{Na2O} \leq 20$  mass% forms the basis for loading limitations on low sulfur LAW glasses to be produced at the WTP.

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## **Appendix B**

### **Summary of LAW Glass Composition Data from Catholic University of America, Vitreous State Laboratory**

This Appendix summarizes LAW glass testing data from glasses that have been developed to support the WTP Research and Technology activities to qualify the Low-Activity Waste form. The data presented represents glass formulations that meet the following conditions:

- Have a Product Consistency Test (PCT) leach rate of less than 2.0 gram/m<sup>2</sup>
- Have a Vapor Hydration Test alteration rate of less than 50 gram/m<sup>2</sup>-day.
- Tested in either a Crucible Melt or in a continuous melter experiment.

Figure C.1 below presents a graphical depiction of the glass data plotted as function of sodium oxide concentration and sulfur trioxide concentration in the glass. This graph also presents the various glass models that have been considered in this assessment. This graph illustrates that the majority of the glasses tested have been formulated to meet the WTP Contract objectives for ILAW waste-loading. Thus these glasses are grouped around the Gimpel Rule and VSL Melter Model. There are a number of glasses however that support the basis that WTP Contract compliant glasses can be formulated to support the DOE Glass Model which has been identified as a performance goal for this assessment.

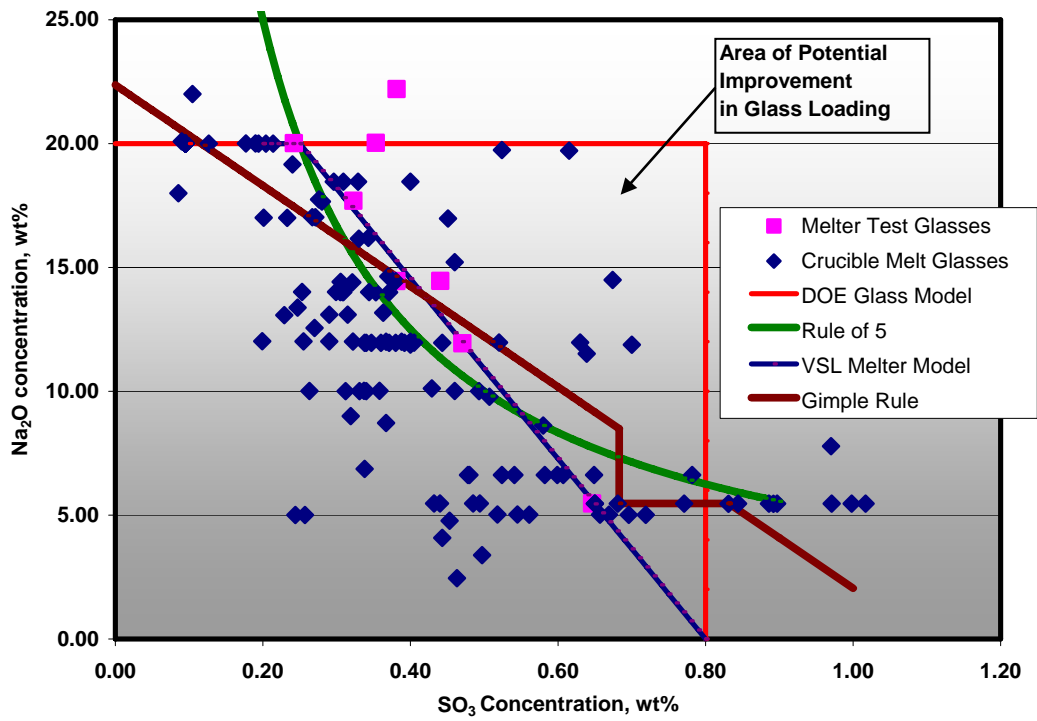


Figure B.1 Plot of CUA-VSL LAW Glass Testing Data and LAW Glass Models

**Table B.1 Summary of LAW Glass Composition Data from Catholic University of America , Vitreous State Laboratory with Acceptable Product Consistency (PCT) and Vapor Hydration Test (VHT) Results.**

Glass Name	Type	Concentration Na <sub>2</sub> O, wt%	Concentration SO <sub>3</sub> wt% (analyzed)	B PCT g/m <sup>2</sup>	Na PCT, g/m <sup>2</sup>	Si PCT, g/m <sup>2</sup>	PCT Total, g/m <sup>2</sup>	VHT, g/m <sup>2</sup> /d
A2_15minus	A2 Melter	17.69	0.32	0.3	0.29	0.14	0.73	0.4
A1-LAWA44	A1 Melter	20.02	0.24	0.54	0.47	0.22	1.23	1
C1-LAWC22	C1 Melter	14.45	0.38	0.48	0.43	0.2	1.11	1.1
A2-LAWA88	A2 Melter	20.03	0.35	0.42	0.37	0.16	0.95	1.4
B1-LAWB83	B1 Melter	5.47	0.65	0.25	0.22	0.1	0.57	1.8
C2-LAWC31	C2 Melter	11.94	0.47	0.24	0.24	0.1	0.58	12
A3-LAWA102	A3 Melter	14.46	0.44	0.4	0.41	0.17	0.98	13
A2_15plus	A2 Melter	22.20	0.38	0.59	0.51	0.21	1.31	32.1
C2_15minus	C2 Melter	10.36	0.41	0.2	0.22	0.09	0.51	NA
B2_15minus	B2 Melter	5.08	0.59	0.22	0.23	0.1	0.55	NA
B1_15plus	B1 Melter	6.21	0.72	0.25	0.23	0.1	0.58	NA
B2_15plus	B2 Melter	5.86	0.72	0.28	0.27	0.11	0.66	NA
C1-15minus	C1 Melter	12.60	0.34	0.29	0.26	0.12	0.67	NA
B2-LAWB96	B2 Melter	5.47	0.65	0.28	0.28	0.12	0.68	NA
A1 15minus	A1 Melter	17.71	0.22	0.31	0.29	0.16	0.76	NA
C2_15plus	C2 Melter	13.45	0.53	0.32	0.35	0.13	0.8	NA
A3_15minus	A3 Melter	16.18	0.48	0.39	0.37	0.14	0.9	NA
C1-15plus	C1 Melter	16.22	0.42	0.46	0.46	0.2	1.12	NA
A3_15plus	A3 Melter	12.88	0.39	0.48	0.48	0.18	1.14	NA
A1 15plus	A1 Melter	22.16	0.26	0.74	0.65	0.24	1.63	NA
B1_15minus	B1 Melter	4.72	0.57	NA	NA	NA		NA
LAWM9	Crucible - Matrix	5.01	0.24	0.11	0.26	0.07	0.42943	0.11

Glass Name	Type	Concentration Na <sub>2</sub> O, wt%	Concentration SO <sub>3</sub> wt% (analyzed)	B PCT g/m <sup>2</sup>	Na PCT, g/m <sup>2</sup>	Si PCT, g/m <sup>2</sup>	PCT Total, g/m <sup>2</sup>	VHT, g/m <sup>2</sup> /d
LAWM19	Crucible - Matrix	13.17	0.36	0.25	0.28	0.09	0.62136	0.11
LAWM22	Crucible - Matrix	16.98	0.45	0.20	0.31	0.14	0.65193	0.22
LAWA134	Crucible	17.74	0.28	0.46	0.39	0.15	0.99907	0.22
LAWM54R1	Crucible - Matrix	5.01	0.26	0.19	0.18	0.07	0.43842	0.33
LAWM46	Crucible - Matrix	12.02	0.20	0.24	0.23	0.09	0.56297	0.33
LAWA136	Crucible	17.03	0.27	0.38	0.35	0.15	0.88236	0.33
LAWM40	Crucible - Matrix	14.01	0.31	0.38	0.36	0.15	0.89245	0.33
LAWA135	Crucible	17.03	0.27	0.43	0.37	0.15	0.95338	0.33
LAWM50	Crucible - Matrix	13.09	0.29	0.32	0.31	0.13	0.76509	0.44
A2B1-1	Turnover crucible	15.21	0.46	0.36	0.32	0.16	0.84	0.5
LAWC15	Crucible	20.00	0.13	0.33	0.34	0.16	0.82645	0.5
LAWM4	Crucible - Matrix	5.02	0.56	0.23	0.30	0.09	0.62307	0.56
LAWM48	Crucible - Matrix	12.02	0.26	0.23	0.28	0.12	0.63385	0.56
LAWA51	Crucible	18.00	0.09	0.35	0.26	0.12	0.73284	0.56
LAWM51	Crucible - Matrix	13.09	0.32	0.35	0.36	0.13	0.83522	0.56
LAWA133	Crucible	20.00	0.20	0.54	0.57	0.22	1.33112	0.56
A2B1-2	Turnover crucible	11.97	0.52	0.34	0.3	0.15	0.79	0.6
LAWA47	Crucible	20.00	0.10	0.38	0.33	0.15	0.86412	0.64
LAWM28	Crucible - Matrix	10.02	0.36	0.18	0.26	0.11	0.5538	0.67
LAWA128	Crucible - Matrix	18.46	0.30	0.31	0.43	0.18	0.92367	0.67
LAWA130	Crucible - Matrix	18.46	0.33	0.46	0.46	0.18	1.10029	0.67
A1C1-1	Turnover crucible	19.16	0.24	0.43	0.43	0.19	1.05	0.7
A1C1-3	Turnover crucible	16.16	0.33	0.45	0.42	0.18	1.05	0.7
A3-AN104	Turnover crucible	14.64	0.37	0.54	0.53	0.2	1.27	0.7
LAWM5	Crucible - Matrix	5.02	0.55	0.01	0.14	0.08	0.22424	0.78
LAWM42	Crucible - Matrix	14.01	0.30	0.27	0.29	0.13	0.69054	0.78

Glass Name	Type	Concentration Na <sub>2</sub> O, wt%	Concentration SO <sub>3</sub> wt% (analyzed)	B PCT g/m <sup>2</sup>	Na PCT, g/m <sup>2</sup>	Si PCT, g/m <sup>2</sup>	PCT Total, g/m <sup>2</sup>	VHT, g/m <sup>2</sup> /d
A2-AP101	Turnover crucible	18.46	0.4	0.78	0.56	0.2	1.54	0.8
LAWA53	Crucible - Matrix	19.72	0.62	0.41	0.53	0.18	1.1157	0.82
LAWM23	Crucible - Matrix	10.02	0.34	0.14	0.26	0.10	0.49492	1.0
LAWM29	Crucible - Matrix	10.01	0.31	0.25	0.24	0.14	0.63536	1.0
LAWM43	Crucible - Matrix	12.00	0.39	0.33	0.33	0.14	0.7926	1.0
LAWM21	Crucible - Matrix	10.01	0.46	0.45	0.48	0.16	1.07954	1.0
LAWA44R10	Crucible - Matrix	20.09	0.09	0.54	0.47	0.22	1.22188	1.00
LAWC22AN107	Crucible	14.42	0.31	0.57	0.56	0.21	1.34	1.1
LAWB80	Crucible - Matrix	6.62	0.58	0.44	0.36	0.13	0.93106	1.1
LAWB92	Crucible	10.11	0.43	0.46	0.40	0.15	1.00296	1.1
LAWM37	Crucible - Matrix	12.01	0.32	0.62	0.49	0.16	1.26786	1.1
LAWB65	Crucible - Matrix	5.46	0.89	0.28	0.24	0.10	0.62121	1.2
LAWB95	Crucible	2.46	0.46	0.33	0.22	0.11	0.66381	1.2
LAWB85	Crucible - Matrix	5.47	0.49	0.33	0.25	0.12	0.69823	1.2
LAWB79	Crucible - Matrix	8.62	0.58	0.55	0.49	0.15	1.18581	1.2
LAWB71	Crucible	6.62	0.48	0.32	0.28	0.12	0.71348	1.3
LAWB91	Crucible	8.72	0.37	0.39	0.35	0.14	0.88503	1.3
LAWA88	Crucible	20.00	0.21	0.43	0.43	0.17	1.03	1.3
LAWA88R1	Crucible - Matrix	20.00	0.19	0.82	0.65	0.23	1.68982	1.3
LAWM8	Crucible - Matrix	5.02	0.70	0.16	0.14	0.07	0.36894	1.4
B1-AZ101	Turnover crucible	5.47	0.65	0.39	0.27	0.13	0.79	1.5
LAWB37	Crucible	7.79	0.97	0.26	0.18	0.11	0.54865	1.6
LAWB94	Crucible	3.38	0.50	0.35	0.23	0.11	0.70299	1.6
LAWB90	Crucible	6.86	0.34	0.31	0.27	0.13	0.71053	1.6
LAWB67	Crucible	5.46	0.97	0.24	0.14	0.11	0.49674	1.7

Glass Name	Type	Concentration Na <sub>2</sub> O, wt%	Concentration SO <sub>3</sub> wt% (analyzed)	B PCT g/m <sup>2</sup>	Na PCT, g/m <sup>2</sup>	Si PCT, g/m <sup>2</sup>	PCT Total, g/m <sup>2</sup>	VHT, g/m <sup>2</sup> /d
LAWM18	Crucible - Matrix	10.01	0.34	0.22	0.25	0.10	0.56573	1.7
LAWB64	Crucible	5.46	0.68	0.28	0.24	0.11	0.62794	1.7
LAWB84	Crucible - Matrix	5.47	0.44	0.34	0.28	0.12	0.74002	1.7
LAWB93	Crucible	4.78	0.45	0.43	0.25	0.11	0.78885	1.7
LAWB86	Crucible - Matrix	5.47	0.43	0.63	0.51	0.17	1.29751	1.7
LAWA56	Crucible - Matrix	19.74	0.52	0.87	0.59	0.16	1.62067	1.67
LAWB89	Crucible	4.08	0.44	0.30	0.23	0.13	0.65738	1.8
LAWB83	Crucible - Matrix	5.47	0.49	0.31	0.26	0.12	0.68463	1.8
LAWC12	Crucible	20.00	0.19	0.42	0.41	0.18	1.01342	1.8
LAWC31-Ca	Crucible	11.96	0.34	0.35	0.38	0.15	0.886	1.9
LAWB66	Crucible - Matrix	5.46	0.65	0.29	0.27	0.11	0.67568	1.9
LAWB77	Crucible	6.62	0.52	0.36	0.30	0.12	0.77758	1.9
LAWC33	Crucible	12.00	0.40	0.35	0.38	0.15	0.88162	1.9
LAWB68	Crucible - Matrix	5.46	0.83	0.25	0.24	0.10	0.58939	2.0
LAWC31+Sn	Crucible	11.96	0.36	0.32	0.34	0.15	0.80786	2.1
LAWM6	Crucible - Matrix	9.00	0.32	0.27	0.36	0.10	0.72707	2.1
LAWM44	Crucible - Matrix	12.01	0.29	0.25	0.28	0.12	0.64819	2.2
LAWC26	Crucible	11.96	0.35	0.34	0.33	0.11	0.78116	2.4
LAWA126	Crucible - Matrix	18.46	0.31	0.60	0.52	0.17	1.28739	2.4
LAWC22Si+15	Crucible	16.19	0.34	0.64	0.83	0.23	1.7	2.5
LAWM49	Crucible - Matrix	14.00	0.35	0.27	0.25	0.11	0.62768	2.6
C100-G-136B	Melter - Matrix	11.89	0.40	0.37	0.35	0.13	0.848	2.6
LAWB72	Crucible	6.62	0.61	0.44	0.38	0.13	0.95303	2.6
LAWB78	Crucible - Matrix	9.78	0.51	0.61	0.56	0.16	1.32955	2.6
LAWB81	Crucible	6.62	0.60	0.45	0.39	0.13	0.97401	2.7

Glass Name	Type	Concentration Na <sub>2</sub> O, wt%	Concentration SO <sub>3</sub> wt% (analyzed)	B PCT g/m2	Na PCT, g/m2	Si PCT, g/m2	PCT Total, g/m2	VHT, g/m2/d
LAWM47	Crucible - Matrix	14.01	0.31	0.26	0.37	0.13	0.7611	2.8
LAWC21S	Crucible	11.88	0.70	0.15	0.17	0.08	0.40185	2.9
LAWM7	Crucible - Matrix	5.01	0.72	0.12	0.21	0.11	0.44601	2.9
LAWM52	Crucible - Matrix	20.01	0.18	0.72	0.58	0.21	1.50995	3.1
LAWC22Si-15	Crucible	12.56	0.27	0.46	0.35	0.18	0.99	3.2
LAWA48	Crucible	20.00	0.10	0.39	0.33	0.15	0.8842	3.2
A1C1-2	Turnover crucible	17.66	0.28	0.41	0.44	0.18	1.03	3.3
LAWA49	Crucible	20.00	0.10	0.31	0.29	0.15	0.75484	3.3
LAWB73	Crucible	5.46	0.90	0.21	0.19	0.09	0.48367	3.4
LAWM26	Crucible - Matrix	10.01	0.49	0.21	0.18	0.11	0.49405	3.4
LAWB70	Crucible	6.62	0.54	0.56	0.47	0.15	1.17962	3.4
LAWB82	Crucible	6.62	0.48	0.25	0.23	0.09	0.56986	3.6
LAWA102R1	Crucible - Matrix	14.50	0.67	0.43	0.37	0.18	0.97574	3.8
LAWM3	Crucible - Matrix	11.52	0.64	0.40	0.58	0.13	1.10176	3.8
LAWB62	Crucible	5.46	0.89	0.16	0.18	0.08	0.42351	4.1
LAWM25R1	Crucible - Matrix	10.01	0.26	0.41	0.29	0.13	0.82713	4.6
LAWM41	Crucible - Matrix	14.00	0.34	0.18	0.29	0.12	0.59003	4.8
LAWM45	Crucible - Matrix	14.01	0.31	0.21	0.29	0.11	0.62068	4.9
LAWM27	Crucible - Matrix	13.38	0.25	0.34	0.42	0.13	0.89513	5.0
LAWB74	Crucible	5.46	0.77	0.23	0.20	0.09	0.51854	5.8
LAWA60	Crucible	20.00	0.10	0.29	0.31	0.11	0.71456	6.2
LAWB75	Crucible	5.46	1.00	0.17	0.14	0.08	0.3958	6.6
LAWA104	Crucible	22.00	0.10	0.58	0.53	0.21	1.31636	6.6
LAWC30	Crucible	11.96	0.34	0.30	0.33	0.13	0.75632	6.7
LAWA52	Crucible	20.00	0.10	0.43	0.55	0.17	1.14828	7.4
LAWB60	Crucible	6.62	0.78	0.22	0.22	0.10	0.53891	7.6

Glass Name	Type	Concentration Na <sub>2</sub> O, wt%	Concentration SO <sub>3</sub> wt% (analyzed)	B PCT g/m <sup>2</sup>	Na PCT, g/m <sup>2</sup>	Si PCT, g/m <sup>2</sup>	PCT Total, g/m <sup>2</sup>	VHT, g/m <sup>2</sup> /d
LAWC22	Crucible	14.40	0.32	0.48	0.43	0.2	1.11	7.7
LAWM16	Crucible - Matrix	10.01	0.33	0.14	0.21	0.08	0.42868	7.9
LAWB63	Crucible	5.46	0.84	0.18	0.17	0.08	0.43644	7.9
LAWM2	Crucible - Matrix	5.02	0.67	0.34	0.43	0.15	0.91496	8.3
LAWB76	Crucible	5.46	1.02	0.21	0.18	0.09	0.4828	8.7
C1-AN107	Turnover crucible	14.45	0.38	0.51	0.53	0.21	1.25	8.9
LAWM1	Crucible - Matrix	5.02	0.52	0.08	0.15	0.07	0.2866	9.1
LAWM53	Crucible - Matrix	5.02	0.66	0.09	0.13	0.06	0.2797	10.0
LAWC28	Crucible	11.96	0.44	0.14	0.22	0.08	0.44414	10.2
LAWC29	Crucible	11.96	0.37	0.15	0.21	0.08	0.44063	11.8
LAWM36	Crucible - Matrix	12.00	0.37	0.24	0.30	0.12	0.66552	11.9
LAWC31	Crucible	11.96	0.39	0.27	0.31	0.12	0.7074	12.2
LAWM39	Crucible - Matrix	14.01	0.25	0.27	0.23	0.11	0.60586	12.4
LAWM10	Crucible - Matrix	13.07	0.23	0.12	0.22	0.07	0.41231	12.7
LAWM24	Crucible - Matrix	17.00	0.23	0.53	0.41	0.14	1.08106	13.7
C2-AN102C35	Turnover crucible	11.97	0.63	0.34	0.38	0.15	0.87	13.7
LAWB69	Crucible	6.62	0.65	0.25	0.24	0.10	0.58298	14.2
LAWA46	Crucible	20.00	0.10	0.43	0.35	0.16	0.94132	16.7
LAWM38	Crucible - Matrix	14.00	0.37	0.19	0.34	0.13	0.66545	19.0
LAWC27	Crucible - Matrix	11.96	0.41	0.19	0.22	0.09	0.49994	19.7
LAWM30	Crucible - Matrix	17.01	0.20	0.59	0.51	0.15	1.25491	20.1
LAWC32	Crucible	11.96	0.38	0.21	0.28	0.10	0.5891	22.9
LAWA64	Crucible	20.00	0.10	0.38	0.50	0.18	1.05361	28.6



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## Appendix C

### Derivation of Equations Used in Excel Spread Sheet Calculations

#### Introduction

The following summarizes:

The derivation of equations that characterize the three sulfate models considered in the assessment of factors affecting the glass waste-loading in WTP LAW glass. These models, referred to as the Gimpel, VSL(Morrey) and DOE Models, determine the permissible Na<sub>2</sub>O (soda) weight percent in the glass as a function of SO<sub>3</sub> (sulfur trioxide) weight percent in the glass.

The derivation of equations that implement the waste classification definitions of 10 CFR 61.55, "Waste Classification." These were applied to the waste characterization data contained from Best Basis Inventory 2002, contained in Excel spreadsheet "Composite BBI Transposed Table\_R6\_03.xls."

#### General:

The glass model calculations are implemented in separate worksheets of an Excel Workbook named "ProcessModels.xls". The calculation worksheets are designated as "Gimpel", "VSL" and "DOE" for the three models. Constants for the calculations are contained in Worksheet "Constants". The input data and calculation results are arranged in columns. The specific data and calculations for each tank are in rows. Attached are copies of the results for the three spreadsheets and the "Constants" worksheet. The following summarizes the calculations performed in the columns of these worksheets and the sources of the input data and constants used in these calculations

#### Tank Waste Constituents

##### Glass Models

The tank waste constituents considered in this calculation include the mass (kg) of sodium (Na) and sulfate (SO<sub>4</sub>) and the curies of Cs-137 and Tc-99. The mass of sodium and sulfate and the curies of cesium and technetium were taken from the Best Basis Inventory (2002). These are stored in Columns C, F, I and J, respectively, as inputs to the calculation.

Sodium is added to the tank waste sodium during the pretreatment process. Some waste sodium and sulfate is also lost to HLW and ETF during pretreatment. The amount added and lost in pretreatment is handled on a percentage basis using data from the most recent System Plan [ ].

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The mass of sodium fed to WTP LAW is calculated in the following expression:

Column D:

$$=IF(OR(B4="TRU"),0,C4*(1+Sludge\_Na+Non\_Waste\_Na-HLW\_Na-ETF\_Na))$$

Where:

Column B defines the type of waste for a specific tank. This calculation does not include the TRU tank waste since it will be processed outside WTP.

Sludge\_Na is a named constant that represents the percentage of Na added in the sludge washing cycle = 12.9%

Non\_Waste\_Na is a named constant that represents the percentage of “non-waste” Na added in pretreatment = 3.1%

HLW\_Na is a named constant that represents the percentage of Na that is sent to HLW = 3.5%

ETF\_Na is a named constant that represents the percentage of Na that is sent to ETF = 0.4%

Similarly, the amount of sulfate fed to the WTP Law Melter is calculated in the following expression:

Column G:

$$=IF(OR(B4="TRU"),0,F4*(1-HLW\_SO4-ETF\_SO4))$$

Where:

HLW\_SO4 is a named constant that represents the percentage of SO<sub>4</sub> that is sent to HLW = 2.7%

ETF\_SO4 is a named constant that represents the percentage of SO<sub>4</sub> that is sent to ETF = 2.5%

From the net calculated Na and sulfate a sulfate to Na ratio is calculated:

Column K:

$$=IF(D4>0,G4/D4,0)$$

This ratio is used in the model calculations.

## Waste Classification

The waste constituents considered for this calculation were obtained from the Best Basis Inventory (2002) resident in Excel Spreadsheet “Composite BBI Transposed Table\_R6\_03.xls”. These include the curies in each tank of the following radionuclides.

Long lived isotopes:

C-14, I-129, Ni-59, Pu-241, Tc-99 and TRU (Am-241, Cm-244, Np-237, Pu-238, Pu-239, Pu-240, Pu-242)

These are contained in columns G through AB.

Short lived isotopes:

Co-60, Cs-137, H-3, Ni-63, Sr-90

These are contained in columns AC through AU

## Gimpel Model

### Modeling Equations

The Gimpel Model is represented by the following expression; also shown graphically in the figure.

$$g_{\text{soda}} = 22.369 - 20.321 g_{\text{sulfate}}; 0 \geq g_{\text{sulfate}} \leq 0.683 \text{ and } g_{\text{sulfate}} \geq 0.832$$

$$g_{\text{soda}} = 5.47; 0.683 < g_{\text{sulfate}} < 0.832$$

Where:

$g_{\text{soda}}$  = weight percent of Na<sub>2</sub>O in the glass

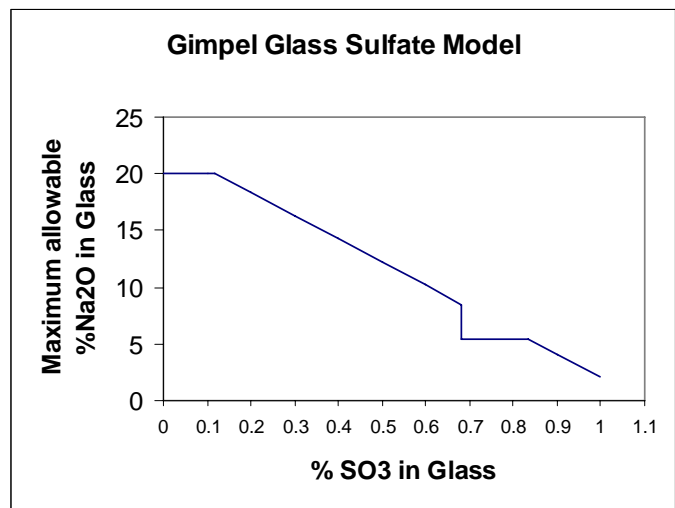
$g_{\text{sulfate}}$  = weight percent of SO<sub>3</sub> in the glass

$$g_{\text{soda}} = M_{\text{soda}} / M_{\text{glass}}$$

$$g_{\text{sulfate}} = M_{\text{sulfate}} / M_{\text{glass}}$$

For a given tank

$$M_{\text{soda}} = M_{\text{Na}} \times \text{Mole}_{\text{Na}_2\text{O}} / \text{Mole}_{\text{Na}_2}$$



$$M_{\text{sulfate}} = M_{\text{SO}_4} \times \text{Mole}_{\text{SO}_3} / \text{Mole}_{\text{SO}_4}$$

Where:

$$\begin{aligned} \text{Mole}_{\text{Na}_2\text{O}} &= 62 \\ \text{Mole}_{\text{Na}} &= 23 \\ \text{Mole}_{\text{SO}_4} &= 96 \\ \text{Mole}_{\text{SO}_3} &= 80 \end{aligned}$$

Therefore:

$$M_{\text{glass}} = (M_{\text{Na}} \times \text{Mole}_{\text{Na}_2\text{O}} / \text{Mole}_{\text{Na}}) / g_{\text{soda}}$$

$$g_{\text{sulfate}} = g_{\text{soda}} (M_{\text{SO}_4} \times \text{Mole}_{\text{SO}_3} / \text{Mole}_{\text{SO}_4}) / (M_{\text{Na}} \times \text{Mole}_{\text{Na}_2\text{O}} / \text{Mole}_{\text{Na}})$$

Writing:

$$M_{\text{R}} = (M_{\text{SO}_4} / M_{\text{Na}}) \times (\text{Mole}_{\text{SO}_3} / \text{Mole}_{\text{SO}_4}) / (\text{Mole}_{\text{Na}_2\text{O}} / \text{Mole}_{\text{Na}})$$

In accordance with the Gimpel Model,  $g_{\text{soda}} = A - B g_{\text{sulfate}}$

Where:

$$\begin{aligned} A &= 22.369 \\ B &= 20.321 \end{aligned}$$

$$g_{\text{soda}} = A - B g_{\text{soda}} M_{\text{R}}$$

$$g_{\text{soda}} = A / (1 + B M_{\text{R}}), \text{ and}$$

$$g_{\text{sulfate}} = g_{\text{soda}} M_{\text{R}}$$

If the (SO<sub>4</sub>/Na) ratio will produce a  $g_{\text{sulfate}}$  between 0.683 and 0.832, then  $g_{\text{soda}} = 5.47$   
and  $g_{\text{sulfate}} = M_{\text{R}} \times g_{\text{soda}}$

In the Excel File "ProcessModels", the following equation is used to represent this model:

Column L:

$$= \text{IF}(\$K4 > 0, \text{IF}(\text{OR}(\$K4 < S\_Na683, \$K4 > S\_Na832), \text{Const\_3} / (1 - \text{Const\_4} * \text{Co1\_Co2} * \$K4), 5.47), 0)$$

Where:

K4 is the SO<sub>4</sub>/Na ratio for tank 4  
S\_Na683 is a named constant = SO<sub>4</sub>/Na at an SO<sub>3</sub> concentration of 0.683  
S\_Na823 is a named constant = SO<sub>4</sub>/Na at an SO<sub>3</sub> concentration of 0.832

$$\text{Const\_3} = 22.369$$

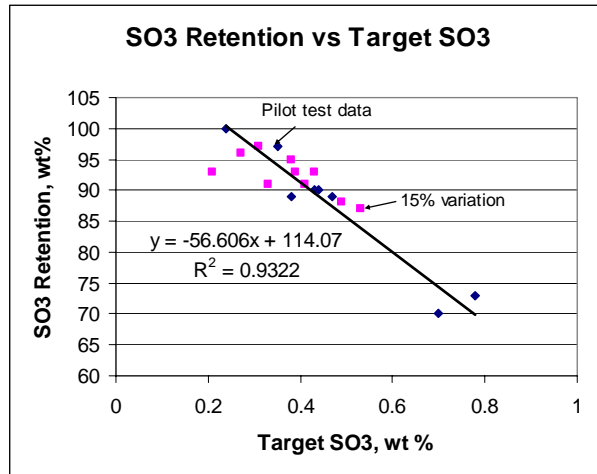
$$\text{Const\_4} = -20.321$$

This formulation is used as an approximation for the condition where the SBS condensate is recycled to pretreatment and, therefore, all sulfate must eventually be incorporated in WTP LAW glass.

The sulfate concentration in the LAW feed is reduced in the glass melt as the sulfate boils off and is captured in the off-gas system and ultimately condensed out in the Submerged Bed Scrubbers. The case where the SBS condensate is not recycled but purged from the WTP is handled by multiplying the SO<sub>4</sub>/Na ratio by the sulfate retention factor determined from the work by Gimpel.

### SO<sub>3</sub> Retention

For the purpose of this analysis we have defined the relationship between the amount of sulfate retained in the glass melt and the target sulfate concentration by a line fit to data reported by Gimpel. The data and the linear curve fit are shown in the figure. Target SO<sub>3</sub> is the wt% of SO<sub>3</sub> that would be present if all of the sulfate were present in the glass. In the Excel spread sheet the percentage of sulfate retained is represented by the following expression:



Column P:

$$=IF(O4>DOE\_cutoff,Reten\_Min,IF(O4>Reten\_LIM,Reten\_2+Reten\_1*O4,100))$$

$$O4=IF(M4>0,Const\_1*G4/M4,0)$$

Where:

Column O contains the sulfate concentration for 100% retention of the sulfate; calculated as described above.

DOE\_cutoff is a named constant = 0.8 wt% SO<sub>3</sub>

Reten\_Min = 68.9 %, the retention at 0.8 wt% SO<sub>3</sub>. It is assumed that the retention does not fall below this value if the SO<sub>3</sub> concentration is above 0.8 wt%.

Reten\_LIM = 100%, the maximum possible retention

Reten\_2 is a named constant = 114.07

Reten\_1 is a named constant = -56.606

This retention value is stored as a percentage in Column P

---

Note that this same correlation by Gimpel is used for the other glass models when calculating the SBS condensate purge condition.

### Waste Loading with SBS Condensate Purge

The following expression is used to determine the glass Na<sub>2</sub>O weight percent when the SBS condensate is purged:

Column Q:

=IF(\$K4>0,IF(OR(\$K4\*P4/100<S\_Na683,\$K4\*P4/100>S\_Na832),Const\_\_3/(1-Const\_4\*Co1\_Co2\*\$K4\*P4/100),5.47),0)

Where the nomenclature is the same as described above and P4 contains the retention value in percent for tank 4.

### Mass of Glass Produced:

The mass of glass produced for each tank (represented by the row number in column M for the case where SBS Condensate is recycled and Column R where the SBS condensate is purged from the cycle) is calculated from the amount of sodium sent to the LAW melter and the Na<sub>2</sub>O wt% calculated for the specific sulfate model used. The quantity of glass is calculated for the SBS condensate recycle and purge conditions as follows:

- SBS Condensate Recycle:

Column M:

=IF(\$L4>0,D4\*Const\_2/\$L4,0)

Where:

Column D is the mass of sodium fed to the LAW melter from tank 4 in kg  
Note that the mass of sodium in column D reflects wash and leach and other process additions in pretreatment, as follows:

=IF(OR(B4="TRU",B4="LLW"),0,C4\*(1+Sludge\_Na+Non\_Waste\_Na-HLW\_Na-ETF\_Na))

Where:

Waste from TRU and LLW tanks (as identified in column B4) is not included since this waste will not be processed in WTP LAW.

C4 is the Na content in Tank 4, in kg

Sludge\_Na is a named constant representing the fraction added in the wash and leach process

Non\_Waste Na is a named constant representing the fraction added by other pretreatment processes

---

HLW\_Na is a named constant representing the fraction of Na that is sent to HLW

ETF\_Na is a named constant representing the fraction of Na that is sent to ETF

(Note that these constants are based on data from the System Plan -- Case 3 Data Figure D-1, pD-4, ORP-11242, Rev 1 April 2003)

Column L is the wt% of Na<sub>2</sub>O calculated for the sulfate model and sulfate concentration in tank4

$$\begin{aligned}\text{Const\_2 is a named constant} &= 100 [\%/unit] \times \text{Na}_2\text{O}[\text{kg moles}] / \text{Na} [\text{kg} \\ &\quad \text{moles}]/1000 [\text{kg/MT}] \\ &= 100 (62/46)/1000 \\ &= 0.1348\end{aligned}$$

- SBS Condensate Purge:

Column R

$$=IF(Q4>0,100*\$D4*\text{Na}_2\text{O\_Na}/Q4/1000,0)$$

Where:

Column Q is the wt% of Na<sub>2</sub>O calculated for the sulfate model and sulfate concentration in tank4

Note that similar equations are used to calculate the mass of glass produced for the other two models for the two options for SBS Condensate .

### **Accumulative Glass Production**

For each model and SBS Condensate path, the accumulative amount of glass produced for all tanks is calculated by summing the amount produced for each tank. This is done in the column directly after the mass of glass calculation, (i.e., Columns M and S for the Gimpel and VSL Models and columns N and S for the DOE Model).

## VSL (Morrey) Model

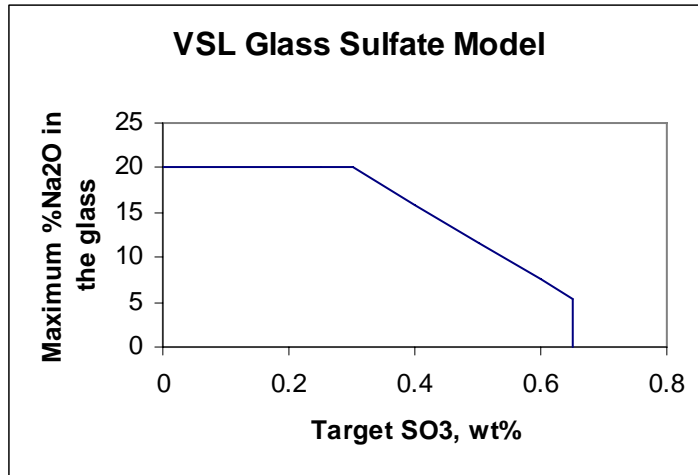
An expression similar to that of the Gimpel Model is used to represent the VSL (also referred to as the Morrey) model as follows; shown graphically in the figure.

$$g_{\text{soda}} = 32.45 - 42.51 g_{\text{sulfate}}; 0.3 \text{ wt}\% \geq g_{\text{sulfate}} \leq 0.65 \text{ wt}\%$$

$$g_{\text{soda}} = 20.0; g_{\text{sulfate}} < 0.3 \text{ wt}\%$$

$$g_{\text{soda}} = 0.0; g_{\text{sulfate}} > 0.65 \text{ wt}\%$$

This model is developed and represented in the same manner as the Gimpel Model for  $g_{\text{Sulfate}} \leq 0.65 \text{ wt}\%$ . If  $g_{\text{Sulfate}} > 0.65 \text{ wt}\%$  then the  $g_{\text{Soda}}$  must be restricted to a value between 5.47 wt%, the value at the second breakpoint and 0. This is determined by the mass of glass that is required to maintain the  $g_{\text{Sulfate}} = 0.65 \text{ wt}\%$ . Writing:



$$M_{\text{Glass}} = M_{\text{SO}_3} \times 100 / g_{\text{Sulfate}} / 1000 \text{ [MT/kg]}$$

$$= M_{\text{SO}_4} \times \text{molesSO}_3 / \text{molesSO}_4 / 0.0065 / 1000; \text{ in MT}$$

$$M_{\text{Na}_2\text{O}} = M_{\text{Na}} (\text{moles Na}_2\text{O} / \text{moles Na}_2) / 1000; \text{ in MT}$$

$$g_{\text{Soda}} = M_{\text{Na}_2\text{O}} / M_{\text{Glass}}; \text{ in percent, inserting the expression for } M_{\text{Glass}}$$

$$g_{\text{Soda}} = M_{\text{Na}} (\text{moles Na}_2\text{O} / \text{moles Na}_2) \times 0.65 / (M_{\text{SO}_4} \times \text{molesSO}_3 / \text{molesSO}_4)$$

The following are the equations used in the "VSL" worksheet to represent the VSL (Morrey) model for the SBS Condensate Recycle and Purge conditions.

- SBS Condensate Recycle

Column L:

$$=IF(\$K4>0,IF(\$K4<S\_Nalow,DOE\_Max,IF(\$K4>S\_Nahi,SO3BrkHi/(Co1\_Co2*\$K4),Intercept/(1-Slope*Co1\_Co2*\$K4))),0)$$

Where:

S\_Nalow is the lower breakpoint in the model at  $\text{SO}_3 = 0.3 \text{ wt}\%$

S\_Nahi is the upper breakpoint in the model at  $\text{SO}_3 = 0.65 \text{ wt}\%$

SO3BrkHi is the  $\text{Na}_2\text{O}$  value at the upper breakpoint = 5.47



---

Co1\_Co2 is a named constant = (moles SO<sub>3</sub> / moles SO<sub>4</sub>) / (moles Na<sub>2</sub>O / moles Na<sub>2</sub>) = 0.6183

- SBS Condensate Purge

Column Q:

=IF(\$K4>0,IF(\$K4\*P4/100<S\_Nalow,DOE\_Max,IF(\$K4\*P4/100>S\_Nahi,SO3BrkHi/(Co1\_Co2\*\$K4\*P4/100),Intercept/(1-Slope\*Co1\_Co2\*\$K4\*P4/100))),0)

The calculations for mass of glass for both conditions are the same as described for the Gimpel Model

## DOE Glass Model

### Equations

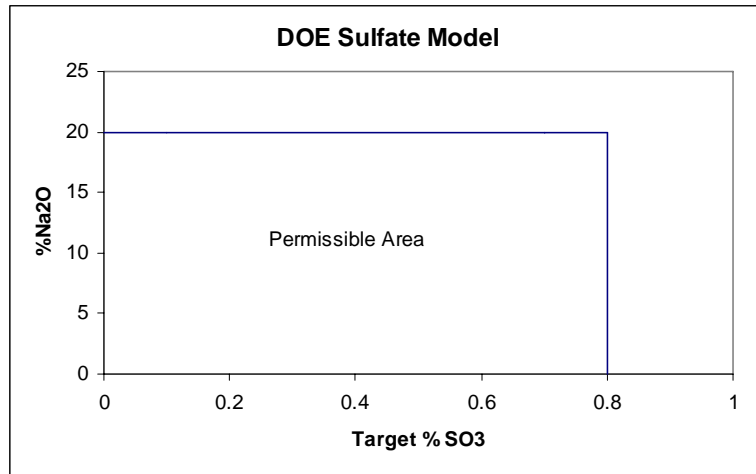
The DOE Model is represented by the following expression; shown graphically in the figure.

$$g_{\text{Soda}} = 20.0; g_{\text{Sulfate}} \leq 0.8 \text{ wt\%}$$

$$= 0.0; g_{\text{Sulfate}} > 0.8 \text{ wt\%}$$

This model is implemented in a manner similar to the Gimpel and DOE Models.

If the Target % SO<sub>3</sub> is greater than 0.8 wt%, g<sub>Soda</sub> must be between 20 wt% and zero. In a manner similar to the VSL Model for a given sulfate and sodium content that exceeds a target of 0.8 wt%,



$$g_{\text{Soda}} = M_{\text{Na}} (\text{moles Na}_2\text{O} / \text{moles Na}_2) \times 0.8 / (M_{\text{SO}_4} \times \text{molesSO}_3 / \text{molesSO}_4)$$

The following expressions are used to represent the DOE Model in the “DOE” worksheet.

- SBS Condensate Recycle

Column L:  
=K4\*20\*SO3\_SO4/Na2O\_Na

Where:

L is the sulfate weight percent for 20 wt% Na<sub>2</sub>O for the SO<sub>4</sub>/Na ratio of tank 4 [Column K4]

(Note these columns in the DOE worksheet are shifted to the right one column when compared with the Gimpel and VSL worksheets.)

Column M:  
=IF(L4>0,IF(L4<=DOE\_cutoff,DOE\_Max,DOE\_cutoff\*Na2O\_Na/K4/SO3\_SO4),0)

---

Where:

DOE\_cutoff is a named constant = 0.8 wt% SO<sub>3</sub>

DOE\_Max is a named constant = 20 wt% Na<sub>2</sub>O

- SBS Condensate Purged

Column Q:

=IF(\$L4>0,IF(\$L4\*P4/100<=DOE\_cutoff,DOE\_Max,DOE\_cutoff\*Na2O\_Na/(\$K4\*P4/100)/SO3\_SO4),0)

Where P4 is the SO<sub>3</sub> retention factor (in percent) for tank 4.

The mass of glass generated for each tank is calculated from the Na<sub>2</sub>O wt% and the mass of Na for each tank as described for the other models.

### **Calculations of Cs 137 and Tc-99 Concentrations and Comparison with 10CFRLimits for Class C waste**

All the model worksheets contain calculations of the Tc-99 concentrations in the glass for the SBS Condensate Purge path (the path for which the higher Na<sub>2</sub>O concentration is calculated and, therefore, the more conservative) and a check of the concentrations against Class C limits for waste disposal. The DOE Model worksheet has an additional calculation and check for Cs-137 assuming that the tank waste is not pre-treated to remove Cs. The limits are based on Tables 1 and 2 of 10 CFR Ch.I (1-I-99 Edition).

Note that these are simple checks for Tc-99 and Cs-137 and are not reflective of the actual classification of the waste. That calculation is performed in another Excel file as described in Section 8.0, below.

The following expressions are used for these calculations:

Column T:

=J16/(R16/Glass\_Density)

Where:

J16 is the Tc-99 curie content for tank 16

R16 is the mass of glass produced for tank 16, MT

Glass\_Density is a named constant = 2.7 MT/m<sup>3</sup>

Column U:

=IF(T16>=3,"EXCEEDS", "")

Where 3 Ci/m<sup>3</sup> is the Class C limit for Tc-99

Column V:

---

=I16/(R16/Glass\_Density)

Where:

I16 is the Cs-137 curie content for tank 16

Column W:

=IF(T16>=3,"Tc Exceeds",IF(T16<=0.3,IF(V16>3000,"Cs Exceeds","ClassC1"),IF(V16<=1,"Class A",IF(V16<=44,"Class B",IF(V16>3000,"Cs Exceeds","ClassC2")))))

Where the limits on Cs-137 depends on the logic in Section 61.55 and Tables 1 and 2 of 10 CFR Ch.I (1-I-99 Edition).

---

## Implementation of Selection Logic

### Equations

The logic for selection of whether a specific tank waste should be treated in WTP LAW or supplemental treatment is implemented in the “DOE” worksheet. Section \_\_\_\_ describes the selection logic considered in this report. In summary, the logic states that the tank waste is to be treated in WTP LAW unless the tank is classified as Low Level Waste (LLW), Low Curie LAW (LCLAW) or the waste cannot be treated at 20 wt% or higher Na<sub>2</sub>O. The LLW and LCLAW tank classifications were obtained from reference [ ] and are listed in Table 1 of the main body of the report.

Columns X thru AA are used to implement the logic. Columns X thru Z list the tanks that are to be immobilized in supplemental treatment, Column AA lists the tanks that are to be immobilized in WTP LAW. The following expressions are applied in each of these columns.

Column X (LLW tanks):

=IF(\$B4="TRU", "", IF(\$B4="LLW", A4, ""))

Where:

B4 is the classification for Tank 4

A4 is the designation (number) for Tank 4

Note that the TRU tanks are not included in the population of tanks to be treated by either WTP LAW or supplemental treatment

Column Y (Low Curie LAW tanks):

=IF(\$B4="TRU", "", IF(\$B4="LCLAW", A4, ""))

Column Z (Tank waste that WTP LAW glass is < 20 wt% Na<sub>2</sub>O):

=IF(\$B4="TRU", "", IF(\$M4 >= 20, "", IF(OR(\$B4="LLW", \$B4="LCLAW"), "", A4)))

Where:

M4 is the calculated wt% Na<sub>2</sub>O for WTP LAW glass for the waste in Tanks 4, assuming recycle of SBS condensate, i.e., all sulfate is processed in WTP LAW

### Data Reduction and Plotting

Manipulation of the data for the specific tanks selected for treatment in WTP LAW or supplemental treatment (ST) is done in a separate Excel workbook entitled “SST WTP-ST Selection.xls”. This workbook contains several worksheets as follows:

WTP – contains Na and Glass data for all the tanks to be sent to WTP

---

ST -- contains Na and Glass data for all the tanks to be sent to supplemental treatment

Note that in both of these worksheets the tank data is arranged in the order of tank retrieval. The order was obtained from the SST retrieval sequence published for the most recent System Plan [ ] and from the DST tank processing sequence used in Case 1 of HTWOS of the TFCOUP [ ]. The latter sequence is covered in worksheets PH1, PH1-WTP and PH1-ST. Also all the glass data assumes the DOE Model and SBS Condensate recycle.

In these worksheets two calculations are performed. In WTP, the time to process the accumulative glass required to immobilize the tank waste sent to WTP-LAW is calculated by tank for the Base Case and Target Case WTP glass production rates, 28.8 MTG/day and 34.0 MTG/day, respectively. The total elapsed time for immobilization is then combined, in worksheet ST, with the total amount of waste to be treated in ST to calculate the required ST treatment rate for each of the WTP treatment rates. The accumulative time required to treat each tank sent to ST is then calculated for each treatment rate in worksheet ST. This data was used to prepare graphs for the main body of the report.

WTP-39% -- calculates the accumulative amount of glass produced by WTP using the DOE Model for the Base Case condition wherein WTP treats 39% of the waste Na. The time to complete the glass production is calculated for the base case production rate of 28.8 MTG/day.

ST - 61% -- calculates the required rate for ST treatment of the remaining 61% of the waste and the times required to treat each tank in the order of retrieval.

The expressions used in these worksheets for these functions are self-evident.

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## Waste Classification

### Glass Loading and Volume of Glass

The waste classification determinations are made using the criteria from 10 CFR 61.55 on the basis that all glass will be loaded to 20 weight percent Na<sub>2</sub>O. This is the stretch goal for DOE and is conservative for classification since it minimizes the amount glass in which the radionuclides will be immobilized. The classifications are based on the number of curies of each constituent per cubic meter of glass or nanocuries per gram of glass depending on the specific nuclide.

The volume of glass required to immobilize the waste in each tank (Column E) is calculated from the amount of sodium in the tank (column C) increased by the amount added in pretreatment and lost to HLW and ETF (column D). The multipliers to account for the sodium added in pretreatment and lost to HLW and ETF are the same as described in Section 4.4, above.

For example, the MTG produced for the quantity of Na that is sent to LAW from tank 6 is calculated as follows:

$$=D6*Na2O\_Na*100/DOE\_Max/1000$$

Where:

The named constant Na<sub>2</sub>O\_Na is as defined above  
DOE\_Max is a named constant = 20 wt% Na<sub>2</sub>O.

The volume of glass is calculated in Column F:

$$=E6/Glass\_Density$$

Where:

Glass\_Density is a named constant = 2.7 MT/m<sup>3</sup>

### 10 CFR 61.55 Classifications

Under this regulation waste classification depends on the concentration of specific radionuclides in the glass specified in curies per cubic meter (Ci/m<sup>3</sup>) or nanocuries per gram (nCi/gm) of glass. The regulation contains two tables providing the limits for long life (LL) radionuclides (Table 1) and shorter life (SL) radionuclides (Table 2) as follows:

**Table 1**

<b>Radionuclide</b>	<b>Concentration, curies per cubic meter</b>
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha emitting transuranic nuclides with half-life greater than 5 years	100 <sup>1</sup>
Pu-241	3,500 <sup>1</sup>
Cm-242	20,000 <sup>1</sup>

<sup>1</sup> Units are nancuries per gram

**Table 2**

<b>Radionuclide</b>	<b>Concentration, curies per cubic meter</b>		
	<b>Col 1</b>	<b>Col 2</b>	<b>Col 3</b>
Total of all nuclides with less than 5 year half-life	700	(1)	(1)
H-3	40	(1)	(1)
Co-60	700	(1)	(1)
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1	44	4600

<sup>1</sup> There are no limits established for these radionuclides in Class B or Class C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling and disposal will limit the concentration for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 2 determine the waste to be Class C independent of these nuclides.

In Table 2 waste concentrations that fall within Col 1 are Class A, within Col 2 Class B and within Col 3 Class C.

Since the Hanford wastes contain more than one of the constituents in each of the tables and constituents that appear in both tables, the sum of fractions rule in paragraph (7) of 10 CFR 61.55 and the rule in paragraph (5), "Classification determined by both long- and short-lived radionuclides" are used to determine the classification.



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In application of the sum of fractions rule the concentration of each nuclide is divided by the appropriate limit (all from the same column) and the resulting values are added. The result must be less than one if that waste class is to be determined by that column.

The sum of fractions rule is carried out in columns G through AB for Table 1 and Columns AG through AW for Table 2. To illustrate for Tc 99:

Ci/m<sup>3</sup> is calculated:

=O7/F7 in Column Q

Where:

O7 is the number of curies of <sup>99</sup>Tc in the tank in row 7

F7 is the amount of glass required to immobilize the sodium in the tank in row 7,  
m<sup>3</sup>

The ratio of this concentration to the limit in Table 1 is calculated in Column P:

=O7/\$F7/O\$2

Where O\$2 is the Table 1 limit for <sup>99</sup>Tc = 3 Ci/m<sup>3</sup>

For Pu-241 and TRU the limit is stated in nCi/m<sup>3</sup>. For TRU this is calculated for the total number of TRU curies in Column Y:

=SUM(R7:X7)

Where R7 through X7 contain the curies of the TRU constituents for the tank in row 7

The nanocuries per gram are calculated in Column Z:

=1000\*Y7/E7

Where:

Y7 is the total number of curies

E7 is the MT of glass for the tank in row 7

1000 converts Ci/MT to nCi/gm; 10<sup>9</sup> nanocuries/curie, 10<sup>6</sup> grams/MT

The ratio of this value to the limit is calculated in Column AA:

=1000\*Y7/\$E7/Y\$3

Where Y\$3 is the limit from Table 1, 100 nCi/gm

---

The fractions for the long life nuclides are summed for Table 1 in Column AB:

$$=H7+J7+L7+N7+P7+AA7$$

Similar calculations are performed for the shorter life nuclides in Columns AC through AU. For the shorter life nuclides, however, there are three limits for Classes A, B and C and fractions are calculated for each limit. They are summed in Columns AS, AT and AU for Classes A, B and C, respectively.

The logic to establish the Class of waste for each tank is implemented in Column AV. Figure C-1 depicts the logic as established in 10CFR61.55. For the tank in row 7 the logic is implemented as follows:

```
=IF($AB7>1,"LL Exceeds",IF($AB7>0.1,IF($AU7<=1,"Class C1","SL Exceeds"),IF($AS7<=1,"Class A",IF($AT7<=1,"Class B",IF($AU7<=1,"Class C2","SL Exceeds")))))
```

Where:

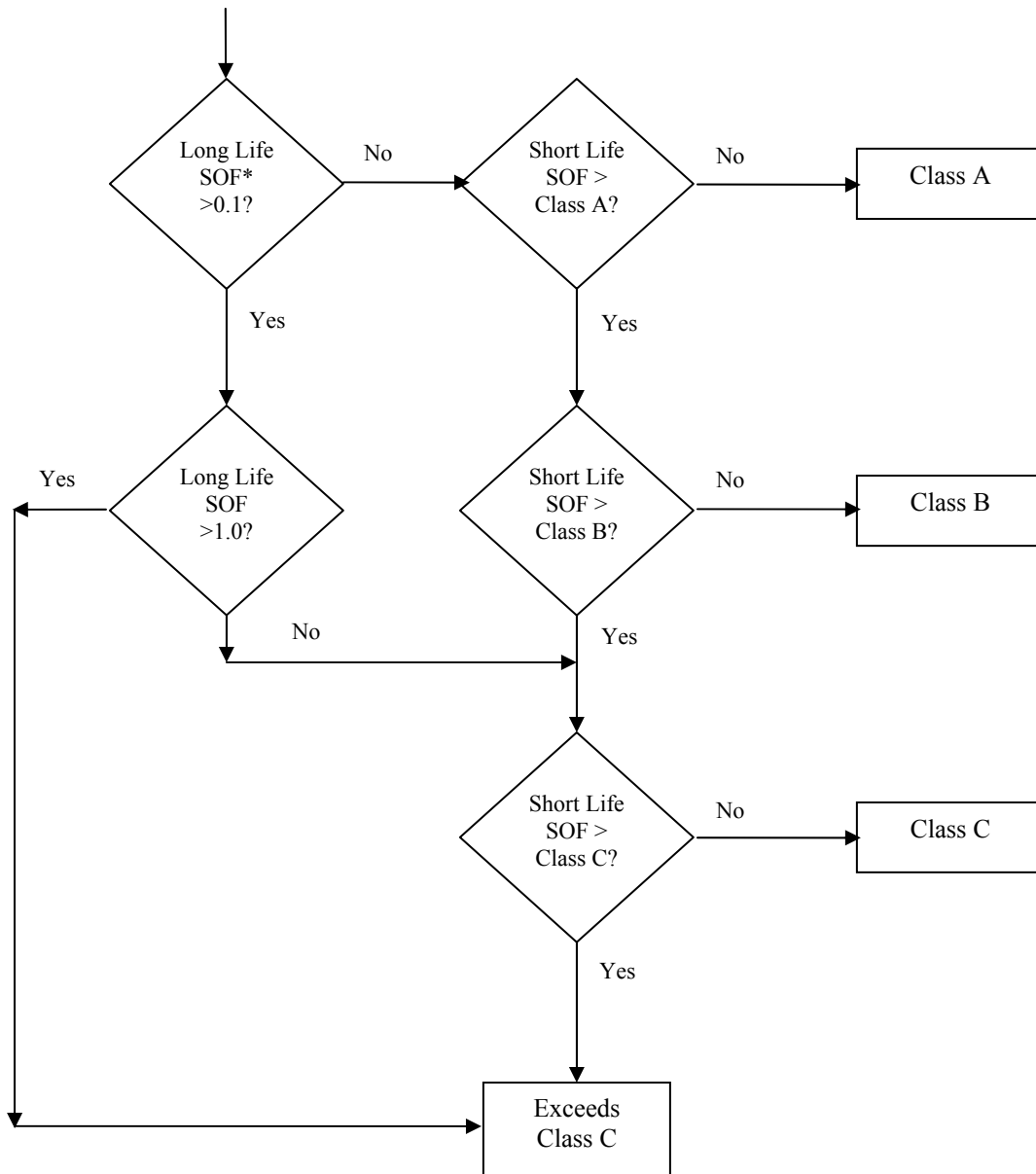
\$AB7 contains the sum of fractions for Table 1 nuclides  
\$AS7, \$AT7 and \$AU7 contain the sum of fractions for Classes A, B and C, respectively for the Table 2 nuclides.

### **Effect of Filtering Tank Waste to Remove Solids on Tank Classifications**

Sheets DF1000, DF100 and DF10 calculate the effect of these levels of filtering of the solids from the tank waste prior to immobilization on the waste classification. In this regard the calculations are identical to those described above except that the concentrations of certain nuclides are reduced depending on the filter DF. The nuclides affected include:

Ni-59, Pu-241, TRU, Co-60, Ni-63 and Sr-90.

The residual concentration of each of these nuclides is calculated by dividing the initial concentration by the filter DF.



\* SOF – Sum of Fractions

**Figure C-1 – 10CFR61.55 Waste Classification Logic**

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## Appendix D

### Summary of Radionuclide Concentration Assessment Data for Selection of Waste Feeds for Supplemental Treatment and WTP

This appendix summarizes an evaluation of the radionuclide concentrations in the Hanford tank wastes to provide an initial basis for the assessment data for the determination if the specific tank wastes need further treatment prior to immobilization in the supplemental treatment technologies or Waste Treatment Plant.

- Table D-1 summarizes the low-level tank wastes that can be directly immobilized.
- Table D-2 summarizes the low curie tank wastes that can be directly immobilized.
- Table D-3 summarizes the tank wastes that if immobilized in supplemental treatment can improve the performance of the WTP LAW Vitrification Facility
- Table D-4 summaries the tank wastes that could be beneficially immobilized in the WTP

Definition of Terms in the following tables:

LL Exceeds Table 1 Class C limits on long-life radionuclides are exceeded

SL Exceeds Table 2 Class C limits on shorter-life radionuclides are exceeded

Class C1 The sum of fractions from Table 1 is greater than 0.1 but less than or equal to 1.0 and the sum of fractions for Table 2 is less or equal to 1.0 for Class C limits

Class A The sum of fractions from Table 1 is less than or equal to 0.1 and the sum of fractions for Table 2 is within Class A limits

Class B The sum of fractions from Table 1 is less than or equal to 0.1 and the sum of fractions for Table 2 is greater than Class A limits but within Class B limits

Class C1 The sum of fractions from Table 1 is less than or equal to 0.1 and the sum of fractions for Table 2 is greater than Class A or B limits but within Class C limits

**Table D.1 Low Level Tank Waste that can be immobilized by Supplemental Treatment without Pretreatment**

Tank	Tank Na	Tc 99	TRU	Cs 137	Sr 90	Unfiltered Class	Comment	Filter Effectiveness		
	kg	Ci/m3	nCi/gm	Ci/m3	Ci/m3			DF=1000	DF=100	DF=10
<b>C-204</b>	595	0.0109	118.53	60.7	319.6	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>T-110</b>	88,300	0.0005	137.72	202.4	124.3	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>U-201</b>	1,430	0.0041	6.56	206.2	58.7	Class C2		Class C2	Class C2	Class C2
<b>U-202</b>	1,250	0.0041	9.16	202.7	57.8	Class C2		Class C2	Class C2	Class C2
<b>U-203</b>	1,140	0.0043	9.58	185.3	53.6	Class C2		Class C2	Class C2	Class C2
<b>U-204</b>	471	0.0080	313.83	461.4	129.0	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1

**Table D.2 Low Curie Tank Waste that could be Immobilized by Supplemental Treatment without WTP Pretreatment**

Tank	Tank Na	Tc 99	TRU	Cs 137	Sr 90	Unfiltered	Comments	Filter Effectiveness		
	kg	Ci/m3	nCi/gm	Ci/m3	Ci/m3	Class		DF=1000	DF=100	DF=10
<b>B-101</b>	111,000	0.0240	1,535.47	33.2	3,085.0	LL Exceeds	High TRU Levels	Class B	Class C1	LL Exceeds
<b>B-103</b>	57,900	0.0044	143.48	33.6	8.4	LL Exceeds	High TRU Levels	Class B	Class B	Class C1
<b>B-104</b>	224,000	0.0326	59.25	129.7	67.7	Class C1		Class C2	Class C2	Class C2
<b>B-105</b>	326,000	0.0047	22.45	33.9	7.2	Class C1		Class B	Class B	Class B
<b>B-106</b>	70,700	0.0304	50.71	52.6	166.8	Class C1		Class C2	Class C2	Class C2
<b>B-107</b>	149,000	0.0401	266.98	54.9	292.7	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>B-109</b>	157,000	0.0027	31.24	34.8	874.3	Class C1		Class B	Class B	Class C2
<b>BX-110</b>	274,000	0.1487	43.39	95.5	21.3	Class C1		Class C2	Class C2	Class C2
<b>BX-111</b>	247,000	0.1679	12.65	111.1	23.0	Class C1		Class C2	Class C2	Class C2
<b>BY-102</b>	429,000	0.1583	41.41	101.7	21.2	Class C1		Class C2	Class C2	Class C1
<b>BY-103</b>	568,000	0.1844	48.02	128.4	66.1	Class C1		Class C2	Class C2	Class C1
<b>BY-105</b>	690,000	0.0423	113.56	93.8	82.4	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>BY-108</b>	233,000	0.1994	41.83	79.2	217.8	Class C1		Class C2	Class C2	Class C1
<b>BY-109</b>	325,000	0.1705	45.28	113.3	262.9	Class C1		Class C2	Class C2	Class C1
<b>BY-110</b>	467,000	0.1615	36.91	152.3	132.4	Class C1		Class C2	Class C2	Class C2
<b>BY-111</b>	458,000	0.1522	56.07	102.2	20.8	Class C1		Class C2	Class C2	Class C1
<b>BY-112</b>	589,000	0.1262	31.41	84.4	17.1	Class C1		Class C2	Class C2	Class C2
<b>S-109</b>	771,000	0.1451	18.07	22.1	28.0	Class C1		Class B	Class B	Class B
<b>S-110</b>	482,000	0.1765	185.06	132.0	183.9	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>S-112</b>	983,000	0.0898	22.36	82.2	38.9	Class C1		Class C2	Class C2	Class C2
<b>T-109</b>	57,400	0.0037	8.49	8.2	6.7	Class B		Class B	Class B	Class B
<b>TX-103</b>	183,000	0.1953	190.06	151.8	38.3	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-105</b>	740,000	0.1903	207.94	142.0	38.8	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-106</b>	439,000	0.1979	202.23	153.9	50.8	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-108</b>	162,000	0.1893	199.95	144.1	48.1	LL Exceeds	High TRU	Class C2	Class C2	Class C1

Tank	Tank Na	Tc 99	TRU	Cs 137	Sr 90	Unfiltered	Comments	Filter Effectiveness		
	kg	Ci/m3	nCi/gm	Ci/m3	Ci/m3	Class		DF=1000	DF=100	DF=10
							Levels			
<b>TX-110</b>	580,000	0.1849	205.33	133.7	38.4	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-111</b>	444,000	0.1819	205.97	131.2	38.1	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-112</b>	819,000	0.1842	198.12	134.9	37.8	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-113</b>	918,000	0.1861	14.18	13.1	2.5	Class C1		Class B	Class B	Class B
<b>TX-114</b>	681,000	0.1701	189.73	122.8	35.7	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-115</b>	712,000	0.1898	201.62	140.1	42.4	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-116</b>	708,000	0.1050	106.75	52.5	4.9	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-117</b>	580,000	0.1177	140.97	85.0	25.0	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-118</b>	301,000	0.1793	10,859.8 1	82.7	213.8	LL Exceeds	High TRU Levels	Class C1	LL Exceeds	LL Exceeds
<b>TY-102</b>	87,400	0.0384	8.47	46.2	11.2	Class C2		Class C2	Class C2	Class C2

**Table D.3 Tank Waste to be Immobilized by Supplemental Treatment to maintain WTP Na<sub>2</sub>O  
Loading at least 20 wt% in the LAW glass**

Tank	Tank Na kg	Tc 99 Ci/m3	TRU nCi/gm	Cs 137 Ci/m3	Sr 90 Ci/m3	Unfiltered Class	Comments	Filter Effectiveness		
								DF=1000	DF=100	DF=10
A-101	660,000	0.18	118.02	343.9	94.2	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
A-102	31,200	0.4239	2,777.92	484.6	979.6	LL Exceeds	High TRU Levels	Class C1	Class C1	LL Exceeds
A-103	378,000	0.1532	146.86	293.1	116.3	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
A-105	55,000	0.4413	11,557.17	747.4	20,277.3	LL Exceeds	High TRU Levels	Class C1	LL Exceeds	LL Exceeds
AN-102	920,000	0.2250	159.01	648.9	155.0	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
AW-104	246,000	0.2921	409.86	344.4	7.4	LL Exceeds	High TRU Levels	Class C1	Class C1	Class C1
AX-101	483,000	0.1110	128.53	334.5	119.2	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
AX-103	110,000	0.5232	1,359.44	364.0	1,572.8	LL Exceeds	High TRU Levels	Class C1	Class C1	LL Exceeds
AX-104	2,170	15.4347	79,233.06	8,779.8	364,041.9	LL Exceeds	High TRU Levels	LL Exceeds	LL Exceeds	LL Exceeds
AZ-101	364,000	1.2275	9,899.73	5,882.3	4,861.0	LL Exceeds	High TRU Levels	SL Exceeds	LL Exceeds	LL Exceeds
AZ-102	229,000	1.2316	12,176.68	6,009.6	4,682.8	LL Exceeds	High TRU Levels	SL Exceeds	LL Exceeds	LL Exceeds
B-102	31,200	0.0051	14.19	31.2	10.8	Class C1		Class B	Class B	Class B
B-108	111,000	0.0029	3.92	25.2	7.0	Class B		Class B	Class B	Class B
B-110	123,000	0.0604	255.84	42.4	305.1	LL Exceeds	High TRU Levels	Class B	Class B	Class C1
B-111	95,200	0.4618	280.32	540.7	841.1	LL Exceeds	High TRU Levels	Class C1	Class C1	Class C1
B-112	28,000	0.1353	6.78	159.6	66.0	Class C1		Class C2	Class C2	Class C2
BX-101	16,300	0.0041	2,348.81	139.3	6,271.9	LL Exceeds	High TRU Levels	Class C2	Class C1	LL Exceeds
BX-103	21,800	0.0040	7,036.72	94.9	3,951.7	LL Exceeds	High TRU Levels	Class C2	Class C1	LL Exceeds
BX-105	53,100	0.0990	291.01	150.8	345.3	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
BX-107	192,000	0.1299	91.24	50.6	28.5	Class C1		Class C2	Class C2	Class C1
BX-108	30,100	0.0321	56.75	44.3	350.3	Class C1		Class C2	Class C2	Class C2
BX-109	117,000	0.0027	20.53	39.1	391.1	Class C1		Class B	Class B	Class C2
BX-112	67,700	0.0898	295.58	186.4	27.5	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
BY-104	469,000	0.2004	63.70	157.8	275.1	Class C1		Class C2	Class C2	Class C1
C-101	57,000	0.0044	1,493.93	228.3	1,793.5	LL Exceeds	High TRU Levels	Class C2	Class C1	LL Exceeds
C-103	29,500	0.4144	36,166.29	1,164.4	36,472.3	LL Exceeds	High TRU Levels	Class C1	LL Exceeds	LL Exceeds
C-105	32,900	0.8844	14,464.42	888.7	5,171.7	LL Exceeds	High TRU Levels	Class C1	LL Exceeds	LL Exceeds
C-107	95,200	0.1423	13,053.77	238.4	8,410.7	LL Exceeds	High TRU Levels	Class C1	LL Exceeds	LL Exceeds
C-109	34,800	0.3318	453.67	1,756.4	2,578.2	LL Exceeds	High TRU Levels	Class C1	Class C1	Class C1
C-110	75,300	0.1510	195.53	68.4	17.7	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
C-111	12,700	0.0760	3,751.12	551.7	25,049.9	LL Exceeds	High TRU Levels	Class C2	Class C1	LL Exceeds
C-112	50,100	0.4359	1,529.23	2,033.4	4,623.3	LL Exceeds	High TRU Levels	Class C1	Class C1	LL Exceeds
SX-115	618	0.1573	178,572.1	1,330.3	209,960.2	LL Exceeds	High TRU Levels	LL Exceeds	LL Exceeds	LL Exceeds



Tank	Tank Na kg	Tc 99 Ci/m3	TRU nCi/gm	Cs 137 Ci/m3	Sr 90 Ci/m3	Unfiltered Class	Comments	Filter Effectiveness		
								DF=1000	DF=100	DF=10
			4							
<b>T-101</b>	85,800	0.1912	194.49	192.5	43.7	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>T-105</b>	39,500	0.3167	720.94	257.0	401.8	LL Exceeds	High TRU Levels	Class C1	Class C1	Class C1
<b>T-106</b>	13,300	0.0696	250.10	129.8	34.4	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>T-107</b>	94,500	0.1827	221.17	60.9	419.9	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>T-112</b>	20,900	0.0003	473.35	88.1	57.6	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-102</b>	271,000	0.2018	194.04	160.9	38.9	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TX-107</b>	40,400	0.1867	1,783.54	185.8	88.5	LL Exceeds	High TRU Levels	Class C2	Class C1	LL Exceeds
<b>TX-109</b>	183,000	0.0920	178.38	76.4	19.5	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TY-103</b>	117,000	0.0742	228.73	67.5	230.7	LL Exceeds	High TRU Levels	Class C2	Class C2	Class C1
<b>TY-105</b>	154,000	0.1021	27.51	20.8	494.4	Class C1		Class B	Class B	Class B
<b>TY-106</b>	8,920	0.4168	51.52	52.5	321.4	Class C1		Class C1	Class C1	Class C1
<b>U-105</b>	412,000	0.3123	490.59	283.7	17.1	LL Exceeds	High TRU Levels	Class C1	Class C1	Class C1

**Table D.4 Tank Waste to be Immobilized in the WTP LAW Facility (Na<sub>2</sub>O waste-loading . 20 wt%)**

Tank	Tank Na	Tc 99	TRU	Cs 137	Sr 90	Unfiltered	Comments	Filter Effectiveness		
	kg	Ci/m3	nCi/gm	Ci/m3	Ci/m3	Class		DF=1000	DF=100	DF=10
A-104	14,200	0.2495	11,241.21	1,669.0	62,680.1	LL Exceeds	High TRU levels	Class C1	LL Exceeds	LL Exceeds
A-106	78,500	0.3283	3,178.75	313.3	2,404.3	LL Exceeds	High TRU levels	Class C1	Class C1	LL Exceeds
AN-101	88,100	0.3497	1.80	385.9	0.2	Class C1		Class C1	Class C1	Class C1
AN-103	1,060,000	0.2337	3.42	596.9	2.5	Class C1		Class C2	Class C2	Class C2
AN-104	1,070,000	0.2653	7.21	671.5	25.8	Class C1		Class C2	Class C2	Class C1
AN-105	1,100,000	0.3640	3.44	490.7	10.1	Class C1		Class C1	Class C1	Class C1
AN-106	30,700	0.2131	364.38	243.3	41.6	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
AN-107	1,010,000	0.1377	523.36	488.4	187.6	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
AP-101	545,000	0.1305	0.32	391.6	0.2	Class C2		Class C2	Class C2	Class C2
AP-102	191,000	0.4772	3.55	477.2	1.7	Class C1		Class C1	Class C1	Class C1
AP-103	196,000	0.8426	3.66	476.0	1.0	Class C1		Class C1	Class C1	Class C1
AP-104	552,000	0.4591	3.30	578.9	5.0	Class C1		Class C1	Class C1	Class C1
AP-105	778,000	0.2127	3.29	400.2	12.4	Class C1		Class C2	Class C2	Class C2
AP-106	449,000	0.2930	1.34	643.3	4.4	Class C1		Class C1	Class C1	Class C1
AP-107	711,000	0.4585	4.41	478.1	2.2	Class C1		Class C1	Class C1	Class C1
AP-108	477,000	0.5246	3.61	544.8	4.2	Class C1		Class C1	Class C1	Class C1
AW-101	1,090,000	0.2745	30.21	564.1	29.3	Class C1		Class C2	Class C1	Class C1
AW-102	467,000	0.3108	120.26	459.3	73.6	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
AW-106	297,000	0.1396	520.83	296.1	59.8	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
AX-102	25,800	0.1214	2,210.86	565.3	3,214.3	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
AY-101	92,400	0.2166	13,888.11	277.4	5,338.6	LL Exceeds	High TRU levels	Class C1	LL Exceeds	LL Exceeds
AY-102	240,000	0.0496	5,614.53	323.2	7,864.0	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
BX-102	10,700	0.0052	9,350.79	240.2	11,558.8	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds

Tank	Tank Na	Tc 99	TRU	Cs 137	Sr 90	Unfiltered	Comments	Filter Effectiveness		
	kg	Ci/m3	nCi/gm	Ci/m3	Ci/m3	Class		DF=1000	DF=100	DF=10
<b>BX-104</b>	42,600	0.1947	1,786.78	349.9	1,082.4	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>BX-106</b>	36,400	0.1090	492.74	130.6	326.0	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>BY-101</b>	603,000	0.1660	22.43	173.1	157.1	Class C1		Class C2	Class C2	Class C2
<b>BY-106</b>	614,000	0.2119	15.42	228.8	85.6	Class C1		Class C2	Class C2	Class C2
<b>BY-107</b>	423,000	0.1462	13.61	177.5	69.6	Class C1		Class C2	Class C2	Class C2
<b>C-102</b>	106,000	0.0045	6,560.30	100.5	2,003.1	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>C-104</b>	178,000	0.1165	9,770.44	191.8	972.0	LL Exceeds	High TRU levels	Class C1	LL Exceeds	LL Exceeds
<b>C-106</b>	12,000	0.0935	3,534.44	521.3	8,400.1	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>C-108</b>	34,100	0.0649	38.80	854.3	88.5	Class C1		Class C2	Class C2	Class C2
<b>C-201</b>	462	0.0109	#####	60.9	319.5	LL Exceeds	High TRU levels	Class C1	LL Exceeds	LL Exceeds
<b>C-202</b>	482	0.0109	14,319.19	61.0	319.6	LL Exceeds	High TRU levels	Class C1	LL Exceeds	LL Exceeds
<b>C-203</b>	921	0.0109	3,754.85	60.9	319.4	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>S-101</b>	391,000	0.1883	257.21	317.2	554.0	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>S-102</b>	364,000	0.2131	95.10	250.4	91.2	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>S-103</b>	264,000	0.3033	169.34	293.8	55.5	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>S-104</b>	224,000	0.0771	431.77	131.8	683.0	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>S-105</b>	625,000	0.2007	7.59	42.4	6.5	Class C1		Class B	Class B	Class B
<b>S-106</b>	601,000	0.1713	18.16	172.5	23.3	Class C1		Class C2	Class C2	Class C2
<b>S-107</b>	231,000	0.0489	1,262.39	289.4	530.8	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>S-108</b>	697,000	0.1641	188.04	201.0	32.8	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>S-111</b>	419,000	0.2184	16.82	260.2	411.2	Class C1		Class C2	Class C2	Class C2
<b>SX-101</b>	508,000	0.1302	246.54	218.8	458.8	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1

Tank	Tank Na	Tc 99	TRU	Cs 137	Sr 90	Unfiltered	Comments	Filter Effectiveness		
	kg	Ci/m3	nCi/gm	Ci/m3	Ci/m3	Class		DF=1000	DF=100	DF=10
<b>SX-102</b>	578,000	0.2202	123.55	327.1	150.3	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>SX-103</b>	642,000	0.1759	176.68	241.1	217.1	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>SX-104</b>	479,000	0.1373	370.01	218.7	398.5	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>SX-105</b>	380,000	0.1787	364.10	225.8	165.6	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
<b>SX-106</b>	444,000	0.2898	181.35	276.9	8.5	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>SX-107</b>	72,600	0.0491	929.61	258.0	1,422.9	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
<b>SX-108</b>	89,100	0.0234	2,357.68	342.6	5,375.8	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>SX-109</b>	258,000	0.0797	327.47	188.4	547.3	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>SX-110</b>	52,500	0.0666	557.85	209.0	878.3	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>SX-111</b>	96,800	0.0643	714.93	251.1	1,104.1	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>SX-112</b>	60,200	0.0570	816.82	254.1	1,252.9	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
<b>SX-113</b>	758	6.4606	2,203.39	1,485.5	3,244.4	LL Exceeds	High TRU levels	LL Exceeds	LL Exceeds	LL Exceeds
<b>SX-114</b>	157,000	0.0918	333.90	239.1	546.4	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>SY-101</b>	645,000	0.5165	104.51	493.8	39.6	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>SY-103</b>	710,000	0.5186	260.32	589.0	36.9	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>T-102</b>	7,670	0.4413	785.31	319.2	1,067.2	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>T-103</b>	7,550	0.1212	5,229.43	224.9	6,344.2	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>T-104</b>	99,800	0.0035	327.23	0.9	12.1	LL Exceeds	High TRU	Class B	Class B	Class C1

Tank	Tank Na	Tc 99	TRU	Cs 137	Sr 90	Unfiltered	Comments	Filter Effectiveness		
	kg	Ci/m3	nCi/gm	Ci/m3	Ci/m3	Class		DF=1000	DF=100	DF=10
							levels			
<b>T-108</b>	14,200	0.0204	64.49	20.2	8.3	Class C1		Class B	Class B	Class B
<b>TX-101</b>	71,400	0.0841	1,356.66	241.8	1,241.6	LL Exceeds	High TRU levels	Class C2	Class C1	LL Exceeds
<b>TX-104</b>	52,200	0.1575	323.29	226.7	680.0	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>TY-101</b>	88,700	0.0217	224.89	0.7	25.5	LL Exceeds	High TRU levels	Class B	Class B	Class C1
<b>TY-104</b>	31,500	0.0986	250.36	100.1	286.0	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>U-101</b>	15,400	0.0313	93.56	264.6	1,782.6	Class C1		Class C2	Class C2	Class C1
<b>U-102</b>	319,000	0.2084	223.94	296.9	232.0	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
<b>U-103</b>	472,000	0.1939	93.78	234.0	39.2	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>U-104</b>	57,700	0.0632	505.21	234.8	786.8	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>U-106</b>	177,000	0.2302	690.86	315.0	128.0	LL Exceeds	High TRU levels	Class C2	Class C1	Class C1
<b>U-107</b>	458,000	0.3980	242.42	183.4	4.3	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>U-108</b>	604,000	0.2675	177.39	255.7	11.6	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>U-109</b>	341,000	0.2369	26.34	223.3	14.2	Class C1		Class C2	Class C2	Class C1
<b>U-110</b>	70,500	0.0553	613.77	111.0	1,003.9	LL Exceeds	High TRU levels	Class C2	Class C2	Class C1
<b>U-111</b>	351,000	0.3096	170.63	302.5	57.2	LL Exceeds	High TRU levels	Class C1	Class C1	Class C1
<b>U-112</b>	22,500	0.0443	51.66	231.9	1,046.9	Class C1		Class C2	Class C2	Class C2