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Nuclear Criticality Safety Analysis Summary Report:
Salt Solution and Sludge Operations in 512-S Facility and DWPF (U)

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REVISION HISTORY

Revision	Author	Reason(s) for Revision	Date
0	L. M. Abney D. A. Eghbali	Develop revision 0 to document the criticality safety of the coupled processing of DWPF sludge batches and MST/sludge solids in DWPF using the relevant baseline NCSEs. This NCSASR is a complete rewrite and supersedes WSRC-RP-94-1132 and WSRC-RP-94-396.	7/2007
1	L. M. Abney D. A. Eghbali	N-NCS-S-00008 was revised and the revision number and date for the NCSE was changed in Table 1 and Section 8.0.	8/2007
2	L. M. Abney D. A. Eghbali	N-NCS-H-00192, Rev. 1 was approved and the barrier associated with neutralizing the oxalic acid in the crossflow filter cleaning process was deleted. Table 1 and Sections 1.3, 5.1, 6.3.1 and 8.0 were revised due to the NCSE revision. Definitions in Section 1.3 were revised to be consistent with the Rev. 20 of SCD-3. Discussion of the de-coupled operation mode was deleted in Section 2.3.1.	11/2007
3	L. M. Abney D. A. Eghbali	N-NCS-S-00008 was revised to change 700 g ^{235}U to 760 g ^{235}U. N-NCS-S-00009 was revised to be consistent with N-NCS-S-00008 in terms of equivalency equations for calculating ^{239}Pu(eq) and ^{235}U(eq) in a sludge batch. N-NCS-H-00192 was deleted as a baseline NCSE. Definitions in Section 1.3 were revised to be consistent with the Rev. 21 of SCD-3. Numerous editorials and clarifications made throughout.	2/2008
4	L. M. Abney D. A. Eghbali	Revised to include Scenario 5.1.1.8 added to N-NCS-S-00008, Rev. 4. The storage of dry oxalic acid in DWPF and the neutralization of residual oxalic acid at 980-S facility are also addressed. Revision bars indicate changes.	7/2008
5	D. A. Eghbali	Revised to be consistent with changes in N-NCS-S-00009 and N-NCS-S-00008.	9/2008

REVISION HISTORY

Revision	Author	Reason(s) for Revision	Date
6	D. A. Eghbali	Revised to be consistent with changes in N-NCS-S-00008 and N-NCS-S-00009. Revision bars indicate changes.	4/2009
7	N. P. Devine T. A. Reilly	Revised to be consistent with changes in N-NCS-H-00192, N-NCS-S-00008, and N-NCS-S-00009. Revision bars indicate changes.	12/2009
8	M. H. Barnett	Revised to be consistent with changes in N-NCS-H-00192 and N-NCS-S-00008. Added the NCSA N-NCS-S-00010.	3/2012
9	M. H. Barnett	Revised to be consistent with changes in N-NCS-H-00192.	7/2012
10	R. L. Reed	Updated revision numbers for N-NCS-H-00192 and N-NCS-S-00008 which addressed use of Next Generation Solvent (NGS) in MCU. Minor editorial updates. Revision bars indicate changes.	3/2013
11	R. L. Reed	Update material related to NCSEs N-NCS-S-00008 (Rev. 12), N-NCS-S-00009 (Rev. 6), and N-NCS-H-00192 (Rev. 9). Allowed uranium enrichment in sludge is ≤ 5 wt% ^{235}U with Mn:^{235}U mass ratio ≥ 70.	7/2013
12	M. H. Barnett	Require the WAC to be elevated to the FSAR/TSR	9/2013
13	M. H. Barnett	Renamed the supplemental analytical laboratories to DWPF outside modular laboratory.	3/2014
14	M. H. Barnett	Added the filter-only operation in 512-S	2/2015
15	H. C. Benhardt	Added discussion to address Glycolic Acid as a reductant in addition to Formic Acid and changed N-NCS-S-00008 revision number to version associated with Glycolic Acid discussion. Also performed editorial changes/corrections.	10/2016
16	M. H. Barnett	Updated material related to revision of N-NCS-H-00192.	2/2017
17	M. H. Barnett	Updated material related to 511-S transfer modifications.	4/2018

ABBREVIATIONS/ACRONYMS

Am/Cm	Americium/Curium
ANS	American Nuclear Society
ANSI	American National Standards Institute
ARP	Actinide Removal Process
BA	Bounding Assumption
CAAS	Criticality Accident Alarm System
CDMC	Contact Decontamination Maintenance Cell
CHAP	Consolidated Hazards Analysis Process
COA	Certificate of Analysis
CPC	Chemical Process Cell
CSPDD	Criticality Safety Program Description Document
CSS	Clarified Salt Solution
CSSX	Caustic Side Solvent Extraction
CSFT	Concentration, Storage, and Transfer Facilities
DCS	Distributed Control System
DWPF	Defense Waste Processing Facility
DWTT	Decontamination Waste Treatment Tank
EU	Extremely Unlikely
FSAR	Final Safety Analysis Report
GWSB	Glass Waste Storage Buildings
HDB-8	H-Area Diversion Box 8
HEME	High Efficiency Mist Eliminator
HEPA	High Efficiency Particulate Air
HLW	High Level Waste
ITL	Interarea Transfer Lines
ITP	In-Tank Precipitation
LPPP	Low Point Pump Pit
LPPP-PPT	Low Point Pump Pit Precipitate Pump Tank
LPPP-RPT	Low Point Pump Pit Recycle Pump Tank
LPPP-SPT	Low Point Pump Pit Sludge Pump Tank
LWHT	Late Wash Hold Tank
LWPT	Late Wash Precipitate Tank
MC	Melt Cell
MCU	Modular CSSX Unit
MFT	Melter Feed Tank
MST	Monosodium Titanate
NCS	Nuclear Criticality Safety
NCSA	Nuclear Criticality Safety Assessment
NCSASR	Nuclear Criticality Safety Analysis Summary Report
NCSE	Nuclear Criticality Safety Evaluation
NGS	Next Generation Solvent
OGCT	Off-Gas Condensate Tank
PPT	Precipitate Pump Tank

PRFT	Precipitate Reactor Feed Tank
PVVH	Process Vessel Vent Header
PVVS	Process Vessel Vent System
RCT	Recycle Collection Tank
REDC	Remote Equipment Decontamination Cell
RPT	Recycle Pump Tank
SB3	Sludge Batch 3
SB7a	Sludge Batch 7a
SEFT	Strip Effluent Feed Tank
SEHT	Strip Effluent Hold Tank
SME	Slurry Mix Evaporator
SMECT	Slurry Mix Evaporator Condensate Tank
SPC	Salt Process Cell
SPT	Sludge Pump Tank
SRAT	Sludge Receipt and Adjustment Tank
SRR	Savannah River Remediation
SSRT	Salt Solution Receipt Tank
TSRs	Technical Safety Requirements
URS PS	URS Professional Solutions
WAC	Waste Acceptance Criteria
WSRC	Washington Savannah River Company

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1.0 INTRODUCTION

1.1 OBJECTIVE

This Nuclear Criticality Safety Analysis Summary Report (NCSASR) summarizes the applicable Nuclear Criticality Safety Evaluations (NCSEs) for the Defense Waste Processing Facility (DWPF) and the 512-S Actinide Removal Process (ARP) Facility. This NCSASR will be the technical criticality safety reference for the Final Safety Analysis Report (FSAR) and Technical Safety Requirements (TSRs) that capture Nuclear Criticality Safety (NCS) assumptions, design features, limits, and requirements from applicable baseline NCSEs (see Table 1) and maintains them current when the NCSEs are revised. This NCSASR is intended to be a "linking document" between the FSAR/TSRs and the applicable NCSEs. This NCSASR simplifies the revision process to the FSAR/TSRs when the baseline NCSEs are revised, often without a need to change the FSAR/TSRs unless the revisions to the NCSEs result in a change to the design features, limits, or requirements that are specifically included in the FSAR or TSRs.

1.2 SCOPE

Due to the current coupled processing of DWPF sludge and Monosodium Titanate (MST)/sludge solids in DWPF, the revised salt treatment methodology [using ARP and the Modular CSSX Unit (MCU) (CSSX is an abbreviation for Caustic Side Solvent Extraction)], the revised baseline NCSEs, and the changes in the sludge batch contents, this NCSASR supersedes WSRC-RP-94-1132 (NCSASR for sludge only operations, Ref. 1) and WSRC-RP-94-396 (NCSASR for coupled sludge/salt operations using In-Tank Precipitation (ITP), Ref. 2). MST/sludge solids slurry refers to either MST/sludge solids slurry from 96H, or potential sludge solids entrainment in the salt solution from Tank 49, depending on whether ARP/MCU is in filter-only operations.

The scope of this NCSASR is limited to the following:

- Processing of Tank Farm sludge (including sludge with non-Tank Farm plutonium) through the DWPF, and
- Processing of salt solution with an equivalent ^{235}U [^{235}U(eq_sol)] enrichment less than or equal to 3.0 wt% and soluble fissile material concentrations less than or equal to 50 mg U/L and 0.3 mg Pu/L, respectively, and then blending the salt solution with the DWPF sludge in the Sludge Receipt and Adjustment Tank (SRAT).

Associated facilities covered herein are:

- ARP at 512-S Facility,
- Low Point Pump Pit (LPPP),
- DWPF, and
- DWPF support facility.

The baseline NCSEs are listed in Table 1. NCSEs and Nuclear Criticality Safety Assessments (NCSAs) that have been superseded or are not applicable to this NCSASR are listed in Table 2.

Table 1. Baseline NCSEs used in this NCSASR

NCSE	NCSE Title/Objective
N-NCS-S-00008 (Ref. 3)	Processing of Salt Solution Containing High Enriched Uranium at DWPF (U) This NCSE demonstrates that processing of Tank Farm salt solution with up to 3 wt% ^{235}U(eq_sol) does not pose a criticality concern in DWPF or the DWPF support facilities. Allowed uranium enrichment in sludge is ≤ 5 wt% ^{235}U with Mn:^{235}U mass ratio ≥ 70 if ^{235}U enrichment exceeds 0.93 wt%.
N-NCS-S-00009 (Ref. 4)	Sludge Processing in DWPF (U) This NCSE demonstrates that processing of future sludge batches (allowed uranium enrichment in sludge is ≤ 5 wt% ^{235}U with Mn:^{235}U mass ratio ≥ 70 if ^{235}U enrichment exceeds 0.93 wt%) does not pose a criticality concern in DWPF or the DWPF support facilities.
N-NCS-H-00192 (Ref. 5)	Actinide Removal Process and Modular CSSX Unit (U) This NCSE addresses the criticality safety concerns of processing salt solution through the ARP/MCU and transfer of concentrated MST/sludge solids slurry to the Precipitate Pump Tank (PPT).

Table 2. Superseded/Not applicable NCSEs/NCSAs

NCSE	NCSE Title
N-NCS-S-00003 (Ref. 6) Superseded by N-NCS-S-00009	DWPF Chemical Process Cell for Sludge Batch 3
N-NCS-S-00004 (Ref. 7) Superseded by N-NCS-S-00009	Sludge Batch 3 Processing in DWPF
N-NCS-S-00005 (Ref. 8) Superseded by N-NCS-S-00008 and N-NCS-H-00192	Actinide Removal Process
N-NCS-S-00006 (Ref. 9) Not Applicable	Np Materials Processing in the DWPF Chemical Process Cell as Part of Sludge Batch 3
N-NCS-S-00010 (Ref. 38) Not Applicable	Evaluation of SRAT Batch 570 Following a Partial Sludge Transfer to DWPF for Processing SEFT Material (U)

1.3 DEFINITIONS

Administrative Control - A control that relies on the actions, judgment, and responsibility of people for its implementation. Because administrative controls are human-based, and therefore subject to error in application, they are less desirable than engineered controls. These controls are sometimes accompanied or enhanced by equipment items that alert an operator to take action (Ref. 26).

Active Engineered Control - Active engineered control is a means of control, intermediate in rank, involving add-on, active hardware (i.e., electrical, mechanical, hydraulic) that protects against criticality. These devices act by sensing a parameter important to criticality safety and providing automatic action to secure the system to a safe condition without the necessity of human intervention. However, active engineered devices are subject to random failure during operation and human error during maintenance and calibration. High quality/low failure rate equipment should be selected in all cases. Failsafe designs should be employed, if possible, and equipment failure should be easily and quickly detectable. The use of redundant systems should be considered as a means of dealing with unavailability (Ref. 26).

Bounding Assumptions - Conditions assumed for those physical parameters of importance to criticality safety (e.g., thick water reflection) other than the parameter upon which a criticality safety limit is based. If a bounding assumption (BA) for a parameter is "unrestricted," it means that the most reactive conditions for the parameter are assumed. If a BA for a parameter is "restricted," potential scenarios involving violation of the BA should be addressed and controls implemented as necessary. BA's include initial design constraints and physical process conditions not frequently altered, not requiring operator action, and not requiring frequent validation.

Credible - The attribute of being believable based on commonly acceptable engineering judgment. Due to the general lack of statistically reliable data, assigning numerical probabilities to events is not usually justifiable and when used should be backed up with references. A credible event is an event expected to occur with a frequency greater than once in a million years (i.e., greater than 1E-06 per year) as determined qualitatively by engineering judgment or more formally as a result of a quantitative analysis. Assigning a numerical probability that defines credible is not required in an NCSE (Ref. 26).

Equivalent Plutonium/Uranium, ^{239}Pu(eq)/^{235}U(eq) - Mass of fissile/fissionable materials expressed as equivalents of ^{239}Pu or ^{235}U when a mixture actually contains several nuclides (such as ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu, ^{244}Cm and ^{247}Cm). Equivalencies in this NCSASR are based on subcritical limits in the American National Standards Institute/American Nuclear Society (ANSI/ANS) standards (Ref. 10 & 11). While the equivalencies based on References 10 and 11 are applicable to sludge with a thermal, or near thermal, neutron energy spectrum, Reference 12 derives conservative equivalencies that are applicable to dry sludge with a fast neutron energy spectrum.

^{235}U(eq_sol) - Equivalent ^{235}U (soluble uranium only) in the MST/sludge solids stream from ARP added to the SRAT.

^{235}U(eq$_{REC}$) - Equivalent ^{235}U (including plutonium) in the DWPF recycle stream sent to the Tank Farm tanks.

^{235}U(eq$_{SLU}$) - Equivalent ^{235}U (uranium only) in a DWPF sludge batch.

Incredible - The attribute of NOT being believable on the basis of commonly acceptable engineering judgment. Due to the general lack of statistically reliable data, assigning numerical probabilities to events is not usually justifiable and when used should be backed up with references. An incredible event is an event expected to occur with a frequency less than once in a million years (i.e., less than 1E-06 per year) as determined qualitatively by engineering judgment or more formally as a result of a quantitative analysis. Assigning a numerical probability that defines incredible is not required in an NCSE (Ref. 26).

Passive-Engineered Control - Passive engineered control is the highest ranked means of criticality control, involving fixed, passive design features or devices rather than moving parts (for example, a nuclear safety blank). Such means of control provide high reliability, a broad range of coverage (i.e., cover many potential criticality accident scenarios), and require little operational support to maintain effectiveness. Human intervention is not required. When practical, advantage is taken of natural forces, such as gravity, rather than electrical, mechanical, or hydraulic action (Ref. 26).

Qualified Personnel - Personnel who have received training specific for a task and have been approved by management to perform that task.

Single Subcritical Mass - Maximum subcritical mass of ^{235}U(eq) corresponding to the equivalent ^{235}U enrichment. The single subcritical masses for various equivalent ^{235}U enrichment ranges for a uniform system of uranyl fluoride are provided below (Ref. 10).

^{235}U(eq) Enrichment (wt%)	^{235}U(eq) Subcritical Mass (kg)
> 10.0	0.76
> 5.0, ≤ 10.0	1.07
> 4.0, ≤ 5.0	1.64
> 3.0, ≤ 4.0	1.98
> 2.0, ≤ 3.0	2.75
≤ 2.0	8.00

Unmitigated (Scenario) - A scenario for which no criticality controls or programs (whose primary purpose contributes to preventing or mitigating the event) are assumed to be in place to provide a reduction in the estimated criticality event frequency or consequences, but as-designed process conditions (e.g., flowsheet and materials) and programs otherwise required or included as part of the Safety Analysis (e. g., nuclear material accountability, safeguards and security, transfer control) are assumed to be in place for normal operation (Ref. 26).

Waste Acceptance Criteria (WAC) - Formal waste characterization criteria (e.g., limits on uranium enrichment and fissile-to-poison mass ratio) that must be met before the waste can be accepted by the facility.

2.0 DESCRIPTION

The information provided in this section is intended only as descriptive information and is not intended to specify controls and limits for the facilities covered by this NCSASR. It should be noted that only materials, equipment, and processes important to NCS are briefly described herein. Detailed descriptions of the entire set of materials, equipment, and processes for DWPF are provided in Reference 13. Bounding assumptions, design features, and limits and requirements credited for criticality safety are provided in Section 6.0 of this NCSASR.

2.1 MATERIALS

2.1.1 Sludge

Sludge can be comprised of sludge/slurry from Tank Farm tanks (e.g., Tank 7), as well as other sources (e.g., plutonium from H-Canyon and processed americium/curium (Am/Cm) material from F-Canyon). The sludge/slurry from the Tank Farm tanks contains low concentrations of fissile material (U and Pu). The presence of Fe (as a neutron absorber) and the low enrichment of the uranium are relied upon for criticality safety. For sludge with uranium enrichment > 0.93 wt% ^{235}U (allowed ^{235}U enrichment ≤ 5 wt%), manganese (Mn) is credited as a neutron absorber relied upon for criticality safety. The neutron absorption in Fe is credited per a minimum Fe:^{239}Pu(eq) mass ratio of 160 in the sludge material, defined as a "safe mass ratio". The neutron absorption in Mn is credited per a minimum Mn:^{235}U(eq) mass ratio of 70 in sludge material with uranium enrichment > 0.93 wt% ^{235}U (allowed ^{235}U enrichment ≤ 5 wt%). The fissile material and the Fe and Mn compounds in the tank sludge/slurry are part of the "insoluble" sludge material (Ref. 13, Chapter 6) and hence do not separate from each other for most of the pH ranges expected in the Chemical Process Cell (CPC) tanks. Some Pu may be accompanied by Gd neutron absorber for NCS purposes in the Tank Farm. The Pu and Gd are known to separate in the CPC when exposed to acidic conditions (e.g., high oxalate concentrations) (Ref. 14).

Because materials important to NCS can come from different streams at different times, they must be well mixed to produce a uniform feed material for a sludge batch. The amount of mixing required to obtain this uniformity was studied and documented in Reference 15. This reference states that if all four slurry pumps in Tank 51 or Tank 40 are run for at least six hours, the sludge slurry is adequately mixed. For Sludge Batch 3 (SB3) a statistical study was performed based on a review of Tank 40 data and SRAT data and concluded that there is little, if any, evidence to suggest that the use of three Tank 40 slurry pumps versus four pumps results in any statistical difference in weight percent solids, iron concentration, aluminum concentration, etc. (Ref. 16). Furthermore, the following strategy has been developed by DWPF and Saltstone Facility Engineering to ensure that the sludge slurry is uniform in composition. Normally, four pumps will be used to mix Tank 40 sludge slurry for transfers to DWPF. However, if a slurry pump is experiencing in-leakage of bearing water, three mixing pumps may be used for three transfers to DWPF and all four mixing pumps must be used for each fourth transfer to DWPF.

The mixing conditions (i.e., times and pumps used) and SRAT receipt/product characteristics are monitored for all batches.

An additional factor involved in ensuring that a uniform mixture is transferred to the DWPF is whether the materials important to NCS remain well mixed when the slurry pump operation is discontinued for an extended period. That is, it must be shown that the NCS important materials maintain a well-mixed proportion after the pumps are stopped and the sludge/slurry begins to settle. According to Reference 15, particles remain suspended in Tank 51 for 60 hours after a full agitation cycle. If this 60-hour period is exceeded, particles would begin to settle. However, separation of Fe from Pu (or Mn from U) would not occur due to settling effects if particle sizes are similar, because the particles would tend to settle at comparable rates (Stoke's Law). According to Reference 17, the particle sizes for the Tank Farm sludge/slurry have a mean size in the range of 3-16 microns. The particle sizes of Gd and Pu in agitated H-Canyon Stored Plutonium material are reported to be from < 1 to 22 microns (Ref. 18). Therefore, the particles are similar in size and hence would tend to settle together even if the sludge material were not transferred within a relatively short period (~ 60 hrs) after a thorough mixing.

2.1.2 Sludge Batches

Since much of the analysis for future sludge batches is based on the analyses for SB3, a brief description of SB3 is taken from N-NCS-S-00009 (Ref. 4) and given here for informational purposes.

The total volume of SB3 material was specified as being no less than 450,000 gallons. The fissionable contents of SB3 included ~190 kg of fissile plutonium and ~31 metric tons of slightly depleted uranium at 0.62 wt% ^{235}U. In addition to fissile uranium and plutonium, SB3 contains a few kg of Cm, a few grams of Am, and ~52 kg of Np. The Fe:$^{239}Pu(eq)$ mass ratio in the SB3 material is greater than 600.

The $^{239}Pu(eq)$ in Reference 4 is defined as the summation of fissile isotopes as given in the following equation:

$$^{239}Pu(eq) = {}^{239}Pu + {}^{241}Pu + {}^{244}Cm + 15\ ({}^{245}Cm) + 35\ ({}^{242m}Am)$$

The $^{235}U(eq_{SLU})$ is defined as the summation of fissile uranium isotopes as given in the following equation:

$$^{235}U(eq_{SLU}) = {}^{235}U + 1.4\ ({}^{233}U)$$

The $^{235}U(eq_{SLU})$ enrichment is defined as given in the following equation:

$$^{235}U(eq_{SLU})\ \text{Enrichment (wt\%)} = 100 \times {}^{235}U(eq_{SLU}) \div U$$

Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

Note that the equation for ^{239}Pu(eq) does not include ^{235}U(eq_{SLU}) because SB3 material had ^{235}U enrichment in uranium ≤ 0.93 wt%. Section 4.1 addresses the inclusion of ^{235}U(eq_{SLU}) in the ^{239}Pu(eq) equivalency equation for sludge material with ^{235}U enrichment in uranium > 0.93 wt%.

The ^{239}Pu(eq) and ^{235}U(eq_{SLU}) equivalency equations are derived based on the subcritical limits in References 10 and 11. The equations are applicable to aqueous thermal and near thermal systems, which with the exception of the sludge/glass frit mixture in the Melter, are representative of sludge conditions during processing through DWPF.

2.1.3 Tank Farm Salt Solution

Alkaline salt solutions containing soluble and insoluble radioisotopes, originally from Tank Farm salt tanks, will be sampled prior to being transferred to Tank 49, the feed tank to either the 241-96H facility for MST strike or 512-S for filter-only operation.

2.1.4 MST

MST Strike

The 241-96H facility may receive salt solution batches containing radioisotopes including plutonium and uranium (soluble and insoluble) from the feed tank (Tank 49). If an MST strike is necessary in 241-96H, approximately 5 gallons of MST slurry (one 5-gallon pail) and about 100 gal of water (to transfer the MST slurry) will be added to each feed batch. This yields a process batch volume of ~3,800 gal, at an MST concentration of ~0.2 g/L. MST ($NaTi_2O_5H$) is added to the salt solution to promote the removal of soluble strontium and soluble actinides such as uranium and plutonium. The MST/sludge solids slurry will be transferred to the 512-S facility for concentration through a crossflow filter.

Filter-Only

The 512-S facility may receive salt solution batches containing radioisotopes including plutonium and uranium (soluble and insoluble) from the feed tank (Tank 49), if an MST strike is not necessary. Depending on operational needs, the feed may be sent to 96H and then sent to 512-S without added MST in the 96H Strike Tanks. Entrained sludge solids in the salt stream will be concentrated through a crossflow filter.

2.1.5 Oxalic Acid

The ARP utilizes a filter cleaning cycle for the crossflow filter and for the secondary filter inside the Late Wash Hold Tank (LWHT) during which oxalic acid is used. A concern is that unneutralized oxalic acid from the filter cleaning operations will be transferred to the SRAT where it may preferentially dissolve Fe, but not plutonium. This would result in a reduction of Fe, a credited neutron poison, in the DWPF sludge and is a criticality safety concern.

2.2 EQUIPMENT DESCRIPTION

2.2.1 Interarea Transfer Lines

The Interarea Transfer Lines (ITLs) consist of buried pipelines connecting the DWPF and H-Area facilities with the ARP in 512-S and the LPPP at intermediate locations. The ITLs consist

of lines with two 3-inch schedule 40 (schedule 10 in H-Area), type 304L stainless steel core transfer lines surrounded by a 10-inch, schedule 20 carbon steel jacket. The ITLs can transfer:

- Sludge from Tank 40 to the SRAT via the LPPP Sludge Pump Tank (LPPP-SPT),
- Salt solutions from Tank 49 to the Strike Tanks in the 241-96H facility,
- Salt solutions from Tank 49 to the Late Wash Precipitate Tank (LWPT),
- MST/sludge solids from the LWPT to the Precipitate Reactor Feed Tank (PRFT) via the LPPP Precipitate Pump Tank (LPPP-PPT),
- MST/sludge solids from the 241-96H Strike Tanks to the PRFT via the LPPP-PPT,
- ARP filtrate from the LWHT to Tank 50 or to MCU,
- Strip Effluent from MCU to the Strip Effluent Feed Tank (SEFT) via the LPPP Cells, and
- Recycle from the Recycle Collection Tank (RCT) to the H-Area Diversion Box-8 (HDB-8) complex via the LPPP Recycle Pump Tank (LPPP-RPT)

2.2.2 512-S Facility

The 512-S ARP tanks important to NCS are the LWPT and the LWHT. The LWPT is used as a multipurpose reactor and filtration feed tank, while the filtrate from the crossflow filter is collected in the LWHT. Each ARP tank is equipped with an agitator to facilitate the uniform mixing of materials. The nominal minimum, overflow, and maximum liquid holding capacities of the ARP tanks are presented in Table 3.

Spills (e.g., tank overflow, jumper leak) in each cell will be collected in the cell sump. Each sump is equipped with a level indicator. In the past, sump steam transfer jets had been provided to transfer waste from each sump to the associated pump tank. However, these jets have been disabled due to aerosolization concerns and alternative methods are being pursued to transfer material from the sump.

The ARP Process Vessel Vent System (PVVS) collects vented gases from the LWPT, LWHT, and the Surge Tank and combines these gases with dilution air from the Precipitate, Filter and Filtrate Cells. This combined vapor stream passes through a heater, a series of High Efficiency Particulate Air (HEPA) filters and an exhaust blower before passing through and out the exhaust stack.

2.2.3 Low Point Pump Pit (LPPP)

The LPPP (Bldg. 511-S) has three contiguous cells: a sludge pump cell, a recycle waste pump cell, and a precipitate pump cell. Each 18' × 18' × 39' cell contains a pump tank. Jumper connections are used to allow for transfers to a tank or for pass-through transfers. Pass-through jumper(s) will be used in the LPPP to connect transfer lines SDP1 and SDP25 to accommodate the transfer of strip effluent from the MCU to the SEFT in the CPC. The LPPP Pump Tanks are not used for this transfer. The PPT is used to transfer the concentrated MST/sludge solids slurry from 512-S to the PRFT.

2.2.4 Low Point Pump Pit Tanks Description

The LPPP is equipped with three pump tanks: the SPT, PPT, and the Recycle Pump Tank (RPT) (Ref. 19). Each LPPP tank is equipped with an agitator to facilitate the uniform mixing of materials. The nominal minimum, overflow, and maximum liquid holding capacities of the LPPP tanks are presented in Table 3.

The pump tanks are housed separately in contiguous concrete cells. The cell floors have a slope for drainage purposes and a shallow trench at the low side for direct flow to the sump in the event of a spill (e.g., tank overflow, jumper leak). The cell floor cross section is about 18' by 18' (Ref. 20). The cell sump dimensions are 3' by 3' by ~2' 8" high (Ref. 20 and 21). Each sump is equipped with a level indicator.

2.2.5 DWPF Tanks Description

The DWPF tanks important to NCS are the SRAT, Slurry Mix Evaporator (SME), Melter Feed Tank (MFT), Slurry Mix Evaporator Condensate Tank (SMECT), PRFT, RCT, Decontamination Waste Treatment Tank (DWTT), SEFT, Melter, and the 4-foot diameter soak tank. The PRFT is located in the Salt Process Cell (SPC), the 4-foot diameter soak tank is located in the Remote Equipment Decontamination Cell (REDC), and the Melter is located in the Melt Cell (MC). The remaining tanks are located in the CPC.

The CPC tanks are equipped with agitators or spargers to facilitate the uniform mixing of materials. These tanks are also equipped with centrally located coils for heating and/or cooling tank contents when required. The liquid holding capacity for each tank is approximately 11,000 gallons (based on the tank inner diameter of 12 feet and the overflow height of 13 feet). The nominal minimum, overflow, and maximum liquid holding capacities of the SPC and CPC tanks are presented in Table 3.

Spills (e.g., tank overflow, jumper leak) from the SPC and CPC tanks will be collected in sumps for ultimate transfer to the RCT.

2.2.6 Melter Description

The melt process is accomplished in a slurry-fed, joule-heated Melter designed to incorporate high level waste (HLW) into a solid, borosilicate glass matrix. Feeding of the Melter with an aqueous slurry of waste and glass-forming material (frit) combines the principal vitrification process operations of drying, calcining, and melting in a single process vessel. The nominal minimum, overflow, and maximum liquid holding capacities of the Melter are presented in Table 3.

Table 3. 512-S/DWPF Tanks Nominal Capacity
(Ref. 22 unless otherwise noted)

Tank Description	Minimum (gal)	Overflow (gal)	Maximum (gal)
512-S Tanks			
Late Wash Precipitate Tank (LWPT)	191	6,204	7,000
Late Wash Hold Tank (LWHT)	191	6,204	7,000
Low Point Pump Pit (LPPP) Tanks			
LPPP Precipitate Pump Tank (LPPP-PPT)	700	6,466	7,050
LPPP Recycle Pump Tank (LPPP-RPT)	650	6,179	7,050
LPPP Sludge Pump Tank (LPPP-SPT)	650	6,217	7,050
Chemical Process Cell (CPC) Tanks			
Strip Effluent Feed Tank (SEFT)	1,400	10,657	12,000
Sludge Receipt and Adjustment Tank (SRAT)	1,400	10,928	12,000
Slurry Mix Evaporator (SME)	1,400	11,298	12,000
Melter Feed Tank (MFT)	1,800	11,089	12,000
Slurry Mix Evaporator Condensate Tank (SMECT)	1,400	11,263	12,000
Recycle Collection Tank (RCT)	1,400	10,479	12,000
Decontamination Waste Treatment Tank (DWTT) (Ref. 22 and 23)	1,400	11,000	12,000
Melt Cell			
Melter	476	888	1,414
Salt Process Cell (SPC) Tank			
Precipitate Reactor Feed Tank (PRFT)	750	8,310	9,000

2.3 PROCESS DESCRIPTION

2.3.1 Actinide Removal Process in the 512-S Facility

The ARP uses the LWPT in 512-S facility to receive MST/sludge solids slurry from the 241-96H Strike Tanks or salt solution directly from Tank 49. MST/sludge solids slurry refers to either MST/sludge solids slurry from 96H, or potential sludge solids entrainment in the salt solution from Tank 49, depending on whether ARP/MCU is in filter-only operations. The MST/sludge solids from processing salt solution batches is accumulated and concentrated in the LWPT by circulating the salt solution with MST/sludge solids through the crossflow filter and allowing the filtrate to collect in the LWHT. The contents of the LWHT are transferred to the MCU facility to remove cesium prior to transfer to Tank 50.

The following process description focuses on the "coupled" operation of the ARP/MCU facilities. The MST/sludge solids from the LWPT are transferred to the PRFT, and the strip effluent solution, containing most of the cesium from the MCU facility, is transferred to the SEFT.

The ARP operations in the 512-S facility include:

- MST/Sludge Solids Concentration,
- Solids Washing,
- Solids Transfer,
- Filtrate Transfer, and
- Filter Cleaning.

MST/Sludge Solids Concentration

The LWPT in the ARP is used to concentrate the salt solution with MST/sludge solids. The MST/sludge solids from processing salt solution batches are accumulated and concentrated in the LWPT by circulating the salt solution with MST/sludge solids through the crossflow filter and allowing the filtrate to collect in the LWHT.

Solids Washing

After concentration is complete, the accumulated MST/Sludge solids may be washed by adding water to the LWPT while circulating the slurry through the crossflow filter to remove spent wash water. Washing continues until the concentration of soluble sodium ions is reduced to about 0.5 M in the resulting 1,600 gallons of MST/sludge slurry. The wash water is filtered similar to the concentration step. The wash water is sent to the LWHT.

Solids Transfer

After washing is complete, about 900 gallons of the MST/sludge slurry in the LWPT are transferred through an underground transfer line to the LPPP-PPT. This slurry is combined with a 1,100-gallon heel remaining from previous transfers from the LPPP-PPT to the PRFT. Cross flow filter cleaning solutions are normally introduced into and mixed with the heel in the LWPT and are transferred to the LPPP-PPT before the LPPP-PPT contents are transferred to the PRFT. The contents of the PRFT are then mixed with DWPF sludge in the SRAT at a controlled rate.

Filtrate Transfer

As the MST/sludge slurry in the LWPT is processed through the cross flow filter, the solids return to the LWPT and the filtrate, Clarified Salt Solution (CSS), is transferred to the LWHT for eventual transfer to a Salt Solution Receipt Tank (SSRT) in MCU for cesium removal or to Tank 50 for disposition at Saltstone.

Filter Cleaning

During filtration, the crossflow filter may become clogged with solids. If the filter requires cleaning, the chemicals used during the crossflow filter cleaning cycle are $\geq$ 1.66 M sodium hydroxide, $\geq$ 0.02 M sodium hydroxide (inhibited water) and 0.4 – 0.6 M oxalic acid. The recommendations for the filter cleaning process are documented in Reference 25.

These chemicals are fed into the Surge Tank and Backpulse Tank, recirculated through the crossflow filter multiple times, and sent to the LWPT. From there, they are transferred to the LPPP-PPT. The cleaning chemicals also serve as a line flush for the underground header between 512-S and the LPPP. This addition of cleaning chemicals to the heel in the LPPP-PPT lowers the solids concentration in the LPPP-PPT. Additionally, oxalic acid used to dissolve MST/sludge solids in the crossflow filter is neutralized by excess caustic in the LWPT prior to transfer to DWPF.

Oxalic acid is also used in 512-S to clean the secondary filter inside the LWHT. The filter cleaning solution is neutralized and transferred to Tank 50. The flush water following the filter cleaning in the LWHT will also be transferred to Tank 50. High molarity sodium hydroxide ($\geq$ 1.66 M) may also be used to clean the secondary filter.

2.3.2 Chemical Process Cell (CPC)

Sludge batch material is transferred from the DWPF feed tank in H-Area (Tank 40), through the LPPP-SPT, to the SRAT as required. MST/sludge solids from the PRFT may be added to the sludge batch material in the SRAT at a controlled rate. SRAT contents are analyzed and formic and nitric acid or glycolic and nitric acid are added to the SRAT. The SRAT contents are concentrated by boiling after acid additions. Next, the acidic solution containing cesium from the SEFT may be added to the SRAT and concentrated as necessary to achieve final batch volume and solids goals. After SRAT processing, the material is sent to the SME where glass frit is added to form a sludge-frit slurry. The slurry mixture in the SME is then transferred to the MFT. Condensate and overflow from the SRAT and the SME are transferred to the SMECT for ultimate transfer to the RCT.

The CPC Primary Purge System provides an air purge to the SEFT, SRAT, SME, SMECT, and MFT. The purge system provides a purge through the vessel to the Process Vessel Vent Header (PVVH), which exhausts into the Zone 1 exhaust tunnel.

2.3.3 Melt Cell (MC)

The sludge-frit slurry from the MFT is fed into the Melter at a controlled rate. In the MC the material is immobilized in a glass matrix and transferred to sealed canisters. The Melter is operated with a crust (cold cap) composed of waste calcine and frit that covers most of the melt surface. The feed slurry is introduced onto the top of the cold cap. Water from the slurry is evaporated and drawn into the off-gas system. The glass melt beneath the cold cap is at molten glass temperature, which causes the cold cap to melt from the bottom and form a glass-waste matrix.

The molten glass flows through the Melter throat, up the riser and down the pour spout into a stainless steel canister connected to the Melter by a bellows. This flow path is surrounded by a ceramic assembly, which keeps the molten glass at an elevated temperature until it is poured into the canister.

2.3.4 DWPF Support Systems

Equipment from the vitrification process and supporting cells (including LPPP) is brought to the REDC for decontamination. Once in the cell, several methods are available to decontaminate the equipment (e.g., high-pressure water, steam cleaning, nitric acid). A soak tank is located in the REDC such that equipment can soak for several days to remove sludge deposits. The soak tank is periodically drained directly to the REDC sump. The highly acidic contents of this sump are then pumped to the DWTT and then to the RCT where the waste is neutralized and transferred to the HDB-8 complex.

The PVVS collects, decontaminates, and discharges the gases from in-cell process vessels to the exhaust system. The PVVS serves all in-cell process vessels, except for the Melter, which has its own off-gas treatment system. The PVVS contains High Efficiency Mist Eliminator (HEME) filters to reduce the concentration of entrained particulates and aerosols in the vapor entering the PVVH. The active filter elements are dissolved in the DWTT.

The Melter off-gas flow consists principally of steam and non-condensable gases containing entrained particulates and feed components that are volatile at the operating temperature of the Melter. The Melter off-gas treatment process consists of two parallel systems. The off-gases are normally processed through the primary system and may be switched to the backup off-gas system when necessary. Cooled off-gas is discharged into the Off-Gas Condensate Tank (OGCT). Liquid collected in the OGCT can be transferred to the RCT. The Melter off-gas treatment process uses HEME and HEPA filters to remove any entrained particulates before discharging the off-gases to the exhaust tunnel. These filters are dissolved in the DWTT.

The DWTT has two major functions: to dissolve the filter media of the HEME and HEPA filters removed from service and to neutralize solutions with caustic. The DWTT also collects spent solutions from equipment decontamination and miscellaneous sumps containing nitric acids.

2.3.5 Spills

The potential for spills of process solutions exists throughout DWPF facilities, including the LPPP and 512-S. A spill may occur as a result of tank overflow, jumper leak, or missing jumper. The potential for tank overflow is mitigated by the level monitoring and alarms systems that are interlocked to stop the appropriate transfer system associated with each process vessel. A pressure-driven leak of slurry from slurry transfers could occur. Sump level monitors and alarms provide a system to detect if a spill or leak has occurred and sample lines permit analysis of sump contents. The potential for an eruption in the evaporators used to prepare Melter feed (SRAT and SME) is mitigated by controlling the rate of steam flow as the boiling temperature is approached and by slurry temperature differential monitoring systems that are interlocked to the steam delivery system. Loss of containment of the glass melt is a spill unique to the vitrification process, since the spilled material is at a greatly elevated temperature and the volatility of certain radionuclides will increase releases to the cell atmosphere.

3.0 REQUIREMENTS DOCUMENTATION

This NCSASR is subject to the general requirements documentation and review processes that are applicable to all nuclear criticality safety summary reports performed at SRS, as outlined in Reference 26.

4.0 METHODOLOGY

This NCSASR summarizes the criticality safety requirements for the processing of radioactive waste in 512-S ARP, DWPF, and the DWPF support facilities. The criticality safety hazards associated with these operations were identified, evaluated, and documented in the applicable baseline NCSEs (see Table 1). The determination of the requirements is based upon the specific methodology utilized in the referenced NCSEs.

The methodology presented in Reference 27 was used in the baseline NCSEs to specify the barriers so that a criticality accident was deemed mitigated Beyond Extremely Unlikely. Reference 27 outlines the overall process and the criteria by which engineering judgments are made and provides guidelines for determining if the identified barriers are sufficient to deem it incredible for a scenario to lead to criticality. The guidance associated with Table 1 in Reference 37 was used to evaluate the criticality accident frequency and consequences and barriers discussed in the NCSEs for inclusion in the DWPF FSAR or TSR, as addressed in Reference 40. Reference 40 was written against Revision 0 of Reference 37. The changes in Revision 1 of Reference 37 do not impact the implementation plan. Reference 37 requires the guidance to be applied on a forward-fit basis.

A multi-discipline team (Criticality Safety Team), representing engineering, operations, procedures, and criticality safety developed scenario identification and incredibility determinations using the Consolidated Hazards Analysis Process (CHAP) per Reference 39.

4.1 EQUIVALENCY EQUATIONS

In order to account for the presence of all isotopes, their quantities will be converted to equivalent ^{235}U or equivalent ^{239}Pu through the use of equivalency factors. Reference 12

provides a number of equivalency factors that are based on the form of the material. The forms include aqueous solutions and slurries, saltcake systems, and dry sludge systems.

DWPF Sludge

The equivalent $^{239}Pu(eq)$ and $^{235}U(eq_{SLU})$ and $^{235}U(eq_{SLU})$ enrichment in the sludge to be processed in DWPF can be determined using the following formulas:

$$^{239}Pu(eq) = {}^{239}Pu + {}^{241}Pu + {}^{244}Cm + 15\ ({}^{245}Cm) + 35\ ({}^{242m}Am) \quad + 0.65\ {}^{235}U(eq_{SLU})\ * \qquad [1]$$

With the requirement that the ^{240}Pu concentration exceeds the ^{241}Pu concentration.

* $^{235}U(eq_{SLU})$ only needs to be included if the uranium enrichment is greater than 0.93 wt%.

$$^{235}U(eq_{SLU}) = {}^{235}U + 1.4\ ({}^{233}U) \qquad [2]$$

$$^{235}U(eq_{SLU})\ \text{Enrichment (wt\%)} = 100 \times {}^{235}U(eq_{SLU}) \div U \qquad [3]$$

Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

The equivalency factors in the $^{235}U(eq_{SLU})$ equation are derived from References 10 and 11. These equations are applicable to aqueous systems which, with the exception of the Melter (where the sludge-frit mixture is completely dry), are representative of sludge conditions during processing through DWPF. While the energy spectrum of neutrons in the molten sludge-frit mixture in the Melter is fast, the above equations can be applied to the Melter as well because of the conservative Fe:$^{239}Pu(eq)$ mass ratio and the presence of other non-fissionable material serving as diluents in the sludge. Note that $^{235}U(eq_{SLU})$, shown in equation 2, is not included in the $^{239}Pu(eq)$ equivalency equation 1 if the maximum $^{235}U(eq_{SLU})$ enrichment in the sludge is no greater than 0.93 wt%. The $^{235}U(eq_{SLU})$ equation does not include plutonium and is given for determining the $^{235}U(eq_{SLU})$ (excluding non-uranium fissile isotopes) used to calculate the $^{235}U(eq_{SLU})$ enrichment in sludge as shown in equation 3.

DWPF Recycle Stream

DWPF uses the equivalency equation from the 2H Evaporator NCSE (Ref. 36) and Tank Farm WAC (Ref. 34), which includes non-uranium fissile isotopes, to calculate the $^{235}U(eq_{REC})$ in the DWPF recycle stream sent to the 2H Evaporator. The DWPF Recycle Stream is transferred to the 2H Evaporator System. The Tank Farm WAC (Ref. 34) limits the enrichment of the transfers. The $^{235}U(eq_{REC})$ and the $^{235}U(eq_{REC})$ enrichment for the DWPF recycle to the 2H Evaporator System are calculated using equations 4 and 5, respectively.

$$^{235}U(eq_{REC}) = {}^{235}U + 1.4 \times {}^{233}U + 2.25 \times ({}^{239}Pu + {}^{241}Pu) \qquad [4]$$

$$^{235}U(eq_{REC})\ \text{Enrichment (wt\%)} = 100 \times {}^{235}U(eq_{REC}) \div [U + 2.25 \times ({}^{239}Pu + {}^{241}Pu)] \qquad [5]$$

Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

MST/Sludge Solids Slurry from 512-S

The MST/sludge solids slurry from the ARP to be processed with the DWPF sludge is limited to a ^{235}U(eq_sol) enrichment no greater than 3 wt% (Ref. 5).

$$^{235}\text{U(eq_sol) Enrichment (wt\%)} = 100 \times (^{235}\text{U} + 1.4 \times {}^{233}\text{U}) \div \text{U} \qquad [6]$$

Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

Barriers identified in Reference 5 preclude a ^{235}U(eq_sol) enrichment greater than 3 wt% within the ARP/MCU boundary. Note that the formula for calculating the ^{235}U(eq_sol) enrichment for the MST/sludge solids slurry is defined in Reference 5 and the formula is not the same as the equation for ^{235}U(eq$_{REC}$) enrichment.

5.0 BASELINE EVALUATIONS FOR THIS NCSASR

The objective of this section is to list the upset scenarios considered in the baseline NCSEs of Table 1. Specific details and the bases for assumptions and limits are documented in the baseline evaluations.

5.1 PROCESSING OF SALT SOLUTION CONTAINING HIGH ENRICHED URANIUM AT DWPF (N-NCS-S-00008)

This section lists the scenarios of N-NCS-S-00008 (Ref. 3) considered in developing the bases for criticality safety of the coupled processing of DWPF sludge (uranium enrichment ≤ 0.93 wt% ^{235}U or allowed uranium enrichment ≤ 5 wt% ^{235}U with Mn: ^{235}U mass ratio ≥ 70) and MST/sludge solids slurry containing enriched uranium [but limited to a maximum ^{235}U(eq_sol) enrichment of 3 wt% in the MST/sludge solids slurry]. A multi-discipline team, representing engineering, operations, chemistry, and criticality safety, performed the Hazard Evaluation, unmitigated scenario identification, incredibility determinations and NCSE review. The criticality safety concerns and credible variances from the normal operating conditions as evaluated in Reference 3 are indicated in the following outline.

Criticality Concerns in the SRAT

- Increase in Fissile Material Concentration in SRAT Due to MST/Sludge Solids Slurry Addition
- Settling Effects in SRAT Results in Increased Fissile Material Concentration Leading to a Criticality Accident
- Fissile Uranium in the SRAT Supernate Spills into the Cell Floor Sump Leading to a Criticality Accident
- Fissile Material Separation in the SRAT due to Acid Addition
- Fissile Material Separation in the SRAT due to Oxalic Acid Addition
- Criticality Accident in the SRAT caused by Evaporation (Long Term or Accelerated by Steam in Coils) of Moderator and Loss of Poison Effectiveness
- Fissile Material Densification in SRAT Results in a Criticality
- Accumulation of Uranium/Plutonium on the CPC Floor/Sump Due to Repeated Spills

- Inadvertent Transfer of Excessive Sludge to the SRAT from the SPT
- Uncharacterized Material sent to the SRAT
- Improper Batch Preparation or Characterization in Sending Facility of Material Transferred to the SRAT Results in an Unexpected Uranium Enrichment
- Addition of Excessive Amounts of MST/Sludge Solids Slurry creates a Low Poison Ratio within the SRAT
- Temperature Variation in the SRAT
- Criticality Accident Caused when Fissile Material Dissolves in the Mercury in the Mercury Trap in the Bottom of the SRAT
- Criticality Concerns in SRAT Associated with Solvent from MCU
- Criticality Concerns in the Mercury Water Wash Tank from Carryover of Fissile Material from the SRAT
- Mn:^{235}U mass ratio < 14 in sludge or solution in DWPF

<u>Criticality Concerns in the SME</u>

- Excess Acid in Frit Stream or Process Addition Causes Dissolution of Poisons in the SME
- Because of similar geometry, other upset scenarios associated with the SME are bounded by the SRAT scenarios

<u>Criticality Concerns in the SMECT</u>

- Carryover from the SRAT and/or SME into the SMECT Results in a High Fissile Mass in the SMECT and a Subsequent Criticality Accident
- Because of similar geometry, other upset scenarios associated with the SMECT are bounded by the SRAT scenarios

<u>Criticality Concerns in the SEFT</u>

- Leakage of MST/Sludge Solids into the SEFT via 3-way Valve Creates an Accumulation of Fissile Solids in the SEFT which Leads to a Criticality
- Criticality Concerns Associated with Inadvertent Transfer from SRAT to SEFT
- Criticality Concerns Associated with Nitric Acid from MCU in the SEFT

<u>Criticality Concerns Associated with Inadvertent Fissile Material Transfer to DWPF Tanks</u>

<u>Criticality Concerns Associated with Use of Oxalic Acid in DWPF</u>

<u>Criticality Concerns in PVVS and PVVH</u>

- Accumulation of Fissile Material in the PVVS and PVVH
- Accumulation of Fissile Material in the Ammonia Scrubbers
- Accumulation of Fissile Material in the Formic Acid Vent Condenser

<u>Criticality Concerns in LPPP-SPT Cell Floor/ Sump</u>

- Criticality on the Sludge Pump Tank Cell Floor/Sump caused by undetected leaks from the SPT that collect due to evaporation or are moderated when a large leak flushes the fissile material to the sump
- Criticality on the Sludge Pump Tank Cell Floor/Sump caused by undetected leaks from the SPT mixed with Strip Effluent Hold Tank (SEHT) material (this scenario bounds strip effluent leaks into other LPPP cells)
- Criticality in the Sludge Pump Tank caused by evaporation of water

<u>Criticality Concerns in DWPF Decontamination Support Facilities</u>

- Criticality Concerns in the REDC from Accumulation of Fissile Material on the Floor or REDC / Contact Decontamination Maintenance Cell (CDMC) Sump

- Criticality Safety Concerns in the REDC Soak Tank from Accumulation of Fissile Material
- Criticality Concerns in DWTT
- Use of Oxalic Acid in DWPF Decontamination Support Facilities
- Criticality Concerns in RCT
- Criticality Concerns in LPPP-RPT
- Criticality Safety Concerns in the REDC due to mechanical cleaning of the REDC

Criticality Concerns in the Melt Cell and MFT

- Criticality Accident in the Melter or Canister Caused by the Separation of Fissile Material from the Neutron Poisons
- Change in the Density or Distribution of Fissile Material in the Melter Results in a Criticality Accident
- Criticality Accident in the Melter Off-Gas System Caused by the Accumulation of Fissile Material Without Sufficient Neutron Poison
- Dissolution of Neutron Poisons in MFT Results in Separation of Fissile Material from Poisons Leading to a Criticality

Criticality Concerns with Interarea Transfer Lines

Criticality Concerns in the Glass Waste Storage Buildings (GWSBs)

- Criticality Accident in a Canister or in the GWSB due to Receiving Excess Fissile Material or Separation of Fissile Material in DWPF Processing
- Criticality Accident Caused by the Settling of Fissile Material in the Canister over Time
- Criticality Accident in the GWSB Caused by the Interaction of Multiple Canisters
- Criticality Accident in the GWSB Caused by the Introduction of Moderator between Multiple Canisters

Criticality Concerns in the PRFT

- Excessive Evaporation in the PRFT Results in a Concentration of Fissile Material Which Leads to a Criticality
- Settling in the PRFT Results in Increased Fissile Material Concentration Which Leads to a Criticality
- Separation of Fissile Material from MST/Sludge Solids Results in an Increased Fissile Concentration in Solution Leading to Criticality
- Criticality Accident in PRFT Caused when the Density of the Solids in the PRFT is Increased
- Criticality Accident in PRFT Caused by Temperature Variation
- Criticality due to an Inadvertent Transfer from SRAT to PRFT
- Criticality Accident in the PRFT due to residual MST during Filter-Only operation

Criticality Concerns in the Salt Process Cell (SPC) Floor/sump

- Criticality on the Salt Process Cell Floor/Sump Caused by Undetected Leaks of MST/Sludge Solids
- Criticality on the Salt Process Cell Floor/Sump Caused by Spills of PRFT Supernate Containing Soluble Fissile Material.

Bounding assumptions, design features, and administrative limits and requirements credited in Reference 3 are listed in Section 6.

5.2 SLUDGE PROCESSING IN DWPF (N-NCS-S-00009)

This section indicates the scenarios from N-NCS-S-00009 (Ref. 4) considered in developing the bases for criticality safety of the radioactive sludge (uranium enrichment ≤ 0.93 wt% ^{235}U or allowed uranium enrichment ≤ 5 wt% ^{235}U with a Mn: ^{235}U mass ratio ≥ 70) to be processed in the DWPF process and the DWPF support facilities. The criticality safety concerns and credible variances from the normal operating conditions as evaluated in Reference 4 are indicated in the following outline.

- Plutonium Oxide Accumulation in the SRAT Mercury Trap
- Separation of Absorber Material from Fissile Material
- Settling Effects from Loss of Stirring Action
- Material Dry-out
- Material Densification
- RCT
- REDC
- Process Vent and Off-gas Systems
- DWTT
- LPPP, SPT, and Slurry Transfer System, and
- Melter.

The scenarios and areas of concern were analyzed based on the assumption that the Fe:^{239}Pu(eq) mass ratio in the sludge is a minimum of 160 and the ^{235}U(eq_{SLU}) enrichment is less than or equal to 0.93 wt% or the ^{235}U(eq_{SLU}) enrichment is ≤ 5 wt% ^{235}U with a Mn: ^{235}U mass ratio ≥ 70. Administrative limits and requirements credited in Reference 4 are listed in Section 6.4.

5.3 ACTINIDE REMOVAL PROCESS AND MODULAR CSSX UNIT (N-NCS-H-00192)

N-NCS-H-00192 (Ref. 5) develops the bases for criticality safety of processing salt solution through the ARP/MCU and transfer of concentrated MST/sludge solids slurry to the PPT, specifically in 512-S as they pertain to the DWPF organization. The soluble fissionable components of the salt batch solutions to be processed have maximum concentrations of 50 mg U/L and 0.3 mg Pu/L, and a maximum uranium enrichment of 3 wt% ^{235}U(eq_sol). Criticality safety concerns and credible variances from the normal operating conditions apply to either or both Concentration, Storage, and Transfer Facilities (CSTF) and DWPF facilities and operations for this NCSE. For the purposes of this report, only those requirements for DWPF facilities and operations are described in Section 6. The scenarios in N-NCS-H-00192 are not listed because only a small number of them apply to DWPF.

5.4 SUMMARY OF SUPERSEDED OR NOT APPLICABLE NCSES/NCSAS

NCSEs that have been superseded or are not applicable to this NCSASR are listed in Table 2. However, the configurations analyzed in these NCSEs are potentially useful for analyses in future NCSEs. For this purpose, the results obtained in these NCSEs are summarized below. Note that some of these NCSEs are referenced in the applicable NCSEs listed in Table 1.

N-NCS-S-00003

N-NCS-S-00003 (Ref. 6) evaluated the processing of SB3 in the CPC of DWPF. Reference 6 demonstrated that a criticality during processing of SB3 with or without ARP MST/sludge solids through the CPC is incredible provided the minimum Fe:^{239}Pu(eq) mass ratio in SB3 is 160 and the maximum ^{235}U(eq_{SLU}) enrichment in SB3 is $\leq$ 0.93 wt%.

N-NCS-S-00004

N-NCS-S-00004 (Ref. 7) evaluated the processing of SB3 in the entire DWPF and the DWPF support facilities. The NCSE also evaluated the effect of considering ^{238}U, as well as iron, as a neutron absorber in both the wet and dry states.

N-NCS-S-00004 demonstrated that SB3 remains subcritical provided the minimum Fe:^{239}Pu(eq) mass ratio in SB3 is 160 and the ^{235}U(eq_{SLU}) enrichment is less than or equal to 0.93 wt%.

N-NCS-S-00005

The requirements in N-NCS-S-00005 (Ref. 8) were superseded by N-NCS-S-00008 (Ref. 3), but the calculations in N-NCS-S-00005 are still valid.

N-NCS-S-00005 evaluated the processing of the F-Tank Farm salt solution in the 512-S ARP. N-NCS-S-00005 demonstrated that 1) oxalic acid used in the filter cleaning process in the ARP will not result in criticality in DWPF and 2) a criticality accident in the 512-S ARP while processing F-Tank Farm salt solution is deemed incredible because of:

- Low ^{235}U enrichment ($\leq$ 0.93 wt%) in salts from F-Tank Farm salt tanks. Thus, the salts from F-Tank Farm salt tanks are inherently subcritical in any condition (solid or liquid) and configuration (e.g., inside piping, on the cell floor, in a sump, in a filter).
- Presence of neutron absorbers (e.g., iron) in the salt.

N-NCS-S-00006

N-NCS-S-00006 (Ref. 9) evaluated the presence of Np as a constituent of SB3 in the CPC of the DWPF and concluded that SB3 with up to 41.78 kg of Np remains subcritical.

N-NCS-S-00010

NCSA N-NCS-S-00010 (Ref. 38) documented that sufficient sludge had been sent to the SRAT prior to transferring a SEFT batch. Reference 3 required that sludge be transferred into the SRAT prior to transferring the SEFT contents to the SRAT. During the transition to Sludge Batch 7a (SB7a), a low pressure interlock on the Tank 51 transfer pump prevented all the intended sludge material from being sent to Tank 40. As a result, DWPF could not take a transfer of the new SB7a material from Tank 40 to the SRAT. Concurrently, the SEFT was full and it was necessary to transfer the SEFT material to the SRAT to prevent MCU from having to shut down processing. This NCSA demonstrated that the first sludge transfer from the SPT to the SRAT (and forming SRAT Batch 570) had sufficient excess iron to maintain the Fe:Pu ratio

above the required 160:1 ratio even after assuming unneutralized oxalic acid was transferred to the SRAT from 512-S chemical cleaning operations.

6.0 DESIGN FEATURES AND ADMINISTRATIVE LIMITS & REQUIREMENTS

The following bounding assumptions, design features, and administrative limits and requirements are required per References 3, 4, and 5 for a criticality accident to be incredible during processing of Tank Farm salt solutions through the ARP, blending the resultant concentrated MST/sludge solids with the sludge batch in the SRAT, and processing of SRAT contents in the CPC and the MC. The applicable NCSE number is identified for each bounding assumption, design feature, or administrative limit and requirement.

6.1 ASSUMPTIONS

1. The Fe:^{239}Pu(eq) mass ratio in the DWPF sludge to be processed is a minimum of 160:1. [N-NCS-S-00008]

2. A DWPF sludge batch contains:
   Uranium with an enrichment less than or equal to 0.93 wt% ^{235}U(eq_{SLU})
   OR
   Uranium with an enrichment less than or equal to 5 wt% ^{235}U(eq_{SLU}) and a minimum Mn: ^{235}U(eq_{SLU}) mass ratio of 70:1. [N-NCS-S-00008]

3. Salt solution processed in ARP has maximum soluble fissile material concentrations of 50 mg U/L and 0.3 mg Pu/L, and a maximum ^{235}U(eq_sol) enrichment of 3 wt%, where ^{235}U(eq_sol) enrichment (wt%) = 100 x (^{235}U + 1.4 ^{233}U) ÷ U. [N-NCS-S-00008]

4. The maximum fissile loading in glass is 897 g fissile/m^3. [N-NCS-S-00008]

5. N-NCS-S-00009 does not evaluate the criticality safety of sludge batches containing plutonium and uranium poisoned with material other than iron and manganese (e.g., gadolinium). [N-NCS-S-00009]

6. There are no known mechanisms in the process tanks in the ARP to separate the insoluble neutron poisons (e.g., Fe, Mn, Na, Al, and Ti) from the insoluble fissile material. [N-NCS-H-00192]

6.2 DESIGN FEATURES

The following design features are credited for nuclear criticality safety in this NCSASR. The design features are the nominal dimensions and volumes of the tanks and equipment. Note that minor deviations (± 2%) from the dimension and volume values listed below do not affect the analysis results given the conservatism used in the analysis. All future modifications of the DWPF facilities affecting these design features shall be evaluated for the effect on criticality safety of the process prior to resumption of processing of fissile-material.

1. The SRAT has a diameter of 12 feet and a height of 18 feet. [N-NCS-S-00008]

2. The SRAT has an overflow volume of 10,928 gallons. [N-NCS-S-00008]

3. The SME has a diameter of 12 feet and a height of 18 feet. [N-NCS-S-00008]

4. The SMECT has a diameter of 12 feet and a height of 18 feet. [N-NCS-S-00008]

5. The SEFT transfer pump height relative to the tank is such that no siphon can be established from the SRAT to the SEFT. [N-NCS-S-00008]

6. The REDC soak tank has a diameter of 4 feet. [N-NCS-S-00008]

7. The DWTT has a diameter of 12 feet. [N-NCS-S-00008]

8. The RCT has a diameter of 12 feet. [N-NCS-S-00008]

9. The PRFT has an overflow volume of 8,310 gallons [N-NCS-S-00008]

10. The PRFT transfer pump height relative to the tank is such that no siphon can be established from the SRAT to the PRFT. [N-NCS-S-00008]

11. The LWPT has an overflow volume of 6,204 gallons and a heel volume of 700 gallons. [N-NCS-H-00192]

12. The LWHT has a volume of 7,000 gallons, an overflow volume of 6,204 gallons, and a heel volume of 1,200 gallons. [N-NCS-H-00192]

13. The PPT has a volume of 7,050 gallons. [N-NCS-H-00192]

14. The filtrate line from the cross-flow filter is the only waste stream transfer line to the LWHT. [N-NCS-H-00192]

6.3 PROGRAMMATIC REQUIREMENTS

The following programs are credited in the Contingency Analysis of N-NCS-S-00008 to help demonstrate that a criticality accident is not credible in DWPF.

1. CSTF TSR Controls on Transfers to DWPF [N-NCS-S-00008]

   The Tank Farm Technical Safety Requirements have a number of criteria specified to control the transfer of material from CSTF into DWPF as identified in Section 11.7.2.2 of the DWPF FSAR (Ref. 13).

2. DWPF Transfer Control Program [N-NCS-S-00008]

   The DWPF Transfer Control Program, established in the Technical Safety Requirements for DWPF, governs radioactive waste transfers. The program includes the following attributes:

a. Provide means to monitor transfers and stop transfers when material is unaccounted for.
b. Establish and maintain continuous communication within the sending and receiving facilities during transfers (this attribute is only applicable to Waste Tank transfers to DWPF).

3. DWPF Configuration Control Program [N-NCS-S-00008]

The DWPF Configuration Control Program, established in the Technical Safety Requirements for DWPF, includes the following attributes:

a. Identifies and documents the technical baseline of structures, systems, components, and computer software;
b. Ensures that changes to the technical baseline are properly developed, assessed, approved, issued, and implemented; and
c. Maintains a system for recording, controlling, and indicating the status of technical baseline documentation on a current basis.

6.4 ADMINISTRATIVE LIMITS AND REQUIREMENTS

1. Prior to introducing filter cleaning oxalic acid in the LWPT, sufficient sodium hydroxide to neutralize the oxalic acid shall be added to the LWPT. [N-NCS-H-00192, N-NCS-S-00008]

2. a. The Certificate of Analysis (COA) accompanying the oxalic acid tanker truck shipment shall be reviewed to ensure that the molarity of the oxalic acid is $\leq$ 0.6 M. [N-NCS-S-00008]
   b. The oxalic acid available to 512-S is $\leq$ 0.6 M. [N-NCS-H-00192]

   (Note: these are the same requirement, worded slightly differently based on the discussion in the specific NCSE.)

3. The use of oxalic acid (or any other acid that preferentially separates iron from plutonium) shall be prohibited in the DWPF and DWPF decontamination support facilities process areas. [N-NCS-S-00008, N-NCS-S-00009] Exceptions to this requirement are:

   - Oxalic acid ($\leq$ 0.6 M) is used in cleaning the 512-S crossflow filter and the secondary filter, which are physically separated from the DWPF and the DWPF decontamination support facilities.

   - Spilled oxalic acid from the 512-S Oxalic Acid Storage Tank diked area may be collected and neutralized at 980-S.

   - Oxalic acid is delivered to the 512-S facility via a tanker truck and stored in the 512-S facility.

   - Samples from the oxalic acid tank in 512-S may be taken and sent to the 221-S DWPF analytical laboratory or the DWPF outside modular laboratory to verify the molarity of the oxalic acid.

- The oxalic acid samples and standards in the 221-S DWPF analytical laboratory will be disposed of in a drain pipe that is connected to the RCT, and the oxalic acid samples and standards in the DWPF outside modular laboratory will be disposed via drains to an S-Area outfall.

- The combined volume of the oxalic acid samples and standards does not exceed 500 ml if the oxalic acid is disposed of to the RCT. The combined volume of oxalic acid samples and standards is not a criticality safety issue if the disposal path is the drains to an S-Area outfall.

4. Prior to performing oxalic acid transfer to the LWHT, valves HV6231 (Distributed Control System (DCS) Indication: HIS6231), HV6244 (DCS Indication: HIS6244), and FV6235 (DCS Indication: HIS6235A) shall be closed and verified to be closed by a second person per written procedures. This may be performed by visual observation or by DCS Indication. [N-NCS-S-00008]

5. During an oxalic acid transfer to the LWHT, the LWHT level shall be monitored. If there is no increase in the LWHT level within three minutes from the start of the transfer, the oxalic acid transfer shall be stopped until an investigation determines why the level did not increase. [N-NCS-S-00008]

6. During an oxalic acid transfer to the LWHT, the LWPT level shall be monitored. If a change in the LWPT level is noticed, the oxalic acid transfer to the LWHT shall be stopped until an investigation determines why the LWPT level increased. [N-NCS-S-00008]

7. The DWPF WAC program shall ensure the following requirements for maintaining the sludge subcritical during DWPF processing are met: [N-NCS-S-00009]

   - The ^{240}Pu concentration shall exceed the ^{241}Pu concentration.
   - The equivalent fissile material masses ^{239}Pu(eq) and ^{235}U(eq$_{SLU}$) and the equivalent ^{235}U enrichment in the sludge shall be determined using the following equations:

$$^{239}\text{Pu(eq)} = {}^{239}\text{Pu} + {}^{241}\text{Pu} + {}^{244}\text{Cm} + 15\ ({}^{245}\text{Cm}) + 35\ ({}^{242m}\text{Am}) + 0.65\ {}^{235}\text{U(eq}_{SLU}) \ *$$

$$^{235}\text{U(eq}_{SLU}) = {}^{235}\text{U} + 1.4\ \ ({}^{233}\text{U})$$

$$^{235}\text{U(eq}_{SLU})\ \text{Enrichment (wt\%)} = 100 \times {}^{235}\text{U(eq}_{SLU}) \div \text{U}$$

   Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U). [This equivalency is also stated in N-NCS-S-00008]

   * ^{235}U(eq$_{SLU}$) only needs to be included if the uranium enrichment is greater than 0.93 wt%.

   - The equivalent uranium enrichment in the sludge shall be:
     - $\leq$ 0.93 wt% ^{235}U(eq$_{SLU}$). Or
     - $\leq$ 5 wt% ^{235}U(eq$_{SLU}$) with a minimum Mn: ^{235}U(eq$_{SLU}$) mass ratio of 70:1.

- The overall Fe: ^{239}Pu(eq) mass ratio shall be $\geq$ 160:1 and only Fe from the Tank Farm material shall be included in the calculation of the ratio.
- The ^{239}Pu(eq) mass (not including ^{235}U) in the SRAT shall be:
  - $\leq$ 6,195 g, if non-Tank Farm Pu is included in the sludge batch.

    Note: Calculations show that 6,195 grams of ^{239}Pu (corresponding to 0.59 g Pu/gallon of sludge) in 10,500 gallons of sludge in the SRAT is subcritical at any moderation (i.e., any degree of settling and densification) as long as the Fe: ^{239}Pu(eq) mass ratio is $\geq$ 80:1 in the overall SRAT contents.
  - No ^{239}Pu(eq) mass limit, if only Tank Farm Pu is included in the sludge batch.

8. Prior to processing each sludge batch beyond SB3, an evaluation shall be performed and documented via the DWPF WAC program to demonstrate that the compositions of that sludge batch comply with the requirements as shown in item 7 above. [N-NCS-S-00009]

9. The DWPF WAC program shall ensure the following requirements for the batch salt solution are met (These salt solution characteristics support the subcriticality of processing the salt solution in DWPF facilities). [N-NCS-H-00192]
   - The soluble uranium concentration in Tank 49 solution is less than or equal to 50 mg/L.
   - The soluble plutonium concentration in Tank 49 solution is less than or equal to 0.3 mg/L.
   - The ^{235}U(eq_sol) enrichment in Tank 49 solution is less than or equal to 3 wt%, using the following equation.

$$^{235}\text{U(eq_sol) Enrichment (wt\%)} = 100 \times (^{235}\text{U} + 1.4 \times {}^{233}\text{U}) \div \text{U}$$

   Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

10. Prior to entering filter-only operations, the LWPT shall be de-inventoried to less than 8493 grams of MST. [N-NCS-H-00192]

6.5 FUNCTIONAL CLASSIFICATION

6.5.1 WAC

The criticality design features and limits are required to be functionally classified (Refs. 26 and 37). The criticality accident frequency of incredible as discussed in the relevant NCSEs (Refs. 3, 4, and 5) is based primarily on the incoming feed stream as controlled by the WAC.

The WAC is considered a robust single barrier sufficient to ensure criticality is incredible, since the current waste in the Tank Farm exceeds the poison to fissile mass ratio limit by a significant margin. In addition, each sludge batch is sampled prior to feeding to the DWPF to ensure that the WAC is met. The estimated sludge inventory for individual tanks demonstrates there is significant iron and manganese in the waste tanks, well in excess of what is necessary to prevent criticality (Reference 24). Therefore, even if confirmatory WAC analyses were not performed or

were incorrect, there would be sufficient absorbers in the tanks to maintain the DWPF process subcritical. As demonstrated in Reference 3, there is significant margin between the WAC limits and criticality concerns. For example, Scenario 5.1.1.2 states that the SRAT could have a maximum of 6,010 grams of fissile with an Fe:Pu ratio of 160:1. It also states that 43 kg of Pu would be subcritical settled in the SRAT with an Fe:Pu ratio of 60:1. Similarly, Scenario 5.1.1.1 states that if only fissile material were dissolved into solution, the concentration would be an order of magnitude below the subcritical concentration limit. In addition, the poisons credited (Fe and Mn) historically have only been ~20% of the material in the sludge. The other 80% of the sludge would provide some additional neutron absorption.

The fissile waste loading of 897 g/m^3 is used in the reference NCSEs. The value is protected in the WAC due to regulatory concerns (Ref. 28). However, the NCSE analyzed significantly higher values. Reference 29, as referenced by Reference 3, assumed 5.5 kg of fissile uranium and 16.4 kg of fissile Pu per cubic meter. [e.g., Pu from Table 1 of Reference 29: 3.974 g glass/cm^3 * 0.00717 g PuO_2/1 g glass * 0.88 g Pu/1 g PuO_2 * (0.6083 g ^{239}Pu/1 g Pu + 0.0449 g ^{241}Pu/1 g Pu) * 1E6 cm^3/m^3 = 16,378 g fissile Pu/m^3]. Even with the factor of over 20 increase in fissile loading, the k_{inf} was calculated to be less than 0.1 for the composition from Table 1 of Reference 29. Such a large fissile plutonium loading is not possible with a Fe:Pu mass ratio of 160:1 as the Fe_2O_3 would be over 90 wt% of the glass. The following provide additional defense in depth. At the poison to fissile mass ratio WAC limit, material in an infinite geometry in DWPF is subcritical. Therefore, the fissile loading is discussed in upset conditions where it is postulated that the poison to fissile ratio is less than the WAC limit. The analysis in the SRAT considered 43 kg of Pu, while the 897 g/m^3 waste loading limits the SRAT to 6 kg, assuming 10 canisters are produced from a single SRAT batch, which has not occurred in previous sludge batches. If the fissile material enters solution, the concentration (1 g/gallon) is over an order of magnitude below the subcritical concentration limit. When compared to mass limits, Reference 3 demonstrates upset conditions are over a factor of two below the subcritical mass limits without considering any absorbers from the sludge or frit as added in the SME or potential to form a critical configuration. Due to the conservatism in the calculations using the fissile waste loading, it is not necessary to raise the fissile waste loading to the level of the FSAR/TSR.

Based on the above discussion, it is determined that for the majority of the scenarios (See Section 6.5.2 for the exception), the only barrier required to be elevated to the FSAR and TSR is the WAC, with the following requirements for criticality:

- The ^{240}Pu concentration shall exceed the ^{241}Pu concentration.
- The equivalent fissile material masses ^{239}Pu(eq) and ^{235}U(eq$_{SLU}$) and the equivalent ^{235}U enrichment in the sludge shall be determined using the following equations:

$$^{239}\text{Pu(eq)} = {}^{239}\text{Pu} + {}^{241}\text{Pu} + {}^{244}\text{Cm} + 15\ ({}^{245}\text{Cm}) + 35\ ({}^{242m}\text{Am}) + 0.65\ {}^{235}\text{U(eq}_{SLU}) *$$

$$^{235}\text{U(eq}_{SLU}) = {}^{235}\text{U} + 1.4\ \ ({}^{233}\text{U})$$

$$^{235}\text{U(eq}_{SLU})\ \text{Enrichment (wt\%)} = 100 \times {}^{235}\text{U(eq}_{SLU}) \div \text{U}$$

Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

* $^{235}U(eq_{SLU})$ only needs to be included if the uranium enrichment is greater than 0.93 wt%.

- The equivalent uranium enrichment in the sludge shall be:
  - ≤ 0.93 wt% $^{235}U(eq_{SLU})$. Or
  - ≤ 5 wt% $^{235}U(eq_{SLU})$ with a minimum Mn: $^{235}U(eq_{SLU})$ mass ratio of 70:1.
- The overall Fe: $^{239}Pu(eq)$ mass ratio shall be ≥ 160:1 and only Fe from the Tank Farm material shall be included in the calculation of the ratio.
- The $^{239}Pu(eq)$ mass (not including ^{235}U) in the SRAT shall be:
  - ≤ 6,195 g, if non-Tank Farm Pu is included in the sludge batch.

    Note: Calculations show that 6,195 grams of ^{239}Pu (corresponding to 0.59 g Pu/gallon of sludge) in 10,500 gallons of sludge in the SRAT is subcritical at any moderation (i.e., any degree of settling and densification) as long as the Fe: $^{239}Pu(eq)$ mass ratio is ≥ 80:1 in the overall SRAT contents.
  - No $^{239}Pu(eq)$ mass limit, if only Tank Farm Pu is included in the sludge batch.
- The soluble uranium concentration in Tank 49 solution is less than or equal to 50 mg/L.
- The soluble plutonium concentration in Tank 49 solution is less than or equal to 0.3 mg/L.
- The $^{235}U(eq_sol)$ enrichment in Tank 49 solution is less than or equal to 3 wt%, using the following equation.

  $^{235}U(eq_sol)$ Enrichment (wt%) = $100 \times (^{235}U + 1.4 \times {}^{233}U) \div U$

  Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

The WAC is a specific administrative control that serves as the basis for criticality safety for all scenarios. It would take multiple engineered controls to provide criticality safety for all scenarios and not all scenarios have engineered controls. Therefore, choosing an administrative control to elevate to the FSAR/TSR is appropriate.

6.5.2 De-inventory of the LWPT

Scenario 5.4.18 in Reference 5 has an unmitigated frequency of Extremely Unlikely (EU). The primary control is to de-inventory the LWPT prior to entering filter-only operations. This ensures that no more than a subcritical mass will adsorb on the MST. The following control shall be raised to the level of a SAC:

> Prior to entering filter-only operations, the LWPT shall be de-inventoried to less than 8493 grams of MST.

As the de-inventory relies on the enrichment of the WAC, the following part of the WAC shall be considered part of the control:

- The ^{235}U(eq_sol) enrichment in Tank 49 solution is less than or equal to 3 wt%, using the following equation.

  ^{235}U(eq_sol) Enrichment (wt%) = 100 × (^{235}U + 1.4 × ^{233}U) ÷ U

  Where U is the summation of all uranium isotopes (e.g., ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U).

The nature of DWPF operations justifies the elevation of only one control to the FSAR/TSR for this scenario, as allowed by Reference 37. Reference 30 demonstrates that the majority of the samples of the tanks in the Tank Farm have an enrichment less than 3 wt%. The samples associated with higher enrichments are associated with lower concentrations. In addition, each Salt Batch is sampled prior to feeding 512-S to ensure that the WAC is met. The amount of allowed residual MST is conservative as its determination does not credit as neutron poisons either the Ti in the MST or any U-238 adsorbed on the MST. In addition, to be a criticality concern, the MST loaded with fissile material would have to settle into a small compact volume to form a critical configuration, which is unlikely (Ref. 5).

7.0 SUMMARY AND CONCLUSIONS

This NCSASR summarizes the identified scenarios and barriers that render criticality incredible in the baseline NCSEs (Ref. 3, 4, and 5). These NCSEs provide the criticality safety basis of the DWPF. These NCSEs demonstrate that no credible criticality scenarios exist for processing of Tank Farm salt solutions through the ARP in the 512-S facility, blending the resultant concentrated MST/sludge solids and MCU Strip Effluent with sludge batches in the SRAT, and processing of the SRAT contents in the CPC and the MC. Furthermore, a criticality event due to addition of the ARP oxalic acid to the SRAT is deemed incredible.

The baseline NCSEs (Ref. 3, 4, and 5) focus on the fate of iron and manganese (neutron poisons) and fissile material throughout the DWPF process that ensures the validity of judging that a criticality is not credible. Administrative requirements help assure that fissile mass and enrichment limits are not exceeded and poison:fissile mass ratio limits are met. Only the WAC, with the requirements as listed in Section 6.5, and the de-inventory of the LWPT prior to entering filter-only operations are required to be elevated to the FSAR/TSR.

Reference 26 states that a Criticality Accident Alarm System (CAAS) is not required if a criticality is not credible. However, the criticality accident frequency criterion for CAAS is based on the total frequency of all scenarios for a facility or sub-facility and not applied to individual scenarios. The criticality safety of scenarios in DWPF relies on the nature of process of the waste (e.g., low fissile material concentration and the presence of large amounts of neutron poisons). In addition, the DWPF is segmented into many facilities and sub-facilities particularly due to shielding. The interaction between facilities (e.g., transfers) is considered in the NCSEs and included in the determination that a criticality is not credible. Therefore, considering the total frequency of a criticality accident as applied to all scenarios in a facility or sub-facility, a criticality accident is still not credible in DWPF and a CAAS is not required.

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37. "Criticality Safety Program Description Document (CSPDD) for the M&O Contractor (Savannah River Nuclear Solutions) and Liquid Waste Contractor (Savannah River Remediation)," N-NCS-G-00136, Rev. 3, October 2016.[4]

38. Elder, H. H., et. al., "Nuclear Criticality Safety Assessment: Evaluation of SRAT Batch 570 Following a Partial Sludge Transfer to DWPF for Processing SEFT Material (U)," N-NCS-S-00010, Rev. 0, May 2011.

39. SCD-11, "Consolidated Hazards Analysis Process—Program and Methods Manual (U)." [5]

40. "Liquid Waste Implementation Plan for the Criticality Safety Program Description Document," SRR-CES-2011-00052, Rev. 0, September 2011.

[4] Note that previous versions of the CSPDD may have been in place at the time of some of the referenced NCSEs. The implementation plan for Revision 0 of the CSPDD is documented in Reference 40 and is not affected by the update to Revision 1 or 2 of the CSPDD.

[5] Note that various versions of the Hazards Analysis Manual may have been in place at the time of some of the referenced NCSEs.

9.0 TECHNICAL REVIEW CHECKLIST

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Document Number: N-NCS-S-00007 Revision: 17

Document Title: NCSASR: Salt Solution and Sludge Operations in 512-S Facility and DWPF (U)

The following checklist is required to be completed and attached to the document under review in compliance with Manual E7 and S4 procedures. This list should not be considered all inclusive. Add any additional notes or comments to the end of the checklist.

Item No.	Item	Yes / No N/A	Comments (use continuation page at end of form if more space is needed)
	VERSION / FORMAT		
1	If revising an existing document, are you starting with the latest, approved version of the document obtained from SmartPlant Foundation (SPF) or DCR?	Yes	
2	Are all OSR or SPF forms properly and completely filled out and is the current approved version of the form used?	N/A	NCSASR follows the format as appropriate from SCD-3
3	Does the document format include all of the sections as described in manual E7 and S4 procedures (2.31A ,3.60, etc.)?	N/A	NCSASR follows the format as appropriate from SCD-3
4	Are all of the pages properly labeled with Document Number, Revision Number, and Sequential Page/Sheet Number?	Yes	
5	Are the Subject and Purpose clearly stated and do they meet the end-users needs?	Yes	
	REFERENCES		
6	Are all References properly documented within the document and can they be easily verified within Document Control, on-line, or within the library, etc.? If reference documents are not readily available, are they attached?	Yes	
7	Have the correct design bases documents been identified (e.g., Codes, Standards, DOE Orders, SRR Requirements, Regulatory Requirements, DSA)?	Yes	
	OPEN ITEMS / INPUT		
8	If data is transferred from other documents, calculations or sources, is this data correct and applicable?	Yes	
9	Are all inputs found in the body of the document or calculation individually listed and if the document is a calculation, numbered in the Inputs section?	N/A	This document is a summary document of NCSEs and has no direct inputs/calculations
10	Is there a reference/source for each input?	N/A	
11	Do the identified references/sources fully support the inputs and does the data meet appropriate quality assurance requirements?	N/A	
12	Have the correct operational and functional requirements of the facility been properly considered?	Yes	

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Item No.	**Item**	**Yes / No N/A**	**Comments** (use continuation page at end of form if more space is needed)
	OPEN ITEMS / INPUT – continued		
13	Have appropriate operational modes and worse case scenarios been considered?	N/A	The NCSEs contain the HA analysis
14	Are all assumptions used to support the document individually listed and numbered in the Assumptions section?	N/A	This is a summary document. The assumptions and justifications are in the NCSEs
15	Is there a justification written for each assumption that includes a technical basis?	N/A	
16	Do the justifications adequately support the assumptions?	N/A	
17	If the document is a calculation and there are Open Items, has the calculation been statused as preliminary? Note: A Confirmed calculation cannot have Open Items.	N/A	
18	If the document is a preliminary calculation, have actions required to change the status from "preliminary" to "confirmed" been listed as "open items"?	N/A	
19	If the document has open items, is there a method identified to track them? List tracking numbers in Comments (STAR, POD item number, etc.).	N/A	
	ANALYTICAL METHODS AND COMPUTATIONS		
20	Are the analytical methods and computations clearly spelled out step-by-step?	N/A	
21	Is the analytical approach in use clearly described with justification along with alternative methods?	N/A	
22	Is the methodology consistent with the purpose and objective?	N/A	
23	Are mathematical derivations correct, including dimensional consistency of results?	N/A	
24	Have calculations been checked for errors as applicable per E7-2.31A, Sections 5.3.2.5 and 5.5.1? Where a calculation has multiple iterations of the same computation with numerous input and output values, the Verifier/Checker may select a representative sample of the total input and output values for review.	N/A	Calculations are performed in NCSEs which have review
25	Were the analysis inputs correctly incorporated into the analysis and are the outputs reasonable compared to the inputs?	N/A	
26	Is the Summary of Conclusion clearly stated? Does it meet the end-user's needs? Clearly state if results meet/do not meet the Objectives of the analysis?	Yes	
27	Are the numeric values consistent with the appropriate accuracy (significant figures) of the analysis?	Yes	
28	Are safety margins consistent with good engineering practice?	Yes	

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Item No.	**Item**	**Yes / No N/A**	**Comments** (use continuation page at end of form if more space is needed)
	SOFTWARE		
29	Is software (including spreadsheets) used? If NO, then "N/A" this section.	No	
30	Have computer software programs used for calculations been evaluated and properly classified for this activity using OSR form 19-337 (SWCD), per 1Q QAP 20-1 and E7-2.25? Notes: A) Engineering Calculations meeting the validation requirements of E7-2.31A, where a documented, approved process provides for verification of the results for each use are Exempt – see Row 38. B) The SWCD (software classification document) form is a site-wide application in Lotus Notes.	N/A	
31	Is computer software used for the analysis being controlled per E7-2.31A, Section 5?	N/A	
32	Were appropriate analysis methods and computer methods used?	N/A	
33	If a computer program or model is used in the calculation, is it used within the range of validity, or is use outside the range of established validity justified?	N/A	
34	Was the software program used within any restriction, criteria or test frequency requirements in the Software Quality Assurance Plan? (SQAP) (e.g., computer operating system/platform criteria, software within testing frequency).	N/A	
35	Is the software used noted on the Calculation cover sheet and referenced appropriately in the calculation?	N/A	
36	If the calculation supports the DSA, is the software and version used on the SSIL (Safety Software Inventory List) when required? Provide explanation in Comments. Notes: A) Engineering Calculations meeting the validation requirements of E7-2.31A, where a documented, approved process provides for verification of the results for each use are Exempt – see Row 38 B) The SSIL is updated on an annual basis so recently approved SQAPs may not be added to the SSIL until the next annual update.	N/A	
37	Are the equations shown in the calculation, including example functions where Excel spreadsheets or MathCad is used?	N/A	
38	If using general-purpose commercially available software as described in E7-2.31A, Section 5.5.1, then answer YES and describe checking method (5.5.1.2.C 1, 2, or 3) in Comments	N/A	
39	Have computer program error reports been checked for potential effect on the analysis?	N/A	

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Item No.	Item	Yes / No N/A	Comments (use continuation page at end of form if more space is needed)
	RESULTS / CONCLUSIONS		
40	Are the results of the document consistent with the input and assumptions?	Yes	
41	Do the results of the document affect any other technical documents?	No	
42	Do the results substantiate the conclusion?	Yes	
	APPROVALS		
43	Does the document identify the method of verification, if applicable, and does it have a signature block for the verifier/checker?	Yes	The NCSASR has a verifier signature block. This verification was by document review.

Checker: Herbert C. Benhardt (Print) / Herbert C. Benhardt (Signature) Date: 4/3/2018

Item No. Cont.	Comment Continuation

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Items 44-56 are only to be completed when Verification by Document Review is being performed. The verifier assures the technical accuracy of the document by performing administrative and mathematical checks as appropriate, and by evaluating the document against the following questions:

Item No.	Item	Yes / No N/A	Comments (use continuation page at end of form if more space is needed)
44	Were the inputs correctly selected and identified?	N/A	Inputs were the NCSEs
45	Are the assumptions made in the performance of the design or analytical activity adequately described and reasonable?	N/A	
46	When necessary, are the assumptions identified for subsequent re-verification when the detailed design activities are completed?	N/A	
47	Were appropriate design or analytical methods and computer programs used?	N/A	
48	Were the design or analytical inputs correctly incorporated into the design, analysis or evaluation?	Yes	
49	Have engineering actions required to support risk handling strategies been verified?	N/A	
50	Is the design output reasonable compared to the design or analytical inputs?	Yes	
51	Are the necessary design inputs for interfacing organizations specified in the design documents or in supporting procedures or instructions?	Yes	
52	Have suitable materials, parts, processes, and inspection and testing criteria been specified?	Yes	
53	Have existing and potential workplace hazards been identified, evaluated, and controls incorporated for the risk to worker injury or illness?	N/A	
54	Was a review conducted to confirm that there are no interferences with other ongoing or planned modifications?	N/A	This incorporated a planned change. The NCSASR is changed as necessary
55	Have engineering judgments been identified, technically justified, and supported?	N/A	
56	Have design optimization strategies been considered / met (e.g., appropriate tailoring of requirements, design attributes, and operating strategies)?	N/A	

Verifier: Herbert C. Benhardt / Herbert C. Benhardt Date: 4/3/2018
Print Signature