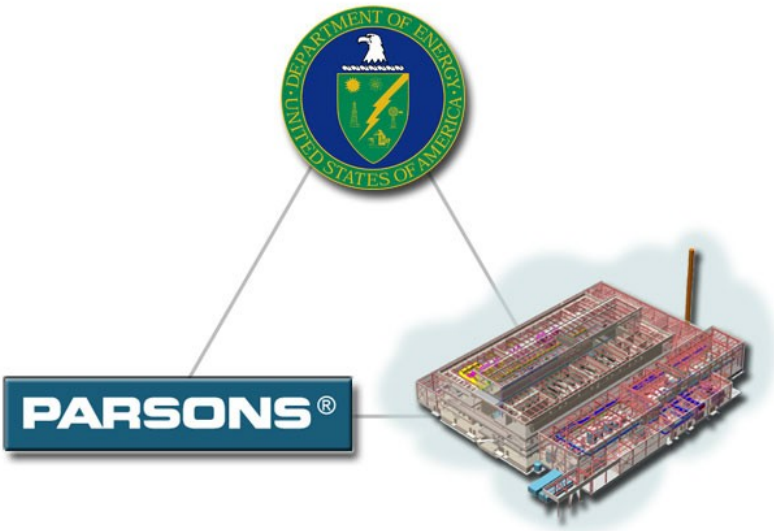
Salt Waste Processing Facility Project

Nuclear Criticality Safety Evaluation: Fissile Concentration Due to MST



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Terms and Definitions

Term/Acronym	Definition
%	Percent
°F	degrees Fahrenheit
AFF	Alpha Finishing Facility
AFP	Alpha Finishing Process
ANECF	Average Neutron Energy Causing Fission
ANS	American Nuclear Society
ANSI	American National Standards Institute
AoA	Area of Applicability
APAs	Air Pulse Agitators
ASDT	Alpha Sorption Drain Tank
ASP	Alpha Strike Process
AST-A	Alpha Sorption Tank-A
AST-B	Alpha Sorption Tank-B
Ba	Barium
CCA	Cold Chemicals Area
CDCSS	Cs-depleted CSS
CFF	Cross-flow Filter
cm	Centimeter
Cs	Cesium
CSDT-A	Cleaning Solution Dump Tank-A
CSDT-B	Cleaning Solution Dump Tank-B
CSS	Clarified Salt Solution
CSSX	Caustic-Side Solvent Extraction
DCS	Distributed Control System
DF	Decontamination Factors
DI	Deionized
DOE	U.S. Department of Energy
DSS	Decontaminated Salt Solution
DSSHT	Decontaminated Salt Solution Hold Tank
DWPF	Defense Waste Processing Facility
EF	Equivalency Factor
E(U)	Uranium Enrichment (g ^{235}U / g U)
ENDF/B-VI	Evaluated Nuclear Data File / Version B-VI
FFT-A	Filter Feed Tank-A
FFT-B	Filter Feed Tank-B
ft	Foot or Feet
ft/sec	Feet per second
g/cc	Grams per Cubic Centimeter
g/L	Grams per liter
gpm	Gallons per minute
gpm/ft^2	Gallons per minute per square foot
H/X	Number of hydrogen atoms per number of fissile atoms
$H_2C_2O_4$	Oxalic Acid
HNO_3	Nitric Acid
IST	Intermediate Storage Tank
LPPP	Low Point Pump Pit
LRW	Liquid Radioactive Waste
M	Molar
MCNP	Monte Carlo N-Particle V5 (radiation transport software)

Term/Acronym	Definition
mg/L	Milligrams per liter
MSM	Minimum Subcritical Margin
MST	Monosodium Titanate
MSTT	MST/Sludge Transfer Tank
Na^+	Sodium ion
NaOH	Sodium Hydroxide
NAS	Sodium Aluminum Silicate
NCSE	Nuclear Criticality Safety Evaluation
O	Order
O:A	Organic to Aqueous Ratio
PCHW	Process Chilled Water
PPT	Precipitate Pump Tank
psig	Pounds per square inch gauge
SDT	Solvent Drain Tank
s.g.	Specific Gravity
SHT	Solvent Hold Tank
SAST	Spent Acid Storage Tank
SPF	Saltstone Production Facility
Sr	Strontium
SRNL	Savannah River National Laboratory
SS	Safety Significant
SSFT	Salt Solution Feed Tank
SSRT	Sludge Solids Receipt Tank
STS	Surface-To-Surface
SWPF	Salt Waste Processing Facility
USL	Upper Subcritical Limit
VF	Volume Fraction
VFD	Variable Frequency Drive
WAC	Waste Acceptance Criteria
wtf.	Weight fraction
wt.%	Weight percent
WWHT	Wash Water Hold Tank

1 Introduction

This Nuclear Criticality Safety Evaluation (NCSE) provides an overview of the entire Salt Waste Processing Facility (SWPF) operation, develops the Area of Applicability (AoA) including Minimum Subcritical Margin (MSM) for criticality calculations contained herein, reviews the methodology used for determining if a hypothetical accident scenario is credible or incredible, analyzes the hypothetical accident scenarios considered, and documents the results of criticality safety calculations performed. The purpose of this NCSE is to demonstrate compliance with Chapter III of the U.S. Department of Energy (DOE) Order (O) 420.1B, *Facility Safety*[1] for Criticality Safety. Specifically, this NCSE demonstrates that all analyzed equipment and operations remain subcritical under normal and credible abnormal accident conditions.

This NCSE supersedes the previous NCSE for the SWPF Project (S-NCS-J-00001: *Nuclear Criticality Safety Evaluation: Salt Waste Processing Facility Operations*[2]).

1.1 *Scope*

The scope of this NCSE is focused on the potential for actinide (uranium and plutonium) concentration due to their adsorption onto monosodium titanate (MST) throughout the SWPF liquid process. The bounds of this analysis begin with the introduction of feed from a Liquid Radioactive Waste (LRW) tank into the first tank in SWPF, which is Alpha Sorption Tank-A (AST-A) (TK-101), and end when solution is transferred out of the SWPF facility. In addition to the normal process flow of the MST-actinide material inside the process equipment, the evaluation herein includes abnormal concentrations of the MST-actinide material in the process sumps, contactors, and cross-flow filters (CFFs) (e.g., FLT-102 A/B/C). Finally, this evaluation considers the actinide separation from the MST due to acid addition during in-place maintenance CFF cleaning.

This NCSE is limited to "normal" (as defined herein) and credible abnormal process upset conditions related to MST-actinide material in major process equipment/tanks. Smaller equipment/tanks and hypothetical combinations of solutions are addressed in N-NCS-J-00008, *Inadvertent Transfers*[3].

Concentration due to Sodium Aluminum Silicate (NAS) is covered in N-NCS-J-00006, *Accumulation of NAS in SWPF Equipment*[4].

1.2 *Open Items*

Per N-NCS-J-00004, *SWPF Criticality Safety Methods Manual*[5]: "Any assumption or design feature that requires future verification prior to operation of the facility/process/system is an Open Item. If the validity of a limit or control is questionable or lacking some required supporting reference document, this situation is an Open Item". This section is dedicated to listing and explaining the Open Items that remain for this NCSE.

No Open Items exist within the scope of this NCSE.

2 Description

The process description presented in the following subsections was largely taken from the *Process Basis of Design* (P-DB-J-00003[6]), unless otherwise noted. This process description does not dictate any controls, requirements, design features, or operating conditions for criticality safety. Section 7.0 contains the complete consolidated collection of assumptions, design features, and controls credited for criticality safety. This section is dedicated to facilitating an understanding of the SWPF facility and process necessary for the contingency analysis, per the requirements documents noted in Section 3.

2.1 *General Overview*

Figure 1 depicts the process flow for SWPF that is described below and was taken from M-M5-J-0001, *SWPF Simplified Process - Flow Schematic*[7].

The SWPF treats salt waste in three successive basic unit operations: Alpha Strike Process (ASP), Caustic-Side Solvent Extraction (CSSX), and Alpha Finishing Process (AFP). These processes separate the radioactive elements (primarily actinides, strontium [Sr], and cesium [Cs]) from the bulk salt waste and concentrate them into a relatively small volume. This small volume is then transferred to the Defense Waste Processing Facility (DWPF) for vitrification. The remaining bulk salt waste contains only low levels of radioactive materials and is sent to the Saltstone Production Facility (SPF) for incorporation into grout.

The ASP occurs first and is used to separate Sr/actinides from the waste feed by MST sorption and filtration. The CSSX process follows the ASP and is used to remove Cs from the ASP filtrate by solvent extraction. The AFP is a process step that mimics the ASP and is used as necessary for additional Sr/actinide removal downstream of the CSSX process.

The ASP is operated as a batch process. Each batch of salt waste received in the SWPF is chemically adjusted and MST is added. The tank contents are mixed to allow the MST to sorb the Sr and actinides (12 hours for single strike and 6 hours each for multiple strikes). The resulting MST slurry is filtered to produce a concentrated MST/sludge slurry, and a clarified salt solution (CSS) filtrate. The concentrated MST/sludge slurry is washed to reduce the sodium ion (Na^+) concentration and transferred to DWPF, while the CSS is routed to the CSSX process.

The second SWPF unit operation is CSSX, which is a continuous-flow process utilizing 36 contactor stages for extraction, scrubbing, stripping, and washing of aqueous and organic streams. The Cs is removed by contacting the CSS (aqueous phase) with an engineered solvent (organic phase) in the extraction stage contactors. The Cs-depleted aqueous outlet stream is sent to the AFP for sampling and analysis prior to transfer to the SPF or for another Sr/actinide removal operation. Following extraction, the Cs-enriched solvent is scrubbed to remove impurities (primarily sodium and potassium). The solvent is then contacted with a dilute nitric acid (HNO_3) strip solution in the stripping stages, where the Cs is transferred to the aqueous strip effluent. The strip effluent (containing a high concentration of Cs) is sent to DWPF for vitrification.

If the Sr/actinide concentration in the CSS sent to the CSSX process is sufficiently low, the aqueous outlet from the extraction stages (decontaminated salt solution [DSS]) is sent to the SPF to be solidified with a cementitious grout mixture. If the Sr/actinide concentration in the CSS is too high, the aqueous outlet from the extraction stages (referred to as Cs-depleted CSS [CDCSS]) is sent to the AFP for a final MST strike.

The AFP, which is located downstream of the CSSX process, is the third SWPF unit operation. When the SWPF is operated in single-strike mode, DSS from the CSSX process is sent to the AFP for confirmatory sampling and staging prior to transfer to the SPF. If the Sr/actinide content of the waste feed is sufficiently high that a single MST strike cannot reduce the concentrations low enough for the CDCSS to meet the Saltstone WAC limits, the CDCSS will be sent to the AFP to perform a second MST strike. Because the CDCSS contains a limited concentration of Cs, the process equipment located in the Alpha Finishing Facility (AFF) can be operated and maintained without the extensive shielding and remote handling provisions required in the ASP.

Figure 1. Simplified Process Flow

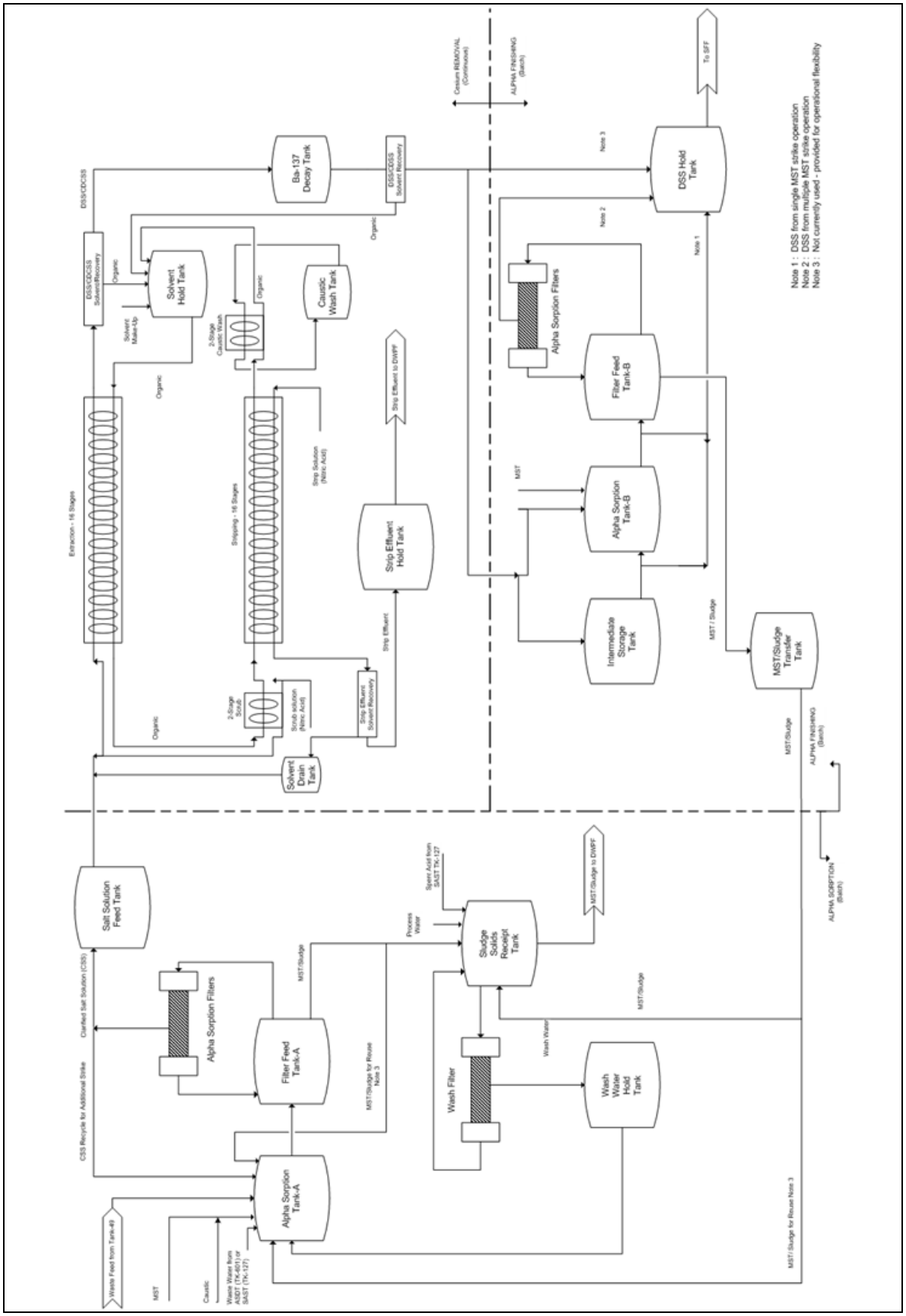


Table 1 provides a quick reference for the volume of many tanks in the SWPF. The references provide the tank overflow and heel volumes in gallons. The volume in liters was calculated by multiplying the volume in gallons by 3.785.

Table 1: Tank Volumes

Tank	Maximum Overflow Volume (gallons)	Maximum Overflow Volume (Liters)	Maximum Tank Heel Volume (gallons)	Maximum Tank Heel Volume (Liters)	Reference
AST-A	37700	142710.0	246.6	933.5	8
FFT-A	37700	142710.0	67.8	256.7	9
SSRT	6300	23848.1	65.3	247.2	10
CSDT-A	1000	3785.4	17.6	66.6	11
ASDT	4300	16277.3	171	647.3	12
WWHT	13700	51860.1	89.9	340.3	13
SSFT	45000	170343.5	42.8	162.0	14
CSWT	500	1892.7	0	0.0	15
SEHT	19756.1	74785.0	171.1	647.7	16
BDT	2100	7949.4	36	136.3	17
DSSHT	43600	165044.0	544.7	2061.9	18
AST-B	37700	142710.0	246.6	933.5	19
IST	37700	142710.0	544.7	2061.9	20
FFT-B	37700	142710.0	67.8	256.7	21
MSTT	2000	7570.8	20.1	76.1	22
SHT	720	2725.5	97.6	369.5	23
SDT	4300	16277.3	171	647.3	24
CSDT-B	1000	3785.4	17.6	66.6	25
AFDT	1800	6813.7	68	257.4	26
SAST	4300	16277.3	171	647.3	27
LDT	600	2271.2	22.6	85.6	28
SEPT	60	227.1	0	0.0	15
Solvent Strip Feed Tank	60	227.1	0	0.0	15

2.2 *Alpha Strike Process*

The following subsections describe the major process and equipment associated with the ASP.

2.2.1 Waste Transfers

At the Tank Farm, waste removed from individual LRW tanks will be blended and staged as macro-batches in designated blend tanks. A macro-batch may be subdivided for transfer to the SWPF feed tank. In the SWPF Feed Tank, portions of several macro-batches may be combined, and then subdivided into mini-batches for transfer and treatment in the SWPF.

Each macro-batch will be blended, mixed, and sampled. If the macro-batch sample results meet SWPF feed specifications, the macro-batch can be qualified for transfer to the SWPF. The Tank Farm waste feed preparation operations, including transfer between tanks, chemical adjustments, blending and mixing, and

sampling and analysis, will be performed by the Site Liquid Waste Operations, and Management & Operating Contractor.

The feed in the SWPF feed tank will be required to conform to the SWPF feed specification provided in X-ESR-J-00001, *SWPF Feed Waste Acceptance Criteria*[29] prior to transfer to the SWPF. Qualification sampling is normally performed in the blend tanks. Because each blend tank will individually meet the SWPF WAC, combined waste volumes within the SWPF Feed Tank from multiple macro-batches contributed from different blend tanks will also meet the SWPF WAC. Feed transfer to the SWPF will be performed in accordance with a transfer procedure, as specified in V-ESR-J-00010, *SWPF Waste Transfer Interface Control Document (ICD-10)*[30] and approved waste transfer operating procedures for the H-Area Tank Farm, DWPF, and SWPF.

Some macro-batches are expected to contain high Sr/actinide concentrations and may require multiple MST strikes. Because transfer of additional waste from the blend tank to the SWPF feed tank may take several days (during which time two or more SWPF feed mini-batches may be processed) there will be a point in time during or after the transfer at which the SWPF Feed Tank concentration will change enough to require a transition in SWPF operations from single-strike to multi-strike, or from multi-strike to single-strike operation. Process samples within SWPF (e.g., SSFT, AST-A) may be used to identify the specific timing of the single-strike/multi-strike transition.

Feed will be received at the SWPF in mini-batch transfers (referred to as a "batch" throughout the remainder of this section) of approximately 23,200 gallons each. This is the batch size necessary to meet the design throughput requirements, given an overall AST-A cycle time of approximately 24 hours for normal operation. AST-A, FFT-A, and the Alpha Sorption Filters have been sized based on this cycle time and batch volume.

2.2.2 Alpha Sorption

Waste transfers are received in AST-A (TK-101). TK-101 serves as a mixing vessel for chemical adjustment of the feed and for sorption of the Sr and actinides in the waste solution by the MST. P-ESR-J-00001, *SWPF Mass Balance Model Summary Description*[31] defines the average TK-101 batch size at approximately 28,300 gallons, based on:

- Receipt of one feed batch (23,200 gallons);
- Addition of wash water (~1,000 gallons), dilute caustic (~3,600 gallons), and drains collected in the Alpha Sorption Drain Tank (ASDT) (TK-601) (~400 gallons) to adjust the Na^+ concentration from 6.44 Molar (M) Na^+ to 5.6M Na^+; and
- Addition of MST (added to achieve 0.4 grams per liter [g/L] of MST) (~70 gallons).

AST-A (TK-101) is sized with a working volume of 28,700 gallons to accommodate a single batch. All process and support tanks are sized with a freeboard allowance typically between 10 and 20 percent (%) of the tank capacity.

The waste feed received in AST-A (TK-101) is chemically adjusted to the target sodium concentration by adding drains collected in the ASDT (TK-601) and SAST (TK-127), recovered wash water from the Wash Water Hold Tank (WWHT) (TK-105), and/or 1.66M sodium hydroxide (NaOH) from the Caustic Dilution Feed Tank (TK-108). The dilution source would depend on the quantity and composition of liquid available from each tank. MST solution will be added to TK-101 to achieve a final MST concentration of 0.4 g/L. The MST addition line is flushed with dilute caustic after MST has been added to TK-101.

AST-A (TK-101) is agitated to mix the tank contents and to maintain the MST and sludge solids in suspension. Air Pulse Agitators (APAs) are used to agitate TK-101, as well as other vessels in the process cells including Filter Feed Tank-A (FFT-A) (TK-102), Sludge Solids Receipt Tank (SSRT) (TK-104), Salt Solution Feed Tank (SSFT) (TK-109), and WWHT (TK-105). At sufficient tank liquid levels APAs use compressed air to force fluid out of pots that are submerged in the tank. The rapid discharge of the pulse pot liquid column, and subsequent venting and refill of the pulse pot, creates sufficient movement of the tank contents to keep solids in suspension and maintain adequate mixing. At low tank levels APAs operate in a "Lift and Drop" mode where only the weight of the liquid column in the pulse pot provides the motive force for mixing.

AST-A (TK-101) is cooled by Process Chilled Water (PCHW) circulated through the tank jacket. TK-101 is maintained at an optimum temperature for sorption by the MST (see CBU-SPT-2004-00153: *Engineering Position on the Need for Temperature Control in the MST Strike Tanks at 241-96H*[32]).

2.2.3 Strontium and Actinide Sorption

The MST added to AST-A (TK-101) selectively sorbs soluble Sr and actinides present in the waste solution. Most of the Sr/actinide sorption occurs rapidly after the MST addition. In order to maximize the MST sorption for one MST strike, the mixing/contact duration within TK-101 is 12 hours. If two strikes are required, the MST sorption time for each MST strike is reduced to 6 hours. Decontamination Factors (DFs) used in P-ESR-J-00001[31], are provided in Table 2 for both single and multi-strike operation. The decontamination factors in Table 2 are not used anywhere in the remainder of this analysis and are only provided for information. Any disconnect between values used in this analysis and that resulting from the use of these decontamination factors is because of the different basis documents used in the derivation. Criticality scenarios herein conservatively assume a greater MST sorption.

Table 2: Decontamination Factor Values from Test Data

Radionuclide	Single-Strike (12 hour DF Values)	Multi-Strike	
		First-Strike (6 hour DF Values)	Subsequent-Strike (6-hour DF Values)
Uranium (U)	1.35	1.3	1.3
Plutonium (Pu)	5.5	4.7	3.9
Strontium (Sr)	20	17	17
Neptunium (Np)	2.4	2.14	1.13

The AST-A (TK-101) slurry will be nominally between 0.03 and 0.08 weight percent (wt.%) solids (see Letter PE-03-166: "*Monosodium Titanate [MST] Performance in Removing Actinides/Strontium from Feed at the Salt Waste Processing Facility [SWPF]*"[33]). After the waste feed is chemically adjusted and sufficient time has been allowed for MST sorption, the TK-101 slurry is transferred to FFT-A (TK-102), using one of the two Alpha Sorption Transfer Pumps (P-101A/B).

The time taken to process a single AST-A (TK-101) batch is estimated to be 24 hours, including waste feed and chemical addition times, MST sorption time, and TK-101 to FFT-A (TK-102) transfer time. The transfer line from TK-101 is flushed between batches with wash water from the WWHT (TK-105).

When the SWPF is operated in single-strike mode, sampling and analysis are performed in either the Intermediate Storage Tank (IST) (TK-220) or Alpha Sorption Tank-B (AST-B) (TK-221) to verify that the waste meets SPF WAC limits.

2.2.4 Alpha Strike Filtration Process

The SWPF uses cross-flow filtration to concentrate the MST/slurry in FFT-A (TK-102) to approximately 5-7 wt.%[6]. Two filtration circuits, each designed for 50% of the required capacity, are normally in service, with a third isolated and maintained in standby. These filters are in operation almost continuously.

A two-pump system is employed for each Alpha Sorption filter circuit. This two-pump system consists of a feed pump and a recirculation pump. The Filter Feed/Solids Transfer Pumps (P-102-1A/B/C) provide positive pressure to the suction of the associated Filter Recirculation Pump (P-102-2A/B/C). Cross-flow through the Alpha Sorption Filters (FLT-102A/B/C) is provided by the Filter Recirculation Pumps. P-102-2A/B/C are designed to maintain a high flow velocity (9-13 feet per second [ft/sec]) through the CFF tubes. Most of the slurry exiting the CFF is recirculated back to the recirculation pump suction. A bleed-back flow, equal to the Feed/Solids Transfer Pump feed flow rate minus the filtrate flow rate, is returned to FFT-A (TK-102).

The CFFs contain parallel one-half-inch-diameter tubes fabricated from sintered stainless steel with a pore size of 0.1 micron. The filter tubes are designated as Safety Significant (SS) for preventing solids break-through which ensures the robustness of tubes. The filter tubes are oriented vertically and operate at a high downward velocity to preclude any solid material accumulation within the ID of the tubes.

The Alpha Sorption Filters (FLT-102A/B/C) are designed so the filter tube bundle is self-draining and vertically removable. Each filter incorporates a back-pulse tank used for back-pulsing of the filter media. The back-pulse tanks are connected to the shell side of each filter. Compressed air at up to approximately 100 pounds per square inch gauge (psig) will be used to provide the motive pressure for back-pulsing of the filters. The filter loop piping arrangements are designed so that concentrated sludge can gravity-drain back into TK-102 at the conclusion of the filtration operation. Each filter loop includes a heat exchanger to cool the liquid.

The FFT-A (TK-102) filtration circuits are designed to process one batch from AST-A (TK-101), using two filter circuits within the same cycle time as TK-101. TK-102 is sized to allow the accumulation of seven batches (six concentrated batch volumes plus the batch volume from TK-101) prior to transfer to the SSRT (TK-104) to approximately match the batch receipt cycle times at DWPF. Each batch is filtered until the FFT level has been reduced to a predetermined minimum value equivalent to approximately 3,000 gallons. TK-102 is equipped with an APA system to mix the tank and maintain solids in suspension.

After addition of the final (seventh) batch, the tank contents can be sampled to verify the final dewatering endpoint. Tank level indication, combined with the total measured quantity of filtrate removed, will be used to determine when the target solids concentration value of 5 wt.% is reached. When the MST slurry concentration approaches the predicted endpoint associated with 5 wt.% solids, the Control Room Operator determines the volume of neutralized acid in the Spent Acid Storage Tank (SAST) (TK-127). The final FFT-A dewatering endpoint is adjusted such that when the neutralized acid is mixed with the MST/sludge in the SSRT, the final sludge solids concentration is 5 wt.% (X-SD-J-00001: *SWPF Alpha Strike Process System Description* [34]). The concentrated sludge is then transferred to the SSRT (TK-104) by one of the three Filter Feed/Solids Transfer Pumps (P102-1A/B/C).

The volume of the concentrated sludge for each batch at 5 wt.% will be approximately 400 gallons. While the number of AST-A batches processed in the SSRT (TK-104) may vary, seven AST-A batches will be used by this NCSE. The combined volume of 7 batches transferred to the SSRT (TK-104) will be approximately 2,800 gallons. The filtrate (CSS) flows to the SSFT (TK-109) for processing in the CSSX section. The capability is provided to recycle filtrate from the Alpha Sorption Filters to AST-A (TK-101) if more than two MST strikes are required.

The filtrate flow line will be equipped with redundant turbidity instruments to provide indication of filter breakthrough. On indication of abnormally high turbidity, a valve on the outlet of the filter will recycle flow to FFT-A (TK-102).

2.2.5 Sludge Washing

During normal operation, the MST/sludge resulting from the concentration of seven batches in the FFT-A (TK-102) is transferred to the SSRT (TK-104) for washing with process water. TK-104 is equipped with an APA system to ensure that tank contents are mixed well and to maintain solids in suspension.

When processing waste feed with 600 mg/L of entrained solids that have been subjected to one MST strike, the combined volume of 7 concentrated batches from FFT-A (TK-102) will be approximately 2,800 gallons. The sludge is washed with process water to reduce the Na^+ concentration to 0.5M. For this reduction in Na^+, approximately 2.4 gallons of process water will be used to wash 1 gallon of MST/sludge. During the wash cycle, process water is added continuously while the SSRT (TK-104) contents are recirculated through the Washing Filter (FLT-104) and the filtrate is removed and sent to the WWHT. Per M-M5-J-0004 *(SWPF Sludge Solids Washing Filter, Sludge Solids Receipt Tank and Wash Water Hold Tank PFD*[35]*)*, the flow rate for the Process Water into the SSRT (Stream #327) equals the flow rate for the Spent Wash Water (Stream #119) out of the Washing Filter. Based on M-M5-J-0002 *(SWPF Feed Receipt, Alpha Sorption Tank-A, Filter Feed Tank-A, and Cleaning Solution Dump Tank-A PFD*[36]*)*, the amount of MST/Sludge expected in the SSRT is 7 x 400 gal (Stream #106) = 2,800 gal.

The Washing Filter circuit uses a two-pump system similar to the Alpha Sorption Filter Systems. The Washing Filter Feed/Sludge Solids Transfer Pump (P-104-1) feeds the filter loop. The Washing Filter Recirculation Pump (P-104-2) is a high-flow pump capable of maintaining a flow velocity of 9 to 13 ft/sec through the Washing Filter (FLT-104) tubes. The filter outlet is recycled back to the recirculation pump suction. The Washing Filter is of same design as the Alpha Sorption Filters (FLT-102A/B/C). Unlike the FFT-A filters, the Washing Filter only operates about 8 hours per 7 day cycle.

The filtrate is collected in the WWHT (TK-105). During washing operations, the quantities of process water added and the filtrate produced are monitored. When the required quantity of water has been added and a corresponding quantity of filtrate removed, the washing operation is stopped. Contents of the SSRT (TK-104) are then sampled for Na^+ concentration and other waste acceptance parameters.

The concentrated MST/sludge produced by FFT-B (TK-222) in the AFP filtration operations will also be transferred to the SSRT (TK-104) for washing prior to transfer to DWPF. The estimated volume of MST/sludge produced from each TK-222 batch is approximately 190 gallons at 5 wt.% solids. The combined MST/sludge volume (from both the ASP and the AFP) produced by processing 7 batches of waste feed through two MST strikes is therefore approximately 4,150 gallons at 5 wt.%.

The washed sludge in the SSRT (TK-104) is pumped to the Precipitate Pump Tank (PPT) located in the Low Point Pump Pit (LPPP) by the Washing Filter Feed/Sludge Solids Transfer Pump (P-104-1).

The SSRT (TK-104) has a working volume of 5,200 gallons to accommodate the combined volume of 7 concentrated batches from both FFT-A (TK-102) and FFT-B (TK-222) and 500 gallons of line flush. After transfers from TK-102 or TK-222 to TK-104, lines are flushed to remove residual solids.

2.2.6 Cross-Flow Filter Cleaning

During normal operation of the filtration systems, it is anticipated that the filter flux will decrease with time, due to fouling of the filter pores with suspended and colloidal solids present in the waste. When filter performance has degraded to a point (based on observed filter flux and transmembrane pressure) where back-pulsing cannot restore filter performance, the fouled filter will be taken off-line and cleaned. Filter cleaning is conservatively planned to be required approximately once every 28 batches.

Nitric Acid Cleaning

Filter cleaning chemicals (0.02M NaOH and 0.5M $H_2C_2O_4$, or 1.0M NaOH and 20 wt.% HNO_3) are transferred to the Cleaning Solution Dump Tank-A (CSDT-A) (TK-103) from the Filter Cleaning Caustic Tank (TK-107), the Nitric Acid Receipt Tank (TK-304) and the Filter Cleaning Acid Feed Tank (TK-106). A line from the Deionized (DI) Water Storage Tank (TK-312) to TK-103 is provided to allow for DI (water) flush of the filter loop and TK-103. TK-103 is sized with a working volume of 850 gallons to contain a volume of cleaning solution sufficient to fill the largest filter circuit volume and maintain head in the CSDT-A for recirculation. TK-106 has a heater installed to preheat the acidic cleaning solution prior to transfer. The acidic cleaning solution is heated to facilitate dissolution and reduce the cleaning cycle time.

Filters are cleaned first with caustic solutions before using acid solution. At the conclusion of each cleaning cycle, the spent cleaning solution will be transferred to either the ASDT (TK-601) or the SAST (TK-127), using one of the Filter Feed/Solids Transfer Pumps (P-102-1A/B/C). TK-601 primarily collects spent caustic wash solutions, while TK-127 primarily collects spent acid solutions. Following neutralization, the spent nitric acid is transferred to the AST-A after the receipt of a mini-batch from the Tank Farm and prior to MST addition.

The filter cleaning procedure for the Cross-Flow Filters (FLT-222A/B/C) in the AFP is similar to the ASP filter cleaning protocol. A separate Cleaning Solution Dump Tank-B (CSDT-B) (TK-223) is provided for AFP filter cleaning. The filter cleaning chemicals for cleaning the filters in ASP and AFP will be supplied from the same tanks. The AFP spent filter cleaning solution will also be transferred to the ASDT (TK-601) and the SAST (TK-127) after each step.

Oxalic Acid Cleaning

Cleaning with oxalic acid (0.5M $H_2C_2O_4$) is the same sequence as cleaning with nitric acid, except for the destination of the spent acid. Spent oxalic acid is transferred to the SSRT after the washing step when Na concentrations have been reduced and prior to the transfer of the MST/sludge slurry to DWPF.

2.3 *Design Basis for Caustic-Side Solvent Extraction Process*

The CSSX process involves the removal of Cs from the waste feed, the scrubbing of the solvent to remove soluble salts, stripping the Cs out of the solvent, and “cleaning” the solvent, using a caustic wash. Most of

these operations involve the use of contactors; their operation is addressed in the final subpart of this section.

2.3.1 Cesium Extraction

The CSSX process will use Costner Industries Nevada Corporation (CINC) model V-10 contactor units. These are centrifugal contactors with a nominal hydraulic capacity of 30 gpm (total aqueous and organic flow through the unit). The contactor speed and flow rates affect the Cs removal efficiency and the facility will seek to operate at the optimum speed and flow control settings.

Extraction of Cs from the waste feed is performed in 16 successive contactors. Sixteen extraction contactors have been chosen to ensure that the target DF of 40,000 will be achieved (see P-ESR-J-00001[31]).

Solvent flows through the extraction stages counter-current to the aqueous feed. Each individual stage provides mixing and separation of the aqueous and organic phases. Cs is transferred from the aqueous phase to the organic phase in the extraction stages. The solvent used in the CSSX process is primarily Isopar®L with a specialty extractant (BOBCalixC6) at 0.007M nominal concentration, a modifier (Cs-7SB) at 0.75M nominal concentration, and a suppressant (tri-n-octylamine) at 0.003M nominal concentration. The Cs is captured by the solvent when the aqueous and organic phases are mixed and separated in the extraction stages.

The Cs is stabilized in the solvent by the calixarene molecule in the extractant (BOBCalixC6). Due to the size of the opening in the calixarene molecule, Cs is removed in dramatic preference to other cations, in particular the sodium and potassium ions. The high selectivity (two orders of magnitude for potassium and four orders of magnitude for sodium) is required to achieve the desired Cs removal efficiency.

The flow rate of CSS feed to the CSSX extraction stages will be set by the Operator, based on plant conditions and feed composition. Salt Solution Feed Pumps (P-109A/B) provide CSS feed to the extraction section from the SSFT (TK-109). The CSS feed is transferred through the Salt Solution Feed Coolers (HX-201) to maintain an appropriate feed temperature (see WSRC-RP-99-00006: *Bases, Assumptions, and Results of the Flowsheet Calculations for the Decision Phase Salt Disposition Alternatives*[37]).

Solvent is fed from the Solvent Hold Tank (SHT) (TK-202) to the extraction stage organic inlet by one of two Solvent Feed Pumps (P-202A/B). The solvent flow set point is controlled to maintain the desired extraction stage O:A ratio. The pump discharge has a control valve installed to provide sufficient back-pressure for a slipstream to be supplied to the laboratory for sampling and solvent adjustment. A mixing eductor is installed in TK-202 to provide homogeneity and improve the heat transfer efficiency of the tank cooling jacket.

DSS/CDCSS exits the extraction stages and gravity-flows to the DSS Stilling Tank (TK-211). Small amounts of solvent are entrained with the aqueous phase from the extraction stages. In TK-211, the heavier aqueous phase overflows a weir in TK-211 and gravity-drains to the Barium (Ba)-137 Decay Tank (TK-206). The lighter organic phase overflows to the SHT (TK-202). The stilling tank provides separation of the aqueous and organic phases and prevents large quantities of solvent from entering TK-206 in the event of a process upset.

The Ba-137 Decay Tank (TK-206) is designed to allow sufficient decay of ^{137m}Ba to effectively measure the Cs concentration prior to transfer of DSS/CDCSS to the AFP. One of the two Ba-137 Decay Tank Transfer Pumps (P-206A/B) will be used to transfer the DSS/CDCSS to the DSS Coalescer (TK-201). Two in-line gamma monitors are installed downstream of the Ba-137 Decay Tank Transfer Pumps to monitor the ^{137}Cs daughter product ^{137m}Ba concentration. A high-gamma alarm at this location is interlocked to reroute the Ba-137 Decay Tank Transfer Pump discharge to the SSFT (TK-109) to ensure that high ^{137}Cs material is not sent to the AFF. Further increases in gamma concentration will activate an interlock that trips the salt solution feed pumps into the CSSX process and the BDT transfer pumps.

The DSS Coalescer (TK-201) recovers solvent with installed coalescing media. Recovered solvent gravity-flows to the SHT (TK-202). The aqueous phase (DSS) gravity-flows to the AFF to either the IST (TK-220) or AST-B (TK-221) during single-strike operation.

2.3.2 Solvent Scrub

Following Cs extraction, the solvent is scrubbed with 0.05M (HNO_3) to remove soluble salts (sodium, potassium, aluminum, iron, and mercury) from the solvent stream. Scrubbing the metal ions from the organic prevents the transfer of these ions to the strip solution. Contacting the organic stream with the dilute acid also has the effect of neutralizing any caustic carryover from the extraction stages. Neutralization of the caustic carryover is necessary to ensure stable operation of the strip stages.

Two stages of scrub are provided. The scrub solution enters the second scrub stage and proceeds counter-current to the solvent. Scrub solution is provided from the Nitric Acid Scrub Make-up Tank (TK-307) by one of the two Scrub Feed Pumps (P-309A/B) located in the Cold Chemicals Area (CCA). The scrub solution flow is controlled to maintain the desired O:A ratio in the scrub stages.

2.3.3 Cesium Strip

The scrubbed solvent gravity-flows to the Solvent Strip Feed Tank (TK-217) and is pumped through the associated Solvent Strip Feed Heater Exchanger (HX-217A/B) to Stripping Contactor EXT-203A. HX-217A/B heats the solvent to a desired temperature range. Scrub acid from TK-307 is diluted by DI water from TK-312 to form strip solution in the strip in-line mixers (MIX-310A/B). The strip solution passes through the associated Strip Feed Heater (HTR-310A/B), which heats the strip solution to the desired temperature range and is subsequently routed to the aqueous inlet of Stripping Contactor EXT-203P.

In the strip section, Cs-laden solvent from the scrub contactors is contacted counter-current with the 0.001M HNO_3 strip solution in a series of 16 centrifugal contactors, resulting in the transfer of Cs to the strip solution. The low nitrate ion concentration in the aqueous phase shifts the equilibrium to favor the transport of the Cs ion from the solvent to the aqueous phase.

Strip effluent exits the strip stages and flows by gravity to the Strip Effluent Stilling Tank (TK-212) and can be pumped using the Strip Effluent Coalescer Feed Pumps (P-212 A/B) to the Strip Effluent Coalescer (TK-203) to remove trace amounts of entrained solvent in the aqueous phase. The recovered solvent from TK-212 and TK-203 gravity-flows to the SDT (TK-208). TK-208 can be pumped by one of the SDT Pumps (P-208A/B) to the aqueous inlet line of the extraction stages. From there, the recovered solvent is separated from the aqueous phase during normal processing of the extraction feed.

Aqueous effluent from the Strip Effluent Coalescer (TK-203) to gravity-flows to the Strip Effluent Pump Tank (TK-215) which is pumped to the Strip Effluent Hold Tank (TK-205).

The strip contactors have water jackets supplied with tempered water. Tempered water serves to heat the strip contactors to optimize the startup of the system and also to remove heat imparted into the fluid due to hydraulic action during continuous system operation. The jackets are designed to maintain the contactor contents in an optimal temperature range.

2.3.4 Caustic Wash

On leaving the strip stages, the stripped solvent flows to a caustic wash process that consists of two centrifugal contactors. Caustic wash solution is contacted counter-current with the solvent through the two stages. The wash process is intended to remove impurities in the solvent that may interfere with solvent performance. The suppressant and modifier contained in the solvent degrade over time. The suppressant (tri-n-octylamine) forms dioctylamine and the modifier (Cs-7SB) forms a phenolic compound. The caustic wash stage is intended to remove these impurities and restore performance of the solvent. The solvent outlet from the wash stages will flow by gravity to the SHT (TK-202).

The Caustic Wash Tank (TK-204) and one of the two Caustic Wash Tank Pumps (P-204A/B) supply the caustic wash solution to the wash contactor aqueous inlet. The operating pump will operate at a flow control set point to maintain the desired O:A ratio.

The caustic wash solution from the caustic wash contactors gravity-flows back to the Caustic Wash Tank (TK-204). The pH of TK-204 will gradually decrease during operation. When the wash stage aqueous outlet pH decreases to a predetermined level, the contents of TK-204 will be transferred to the DSS Stilling Tank (TK-211) and pass out of the system with the DSS/CDCSS through the Ba-137 Decay Tank (TK-206). The wash solution in TK-204 will then be replenished from the Caustic Make-up Tank (TK-303).

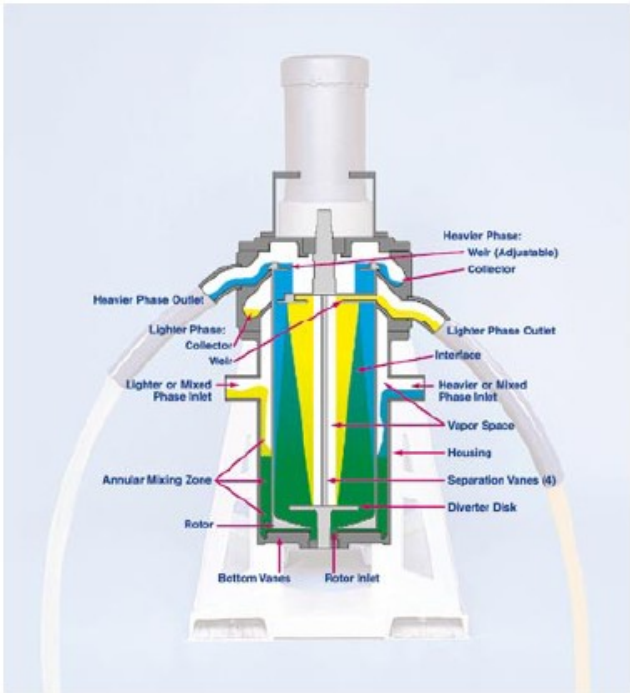
The Caustic Wash Tank (TK-204) level will remain approximately constant because the caustic wash solution is recirculated back from the wash stages. The tank has a working volume of 400 gallons, so caustic wash inventory should require periodic purging and replacement.

2.3.5 Contactor Operation

Each contactor has two process inlets and two process outlets, one each for the higher specific gravity (s.g.) aqueous phase and one each for the lower s.g. solvent phase. Drain and flush connections are provided at the bottom of each contactor to allow for flushing of the contactor internals. A motor with a Variable Frequency Drive (VFD) drives each contactor. The VFD will be automatically controlled by the DCS or manually controlled by the Operator. Instrumentation requirements for the contactors include speed, motor amperage, and vibration.

Figure 2 depicts a cutaway view of the contactors and labels the inputs, outputs, and various important parts and concepts of the contactors.

Figure 2: Contactor Cutaway View



From Figure 2, the lighter (lower s.g.) liquid enters the horizontal pipe on the left and flows down to the mixing region in bottom of the outer annulus. The heavier liquid enters the horizontal pipe on the right and flows down to the mixing region. The mixed liquid is forced up through the rotor inlet and rotated at a high speed in the inner housing so that the heavier liquid is forced toward the outer wall and the lighter liquid remains closer to the rotor shaft. The separation of heavier and lighter liquids within the contactor results in two intersecting cones, as depicted in Figure 2. One set of weirs at the top of the inner housing allows for the heavier liquid to exit closer to the inner housing wall and the lighter liquid to exit closer to the rotor shaft. Another set of weirs (adjustable) located in the top of the contactor provide for flow control.

Contactors arranged in series (e.g., contactor banks) have the inlets and outlets connected such that the lighter liquid outlet feeds the lighter liquid inlet of the adjacent contactor. Similarly, the heavier liquid outlet feeds the heavier liquid inlet of the adjacent contactor.

The contactor Operating Deck contains 2 rows of 18 contactors each (see P-PH-J-0035, *SWPF Process Building HVAC Central Process Area CSSX Contactor Support Floor, Floor Plan at el 116'-0*[38], and P-PH-J-0036, *SWPF Processing Building HVAC Central Process Area CSSX Contactor Support Floor, Floor Plan at el 116'-0"*[39]. The contactors in each row are 4 feet-6 inches center to center apart and the rows are separated 6 feet center to center.

Some amount of solids entrained in the solution sent to the contactors is credible. The build-up of solids in a contactor (or the whole contactor bank) may result in decreased efficiency until the contactor rotor abruptly stops spinning (fails) or a controlled shutdown is performed. If failure of a contactor appears imminent based on vibration, temperature, or other indicators, a controlled system shutdown will be performed. In addition to solids build-up, there are numerous interlocks that may produce an abrupt stop to the contactors in a bank. The abrupt stop of a contactor will result in the collapse of the two intersecting cones of different s.g. liquid into one static liquid level reflecting the liquid volume during operation until the contactors can be drained.

2.4 *Alpha Finishing Process*

This section describes the process operations for waste requiring additional MST strike(s) in the AFP. Descriptions of the equipment required to perform these operations are provided, along with information on tank/equipment sizing requirements, where appropriate. Because most of the operations in the AFP are similar to corresponding operations in the ASP, the appropriate ASP operations are referenced. The purpose of the AFP is to remove Sr and actinides that may still be present in the CDCSS at levels exceeding the Saltstone WAC limits. An additional MST strike can be performed in the AFP with no impact to plant design throughput. Because the Cs concentration in the feed to AFP is significantly lower than that in the ASP, AFP equipment is designed to allow contact-handled operations and maintenance.

During single-strike operations, DSS in the Ba-137 Decay Tank (TK-206) is pumped to the DSS Coalescer (TK-201). DSS from TK-201 gravity-flows to either the IST (TK-220) or AST-B (TK-221). During single-strike operation, TK-220 and TK-221 are alternately used to receive and stage DSS for transfer to the DSSHT (TK-207). These tanks also provide a convenient point for sampling of the DSS to verify compliance with the Saltstone WAC. Once the receiving tank is full, the flow is switched to the alternate tank and the isolated tank is sampled. TK-207 stores the DSS product until the tank is pumped out of the facility. If material is transferred to TK-220 or TK-221 that does not meet the SPF WAC during single-strike operation, a second strike is performed or the material is recycled to the ASP section for additional processing.

During multi-strike operations, CDCSS from the DSS Coalescer (TK-201) gravity-flows to the IST (TK-220). TK-220 contents are then transferred to AST-B (TK-221) to perform a second MST strike. After the MST sorption period has been completed, TK-221 is sampled and analyzed to verify that the Sr/actinides and Cs in solution meet the SPF WAC limits. If the WAC limits are satisfied, the TK-221 contents are transferred to FFT-B (TK-222) for filtration. If WAC limits are not met, additional strikes can be performed or material can be recycled to the ASP section for additional processing. Filtrate from the filtration process is routed to the DSSHT (TK-207). TK-207 is transferred out of the facility approximately once per day (see V-ESR-J-00010[30]).

2.4.1 Intermediate Storage Tank

The IST (TK-220) receives waste from the DSS Coalescer (TK-201). If it is necessary to recycle material in TK-207 for further processing through AFP, the IST is capable of receiving the recycled material. The working volume of TK-220 is 30,300 gallons. One of the two IST Transfer Pumps (P-220 A/B) is used to transfer CDCSS/DSS from TK-220 to either TK-221 or TK-207. TK-220 is equipped with eductors fed off a recirculation loop from P-220A/B for tank mixing.

The IST (TK-220) has a sample pump installed that allows pumped recirculation of material to the Analytical Laboratory for analysis. The outlet is normally recirculated to the Analytical Laboratory for sampling. The discharge of SP-220 can also be routed to the SDT (TK-208) for solvent recovery. During normal operations, it is possible that a thin layer of solvent might accumulate on the surface of the contents in TK-220. To recover solvent, the tank contents are pumped down to a minimum level using P-220A/B. The sample pumps are then used to transfer the remaining contents to TK-208, where the mixed solvent/aqueous waste can be recovered by pumping to the CSSX extraction process.

2.4.2 Strontium and Actinide Sorption in Alpha Sorption Tank-B

As described in Section 2.4, AST-B (TK-221) is used as a receiving vessel during single-strike operations, or to perform a second strike during a double-strike campaign. The working volume of TK-221 is 30,700 gallons. Following completion of a batch transfer from the IST (TK-220) to TK-221 during double-strike

mode, approximately 75 gallons of MST/slurry at 15 wt.% are added to achieve a concentration of 0.4 g/L. A dilute caustic flush from the Caustic Dilution Feed Tank (TK-108) is performed to flush the MST addition line from the CCA. The sorption time is six hours. The contents are mixed with a mechanical agitator (AGT-221) during the sorption period. TK-221 has a cooling jacket to remove heat of mixing.

The AST-B (TK-221) contents are sampled and analyzed after MST sorption to ensure that the filtered concentrations of Sr and actinides will be within the Saltstone WAC limits. After the AST-B (TK-221) contents have been qualified, they are transferred to FFT-B (TK-222), using one of the two AST-B Transfer Pumps (P-221 A/B).

AST-B (TK-221) has a sample pump configuration similar to that of the IST (TK-220). The AST-B Sample Pump (SP-221) allows for sampling and solvent recovery. Particulate filters in the solvent recovery lines prevent sending solids to TK-208. The discharge from the pumps can be routed to either the Analytical Laboratory or the SDT (TK-208).

2.4.3 Filtration

Similar to FFT-A (TK-102) in the ASP, FFT-B (TK-222) is used to concentrate waste processed in AST-B (TK-221) during double-strike operation. TK-222 has a working volume of 31,900 gallons, which accommodates one batch from TK-221. The contents of TK-222 are circulated through two of the three CFFs to concentrate the MST solids to 5 wt.%. A mechanical agitator (AGT-222) is used to mix the MST slurry in TK-222. The size and operation of the CFFs, back-pulse tanks, and pumping system for the AFP filter systems are identical to the ASP. The AFP filter systems will differ in that they are designed with flanged connections to allow for removal of the entire filter assembly, as opposed to removal and replacement of the cartridge, as is planned for the ASP.

Similar to ASP, multiple batches will be accumulated in FFT-B (TK-222) at lower than 5 wt.% solids to facilitate level monitoring and mixing. The final (seventh) batch will be concentrated to the target concentration of 5 wt.% and transferred to the MST/Sludge Transfer Tank (MSTT) (TK-224).

Filtrate from the AFP Alpha Sorption Filters (FLT-222A/B/C) is routed to the DSSHT (TK-207). The filtrate flow line is equipped with a turbidity instrument to provide indication of filter breakthrough. Similar to the ASP, the filtrate flow can be returned to FFT-B (TK-222) during filter start-up operations or in the event of a filter breakthrough.

FFT-B (TK-222) has a sample pump configuration similar to that of the IST (TK-220). The FFT-B Sample Pump (SP-222) allows for sampling and for solvent recovery. The discharge from the pumps can be routed either to the Analytical Laboratory or the SDT (TK-208).

2.4.4 MST/Sludge Transfer Tank

Following concentration in FFT-B (TK-222), concentrated MST slurry is transferred to the MSTT (TK-224) for interim storage and subsequent transfer to the SSRT (TK-104) for washing. Transfers to TK-104 from TK-224 will be coordinated with transfers of concentrated MST/sludge from FFT-A (TK-102).

The working volume of the MSTT (TK-224) is 1,600 gallons. This accommodates the combined volumes of seven batches from the FFT-B (TK-222) and line flush volume. TK-224 is equipped with an agitator (AGT-224) to keep the MST/sludge in suspension. TK-224 is also equipped with a cooling jacket to remove the heat generated by the agitator.

2.4.5 Decontaminated Salt Solution Storage and Transfer

The DSSHT (TK-207) receives DSS from the IST (TK-220) and AST-B (TK-221) during single-strike operation, and filtrate from FFT-B (TK-222) during double-strike operation. The DSSHT (TK-207) is designed/required to store DSS generated by 24 hours of operation. At a design DSS production rate of 22.9 gpm, the DSS produced after 24 hours of operation would be approximately 33,000 gallons. TK-207 has been conservatively sized to provide a working volume of 35,900 gallons (approximately 26 hours of DSS production).

The DSS transfer pumps (P-207A/B) are capable of transferring DSS to Saltstone and the Saltstone Feed Facility. These Transfer Pumps are also used to recirculate DSS through mixing eductors installed in the

DSSHT (TK-207). The eductors are installed to ensure tank mixing prior to sampling. A pressure control valve is installed on the outlet of P-207A/B to control transfer line pressure. The transfer requirements for DSS are specified in V-ESR-J-00010[30].

The DSSHT (TK-207) has a sample pump configuration similar to that of the IST (TK-220). The DSSHT Sample Pump (SP-207) allows for sampling and for solvent recovery. Discharge from the pumps can be routed to either the Analytical Laboratory or the SDT (TK-208).

2.4.6 Filter Cleaning

During routine operation, it is anticipated that the filter flux will decrease as each FFT-B (TK-222) batch is processed. When the filter flux decreases significantly below the design value, the fouled filter is isolated and cleaned to restore normal operation. The cleaning procedure will be identical to the procedure used for cleaning the ASP filters (see Section 2.2.6). The design basis frequency of cleaning these filters is assumed to be same as for ASP filters (i.e., once every 28 batches). CSDT-B (TK-223) provides an identical function in the filter cleaning process for the AFP as CSDT-A (TK-103) provides in the ASP.

2.5 *Flow of Fissile Material*

The SWPF treats salt waste with chemical and mechanical processes to separate the radioactive elements (primarily actinides, strontium [Sr], and cesium [Cs]) from the bulk salt waste and concentrate them into a relatively small volume. The above sections discuss these processes; however the balance of this NCSE is concerned with the concentration of the uranium and plutonium actinides. This section discusses the process flow with respect to the movement and concentration of these actinides. Additionally, the balance of this NCSE utilizes hypothetical, accident or bounding configurations of actinides while this section seeks to estimate the actual mass and concentrations of these materials in the normal process. These estimates can be used to frame the very conservative configurations used in Sections 5 and 6.

The uranium concentration in the feed to SWPF will be less than or equal to 25 mg U/L and the plutonium concentration will be less than or equal to 2.5 mg Pu/L. While the following discussion focuses on uranium, the plutonium will be at the same locations and the concentrating ratios for uranium will also apply for plutonium provided both remain attached to the MST.

The nominal AST-A (TK-101) batch volume is approximately 28,300 gallons (107,127 L) which results in approximately 2.67 kg U in the AST-A. Cold chemical additions in AST-A of approximately 5,070 gallons (19,192 L) are included in the nominal AST-A batch volume. In the AST-A and FFT-A (TK-102), the MST will load with actinides. Approximately 50.4 kg of MST is required to achieve the target concentration of 0.4 g/L. The recycle loop from FFT-A through the CFF results in concentrating the material remaining in the FFT-A by removing solution. Uranium loaded on MST will remain in the FFT-A through CFF loop because the procured MST particles are sufficiently large to preclude passing through the sintered metal of the tubes in the CFF. Based on nominal decontamination factors for MST, approximately 940 g of uranium could remain in the FFT-A from each AST-A batch. The remaining 1.73 kg of uranium per AST-A batch is expected to remain in solution, pass through the CFF to the SSFT (TK-109).

By concentrating seven AST-A batches in the FFT-A before transfer to the SSRT (TK-104), approximately 6.6 kg U could be loaded on the MST sent to the SSRT. Based on 283 gallons (1,071 L) per batch transfer to the SSRT (M-M5-J-0002[36]), the resulting uranium concentration in the SSRT is approximately 264 mg U/L (without any water or cold chemical additions). From the SSRT, the concentrated sludge/solids are sent to DWPF.

Based on 27,862 gallons (105,961 L) per AST-A batch passing through the CFF to the SSFT (M-M5-J-0003, *SWPF Alpha Sorption Filters FLT-102A/B/C PFD*[40]), the resulting uranium concentration in the SSFT is approximately 16.3 mg U/L (without any recycle material). From the SSFT the material passes through the contactors to the Ba-137 Decay Tank (TK-206), that has a hold time long enough for Ba-137 to decay. Past the Ba-137 Decay Tank the material goes to either the IST (TK-220) or the AST-B based on the processing scheme at that time.

3 Requirements Documentation

The purpose of this section is to identify those requirements documents that are applicable to the project/facility analyzed that are outside the set of requirements documents common for an NCSE in the DOE complex.

A review was conducted to identify other requirements documents. The review concluded that there are no applicable requirements documents beyond those common to NCSEs. Chapter III of DOE O 420.1B[1] requires the use of DOE-STD-3007-2007, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Non-reactor Nuclear Facilities*[41] and compliance with the applicable American National Standards Institute (ANSI) and American Nuclear Society (ANS) Standards, in particular ANSI/ANS-8.1-1998, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*[42]. The criticality safety program for the SWPF project is established by N-NCS-J-00003, *SWPF Criticality Safety Program Description*[43] and implemented by N-NCS-J-00002, *SWPF Criticality Safety Program Manual*[44]. N-NCS-J-00004[5] provides guidance on the acceptable method(s) for complying with the Orders and required/applicable Standards.

4 Methodology

This section presents an overview of the criticality safety code used for calculations, the area of applicability comparison between the validation report and the models in this NCSE, a derivation of the k_{safe} value, an overview of the contingency analysis method, and some discussions on the material compositions used.

4.1 *Criticality Safety Code Used*

All calculations of k_{eff} utilized the MCNP Monte-Carlo computer code (see LA-CP-13-00634, Rev. 0, *MCNP6 User's Manual* [45]). MCNP is a general-purpose Monte Carlo N–Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate k_{eff} values for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori.

Pointwise cross-section data are used. For neutrons, all reactions given in a particular cross-section evaluation (such as ENDF/B-VII.1) are accounted for. Thermal neutrons are described by both the free gas and S(α,β) models.

Calculations for this analysis were performed by specifying the "80c" cross-section data within the MCNP code as directed by the validation report (see N-NCS-J-00011, *MCNP 6.1 Validation for Uranium and Plutonium Systems using ENDF/B-VII.1 Cross Section Library*[46]. The actual nuclide sets used are listed in Table 3. The S(α,β) model for light water and water in concrete was *lwtr.20t*.

Table 3: Cross-Section Libraries Used

Element/ Isotope	Cross-Section Set ID	Isotopic Fraction	Element/ Isotope	Cross-Section Set ID	Isotopic Fraction
H-1	1001.80c		Ni-58	28058.80c	0.68077
O-16	8016.80c		Ni-60	28060.80c	0.26223
Na-23	11023.80c		Ni-61	28061.80c	0.011399
Al-27	13027.80c		Ni-62	28062.80c	0.036346
Si-28	14028.80c	0.92223	Ni-58	28058.80c	0.68077
Si-29	14029.80c	0.04685	Mo-94	42094.80c	0.0915
Si-30	14030.80c	0.03092	Mo-95	42095.80c	0.1584
Ca-40	20040.80c	0.96941	Mo-96	42096.80c	0.1667
Ca-42	20042.80c	0.00647	Mo-97	42097.80c	0.0960
Ca-43	20043.80c	0.00135	Mo-98	42098.80c	0.2439
Ca-44	20044.80c	0.02086	Mo-100	42100.80c	0.09820
Ca-46	20046.80c	0.00004			
Ca-48	20048.80c	0.00187	U-235	92235.80c	Application Specific
Cr-50	24050.80c	0.04345	U-238	92238.80c	
Cr-52	24052.80c	0.83789	Pu-239	94239.80c	
Cr-53	24053.80c	0.09501	Pu-240	94240.80c	
Cr-54	24054.80c	0.02365			
Fe-54	26054.80c	0.05845			
Fe-56	26056.80c	0.91754			
Fe-57	26057.80c	0.02119			
Fe-58	26058.80c	0.00282			

4.2 *Area of Applicability*

The MCNP6 validation report (N-NCS-J-00011[46]) documents the results from executing numerous critical benchmark experiments. These results were analyzed for trends with respect to independent variables, graphed, and subjected to the appropriate statistical analysis. The AoA, as stated in N-NCS-J-00011, is

repeated in Table 4. This table provides a direct comparison between the AoA for the validation to that modeled in this NCSE. Deviations from the parameter ranges of the validation AoA are addressed below the table.

Table 4: Area of Applicability

Parameter	Validation N-NCS-J-00011[46]	Model System	AoA Penalty
Fissile Material	UO_2, PuO_2, $UO_2(NO_3)_2$, $PuO_2(NO_3)_2$	UO_2, PuO_2,	0
Fissile Material Form	Solid and Solution	Solution	0
H/X (^{235}U)	$38 \leq H/^{235}U \leq 2800$	$32 \leq H/^{235}U \leq 2800$	0
Enrichment: ^{235}U	1 to 10 wt.% ^{235}U; 2 to 48 atom % X	2.5 to 16 wt.% ^{235}U; $5.5 \leq X \leq 38$	0
Moderating Materials	Water	Water	0
Reflecting Materials	None, Water, Concrete, Hydrocarbon Material, Steel	Concrete	0
Absorber Materials	Boron, Cadmium, Copper, Zirconium, Aluminum, Steel, Stainless Steel, Hydrocarbon Material	Iron, Aluminum	0
Geometry	Homogeneous and Heterogeneous Spheres, Hemispheres, Cylinders, Cuboids Single Units and Arrays	Sphere, Cylinder, Torus	0
Average Neutron Energy Causing Fission (ANECF)	$0.004 < ANECF < 0.35$	$0.003 \leq ANECF \leq 0.2$	0

Due to the absence of deviations indicated in Table 4, no additional AoA margin is taken for the modeled system. This results in an AoA = 0.000 that will be used to calculate the k_{safe} value. Explainiations of a few important parameters are provided below.

Parameter: H/X

The ANSI/ANS-8.1-1998[42] subcritical H/X limits for ^{235}U and ^{239}Pu are 2250 and 3630 respectively. Thus, for a system composed of mostly uranium with some plutonium added, the H/X=2800 upper bound for the validated system (per N-NCS-J-00011[46]) is consistent with the point of hydrogen poisoning. While MCNP cases were run herein with an H/X>2800, none of these cases resulted in limiting conditions; these cases only represented a continued data trend. Hence, the cases with an H/X>2800 were inconsequential to the analysis and no AoA penalty is taken.

The case series *hor_c_pu* herein analyzed the H/X=32 value for the smallest volumes of the other parameter values selected. None of the cases with an H/X=32 resulted in limiting conditions; these cases only represented a continued data trend. Furthermore, Section 7.1 of N-NCS-J-00011[46] indicates that a ±20% extension is considered acceptable which indicaticates the minimum H/X value of 30 is appropriate. Therefore, no AoA penalty is taken.

Parameter: Enrichment

The ^{235}U enrichment of the water-moderated LEU experiments in N-NCS-J-00011[46] had values ranging from 1.6 to 10 wt. % ^{235}U. While the modeled system herein analyzed the single parameter upset condition of double the nominal enrichment (16 wt. % ^{235}U instead of 8 wt. % ^{235}U), enrichment was not the limiting parameter.

In Section 6.2.3, all the cases in the uranium enrichment series (*u_enrich_pu*) had an H/X greater than 3130 even though the enrichment reached 30%. Thus, these cases were hydrogen poisoned as indicated by the

maximum k_{eff}+2σ below 0.7. Hence, this case series was inconsequential to the analysis and no AoA penalty is taken.

In Section 6.5.3, a series of cases investigated 16% ^{235}U in the CFF, but the series results were not utilized for any limits or contingency analysis. The higher enrichment cases were investigated and reported to indicate the margin in the analysis. Hence, this case series was inconsequential to the analysis and no AoA penalty is taken.

In Section 6.7, the contactors were analyzed with 8% and 16% ^{235}U. The 16% ^{235}U were presented as bounding the 8% results. None of the 16% ^{235}U results exceeded a k_{eff}+2σ value of 0.6 and the 8% results were lower. The higher enrichment cases were investigated and reported to indicate the margin in the analysis. Hence, this case series was inconsequential to the analysis and no AoA penalty is taken.

The ^{239}Pu enrichment of the water-moderated MOX experiments had values ranging from 1.5 to 48 wt. % ^{239}Pu. However, the SWPF applications are a mixture of ^{235}U and ^{239}Pu in ^{238}U. For this reason, a new parameter X was selected in N-NCS-J-00011[46] to characterize the benchmark experiments and the SWPF applications.

$$X = \frac{^{235}U + {}^{239}Pu + {}^{241}Pu}{All\ U + All\ Pu}\ x\ 100$$

Where all isotopes are included as atom densities. The parameter X for the calculations herein were within the bounds set by N-NCS-J-00011[46], thus, no AoA penalty was taken.

Parameter: ANECF

The single parameter upset series investigating uranium enrichment was the only series that contained cases with an ANECF below that in the validation (N-NCS-J-00011[46]). All the cases in the uranium enrichment series (*u_enrich_pu*) had an H/X greater than 3130. Thus, these cases were hydrogen poisoned as indicated by the maximum k_{eff}+2σ below 0.7. Hence, this case series was inconsequential to the analysis and no AoA penalty is taken.

Parameter: Absorber Materials

The scope of this analysis required an accounting of the neutron absorption by the titanium that comprises the MST. Per Section 7.6.1 of the validation report (N-NCS-J-00011[46]), the titanium was substituted with iron on an atom for atom basis using the atom fraction distribution specified in Table 3. Iron was included as absorber material in the validation system of N-NCS-J-00011[46]. This substitution was conservative due to the thermal neutron absorption cross section of these two elements. Table 5 demonstrates that iron has a thermal absorption cross section less than half that of titanium, and therefore, no AoA penalty is taken.

Table 5: Selected Material Thermal Neutron Absorption Cross Section

Element	Symbol	Cross Section σ_a (barns)
Sodium	Na	0.53
Aluminum	Al	0.23
Titanium	Ti	6.09
Iron	Fe	2.56
Magnesium	Mg	0.06
Manganese	Mn	13.3
Nickel	Ni	4.5
Chromium	Cr	3.1

It was also necessary to account for sodium in the modeled system. Per Section 7.6.2 of the validation report (N-NCS-J-00011[46]), the sodium was substituted with aluminum on an atom for atom basis. Aluminum was included as absorber material in the validation system of N-NCS-J-00011[46]. This substitution was conservative due to the thermal neutron absorption cross section of these two elements. Table 5 demonstrates that aluminum has a thermal absorption cross section less than half that of sodium, and therefore, no AoA penalty is taken.

4.3 Code Bias, Statistical Uncertainty, and Acceptance Criteria

N-NCS-J-00011[46] documents the derivation of the Upper Subcritical Limit (USL) for the AoA of the validation system, with specified cross-section sets, based on MCNP calculations. The USL includes a 0.02 Margin of Subcriticality (N-NCS-J-00004)[5] and a total bias and bias uncertainty (σ_B) of 0.005. The analyzed system k_{eff} value (k_s) is determined to be acceptable (i.e., acceptably subcritical, implying some margin of safety, thus termed k_{safe}) if:

$$k_s + 2\sigma_s \leq \text{USL } (0.9679) - \text{AoA}$$

where:

k_s = k_{eff} from MCNP 6.1 for individual cases evaluated in this NCSE,
σ_s = the standard deviation in k_{eff} from MCNP 6.1, and
AoA = 0.00 from Section 4.2.

Thus, the derivation of k_{safe} is: $k_{safe} \equiv \text{USL} - \text{AoA} = 0.9679 - 0.00 = 0.9679$.

4.4 Contingency Analysis

Section 7 of N-NCS-J-00004[5] documents the overall process for the methodology used in development of this analysis, and the criteria by which engineering judgments are made. This is of particular importance when determining which scenarios are credible, and which are incredible. The methodology provided in N-NCS-J-00004 does not require that a hypothesized scenario be physically impossible to be declared incredible.

Based on N-NCS-J-00004 methodology, the operations within each unit operation are reviewed and scenarios developed. Each scenario is evaluated to determine if it could lead to a critical configuration (see Section 4.4.1 below). Of those which could result in achieving a critical configuration, further evaluations are performed to apply engineering judgment as to whether the scenario is credible or not, per the methodology detailed in N-NCS-J-00004. The following sub-sections summarize some of the important terms and methodologies from N-NCS-J-00004.

4.4.1 Critical Configuration

The critical configuration is defined by the appropriate subcritical limit for the given scenario. For example, if the scenario limit is based on close and full reflection, close and full reflection is taken to be the reflection component of the critical configuration. If the scenario limit is based on mass control, all conceivable means by which to exceed that limit are considered. If a credible means by which a given subcritical limit may not be achieved, the scenario is deemed incredible.

It should be noted that this definition provides some conservatism, as exceeding the subcritical limit means only that the configuration can no longer be said to be safely subcritical. In reality, additional reactivity would have to be added to the system in an amount greater than the margin of safety (MSM) used in establishing the subcritical limit, before the configuration could actually reach a critical state.

4.4.2 Guidelines for Incredibility

N-NCS-J-00004[5] details the process and guidelines used in this contingency analysis development process, but the guidelines for "incredibility" are summarized here for convenience. Basically, a scenario is determined to be incredible if enough errors would have to occur before a criticality could occur. One of the following guidelines was used when deciding if enough errors have been identified to deem a scenario incredible:

1. Four or more independent, robust, and unlikely human failures of robust barriers;
2. Three or more independent equipment failures;
3. Any justifiable combination of the above two criteria; or
4. A critical configuration could not be assembled, due to insufficient mass or less than optimal configurations.

If a hypothetical accident scenario can be shown to satisfy any of the above guidelines (with adequate documented justification), the scenario may be deemed incredible.

4.4.3 Implications of Scenarios

It should be noted that simply because a scenario considered a certain upset condition parameter value, that does not imply that an operation above (i.e., in the non-conservative direction) the nominal parameter value can be approved without further analysis. This condition is true even for scenarios deemed incredible. For example, one of the scenarios in this NCSE considered a uranium feed concentration of 50 mg/L which was double the nominal concentration of 25 mg/L. Criticality for this scenario was deemed incredible, but this does not imply that any (even a "one time only") feed transfer can be allowed that exceeds the nominal value without further analysis. At the point that a deviation (in the non-conservative direction) from nominal is requested, the impact of that deviation must be fully documented throughout the analysis. A deviation in the non-conservative direction is a change to the process and requires an analysis, review and approval process equivalent to the original NCSE per DOE Order 420.1B[1] and as implemented in N-NCS-J-0004[5].

4.5 *Material Composition*

One of the primary materials for this analysis is MST ($NaTi_2O_5H$). MST has a maximum theoretical density of 2.765 grams per cubic centimeter (g/cc), per WER-HLE-930558, *Nuclear Criticality Safety Analysis WM-93-1, Determination of the Safe Accumulated MST Mass for MST Mass Additions in the In-tank Precipitation Process*[47]. Table 6 contains the atom density and weight fraction per element for dry MST. The ASP uses 15 wt.% MST in water to achieve the 0.4 g/L MST value for the process design described in Section 2.2.2.

Table 6: MST Composition

Element	Atom Density	Weight Fraction
Na	8.33679E-03	1.15E-01
Ti	1.66736E-02	4.79E-01
O	4.16839E-02	4.01E-01
H	8.33679E-03	5.05E-03
Total	7.50311E-02	

Note that some question remains as to the mechanism of uranium and plutonium sorption onto MST. Earlier evaluation thought this sorption was an ion replacement on the sodium titanate; however a synchrotron-based x-ray absorption fine structure analysis concluded that this is not the case (WSRC-MS-2004-00828, *Mechanisms of Strontium and Uranium Removal from Radioactive Waste Simulant Solutions by the Sorbent Monosodium Titanate*[48]). Rather it was concluded that UO_2^{2+} (the uranyl ion) exhibit inner sphere (specific adsorption) sorption behavior with the MST. It was judged that at high uranium sorption loadings the uranyl ions form thread-like chains stemming from the MST particles. Therefore, it was judged that simple volumetric addition of the UO_2 theoretical density (11.04 g/cc) and the MST theoretical density could conservatively be used to calculate the material atom densities. There was no specific information about the sorption of plutonium. However, it was judged that volumetric addition of plutonium metal at its theoretical density (19.84 g/cc) was conservative. Note that Section 4.6 describes the methodology to determine the minimum volume of the MST-water mixture, and thus the minimum water volume in the volumetric addition. Appendix B details this atom density calculation.

WSRC-STI-2006-00012, *Results of Supplemental MST Studies*[49] provides the weight fraction loading of uranium and plutonium onto MST per strike. The weight fraction was calculated as the mass of uranium (or plutonium) per mass of MST present. Thus, the mass of uranium or plutonium was calculated by multiplying the weight fraction loading value for the appropriate strike by the mass of MST present. Associated with each loading value is a measurement uncertainty error value. This is reported as one standard deviation. The calculations in this NCSE that utilize the loading values from WSRC-STI-2006-00012 include the two standard deviation error value in the calculation of uranium and plutonium present. The results from the MST loading study found in WSRC-STI-2006-00012 and the loading values used for this NCSE are consolidated in Table 7 below. For each strike, the weight fraction (wtf.), uncertainty (σ),

and weight fraction used are reported for both plutonium and uranium. The weight fraction used included two times the uncertainty.

Table 7: Weight Fraction Loading on MST

Strike #	Wtf. Pu	σ (Pu)	Wtf. Pu Used	Wtf. U	σ (U)	Wtf. U Used
1	1.94E-03	1.99E-05	1.98E-03	1.63E-02	2.29E-03	2.09E-02
2	4.02E-03	8.08E-05	4.18E-03	4.35E-02	3.49E-03	5.05E-02
3	6.07E-03	1.10E-04	6.29E-03	7.24E-02	1.05E-02	9.34E-02
4	8.14E-03	1.12E-04	8.36E-03	1.07E-01	1.05E-02	1.28E-01
5	1.02E-02	1.12E-04	1.04E-02	1.40E-01	1.05E-02	1.61E-01

Table 10 references a ^{240}Pu enrichment of 1E-7 (g ^{240}Pu/ g Pu). This enrichment is a minimum value of ^{240}Pu that is assumed to be present. The more ^{240}Pu that is present in the actual waste, then the calculations become increasingly conservative.

4.6 *Material Density*

As stated in Section 4.5, the theoretical density of dry MST is 2.765 g/cc. However, MST is highly amorphous and in water forms spherical (snowball-like) particles with a typical size range of 5 to 12 microns (WSRC-MS-2004-00828)[48]. Thus, the density of the MST solids in water cannot be determined from the theoretical density. This section discusses the empirical methodologies employed to determine the maximum density of the MST solids in water; and thus the minimum volume of a specific mass of MST in water.

The MST density is significant for three separate applications. The first application is for the potential accumulation inside a tank, CFF or other process vessel where the MST solids are allowed to remain unmixed for an extended period of time. Second, potential accumulation on a well mixed shell side of a CFF. And third, the potential accumulation inside a contactor. The density for each of these applications will be different and the following sections provide appropriate bounding density values for each application.

4.6.1 Centrifuge Tests

A series of laboratory tests were performed to determine the maximum concentration of MST as a function of the initial MST concentration. Samples of MST were produced in three basic initial concentration ranges representing low, medium, and high values. The low initial concentration was approximately 26 g/L, the medium concentration was approximately 93 g/L and the high concentration was approximately 154 g/L.

Based on the process design in Section 2.2.2, the initial concentration in the AST-A tank is 0.4 g/L. Stream 310 on design drawing M-M5-J-0002[36] indicates that 95 lb of MST will be added to each AST-A batch. The seven AST-A batches that will be concentrated and then collected in the SSRT would amount to 301.64 kg of MST. Stream 106 on design drawing M-M5-J-0004[35], indicates that each transfer from FFT-A to the SSRT will consist of 283 gal per AST-A batch. For the total volume of the seven concentrated AST-A batches, the design volume sent in one transfer to the SSRT is 1981 gal (7498.9 L). Thus, the MST design concentration in the SSRT will be 40.2 g/L, which is well within the experimental range for the MST density test.

The samples of known MST mass were placed in a centrifuge and rotated at 4,000 rpm for half an hour. When the centrifuge process was complete, the volume of the MST solids was obtained and a report was issued that provided the raw data (see P-RPT-J-00013, *SWPF Test Report: Density of Settled Monosodium Titanate*[50]. As noted in Section 2.1 of P-RPT-J-00013, the relative centrifugal force (RCF) of the centrifuge is double the RCF of the contactors of the SWPF process. The report also indicated that at the completion of the centrifuge run time at 4,000 rpm, the final density was determined to be dependent on the initial concentration of the MST slurry, not the particle size. Although the testing in P-RPT-J-00013 was conducted for a maximum of 30 minutes versus the continuous run time of the contactors in the SWPF process, sample results indicated the mixture density had plateaued before the selected combination of run time and centrifuge speed. Thus, the centrifuge testing bounds the conditions designed for the facility.

The raw data from the MST density test was analyzed in P-RPT-J-00017, *SWPF Analysis Of Monosodium Titanate Density Test Data*[51]. Table 8 presents a summary of the average and statistical uncertainty values reported in Table 8-1 of P-RPT-J-00017. Per Section 2.5 of P-RPT-J-00017, Rev. 0 and Section 3.4.7 of P-RPT-J-00013[50], Rev. 0, the measurement uncertainty is 15.6% of the average measured density value. The total error is the square root of the sum of the two uncertainty values squared (i.e., $\sigma = (\sigma_s^2 + \sigma_m^2)^{1/2}$). The total error was doubled in Table 8 to provide a 95% upper confidence value for the MST density.

Table 8: MST Density Test Results Summary

Initial MST Concentration (g/L)	Average Density (g/cc)	Statistical Uncertainty σ_s (g/cc)	Measurement Uncertainty σ_m (g/cc)	Total Error σ (g/cc)	Average +2σ (g/cc)
25.96	0.2	0.02	0.0312	0.0371	0.2741
93.03	0.25	0.02	0.0390	0.0438	0.3377
154.1	0.31	0.01	0.0484	0.0494	0.4088

4.6.2 Gravity Settling Measurements

It was necessary to determine if long-term gravity settling of MST was bounded by the short-term centrifuge testing. Eight 55-gallon drums of unused MST were located in storage. These drums were procured in 2005 and moved to their current storage location in October 2008 with minimal disturbance since. Empirical measurements were performed on February 9, 2011 as documented in 00-700-17666, *PTC Laboratory Analytical Report*[52]. The resulting average MST settled density was 0.233 g/cc with a total uncertainty of 0.0193 g/cc. Thus, the average plus 2σ value for the long-term gravity settling of MST was determined to be 0.2716 g/cc.

4.6.3 MST Density Summary

It was observed that the average plus 2σ density value for the long-term gravity settling of MST was slightly less than the lowest value from the centrifuge MST density testing. Therefore, the lowest value from the centrifuge MST density testing from Table 8 (0.2741 g/cc) was used for the MST throughout the calculations and analysis in Sections 5 & 6 for potential accumulation inside a tank, CFF or other process vessel allowed to remain unmixed for an extended period of time. The three values from the centrifuge tests are evaluated for MST accumulations in the contactors (see Section 6.7).

4.7 *Overview of MCNP Calculations*

MCNP calculations in Section 6 follow a progression that generally follows the process which begins with the large tanks, moves to the cross-flow filters, then the contactors.

There were two geometries/conditions analyzed for the large tank. The first condition bounded the gravity settling of solids (including MST) across the bottom of the tanks. The second condition considered a bounding hypothetical torus lump on the bottom of the tank that builds up the wall. Analysis of both conditions considered variables such as uranium enrichment and mass of MST present; the selected MST mass determined the amount of water in the mixture based on available volume and greatly influenced the centerline depth of solution in the tank. The volume of the torus was fixed based on selected radii for the torus and the intersecting cylinder. The MST solids were the portion of the torus inside the tank but outside the intersecting cylinder. The center of the intersecting cylinder was located at the tank wall in the –x direction.

These configurations are considered to be normal configurations (which is extremely conservative for the hypothetical configuration). Additionally, it is considered to be normal for the single parameter upset conditions for 277 g ^{235}U and 223 g ^{239}Pu to be added to each collection of seven batches to account for the routine cleaning of the CFFs. This fissile mass was selected to bound (with a 53% margin) four CFFs at the fissile mass estimated in Table 28. Section 5.1 evaluates each configuration parameter over its credible range showing that the system remains subcritical and only limited by the input assumptions (see Section 7.1). Supporting MCNP calculations are documented in Sections 6.2 and 6.4.

Several normal and upset configurations were analyzed for the CFFs:

1. As fouling of the filter tubes with MST solids is considered a normal configuration, conservative hypothetical configurations were used to constrain the quantity of material that could collect inside the CFF tubes of one filter. From this condition, the filter can be cleaned or removed from service. If the filter is cleaned Section 6.6 estimates the fissile contribution to a process tank. If the filter is removed from service, the material could dry out and additional configurations must be considered. Section 5.2 evaluates these configurations over the credible range showing that they remain subcritical bounded by the input assumptions and design features (see Sections 7.1 and 7.2). Supporting MCNP calculations are documented in Section 6.5.2.
2. Another configuration considered was the accumulation of MST material on the shell side of the CFF. A hole or tear in a tube would allow material to pass to the shell side. As these tubes were designed as Safety Significant (SS) for preventing solids break-through, they are very robust and this would be an upset configuration. From this condition, the filter can be cleaned or removed from service. If the filter is cleaned, Section 6.6 estimates the fissile contribution to a process tank. If the filter is removed from service, the material could dry out and additional configurations must be considered. Section 5.3 evaluates these configurations over the credible range showing that they remain subcritical bounded by the input assumptions and design features (see Sections 7.1 and 7.2). Supporting MCNP calculations are documented in Section 6.5.3.
3. The expected CFF cleaning frequency is one filter every 28 batches (Section 2.2.6). As tube fouling is considered a normal configuration, the single parameter upset conditions added 277 g ^{235}U and 223 g ^{239}Pu to each collection of seven AST-A batches to account for the routine cleaning of the CFFs. While no control prevents the simultaneous cleaning of multiple filters, the capacity of the cleaning solution collection tank restricts the number of simultaneously cleaned CFFs to four. Supporting calculations using physical process conditions to bound the credible ^{235}U mass and supporting MCNP calculations are documented in Section 6.6.

For filters removed from service there were two conditions analyzed. The first condition was where the tube side of the filter was plugged with solids. The second represented the condition where solids were present on the shell side. In both conditions, the volume fraction of water was varied in the defined volume over the full spectrum. Two cross-flow filters were modeled next to each other in a concrete corner with tight concrete reflection on the top and bottom. The full volume fraction (VF) range of water conditions were analyzed to demonstrate that optimum moderation conditions remained subcritical.

The contactors were modeled similar to the cross-flow filters. Two contactors were modeled next to each other in a concrete corner with tight concrete reflection on the top and bottom. The thickness of the MST solids layer built up inside the contactor was varied over a range of values. Additionally, higher MST densities were evaluated. See Sections 5.4 and 6.7.

Material collected following CFF cleaning will be transferred to a horizontal cylindrical tank. A horizontal cylindrical tank was modeled with tight concrete reflection. UO_2 and water were mixed for the solution in the tank to bound the effect of possible chemistry adjustments. For each selected mass of MST solids, a wide range of moderation conditions were considered to demonstrate that optimum moderation remained subcritical. See Section 6.3.2.

4.8 *Operational Variance and Flexibility*

Operational variance is defined as the unintentional changes to process conditions that are usually outside of actions prescribed or responses expected in a procedure. Operational flexibility is defined as the intentional changes in procedure(s) or facility conditions. Operational flexibility is necessary to operate a facility.

Sufficient margin should be incorporated into all aspects of the analysis to accommodate some amount of operational variance. It is especially important to incorporate margin for operational variance when defining “normal” conditions. Operational flexibility needs to be built into the analysis as a whole and is not usually an issue for individual definitions of “normal”.

5 Discussion of Contingencies

Per the scope of this analysis (see Section 1.1), the contingency analysis in this section is focused on the concentration of fissile material due to MST (including gravity settling) in the SWPF process. The SWPF process is addressed by the different types of basic tanks/equipment that are in the ASP, CSSX, and AFP. The ASP is addressed in more detail because all the material of concern will be present and deliberately concentrated in this section of the process. Single parameter upset conditions for ASP are hypothesized and addressed first. Next, CFFs, horizontal cylindrical tanks, and contactors are addressed in individual sections because these pieces of equipment are unique.

5.1 *Single Parameter Upsets for the Alpha Strike Process*

The purpose of this section is to document the contingency analysis for the concentration of fissile material due to loading on MST in a process tank. The primary focus of the analysis is summarized in Table 9. The stated upset (U1 – U6) to each of the Nominal parameters is taken as the credible abnormal condition considered for the contingency analysis, as indicated by the bold and underlined value in each row of Table 9 below. The Nominal AST-A batch volume was conservatively taken at the tank overflow as opposed to the realistic volumes discussed in Sections 2.2.1, 2.2.2, and 2.5. The plutonium enrichment does not have an upset value listed because the ^{240}Pu enrichment selected is essentially zero and any increase would decrease the calculated k_{eff}+2σ values thus creating the need to verify a minimum ^{240}Pu enrichment in the feed to SWPF.

Table 9: Single Parameter Upset Condition Summary for ASP Process Tanks

1	Input Parameters	Units	Nominal	→	U1	U2	U3	U4	U5	U6
2	AST-A Batch Volume	gal	38000.0		38000.0	38000.0	38000.0	38000.0	38000.0	38000.0
3	Target MST Concentration	g/L	0.4		**0.025**	**0.800**	0.400	0.400	0.400	0.400
4	Uranium Feed Concentration	mgU/L	25		25	25	**50**	25	25	25
5	Uranium (^{235}U) Enrichment	g^{235}U/gU	0.08		0.08	0.08	0.08	**0.16**	0.08	0.08
6	Plutonium Feed Concentration	mgPu/L	2.5		2.5	2.5	2.5	2.5	**5**	2.5
7	Plutonium (^{240}Pu) Enrichment	g^{240}Pu/gPu	1.0E-07		1.0E-07	1.0E-07	1.0E-07	1.0E-07	1.0E-07	1.0E-07
8	# AST-A Batches in one tank (SSRT)	#	7		7	7	7	7	7	**14**
9	# MST Strike for loading in settled region	#	5		5	5	5	5	5	5
10	^{235}U mass from acid cleaning CFF	g ^{235}U	277.0		277.0	277.0	277.0	277.0	277.0	554.0
11	^{239}Pu mass from acid cleaning CFF	g ^{239}Pu	223.0		223.0	223.0	223.0	223.0	223.0	446.0

Appendix A contains a full listing of the Table 10 cell formulas for the Nominal case calculations. The calculations for all the upset conditions are duplicates of the Nominal case calculations, based on the upset condition input parameter values. These upset conditions are hypothesized for the ASP tanks and they are considered to bound any credible upset condition in the tanks for other parts of the SWPF process (e.g., CSSX, AFF). Additional discussion is provided in appropriate following sections of this contingency analysis.

Each parameter upset condition is evaluated by first calculating the atom density of the material resulting from the proposed upset condition. In Table 10 additional detail (beyond that in Table 9) is provided, as well as the final atom densities calculated for each hypothesized upset condition. Second, Section 6.2 uses MCNP to calculate the k_{eff}+2σ value for the system in a uniform settling configuration and justifies each upset condition to be subcritical.

In Table 10, a comparison is made between the masses of ^{235}U (row 34) and ^{239}Pu (row 36) that could be loaded on the MST (based on the loading values in Table 7) and the masses of ^{235}U (row 20) and ^{239}Pu (row 22) present in the tank based on the selected input parameters. The rows labeled "Mass ^{235}U per SSRT tank" (row 20) and "Mass ^{239}Pu per SSRT tank" (row 22) contain the mass of the referenced isotope in the SSRT based on the input parameters. This is the mass available assuming no losses through the CFF. The rows labeled "Possible Mass ^{235}U on MST (in settled region) per tank" (row 34) and "Possible Mass ^{239}Pu

on MST (in settled region) per tank" (row 36) contain the mass of the referenced isotope resulting from the loading values in Table 7. In the rows labeled "Mass ^{235}U in settled region" (row 37) and "Mass ^{239}Pu in settled region" (row 38), the logical test in Excel selected the minimum ^{235}U and ^{239}Pu masses between the two mass values compared, then added the mass from acid cleaning CFF for each isotope (row 10 or 11 as appropriate). The selection of this minimum value was justified by acknowledging the reality that the MST is not able to load more U/Pu than could be present in the tank due to the design of the SWPF process.

Table 10: Single Parameter Upset Conditions for ASP Process Tanks with Additional Detail

1	Input Parameters	Units	Nominal	→	U1	U2	U3	U4	U5	U6
2	AST-A Batch Volume	gal	38000 0		38000 0	38000 0	38000 0	38000 0	38000 0	38000 0
3	Target MST Concentration	g/L	0 4		**0.025**	**0.800**	0 400	0 400	0 400	0 400
4	Uranium Feed Concentration	mgU/L	25		25	25	**50**	25	25	25
5	Uranium (^{235}U) Enrichment	g^{235}U/gU	0 08		0 08	0 08	0 08	**0.16**	0 08	0 08
6	Plutonium Feed Concentration	mgPu/L	2 5		2 5	2 5	2 5	2 5	**5**	2 5
7	Plutonium (^{240}Pu) Enrichment	g^{240}Pu/gPu	1 0E-07		1 0E-07	1 0E-07	1 0E-07	1 0E-07	1 0E-07	1 0E-07
8	# AST-A Batches in one tank (SSRT)	#	7		7	7	7	7	7	**14**
9	# MST Strike for loading in settled region	#	5		5	5	5	5	5	5
10	^{235}U mass from acid cleaning CFF	g ^{235}U	277 0		277 0	277 0	277 0	277 0	277 0	554 0
11	^{239}Pu mass from acid cleaning CFF	g ^{239}Pu	223 0		223 0	223 0	223 0	223 0	223 0	446 0
12	**Calculated Parameters**									
13	AST-A Batch Volume	L	143845 6		143845 6	143845 6	143845 6	143845 6	143845 6	143845 6
14	Mass U per batch	gU	3596 1		3596 1	3596 1	7192 3	3596 1	3596 1	3596 1
15	Mass ^{235}U per batch	g^{235}U	287 7		287 7	287 7	575 4	575 4	287 7	287 7
16	Mass Pu per batch	gPu	359 6		359 6	359 6	359 6	359 6	719 2	359 6
17	Mass ^{239}Pu per batch	g^{239}Pu	359 6		359 6	359 6	359 6	359 6	719 2	359 6
18	Mass MST per batch	g	57538 3		3596 1	115076 5	57538 3	57538 3	57538 3	57538 3
19	Mass U per SSRT tank	gU	25173 0		25173 0	25173 0	50346 0	25173 0	25173 0	50346 0
20	Mass ^{235}U per SSRT tank	g^{235}U	2013 8		2013 8	2013 8	4027 7	4027 7	2013 8	4027 7
21	Mass Pu per SSRT tank	gPu	2517 3		2517 3	2517 3	2517 3	2517 3	5034 6	5034 6
22	Mass ^{239}Pu per SSRT tank	g^{239}Pu	2517 3		2517 3	2517 3	2517 3	2517 3	5034 6	5034 6
23	Mass MST per SSRT tank	gMST	402767 8		25173 0	805535 6	402767 8	402767 8	402767 8	805535 6
24	Mass of U+Pu+MST per SSRT tank	g	430458 1		52863 3	833225 9	455631 1	430458 1	432975 4	860916 2
25	Mass UO_2 from CFF	g	3928 4		3928 4	3928 4	3928 4	1964 4	3928 4	7856 8
26	Mass PuO_2 from CFF	g	252 9		252 9	252 9	252 9	252 9	252 9	505 7
27	Volume UO_2 from CFF	cc	355 9		355 9	355 9	355 9	178 1	355 9	711 8
28	Volume PuO_2 from CFF	cc	22 1		22 1	22 1	22 1	22 1	22 1	44 1
29	MST concentration in settled region	gMST/cc	0 2741		0 2741	0 2741	0 2741	0 2741	0 2741	0 2741
30	Volume of settled region	L	1469 80		92 2166	2939 22	1469 80	1469 62	1469 80	2939 59
31	SRNL: U Loading on MST	gU/gMST	0 161		0 161	0 161	0 161	0 161	0 161	0 161
32	SRNL: Pu Loading on MST	gPu/gMST	0 0104		0 0104	0 0104	0 0104	0 0104	0 0104	0 0104
33	Possible Mass U on MST (in settled region) per tank	gU	64845 6		4052 9	129691 2	64845 6	64845 6	64845 6	129691 2
34	Possible Mass ^{235}U on MST (in settled region) per tank	g^{235}U	5187 6		324 2	10375 3	5187 6	10375 3	5187 6	10375 3
35	Possible Mass Pu on MST (in settled region) per tank	gPu	4198 5		262 4	8396 9	4198 5	4198 5	4198 5	8396 9
36	Possible Mass ^{239}Pu on MST (in settled region) per tank	g^{239}Pu	4198 5		262 4	8396 9	4198 5	4198 5	4198 5	8396 9
37	Mass ^{235}U in settled region	g^{235}U	2290 8		601 228	2290 8	4304 7	4304 7	2290 8	4581 7
38	Mass ^{239}Pu in settled region	g^{239}Pu	2740 3		485 403	2740 3	2740 3	2740 3	4421 5	5480 6
39	^{235}U delta	g^{235}U	277 0		-1412 6	277 0	277 0	277 0	277 0	554 0
40	^{239}Pu delta	g^{239}Pu	223 0		-2031 9	223 0	223 0	223 0	-613 1	446 0
41	^{235}U Concentration in settled region	g^{235}U/L	1 6		6 5	0 8	2 9	2 9	1 6	1 6
42	^{239}Pu Concentration in settled region	g^{239}Pu/L	1 9		5 3	0 9	1 9	1 9	3 0	1 9
43	Mass U in settled region	gU	28635 5		7515 4	28635 5	53808 5	26904 2	28635 5	57271 0
44	Mass UO_2 in settled region	gUO_2	32488 6		8526 6	32488 6	61048 8	30528 1	32488 6	64977 2

1	Input Parameters	Units	Nominal	→	U1	U2	U3	U4	U5	U6
45	Volume UO_2 in settled region	cc	2943 2		772 4	2943 2	5530 4	2768 4	2943 2	5886 3
46	Mass Pu in settled region	gPu	2740 3		485 4	2740 3	2740 3	2740 3	4421 5	5480 6
47	Mass PuO_2 in settled region	$gPuO_2$	3107 1		550 4	3107 1	3107 1	3107 1	5013 3	6214 2
48	Volume PuO_2 in settled region	cc	271 126		48 026	271 126	271 126	271 126	437 460	542 253
49	Volume of MST in settled region	cc	145666 5		9104 2	291333 0	145666 5	145666 5	145666 5	291333 0
50	Volume of Water in settled region	cc	1320916 4		82292 0	2644669 2	1318329 1	1320913 5	1320750 1	2641832 8
51	Mass of Water in settled region	g	1318538 8		82143 9	2639908 8	1315956 1	1318535 8	1318372 7	2637077 5
52	Mass of settled region	g	1756902 3		116393 9	3481040 1	1782879 9	1754938 8	1758642 5	3513804 6
53	Density of settled region	g/cc	1 1953		1 2622	1 1843	1 2130	1 1941	1 1965	1 1953
54	wt% UO_2 in settled region	%	1 85%		7 33%	0 93%	3 42%	1 74%	1 85%	1 85%
55	wt% PuO_2 in settled region	%	0 18%		0 47%	0 09%	0 17%	0 18%	0 29%	0 18%
56	wt% U in settled region	%	1 63%		6 46%	0 82%	3 02%	1 53%	1 63%	1 63%
57	wt% Pu in settled region	%	0 16%		0 42%	0 08%	0 15%	0 16%	0 25%	0 16%
58	wt% MST in settled region	%	22 92%		21 63%	23 14%	22 59%	22 95%	22 90%	22 92%
59	wt% water in settled region	%	75 05%		70 57%	75 84%	73 81%	75 13%	74 97%	75 05%
60	density of U	g/cc	19 05		19 05	19 05	19 05	19 05	19 05	19 05
61	density of UO_2	g/cc	11 04		11 04	11 04	11 04	11 03	11 04	11 04
62	density of Pu	g/cc	19 84		19 84	19 84	19 84	19 84	19 84	19 84
63	density of PuO_2	g/cc	11 46		11 46	11 46	11 46	11 46	11 46	11 46
64	density of MST	g/cc	2 765		2 765	2 765	2 765	2 765	2 765	2 765
65	density of H_2O	g/cc	0 9982		0 9982	0 9982	0 9982	0 9982	0 9982	0 9982
66	mole wt H	g/mole	1 00794		1 00794	1 00794	1 00794	1 00794	1 00794	1 00794
67	mole wt O	g/mole	15 9994		15 9994	15 9994	15 9994	15 9994	15 9994	15 9994
68	mole wt Na	g/mole	22 98977		22 98977	22 98977	22 98977	22 98977	22 98977	22 98977
69	mole wt Ti	g/mole	47 867		47 867	47 867	47 867	47 867	47 867	47 867
70	mole wt ^{235}U	g/mole	235 044		235 044	235 044	235 044	235 044	235 044	235 044
71	mole wt ^{238}U	g/mole	238 051		238 051	238 051	238 051	238 051	238 051	238 051
72	mole wt U	g/mole	237 807		237 807	237 807	237 807	237 565	237 807	237 807
73	mole wt ^{239}Pu	g/mole	239 052		239 052	239 052	239 052	239 052	239 052	239 052
74	mole wt ^{240}Pu	g/mole	240 054		240 054	240 054	240 054	240 054	240 054	240 054
75	mole wt Pu	g/mole	239 052		239 052	239 052	239 052	239 052	239 052	239 052
76	mole wt $NaTi_2O_5H$ (MST)	g/mole	199 73		199 73	199 73	199 73	199 73	199 73	199 73
77	mole wt UO_2	g/mole	269 81		269 81	269 81	269 81	269 56	269 81	269 81
78	mole wt PuO_2	g/mole	271 05		271 05	271 05	271 05	271 05	271 05	271 05
79	mole wt H_2O	g/mole	18 02		18 02	18 02	18 02	18 02	18 02	18 02
80	wt% U in UO_2	%	88 14%		88 14%	88 14%	88 14%	88 13%	88 14%	88 14%
81	wt% O in UO_2	%	11 86%		11 86%	11 86%	11 86%	11 87%	11 86%	11 86%
82	wt% Pu in PuO_2	%	88 19%		88 19%	88 19%	88 19%	88 19%	88 19%	88 19%
83	wt% O in PuO_2	%	11 81%		11 81%	11 81%	11 81%	11 81%	11 81%	11 81%
84	wt% H in H_2O	%	11 19%		11 19%	11 19%	11 19%	11 19%	11 19%	11 19%
85	wt% O in H_2O	%	88 81%		88 81%	88 81%	88 81%	88 81%	88 81%	88 81%
86	wt% H in $NaTi_2O_5H$ (MST)	%	0 50%		0 50%	0 50%	0 50%	0 50%	0 50%	0 50%
87	wt% O in $NaTi_2O_5H$ (MST)	%	40 05%		40 05%	40 05%	40 05%	40 05%	40 05%	40 05%
88	wt% Ti in $NaTi_2O_5H$ (MST)	%	47 93%		47 93%	47 93%	47 93%	47 93%	47 93%	47 93%
89	wt% Na in $NaTi_2O_5H$ (MST)	%	11 51%		11 51%	11 51%	11 51%	11 51%	11 51%	11 51%
90	b Na	#/b-cm	0 60220		0 60220	0 60220	0 60220	0 60220	0 60220	0 60220
91	atom density H from water	#/b-cm	5 9975E-02		5 9552E-02	6 0047E-02	5 9857E-02	5 9982E-02	5 9967E-02	5 9975E-02
92	atom density H from MST	#/b-cm	8 2623E-04		8 2306E-04	8 2634E-04	8 2623E-04	8 2633E-04	8 2623E-04	8 2623E-04
93	Total H		6 0801E-02		6 0375E-02	6 0873E-02	6 0684E-02	6 0808E-02	6 0793E-02	6 0801E-02
94	atom density ^{235}U	#/b-cm	3 9933E-06		1 6704E-05	1 9969E-06	7 5037E-06	7 5047E-06	3 9933E-06	3 9933E-06
95	atom density ^{238}U	#/b-cm	4 5343E-05		1 8967E-04	2 2674E-05	8 5203E-05	3 8902E-05	4 5343E-05	4 5343E-05
96	atom density ^{239}Pu	#/b-cm	4 6967E-06		1 3260E-05	2 3486E-06	4 6967E-06	4 6973E-06	7 5781E-06	4 6967E-06
97	atom density ^{240}Pu	#/b-cm	4 6771E-13		1 3205E-12	2 3388E-13	4 6771E-13	4 6777E-13	7 5465E-13	4 6771E-13

1	Input Parameters	Units	Nominal	→	U1	U2	U3	U4	U5	U6
98	atom density Ti	#/b-cm	1 6525E-03		1 6461E-03	1 6527E-03	1 6525E-03	1 6527E-03	1 6525E-03	1 6525E-03
99	Ti: atom density ^{54}Fe	#/b-cm	9 7505E-05		9 7130E-05	9 7518E-05	9 7505E-05	9 7517E-05	9 7505E-05	9 7505E-05
100	Ti: atom density ^{56}Fe	#/b-cm	1 5156E-03		1 5098E-03	1 5158E-03	1 5156E-03	1 5158E-03	1 5156E-03	1 5156E-03
101	Ti: atom density ^{57}Fe	#/b-cm	3 4713E-05		3 4580E-05	3 4718E-05	3 4713E-05	3 4717E-05	3 4713E-05	3 4713E-05
102	Ti: atom density ^{58}Fe	#/b-cm	4 6368E-06		4 6190E-06	4 6374E-06	4 6368E-06	4 6374E-06	4 6368E-06	4 6368E-06
103	atom density Na (modeled as Al)	#/b-cm	8 2623E-04		8 2306E-04	8 2634E-04	8 2623E-04	8 2633E-04	8 2623E-04	8 2623E-04
104	atom density O from MST	#/b-cm	4 1311E-03		4 1153E-03	4 1317E-03	4 1311E-03	4 1316E-03	4 1311E-03	4 1311E-03
105	atom density O from UO_2	#/b-cm	9 8672E-05		4 1275E-04	4 9343E-05	1 8541E-04	9 2813E-05	9 8672E-05	9 8672E-05
106	atom density O from PuO_2	#/b-cm	9 3934E-06		2 6520E-05	4 6973E-06	9 3934E-06	9 3945E-06	1 5156E-05	9 3934E-06
107	atom density O from water	#/b-cm	2 9987E-02		2 9776E-02	3 0023E-02	2 9929E-02	2 9991E-02	2 9984E-02	2 9987E-02
108	Total O		3 4227E-02		3 4331E-02	3 4209E-02	3 4255E-02	3 4225E-02	3 4229E-02	3 4227E-02
109	**Total**	#/b-cm	9 75603E-02		9 73950E-02	9 75884E-02	9 75142E-02	9 75631E-02	9 75576E-02	9 75603E-02

Rows 10 and 11 of Table 10 indicate the respective ^{235}U and ^{239}Pu mass assumed to be present due to cleaning the CFF. The expected CFF cleaning frequency is one filter every 28 batches (Section 2.2.6). As tube fouling is considered a normal configuration, the CFF cleaning fissile mass is added to each collection of seven batches to account for the routine cleaning of the CFFs. This fouling of a single filter is discussed in Sections 5.2 and 5.3. While not considered normal, or evaluated in conjunction with the single parameter upsets, cleaning of multiple CFFs is discussed in Sections 5.5.1 and 5.5.2.

The following scenarios consider the potential for a criticality accident in the ASP tanks, but are also applicable to tanks in the other parts of the SWPF process. Because all the Alpha Finishing tanks are downstream of the CFF in the ASP and the Cesium Removal contactors (see Figure 1), there is no known process by which the material in the AFP would have a fissile (or MST) content that exceeds that analyzed in the ASP process (see Section 2.5). Thus, the material compositions analyzed for the ASP tanks bound those present in the Alpha Finishing tanks. In terms of tank sizes or geometries, the discussion in Section 6.2 concludes that regardless the volume, the material compositions derived from the single parameter upset conditions analyzed will remain subcritical.

5.1.1 Low MST Concentration

This scenario hypothesizes a criticality in an ASP process tank (e.g., AST-A, FFT-A, SSRT), due to adding too little MST in AST-A (see U1 in Table 10). The normal process flow calls for the addition of MST to achieve a 0.4 g/L concentration in AST-A (see Section 2.2.2). So this scenario assumes a lower amount of MST present thus allowing for a potential higher fissile loading on the MST. The MST may not be fully loaded to the weight fraction values in Table 7 when the fissile concentration is low. This scenario assumes an MST concentration (0.025 g/L) that is less than half of the Nominal value in each of seven consecutive AST-A batches and this is collected in SSRT. The same resulting MST mass and concentration may be achieved in any large process tank by various means.

Section 6.2.1 demonstrates that uniform settling of MST solids where the MST concentration in each AST-A tank was 0.025 g/L is subcritical. The analysis of Section 6.2.1 also concludes that regardless of the MST concentration in AST-A, the uniform settling of MST solids remain subcritical.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.1.2 High MST Concentration

This scenario hypothesizes a criticality in an ASP process tank (e.g., AST-A, FFT-A, SSRT) due to the addition of too much MST in AST-A (see U2 in Table 10). The normal process flow calls for the addition of MST to achieve a 0.4 g/L concentration in AST-A (see Section 2.2.2). The Nominal process flow sheet value was doubled to 0.8 g/L for upset condition U2 for each of the seven batches collected in the SSRT. The same resulting MST mass and concentration may be achieved in any large process tank by various means.

Section 6.2.1 demonstrates that uniform settling of MST solids where the MST concentration in each AST-A tank was 0.8 g/L is subcritical. The analysis of Section 6.2.1 also concludes that regardless of the MST concentration in AST-A, the uniform settling of MST solids remain subcritical.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.1.3 High Uranium Concentration in Feed to SWPF

This scenario hypothesizes a criticality in an ASP process tank (e.g., AST-A, FFT-A, SSRT) due to the feed to SWPF containing a uranium concentration that exceeds the normal upper bound (see U3 in Table 10). Per LWO-LWE-2006-00142, *Maximum Tank Farm Supernate Uranium Solubility*[53], the fissile concentration in the receipt solution is expected to be less than 25 mg/L. The 25 mg U/L value is the historical bounding value. Since WSRC-STI-2006-00012[49] is based on a maximum of 25 mg U/L and provides the fissile loading on MST values, any feed above 25 mg U/L is outside the bounds of analysis. Thus, 25 mg U/L is a Restricted Bounding Assumption in Section 7.1.1. Per upset condition U3 in Table 10, this scenario assumes that each of the seven normal AST-A batches contained a uranium concentration of 50 mg/L. This scenario requires that seven consecutive AST-A batches contain a uranium concentration (including solids) that is double the normally allowed (SWPF WAC limit) concentration to account for over-batching, per the expectations of ANSI/ANS-8.1-1998[42].

Section 6.2.2 analyzed the upset condition of excessive uranium concentration in the feed to SWPF. The Section 6.2.2 analysis demonstrated that the uniform settling of MST solids remains subcritical over the uranium concentration range of 10 – 90 mg/L.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.1.4 High Uranium Enrichment in Feed to SWPF

This scenario hypothesizes a criticality in an ASP process tank (e.g., AST-A, FFT-A, SSRT) due to feed to SWPF that exceeds the WAC limit of 8% ^{235}U enrichment (see U4 in Table 10). The SWPF process does not effect the uranium enrichment. So the enrichment in the feed into SWPF is the enrichment in the transfer out of SWPF. For the purposes of this scenario it is assumed that seven consecutive AST-A batches containing uranium at 16% ^{235}U enrichment are received and processed through the ASP and collected in the SSRT.

Section 6.2.3 analyzed the effect of uranium enrichment in the SWPF feed on the uniform settling of MST solids. Section 6.2.3 demonstrated that the system remained subcritical over the ^{235}U enrichment range from 8% to 30%. Thus, the hypothesized upset condition of 16% ^{235}U enrichment feed to SWPF for seven consecutive batches was subcritical.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.1.5 High Plutonium Concentration in Feed to SWPF

This scenario hypothesizes a criticality in an ASP process tank (e.g., AST-A, FFT-A, SSRT) due to the feed to SWPF containing a plutonium (and trace actinide) concentration that exceeds the normal upper bound (see U5 in Table 10). The Nominal Pu feed concentration of 2.5 mg Pu/L was specified in Table 10 to bound the total plutonium and trace actinides sent to SWPF. Per upset condition U5 in Table 10, this scenario assumes that each of the seven normal AST-A batches contained a plutonium concentration of 5 mg/L.

Section 6.2.4 analyzed the upset condition of high plutonium concentration in the feed to SWPF. Section 6.2.4 demonstrated that a plutonium feed concentration range of 1 – 10 mg/L remained subcritical for uniform settling of MST solids.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.1.6 Excessive Number of AST-A Batches

This scenario hypothesizes a criticality in an ASP process tank (e.g., AST-A, FFT-A, SSRT) due to the addition/concentration of too many batches from AST-A in FFT-A (see U6 in Table 10). The normal process flow calls for the concentration of seven AST-A batches in the FFT-A (Section 2.2.4). Seven is the Nominal value for the parameter. To account for double-batching, this scenario accounts for fourteen AST-A batches concentrated in FFT-A. This scenario acknowledges there is sufficient tank space to contain the volume of 14 normal-volume batches. The upset condition for scenario U6 differs from the upset condition U2, in that 14 AST-A batches are considered present (see rows 8, 10 and 11 in Table 10). This results in double the fissile mass compared to U2 (see rows 37 and 38 in Table 10).

Section 6.2.5 analyzed the upset condition of collecting/concentrating too many AST-A batches in the SSRT. Section 6.2.5 demonstrated that a range from 7 to 28 AST-A batches remained subcritical during uniform settling in the SSRT.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.2 *Accumulation Inside Cross-Flow Filter Tubes*

This scenario hypothesizes a criticality in one of the four ASP CFFs due to solids accumulation within the sintered metal tubes of the filters. The cross flow filter tubes are oriented vertically and operate at a high downward axial velocity to preclude any solid material accumulations within the ID of the tubes (Section 2.2.4). Testing at nearly three times the nominal solids loading (i.e.; 20 wt%) did not introduce any solid material accumulations within the ID of the filter tubes[54]. Thus, solid material accumulation on the ID of the filter tubes is not expected. For conservatism, a bounding condition (full tube pluggage) that is not considered credible to achieve was analyzed. For the evaluation in this section only, the volume of the tubes was used by the calculations in Section 6.5.2 to bound the quantity of material that could collect inside the CFF tubes.

A fouled filter with hypothetically assumed full tube pluggage will not necessarily remain full of liquid. The filter could be removed from service and drained prior to acid cleaning being performed. Acid cleaning is evaluated in Section 5.5.

The H/X in the filter tubes may be very low if the filter is shut down, drained, and allowed to dry out over some period of time. At some point in the drying out process the material remaining in the CFF is expected to be optimally moderated. Section 6.5.2 evaluated the tank material in the filter tubes and demonstrated that, regardless of the MST density (concentration) or tube surface-to-surface (STS) spacing, the system remained subcritical, even if the uranium enrichment was 16%.

Because the material in the AFP would have already come through the ASP, it is expected that a significant quantity of the fissile material would have been removed. At a minimum, there is no known process by which the material in the AFP would have a fissile content that exceeds that analyzed in the ASP process. Thus, the material in the ASP process bounds that present in the AFP.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

The physical features of the CFF that were important to the analysis in Section 6.5.2 are the Design Features detailed Section 7.2.

Additional Considerations

The following considerations were not credited in the conclusions above, but are provided for additional confidence.

Based on P-RPT-J-00007, *SWPF Test Report: Cross-Flow Filter System Full-Scale Test*[54], testing data with sludge and solids simulant indicate that the filter still functioned when the feed contained 20 wt.% solids. If the filter does not plug, there is no motive force to increase MST density in the tubes beyond that analyzed for the process tanks in Section 6.3 for material settling to and concentrating in the bottom of a tank. Thus, the Section 6.5.2 analysis is very conservative compared to the unlikely event that the CFF would accumulate the bounding amount of solids.

Pumps P-102-2A/B/C that feed the CFFs are designed to maintain a high flow velocity (9-13 feet per second [ft/sec]) through the CFF tubes (M-M5-J-0001)[7]. One purpose of the high flow rate through the CFF is to prevent accumulation of solids material in the pores of the sintered metal tubes. The DCS monitors the flow rate across each CFF and automatically adjusts pump speed in attempt to correct any situation where the flow rate is outside the desired range. The DCS provides notification to Operations personnel in the event the flow rate through the CFF tubes remains outside of the acceptable range and may terminate flow if necessary.

In order for a sintered metal tube to plug, a large lump of solids must enter the CFF and deposit in a single tube. To achieve the configuration analyzed in Section 6.5.2, all the filter tubes must fill with solids that only contain MST and fissile material, then are allowed to dry out.

It is likely that the build-up of fissile material on the filter tube walls will noticeably decrease filter flow rates and/or processing efficiency. It is highly unlikely (possibly non-physical) for the only material to build up on the filter tube walls to be MST loaded with uranium and plutonium, while allowing all the liquid and other solids to pass through. Further, a sufficient build-up of fissile material must occur and this is not likely to occur quickly without reducing the filter flow rates or processing efficiency. Once the filter flow rates and/or the processing efficiency decline to an unacceptable level for Operations or Engineering, it is likely that the condition will receive abundant attention. Thus, it is unlikely that fewer than four human/programmatic or equipment failures would be required to collect the material and allow it to dry out such that the MST solids concentration would exceed the nominal value.

5.3 *Accumulation Inside Cross-Flow Filter Shell*

This scenario hypothesizes a criticality in one of four ASP CFFs. As the material in FFT-A (or SSRT) is cycled through the CFFs to achieve the desired (normal) volume reduction, some amount of fissile material may build up inside the filters, but outside the walls of the sintered metal filter tubes. The most likely source for the build-up of a deposit on the shell side of the CFF is the failure of one or more of the sintered metal tubes.

As these tubes were designed as Safety Significant (SS) for preventing solids break-through they are very robust and their failure is an upset configuration. Therefore, the MST material accumulation is based upon conservative calculations from the actual process parameters. From this condition, the filter can be cleaned or removed from service. Acid cleaning is evaluated in Section 5.5. If the filter is removed from service, the material could dry out. Thus, the H/X in the filter shell may be very low if the filter is shut down, drained, and allowed to dry out over some period of time. At some point in the drying out process the material remaining in the CFF is expected to be optimally moderated.

The Section 6.6.2 analysis evaluated two different mechanisms for accumulating MST solids on the shell side of a CFF. The first mechanism evaluated in Section 6.6.2 for material on the shell side of a CFF was for a slow accumulation. It was hypothesized that MST solids loaded with fissile material may escape the filter tubes through a small break in one or more tubes and accumulate on the shell side over a long time period. Table 29 of Section 6.6.2 demonstrated that it was only credible to accumulate approximately 83.8 g ^{235}U and 67.8 g ^{239}Pu below the 2 inch drain line. Section 6.5.3 evaluated 3,190 g ^{235}U and 2,581 g ^{239}Pu on the shell side of the CFF and demonstrated that the system remained subcritical for all moderation conditions, provided the uranium enrichment was a maximum of 8%.

Therefore, the hypothesized upset condition of a slow accumulation is not credible due to the inability of the system to achieve a critical configuration.

The second mechanism evaluated in Section 6.6.2 for material on the shell side of a CFF was for a rapid accumulation on the shell side that was conservatively assumed to occur after all the filter tubes are full of 7 wt.% MST solids material. At that point a guillotine break could occur and fill the shell side. Based on the calculations in Table 30 of Section 6.6.2 it is known that approximately 542 g ^{235}U and 438.6 g ^{239}Pu is the fissile mass of concern for this situation. Section 6.5.3 evaluated 3,190 g ^{235}U and 2,581 g ^{239}Pu on the shell side of the CFF and demonstrated that the system remained subcritical for all moderation conditions, provided the uranium enrichment was a maximum of 8%.

Therefore, the hypothesized upset condition of a rapid accumulation is not credible due to the inability of the system to achieve a critical configuration.

The physical features of the CFF that were important to the analysis in Section 6.5.3 are the Design Features detailed Section 7.2.

Additional Considerations

The following considerations were not credited in the conclusions above, but are provided for additional confidence. Based on P-RPT-J-00007[54], testing data with sludge and solids simulant indicate that the filter still functioned when the feed contained 20 wt.% solids. If the filter does not plug, there is no motive force to increase MST density in the shell beyond that analyzed for the process tanks in Section 6.3 for material settling to and concentrating in the bottom of a tank. Thus, the Section 6.5.3 analysis is very conservative compared to the unlikely event that the CFF would accumulate solids.

To achieve solids build-up on the shell side of the CFF to the quantity or configuration analyzed in Section 6.5.3, numerous failures must occur. The first event in the chain of necessary failures is the failure of a sintered metal tube to allow solid particles to the shell side of the CFF. These sintered metal tubes were designated as Safety Significant for the purpose of preventing solids break-through, but this functional classification is conservatively not credited in this scenario. Instead it is assumed that the tubes will fail. The first required failure is one set of turbidity meters that are installed between the CFF and SSFT (TK-109) that monitor the solids in the process line, M-M6-J-0010, *SWPF Process Building Alpha Sorption Filter FLT-102A*[55]. One alarm set-point diverts the process flow back to FFT-A (TK-102) (M-M5-J-0001)[7] and a higher alarm set-point terminates material flow. While the Washing Filter (FLT-104) only has one turbidity meter downstream there is no concern for criticality safety with the same material in the SSRT moving to the WWHT and subsequently back to AST-A in the event of a filter tube failure. Second, one set of turbidity meters are installed between the SSFT and the contactor bank[56]. One alarm set-point stops the salt solution feed pumps. Thus, there are two redundant pairs of turbidity meters that monitor this process stream for the presence of solids and initiate action when solids are present in excess of set-point values. Third, regardless which set of turbidity meters initiate action, Operations personnel will be aware of the alarm status and begin researching the situation to discover the origin of the solids. Fourth, to return to normal operations, Engineering personnel will likely be consulted and involved in any investigation. Even if the shell side of the CFF were able to fill with solids, it is highly unlikely (non-physical) for the only material to build up on the shell side of the CFF to be MST loaded with uranium and plutonium, while allowing all the liquid and other solids to pass through. (Although there is no guarantee of some minimum "other solids" present, it is expected to be normal and nothing is done in the process to prevent or eliminate them.) Thus, it is unlikely that fewer than four human/programmatic or equipment failures would be required to collect the material and allow it to dry out such that the MST solids concentration could exceed the nominal value.

Because the material in the AFP would have already come through the ASP, it is expected that a significant quantity of the fissile material would have been removed. At a minimum, there is no known process by which the material in the AFP would have a fissile content that exceeds that analyzed in the ASP process. Thus, the material in the ASP process bounds that present in the AFP.

5.4 *Accumulation Inside Contactors*

Contactors are used in four different parts of the Cesium Removal Process: Extraction (16 contactors), Stripping (16 contactors), Scrub (2 contactors), and Caustic Wash (2 contactors). All the contactors are located in a single array of 18x2. This scenario hypothesizes a criticality in one of the contactors due to MST concentration of fissile material. Section 6.7 analyzed bounding upset conditions and demonstrated the system remained subcritical, thus concluding that a criticality in a single contactor is not possible.

It is likely that if any build-up of fissile material on the internal wall of a contactor were to occur, it would noticeably decrease flow rates and/or processing efficiency. It is highly unlikely (non-physical) for the only material to build up on the walls to be MST loaded with fissile material, while allowing all the liquid and other solids to pass through. Further, a sufficient build-up of fissile material must occur and this is not likely to occur quickly without reducing the flow rates or processing efficiency.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.5 *Acid Cleaning of CFFs*

Scenarios 5.2 and 5.3 addressed accumulation of fissile material inside the CFFs. The location of concern for the following scenarios is inside large process vessels. The material of concern (calculated in Section 6.6) is that removed from CFFs during acid cleaning. Some of the material may come from "tube side" and some from the "shell side" but the total is the material of concern for the specific scenario. This material of concern is assumed to be separated from the MST due to chemistry changes in the acid neutralization process (Section 2.2.6). Section 6.3.2 provides the maximum subcritical limits for horizontal tanks and Sections 6.3.1 and 6.4 provides the same for vertical process vessels. The material at risk for each of the following scenarios is provided in Section 6.6.3 and compared to the applicable limits. The CFF tube side accumulation is addressed in a single scenario whereas the shell side accumulation is addressed in multiple scenarios for acute and chronic accumulations.

These scenarios differ from all other MST scenarios in that the others were concerned with uranium and plutonium concentration due to sorption on MST. A hypothetical mechanism for obtaining a critical configuration of fissile material is the precipitation of uranium or plutonium due to the use of oxalic acid ($H_2C_2O_4$) or nitric acid (HNO_3) separating the actinides from the MST. This separation may occur by the acid destroying the MST or by precipitation when the acid solution is neutralized.

5.5.1 Horizontal Tanks with CFF Acid Cleaning Material

For this scenario, the location of concern is a horizontal cylindrical collection tank (e.g., SAST or ASDT). These are the first large tanks where the acid cleaning solution may reside for some time period. These horizontal tanks may also collect acid cleaning solution from multiple CFFs. The limit for this scenario is 7.11 kg ^{235}U at an enrichment of 8% ^{235}U and 5.75 kg ^{239}Pu uniformly distributed in a horizontal tank (see Section 6.3.2).

As discussed in Section 2.2.6, an acid may be used during the filter cleaning process. Normally, caustic wash solution will be transferred into the CSDT-A which supplies the filter cleaning loop and is the collection tank for the cleaning solution at the end of the wash cycle until it is emptied. Due to the cleaning loop design, the CSDT-A will either contain caustic or acid solution. The CSDT-A contents (first caustic, then acid) will be transferred to the SAST or the ASDT. It was hypothesized that the CFF may contain MST solids inside the filter tubes or in the shell of the CFF.

Section 6.6.3 demonstrated that the maximum bounding credible fissile material accumulation for material from acid cleaning CFFs is 1083.9 g ^{235}U and 877.2 g ^{239}Pu. This mass bounds credible acute and chronic accumulations for material inside the filter tubes and the shell and is below the sub-critical limit for this scenario. Thus, the bounding material at risk is significantly less than the limit for this scenario.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.5.2 Vertical Tanks with CFF Acid Cleaning Material

For this scenario, the location of concern is a vertical process tank (e.g., SSRT or AST-A). CFF acid cleaning solution is transferred from the horizontal tanks to vertical process tanks. The vertical process tanks contain the nominal process material in addition to the acid cleaning solution. The concern for the acid cleaning solution in the process tanks is precipitation of the fissile material. The resulting precipitated material cannot exceed the material in the CFF(s) at the time of acid cleaning (i.e., material at risk) and may accumulate in the tank bottom under certain conditions. The accumulation of fissile material may be uniform or non-uniform across the tank bottom. Conservatively it was assumed that all fissile material from CFF acid cleaning accumulated in a non-uniform distribution in the tank bottom.

The limit for this scenario is 1.2 kg ^{235}U at 8 wt.% ^{235}U and 0.9 kg ^{239}Pu in a non-uniform distribution in a vertical process tank (see Section 6.4).

Section 6.6.3 demonstrated that the maximum bounding credible fissile material accumulation for material from acid cleaning CFFs is 1083.9 g ^{235}U and 877.2 g ^{239}Pu. This mass bounds acute and chronic accumulations for material inside the filter tubes and the shell. Thus, the bounding material at risk is less than the limit for this scenario.

Therefore, the hypothesized upset condition is not credible due to the inability of the system to achieve a critical configuration.

5.6 *Seismic Event*

This scenario hypothesizes a criticality due to a seismic event. It is hypothesized that a seismic event could rearrange material or reflection, inside or outside of process equipment, such that the conditions could achieve a defined critical configuration. A seismic event was considered to have the potential for removing solution from tanks/pipes into local sumps, and CFF or contactors may be relocated next to each other with close reflection. The purpose of this scenario is to summarize how the conditions of a seismic event are bound by the analysis in Section 6.

Large process vessels and pipes could hypothetically spill/drain a significant quantity of their contents to a cell floor that would collect in a sump. The analysis in Section 6.8 evaluated this condition as the nominal process liquid evaporated over time. The analysis demonstrated that this upset condition remained subcritical for all moderation conditions.

The contactors are designed to be installed in a fixed array during operations. The Section 6.7 analysis modeled two contactors next to each other in a concrete corner with tight concrete reflection on top and bottom. This modeled configuration bounds a post-seismic condition where all the piping and structural support connected to the contactors has been removed from two contactors that are perfectly intact and relocated next to each other in a corner with tight concrete reflection on the top and bottom.

Similar to the contactors, the CFFs are designed to be installed in a fixed location during operation. The installed location of the CFFs are several feet apart (separated by the holes in the concrete floor) and held in their elevated place above the cell floor by considerable amounts of structural support. The modeled configuration (see Section 6.5) bounds a post-seismic condition where all the piping and structural support connected to the CFF has been removed from two CFFs that are perfectly intact and relocated next to each other in a corner with tight concrete reflection on the top and bottom.

Normally, CFFs and contactors do not contain the quantity of fissile material analyzed for the upset conditions of Sections 6.5 and 6.7 (respectively). Thus, the analyses of these two sections for CFFs and contactors compound upset conditions. Not only are the CFFs and contactors analyzed with significantly more fissile material than normally present, a major event would be required to alter the installed location to the hypothetical condition of two intact units next to each other in a concrete corner. Sections 6.5 and 6.7 demonstrated that even if such an upset condition occurred, the systems remained subcritical.

Therefore, the hypothesized seismic event is bounded by the current analyses.

6 Evaluation and Results

The results presented in the following subsections rely on the SRNL testing results documented in WSRC-STI-2006-00012, *Results of Supplemental MST Studies* [49] that are summarized in Table 7. The testing was designed in part to determine the maximum loading of uranium and plutonium onto MST. For testing purposes, the MST was held in a fixed location and the strike consisted of the fissile mixture contacting the MST. This is the opposite situation for the ASP in SWPF, where the uranium/plutonium mixture will be contacted by the MST addition. The two different strike techniques are expected to produce the same results.

As stated in Section 4.3, the safe k_{eff} value for this analysis is k_{safe} = 0.9679 and a solid red line is present on the figures in this section to provide a visual indication of which results are adequately subcritical

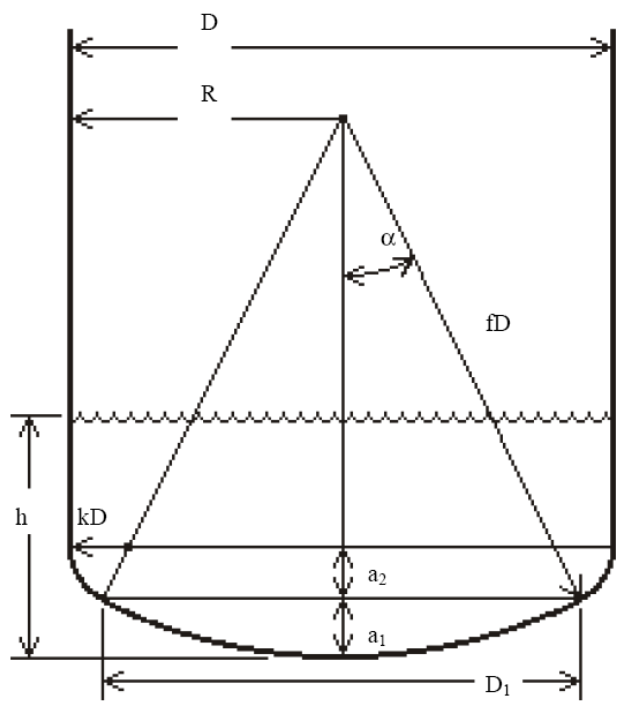
6.1 *Large Tank Geometry*

The purpose of the large tank analysis was to study a broad range of parameters and values to cover normal and credible upset conditions for the SWPF process in the process tanks. Thus, the large tank models were not intended to address a specific process condition, but rather to produce bounding results for a range of parameter values that encompass process conditions.

An 9 foot (ft) diameter tank was studied for this model. This diameter was selected because the SSRT has a diameter of approximately 9 ft and it was desired to provide a bounding analysis. No material was modeled for the tank walls, nor was the thickness of the tank walls modeled as a spacer between the fissile solution and any reflection. The nominal tank ID was conservatively used as the OD (with zero tank wall thickness). The dish radius equaled the tank diameter. This selection produced a deeper dish than designed for the tanks which optimized the surface to volume ratio of the tank bottom and produced bounding k_{eff} results.

According to M-CLC-J-00029[10], the SSRT is a torispherical bottom tank with a dish spherical radius equal to the tank Inside Diameter. The dish knuckle radius equals 0.06 times the dish spherical radius. In relation to Figure 3, D=9 ft = 274.32 centimeters (cm), f=1.0, k=0.06. The values of α, a_1, and a_2 are calculated by the following standard equations (per *Calculating Tank Volume: Saving Time, Increasing Accuracy*[57]).

Figure 3: Torispherical Tank Bottom



$$V_f = \begin{cases} \dfrac{\pi h^2}{4}\left(2a_1 + \dfrac{D_1^2}{2a_1} - \dfrac{4h}{3}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 0 \le h \le a_1 \\ \dfrac{\pi}{4}\left(\dfrac{2a_1^3}{3} + \dfrac{a_1 D_1^2}{2}\right) + \pi u\left[\left(\dfrac{D}{2} - kD\right)^2 + s\right] + \dfrac{\pi t u^2}{2} - \dfrac{\pi u^3}{3} \\ \qquad + \pi D(1-2k)\left[\dfrac{2u-t}{4}\sqrt{s + tu - u^2} + \dfrac{t\sqrt{s}}{4} + \dfrac{k^2D^2}{2}\left(\cos^{-1}\dfrac{t-2u}{2kD} - \alpha\right)\right] \quad \ldots\ldots \quad a_1 < h \le a_1 + a_2 \\ \dfrac{\pi}{4}\left(\dfrac{2a_1^3}{3} + \dfrac{a_1 D_1^2}{2}\right) + \dfrac{\pi t}{2}\left[\left(\dfrac{D}{2} - kD\right)^2 + s\right] \\ \qquad + \dfrac{\pi t^3}{12} + \pi D(1-2k)\left(\dfrac{t\sqrt{s}}{4} + \dfrac{k^2D^2}{2}\sin^{-1}(\cos\alpha)\right) + \dfrac{\pi D^2}{4}\left[h - (a_1 + a_2)\right] \quad \ldots\ldots \quad a_1 + a_2 < h \end{cases}$$

$$\alpha \equiv \sin^{-1}\frac{1-2k}{2(f-k)} = \cos^{-1}\frac{\sqrt{4f^2 - 8fk + 4k - 1}}{2(f-k)}$$

$$a_1 \equiv fD(1-\cos\alpha)$$
$$a_2 \equiv kD\cos\alpha$$
$$D_1 \equiv 2fD\sin\alpha$$
$$s \equiv (kD\sin\alpha)^2$$
$$t \equiv 2kD\cos\alpha = 2a_2$$
$$u \equiv h - fD(1-\cos\alpha)$$

Table 11 provides the torispherical tank dimension parameters for various tank diameters consistent with parameters specified in M-CLC-J-00029[10] for the SSRT.

Table 11: Torispherical Tank Dimension Parameters

D (ft)	D (cm)	a_1 (cm)	a_2 (cm)	D_1 (cm)	s	fD (cm)	t	α	f	k
6	182.88	21.12	9.71	170.64	26.21	182.88	19.41	0.49	1	0.06
8	243.84	28.16	12.94	227.52	46.59	243.84	25.88	0.49	1	0.06
9	274.32	31.68	14.56	255.96	58.96	274.32	29.12	0.49	1	0.06
12	365.76	42.24	19.41	341.28	104.82	365.76	38.82	0.49	1	0.06
15	457.20	52.80	24.26	426.60	163.79	457.20	48.53	0.49	1	0.06
18	548.64	63.37	29.12	511.92	235.85	548.64	58.23	0.49	1	0.06

However, for simplicity of analysis, a spherical bottom tank was modeled instead of the torispherical shape designed. This simplification was conservative in that the spherical bottom has more curvature than the torispherical which slightly increases the centerline depth of the dish. The spherical bottom was modeled as the intersection of an 9 ft diameter cylinder with a sphere that had a radius (*L*) equal to the tank diameter (*D*) as shown in Figure 4.

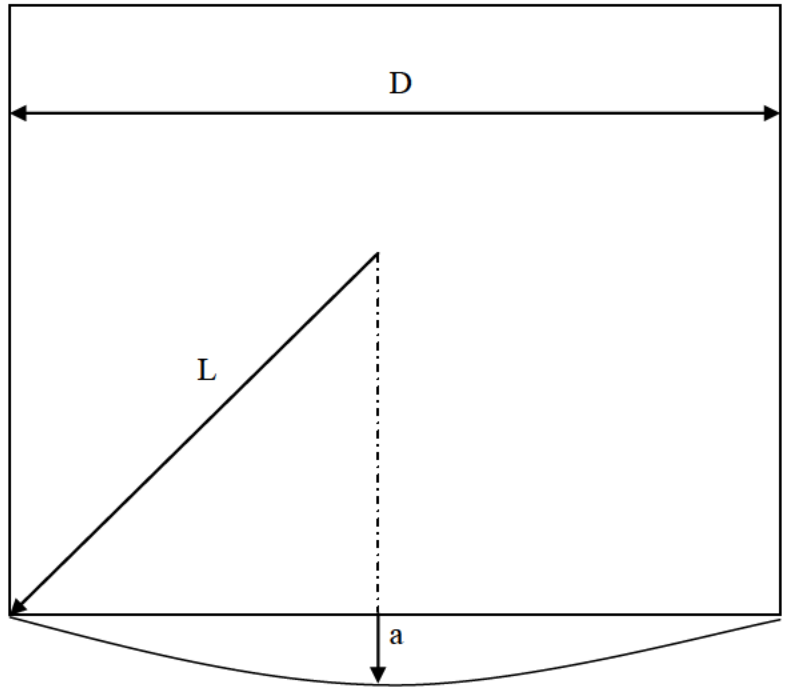


Figure 4: Spherical Tank Parameters

Figure 5 focuses on the bottom of the tank where the solution height (*h*) shown is less than the centerline depth of the dish (*a*).

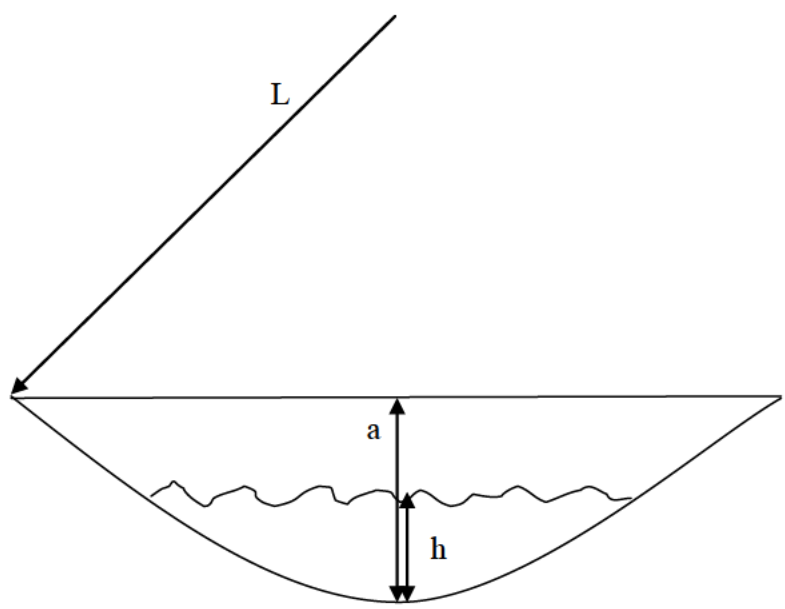


Figure 5: Bottom of Spherical Bottom Tank

The solution height was calculated in the spherical dish using the following equation.

$$V = \frac{\pi}{3} h^2 (3L - h)$$

For a known volume, an iterative solution was used to solve for the solution height (*h*). The volume of the spherical dish region was a function of the tank diameter and radius of the sphere. According to M-CLC-J-00029[10], the tank diameter (*D*) is equal to the radius of the sphere (*L*). Thus, the value of parameter *a* from Figure 5 is calculated by the following equation.

$$a = L - \sqrt{L^2 - \left(\frac{D}{2}\right)^2}$$

For the 9 foot (243.84 cm) diameter tank of interest for this analysis, *a*=36.7519 cm. Thus, the volume of the dish region can be calculated for *a*=*h* to be approximately 1,112 liters. For a solution volume greater than this, the solution height in the tank was calculated by subtracting the dish volume from the solution volume, then using the standard formula for a cylinder ($V = \pi r^2 h$) to solve for the solution height in the tank above the dish.

6.2 Single Parameter Uniform Settling

The purpose of this section is to evaluate the single parameter upset conditions hypothesized in Table 9 of Section 5.1. Uniform settling of MST solids in a large tank was considered to occur when the uniformly mixed MST solids in the tank settle to the bottom of a tank following the termination of mixing. Table 10 details the process parameters and their values important to the facility and this analysis. The Nominal process condition and each of the single parameter upset conditions found in Table 10 were analyzed with uniform settling.

The tank volume above the settled region was filled with a low concentration fissile solution that consisted of 25 mg/L of uranium at an enrichment of 8% ^{235}U, and 2.5 mg/L of Pu. Void could have been modeled in the tank above the concentrated solution because it is not possible to justify how gravity would concentrate the MST and remove sufficient water to span a wide range of concentration values while submerged in liquid. Thus, the model was conservative compared to the physical conditions possible.

The AST-A batch volume was taken as 38,000 gallons which approximates the tank overflow level. The MST addition to AST-A, the uranium and plutonium feed concentrations, the uranium enrichment, and the number of AST-A batches in the SSRT were all varied from the Nominal values in the analysis. Each of the following sub-sections analyzes one of these parameters from Table 10.

Tank Geometry

The tank analyzed had a 9 foot diameter and the dish radius equaled the tank diameter. This selection produced a deeper dish than designed for the larger (e.g., 19 foot) diameter tanks such as AST-A or FFT-A in the ASP. The smaller diameter tank with the deeper dish is bounding and therefore was the only geometry investigated in this analysis (see Section 6.1). Due to the normal process flow of the ASP, seven AST-A tanks of material will be concentrated in the FFT-A then collected in the SSRT. Figure 6 depicts the dish bottom tank with 2 foot of tight fitting concrete reflection.

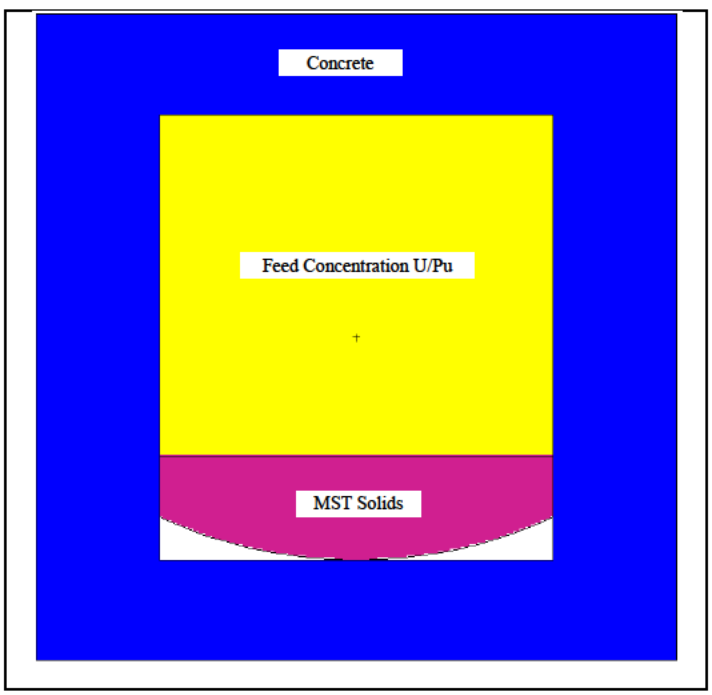


Figure 6: General Dish Bottom Tank With Tight Reflection

Reflection Conditions

The reflection conditions for the tank with uniform settling was to model the tank in a tight fitting rectangular cell of concrete that was 2 foot thick. Void was modeled outside the tank bottom and above the concrete floor. This amount of close reflection bounds any installed location of a large tank simply due to piping, electrical, and other equipment commonly between the tank and the concrete structure.

Volume of Settled Region

The volume of the settled region was calculated based on the inputs shown in Table 10. The volume of the settle region varied during the analysis based on the single parameter changes to the input values. Once the volume of the settled region was calculated, the height of the solution in the tank was calculated. See Section 6.1 for the discussion on spherical bottom tanks.

Uranium and Plutonium Mass on MST

There were two different methods available for selecting the mass of uranium and plutonium on the MST in the settled region mixture. The first method simply involved taking some percentage of the total uranium and plutonium mass in the tank (e.g., SSRT) and placing that mass in the mixture with the MST. It was decided that when this method was used, 100% of the uranium and plutonium mass in the tank should be placed in the mixture with the MST.

The second method for selecting the mass of uranium and plutonium on the MST in the settled region mixture relied completely on the MST loading data provided in Table 7. It was decided that when this method was used, only the five strike data should be relied on.

Thus, a decision of which method to use had to be made. In most cases, the five strike MST loading data resulted in a significantly greater uranium and plutonium mass than the mass of these elements in the tank. It was desirable to avoid the appearance of "creating" uranium and plutonium in the models that would not be present based on process and feed assumptions, thus preserving some element of physical reality. It was also desirable to produce a conservative analysis. Therefore, both methods were used to calculate the uranium and plutonium mass on the MST in the settled region and the minimum values were selected for calculating the mixture atom density. This decision resulted in allowing all the uranium and plutonium present in a tank to be loaded on the MST up to the point that there was more uranium and plutonium in the tank than could be loaded onto the MST based on the five strike data.

As discussed in Section 6.6, CFF cleaning is assumed to result in the precipitation of some fissile mass when the cleaning solution is transferred to a large process tank (e.g., SSRT). Thus, to account for CFF cleaning all the cases in this section contain the CFF cleaning fissile mass per seven AST-A batches in the SSRT. Hence, one CFF cleaning per seven AST-A batches was considered part of the Nominal conditions (see Table 9).

6.2.1 MST Concentration

As discussed in Section 2.2.2, MST will be added to AST-A to achieve a 0.4 g/L concentration in the tank. Thus, each AST-A batch was considered to contain a MST mass equal to the MST concentration in the AST-A times the batch volume. To adequately bound all credible variations to this Nominal condition, the MST concentration in AST-A was varied from 0.025 – 0.8 g/L. All the other parameter values from Table 10 were considered at their Nominal values. The material composition atom densities for MST concentrations of 0.025 and 0.8 g/L are provided in the U1 and U2 columns of Table 10 respectfuly.

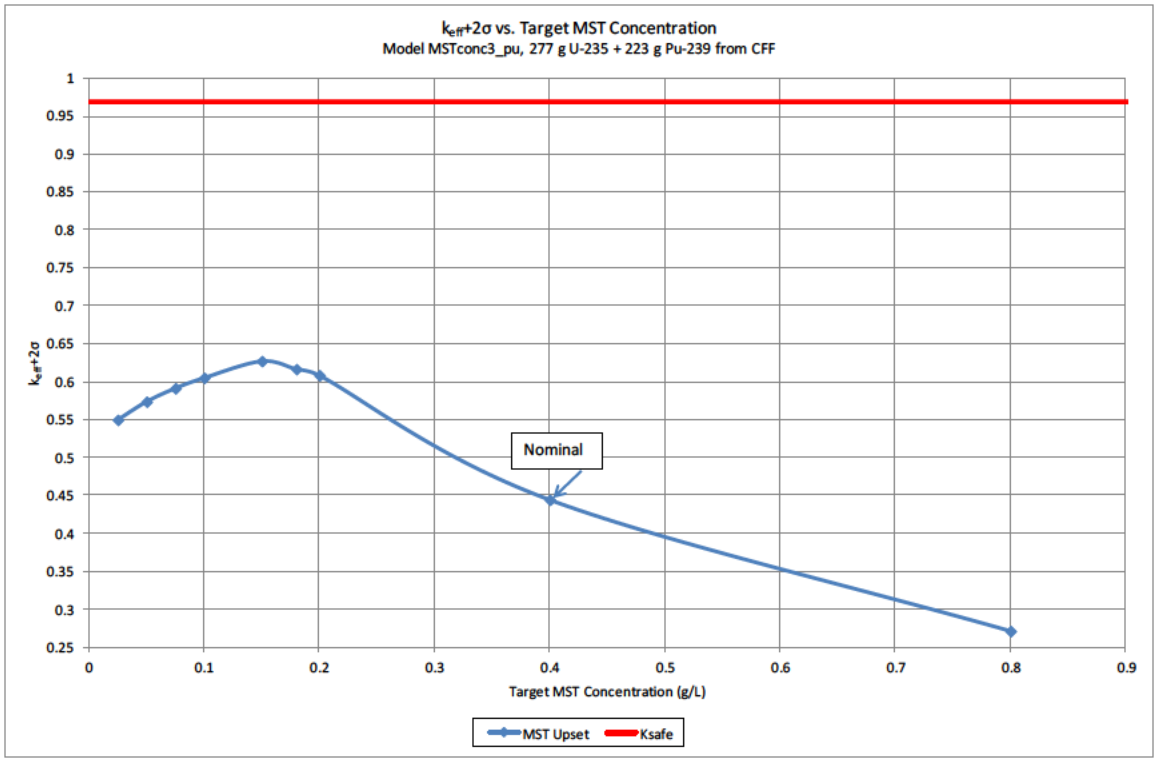


Figure 7: MST Concentration Parameter Variation Results

Figure 7 presents the model results. As noted in the figure, the Nominal and all analyzed upset MST concentrations in AST-A result in a k_{eff}+2σ value that is less than k_{safe}. Figure 7 also demonstrates that all MST concentrations above 0.8 g/L will remain subcritical due to the decline in k_{eff}+2σ values from a MST concentration of approximately 0.2 g/L up to 0.8 g/L. Therefore, based on this analysis, any MST concentration in AST-A from 0.025 – 0.8 g/L will result in a subcritical configuration when concentrated and collected in the SSRT under uniform settling conditions.

Figure 7 indicates a maximum k_{eff}+2σ value occurs around an MST concentration in AST-A of approximately 0.15 g/L. This maximum is a product of the methodology for analyzing MST loading of uranium and plutonium. At low MST concentrations the mass of uranium and plutonium in the tank exceeded the five strike loading values, so the five strike loading values were used to define the mass of uranium and plutonium on the MST. At high MST concentration the five strike loading data exceeded the mass of uranium and plutonium in the tank, so the mass of uranium and plutonium in the tank was used to define the mass of uranium and plutonium on the MST. The transition (equilibrium) point between the two methods occurred at an MST concentration around 0.15 g/L.

Table 12 provides the data depicted in Figure 7. The MST Concentration column was the MST concentration in AST-A for each of the normal seven batches. The Volume Settled Region column was the mixture volume consisting of loaded MST, the CFF cleaning fissile mass, and water.

Table 12: MST Concentration Parameter Result Data

File Name	MST Concentration (g/L)	Volume Settled Region (L)	H/X	$k_{eff}+2\sigma$	ANECF	Validation X
MSTconc3_pu_1_3_in	0.025	92.2	2015	0.5494	8.90E-03	18.5
MSTconc3_pu_2_3_in	0.05	184.1	2617	0.5733	7.35E-03	14.9
MSTconc3_pu_3_3_in	0.075	275.9	2907	0.5910	7.08E-03	13.6
MSTconc3_pu_4_3_in	0.1	367.7	3077	0.6047	6.80E-03	13.0
MSTconc3_pu_5_3_in	0.15	551.4	3268	0.6268	6.45E-03	12.3
MSTconc3_pu_6_3_in	0.18	661.6	3585	0.6163	5.99E-03	10.8
MSTconc3_pu_7_3_in	0.2	735.1	3805	0.6081	5.65E-03	9.8
MSTconc3_pu_8_3_in	0.4	1469.8	6997	0.4440	4.38E-03	5.2
MSTconc3_pu_9_3_in	0.8	2939.2	14008	0.2709	3.58E-03	2.7

The input file `MSTconc3_pu_5_3_in` is provided in Appendix C.

6.2.2 Uranium Feed Concentration

The total uranium concentration in the feed to SWPF (received into AST-A) may vary. The Nominal uranium concentration value in Table 10 was conservatively set at 0.025 g/L. While it is not likely that feed to SWPF will exceed this concentration value, it was selected sufficiently large to account for the uranium in solution and in any sludge solids. Thus, this analysis considered the uranium feed concentration to include each unit mass of uranium per unit volume in the transfer pipe.

The MST concentration, uranium enrichment, plutonium feed concentration, and number of AST-A batches in the SSRT parameters were held at their Nominal values. The uranium feed concentration was varied from 0.010 g/L to 0.09 g/L. The material composition atom densities for a uranium feed concentration of 0.050 g/L are provided in column U3 of Table 10.

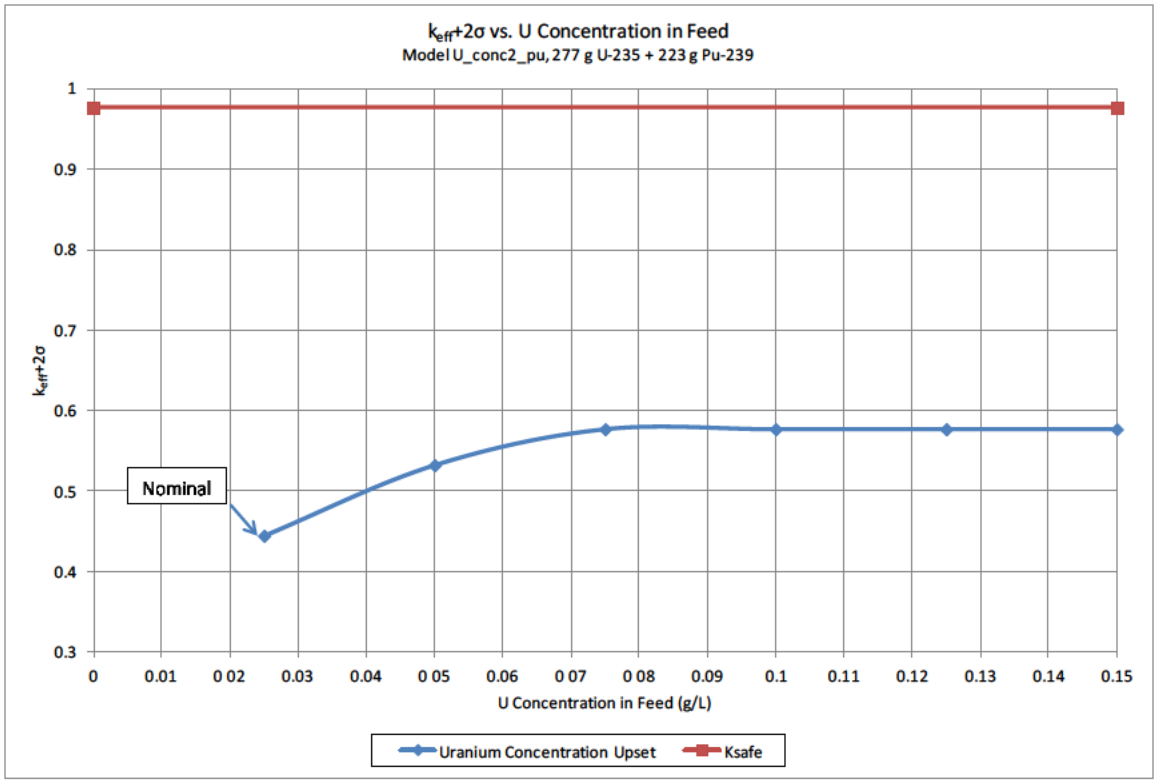


Figure 8: Uranium Concentration Upset Results

Figure 8 depicts the results of varying the uranium feed concentration on the uniform settled region that has been concentrated and collected in the bottom of the SSRT. As seen in this figure, the Nominal parameter value and all evaluated upset conditions remained subcritical ($k_{eff}+2\sigma \leq k_{safe}$).

Figure 8 also depicts the $k_{eff}+2\sigma$ values reaching a constant maximum somewhere between 0.06 and 0.07 g/L uranium. This indicates that at some uranium concentration above 0.06 g/L the mass of uranium in the tank equals the mass of uranium able to be loaded onto the MST based on the five strike data. Once that point was achieved, no more uranium could be loaded onto the MST and the system $k_{eff}+2\sigma$ values remained constant as the material composition was constant.

Table 13 provides the data depicted in Figure 8. The Uranium Feed Concentration column was the concentration in the feed to SWPF as found in AST-A for each of the normal seven batches. Row 30 of Table 10 provides the volume of the settled region for the Nominal and upset condition.

Table 13: Uranium Concentration Feed Parameter Results Data

File Name	Uranium Feed Concentration (g/l)	H/X	$k_{eff}+2\sigma$	ANECF	Validation X
U_conc2_pu_1_3_in	0.025	6997	0.4440	4.38E-03	16.1
U_conc2_pu_2_3_in	0.05	4974	0.5318	5.78E-03	12.5
U_conc2_pu_3_3_in	0.075	4262	0.5766	6.53E-03	11.6
U_conc2_pu_4_3_in	0.1	4262	0.5766	6.53E-03	11.6
U_conc2_pu_5_3_in	0.125	4262	0.5766	6.53E-03	11.6
U_conc2_pu_6_3_in	0.15	4262	0.5766	6.53E-03	11.6

The input file `U_conc2_pu_3_1_in` is provided in Appendix C.

6.2.3 Uranium Enrichment

The uranium enrichment in the feed to SWPF (received into AST-A) may vary. The Nominal uranium enrichment value in Table 10 was conservatively set at 8 wt.% ^{235}U. While it is not likely that feed to SWPF will exceed this enrichment value, a range of upset condition values was evaluated.

The MST concentration, uranium feed concentration, plutonium feed concentration, and number of AST-A batches in the SSRT parameters were held at their Nominal values. The uranium enrichment was varied from 8% to 32% ^{235}U by weight. The material composition atom densities for uranium enrichment of 16% are provided in column U4 of Table 10.

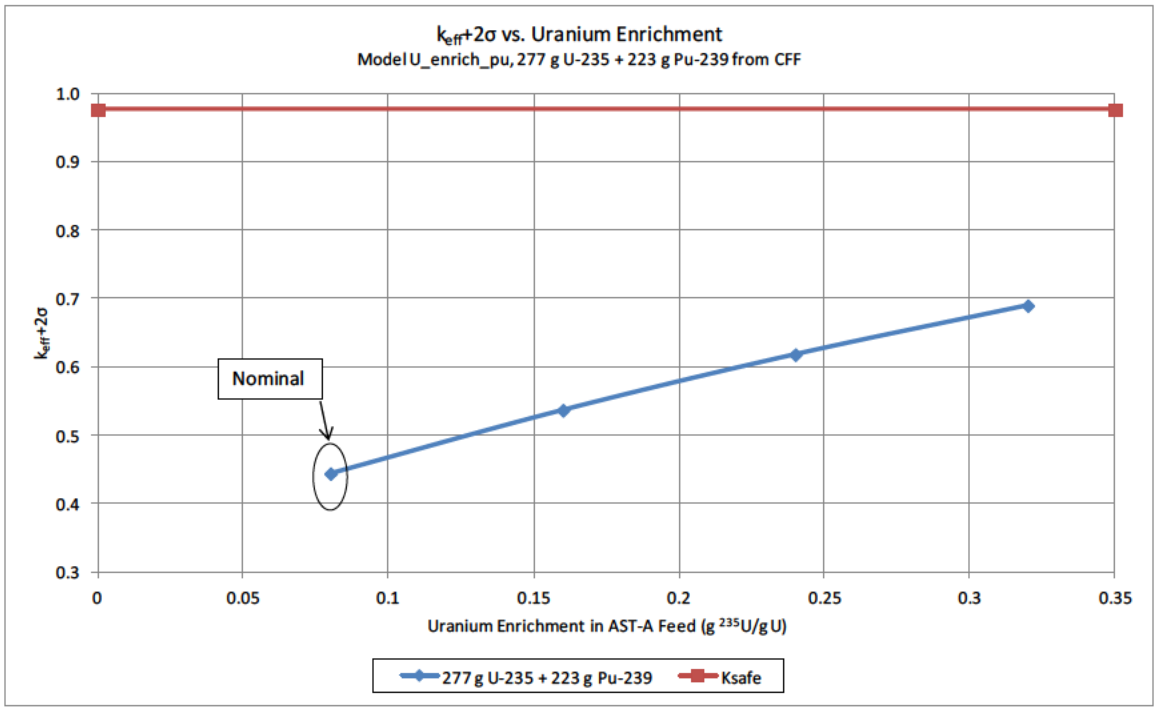


Figure 9: Uranium Enrichment Upset Results

Figure 9 depicts the change in k_{eff}+2σ values over the range of uranium enrichment values evaluated. This figure demonstrates that in the uniform settling configuration evaluated, with the single parameter upset being uranium enrichment, the system will remain subcritical up to a uranium enrichment of 32 wt.% ^{235}U.

Table 14 provides the data depicted in Figure 9. The E(U) column denotes the enrichment (g ^{235}U/g U) of the uranium in the feed to SWPF as found in AST-A for each of the normal seven batches. Row 30 of Table 10 provides the volume of the settled region for the Nominal and upset condition.

Table 14: Uranium Enrichment Parameter Results Data

File Name	E(U) (g ^{235}U/ g U)	H/X	k_{eff}+2σ	ANECF	Validation X
U_enrich2_pu_1_3_in	0.08	6997	0.4440	4.38E-03	16.1
U_enrich2_pu_2_3_in	0.16	4984	0.5367	3.55E-03	23.9
U_enrich2_pu_3_3_in	0.24	3870	0.6181	3.17E-03	31.3
U_enrich2_pu_4_3_in	0.32	3163	0.6897	3.03E-03	38.7

The input file `U_enrich_pu_2_3_in` is provided in Appendix C.

6.2.4 Plutonium Feed Concentration

The plutonium concentration in the feed to SWPF (received into AST-A) may vary. The Nominal plutonium concentration value in Table 10 was conservatively set at 2.5 mg Pu/L. While it is not likely that feed to SWPF will exceed this concentration value, it was selected sufficiently large to account for any trace actinides in solution or in any sludge solids. Thus, this analysis considered the plutonium feed concentration to include each unit mass of plutonium per unit volume in the transfer pipe.

The MST concentration, uranium feed concentration, uranium enrichment, and number of AST-A batches in the SSRT parameters were held at their Nominal values. The plutonium feed concentration was varied from 0.001 to 0.01 g Pu/L. The material composition atom densities for plutonium feed concentration of 0.005 are provided in column U5 of Table 10.

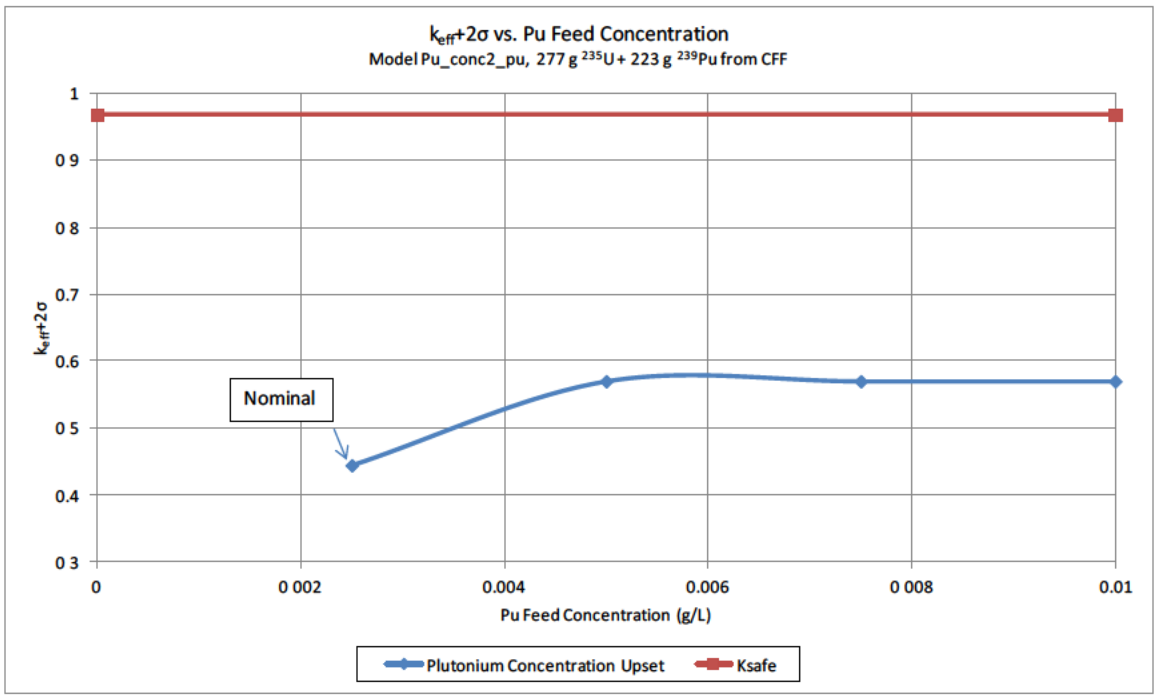


Figure 10: Plutonium Feed Concentration Results

Figure 10 depicts the change in k_{eff}+2σ values over the range of plutonium feed concentration values evaluated. This figure demonstrates that in the uniform settling configuration evaluated, with the single parameter upset being plutonium feed concentration, the system will remain subcritical up to a plutonium feed concentration of 0.01 mg Pu/L.

Figure 10 also depicts the k_{eff}+2σ values reaching a constant maximum at approximately 0.004 g/L plutonium. This indicates that at this plutonium concentration the mass of plutonium in the tank equals the mass of plutonium able to be loaded onto the MST based on the five strike data. Once that point was achieved, no more plutonium could be loaded onto the MST and the system k_{eff}+2σ values remained constant as the material composition was constant.

Table 15 provides the data depicted in Figure 10. The Plutonium Feed Concentration column denotes the concentration of plutonium in the feed to SWPF as found in AST-A for each of the normal seven batches. Row 30 of Table 10 provides the volume of the settled region for the Nominal and upset condition.

Table 15: Plutonium Feed Concentration Parameter Results Data

File Name	Plutonium Feed Concentration (g/l)	H/X	$k_{eff}+2\sigma$	ANECF	Validation X
Pu_conc2_pu_1_3_in	0.0025	6997	0.4440	4.38E-03	16.1
Pu_conc2_pu_2_3_in	0.005	5254	0.5697	4.05E-03	20.3
Pu_conc2_pu_3_3_in	0.0075	5254	0.5697	4.05E-03	20.3
Pu_conc2_pu_4_3_in	0.01	5254	0.5697	4.05E-03	20.3
Pu_conc2_pu_5_3_in	0.0125	5254	0.5697	4.05E-03	20.3
Pu_conc2_pu_6_3_in	0.015	5254	0.5697	4.05E-03	20.3

The input file `Pu_conc2_pu_2_3_in` is provided in Appendix C.

6.2.5 Number AST-A Batches in SSRT

The number of AST-A batches in the SSRT may vary. The Nominal number of AST-A batches (seven) was established for the SWPF process and was discussed in Section 5.1.6. This number of batches was utilized in Table 10 and in the calculations of material atom densities for MCNP input files.

As noted in the introduction to Section 6.2, all the cases in this section contain the CFF cleaning fissile mass per seven AST-A batches in the SSRT to account for CFF cleaning. So the analysis performed was in increments of seven AST-A batches and each set of seven AST-A batches added the CFF cleaning fissile mass. This subsection differs from all the others in Section 6.2 because it adds more than the normal CFF cleaning fissile mass as part of the upset condition. For each 7 AST-A batches, the normal CFF cleaning fissile mass was added to mixture.

The MST concentration, uranium feed concentration, uranium enrichment, and plutonium feed concentration parameters were held at their Nominal values. The number of AST-A batches in the SSRT was varied from 7 to 28. The material composition atom densities for fourteen AST-A batches in the SSRT are provided in column U6 of Table 10.

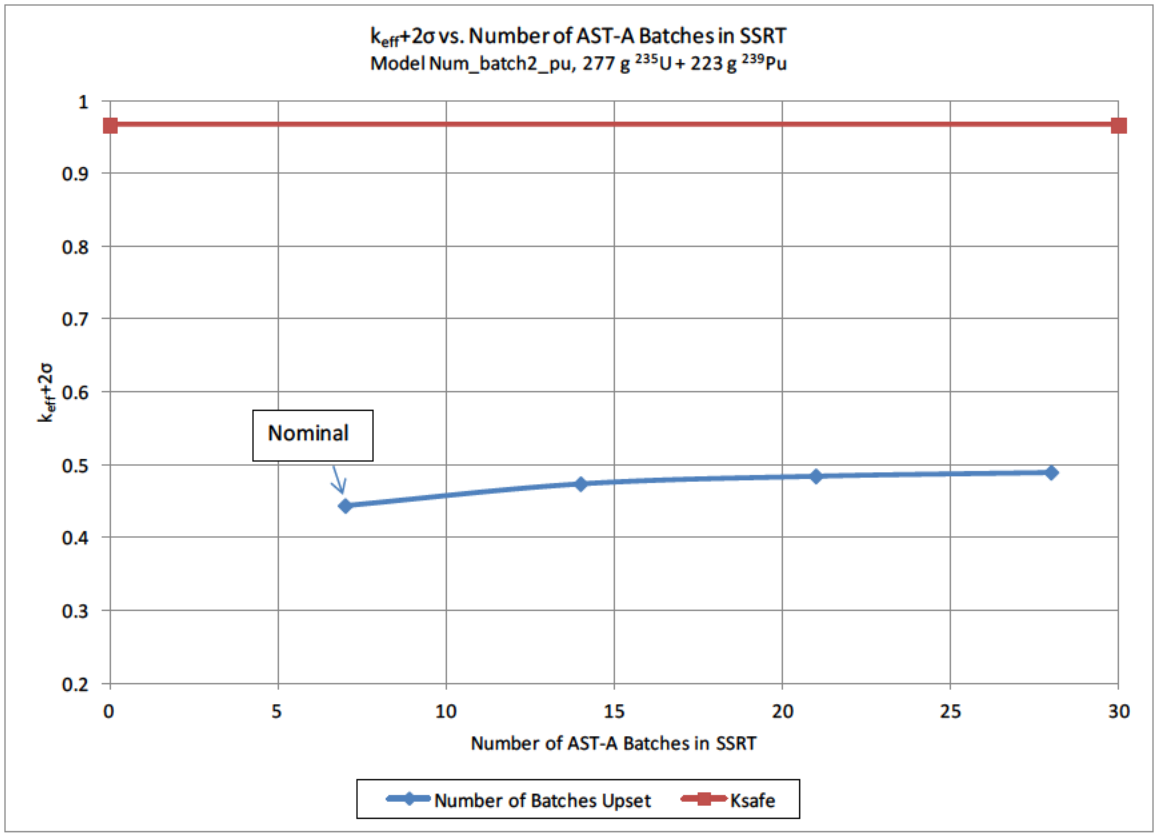


Figure 11: Number of AST-A Batches in SSRT Upset

Figure 11 depicts the change in k_{eff}+2σ values over the range of number of AST-A batches in the SSRT values evaluated. This figure demonstrates that in the uniform settling configuration evaluated, with the single parameter upset being the number of AST-A batches in the SSRT, the system will remain subcritical up to 63 AST-A batches in the SSRT.

Figure 11 also depicts the k_{eff}+2σ values reaching a constant maximum at approximately 28 AST-A batches. It appears that at this parameter value, the mixture height in the bottom of the tank began to approximate an infinite system. Thus, the addition of more of the same material ceased to continue increasing the system k_{eff}+2σ value.

Table 16 provides the data depicted in Figure 11. The Number of AST-A Batches in SSRT column denotes the number of Nominal AST-A batches of material present in the SSRT. The volume of the settled region was a function of the number of AST-A batches present. Row 30 of Table 10 provides the volume of the settled region for the Nominal and upset condition.

Table 16: Number of AST-A Batches in SSRT Parameter Results Data

File Name	# AST-A Batches in SSRT	Volume Settled Region (L)	H/X	k_{eff}+2σ	ANECF	Validation X
Num_batch2_pu_1_3_in	7	1469.8	6997	0.4440	4.38E-03	16.1
Num_batch2_pu_2_3_in	14	2939.6	7363	0.4740	4.27E-03	16.1
Num_batch2_pu_3_3_in	21	4409.4	7494	0.4847	4.24E-03	16.1
Num_batch2_pu_4_3_in	28	5879.2	7561	0.4898	4.35E-03	16.1

The input file `Num_batch2_pu_2_3_in` is provided in Appendix C.

6.3 *General Uniform Settling*

The analysis in Section 6.2 only considered single parameter upset conditions with uniform settling of material in a large tank. The purpose of this section is to determine the maximum subcritical mass limit for uniform settling without respect to single parameter upsets. Two different tanks were analyzed: a vertical tank and a horizontal tank. The horizontal tanks are the location where CFF acid clean solution may be accumulated waiting to be transferred to a vertical process tank. The vertical tank analyzed was identical to that in Section 6.2.

6.3.1 Vertical Tanks

The same tank geometries and reflection conditions as in Section 6.2 were modeled. The solution height in the tank was varied from 100-600 liters for each selected ^{235}U solids mass. The fissile material placed in the defined volume had two components. First, the volume was assumed to be filled with MST solids at 0.2741 g/cc and loaded with the 5 strike data per Table 7. So as the volume varied, the concentration of fissile material due to MST solids remained constant. Second, a mass of ^{235}U and ^{239}Pu solids was placed in the volume to account for uniform settling of fissile material. A range of ^{235}U solids mass values were evaluated from 2-2.6 kg ^{235}U, and the ^{239}Pu mass values were evaluated from 1.9-2.2 kg ^{239}Pu. Figure 12 depicts the results for the uniform settling analysis.

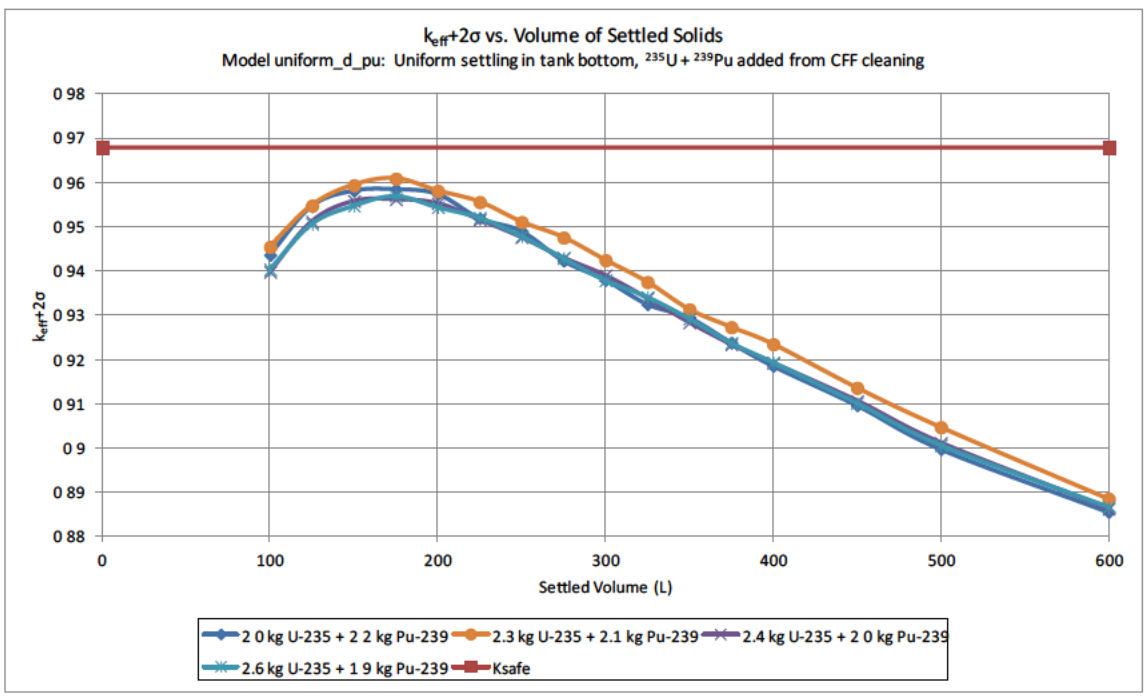


Figure 12: Uniform Settling Results

The results depicted in Figure 12 demonstrate that optimum moderation was evaluated in the geometry with the materials modeled. Figure 12 demonstrates four combinations of ^{235}U and ^{239}Pu mass values that remain subcritical (k_{eff}+2σ below k_{safe}) when homogenously mixed in uniform settling with MST solids at 0.2741 g/cc and loaded with the 5 strike data per Table 7. The curves for these four combinations are very similar. The results depicted in Figure 12 are provided in Table 17.

Table 17: Uniform Settling Results Data

File Name	Settled Volume (L)	^{235}U from CFF (g)	^{239}Pu from CFF (g)	H/X	$k_{eff}+2\sigma$	ANECF (MeV)	Validation X
uniform_d_pu_3_8_10_in out	100	2000	2200	478	0 9447	2 00E-02	15 2
uniform_d_pu_3_8_11_in out	125	2000	2200	582	0 9556	1 73E-02	15 2
uniform_d_pu_3_8_12_in out	150	2000	2200	680	0 9591	1 56E-02	15 1
uniform_d_pu_3_8_13_in out	175	2000	2200	772	0 9594	1 42E-02	15 1
uniform_d_pu_3_8_14_in out	200	2000	2200	858	0 9583	1 31E-02	15 0
uniform_d_pu_3_8_15_in out	225	2000	2200	940	0 9528	1 24E-02	15 0
uniform_d_pu_3_8_16_in out	250	2000	2200	1017	0 9498	1 15E-02	14 9
uniform_d_pu_3_8_17_in out	275	2000	2200	1089	0 9431	1 11E-02	14 9
uniform_d_pu_3_8_18_in out	300	2000	2200	1158	0 9388	1 07E-02	14 9
uniform_d_pu_3_8_19_in out	325	2000	2200	1224	0 9332	1 03E-02	14 8
uniform_d_pu_3_8_20_in out	350	2000	2200	1286	0 9302	1 01E-02	14 8
uniform_d_pu_3_8_21_in out	375	2000	2200	1346	0 9245	9 66E-03	14 8
uniform_d_pu_3_8_22_in out	400	2000	2200	1402	0 9192	9 30E-03	14 7
uniform_d_pu_3_8_23_in out	450	2000	2200	1507	0 9103	8 93E-03	14 7
uniform_d_pu_3_8_24_in out	500	2000	2200	1604	0 9004	8 61E-03	14 6
uniform_d_pu_3_8_25_in out	600	2000	2200	1773	0 8861	8 32E-03	14 6
uniform_d_pu_6_7_10_in out	100	2300	2100	457	0 9454	2 19E-02	14 2
uniform_d_pu_6_7_11_in out	125	2300	2100	558	0 9547	1 87E-02	14 2
uniform_d_pu_6_7_12_in out	150	2300	2100	652	0 9594	1 64E-02	14 2
uniform_d_pu_6_7_13_in out	175	2300	2100	741	0 9608	1 52E-02	14 2
uniform_d_pu_6_7_14_in out	200	2300	2100	826	0 9581	1 40E-02	14 2
uniform_d_pu_6_7_15_in out	225	2300	2100	905	0 9555	1 29E-02	14 2
uniform_d_pu_6_7_16_in out	250	2300	2100	980	0 9510	1 24E-02	14 1
uniform_d_pu_6_7_17_in out	275	2300	2100	1052	0 9475	1 18E-02	14 1
uniform_d_pu_6_7_18_in out	300	2300	2100	1120	0 9424	1 12E-02	14 1
uniform_d_pu_6_7_19_in out	325	2300	2100	1184	0 9375	1 08E-02	14 1
uniform_d_pu_6_7_20_in out	350	2300	2100	1245	0 9313	1 05E-02	14 1
uniform_d_pu_6_7_21_in out	375	2300	2100	1304	0 9273	1 02E-02	14 1
uniform_d_pu_6_7_22_in out	400	2300	2100	1360	0 9234	9 88E-03	14 1
uniform_d_pu_6_7_23_in out	450	2300	2100	1464	0 9136	9 51E-03	14 0
uniform_d_pu_6_7_24_in out	500	2300	2100	1559	0 9046	9 08E-03	14 0
uniform_d_pu_6_7_25_in out	600	2300	2100	1728	0 8885	8 65E-03	14 0
uniform_d_pu_7_6_10_in out	100	2400	2000	456	0 9397	2 23E-02	13 8
uniform_d_pu_7_6_11_in out	125	2400	2000	557	0 9511	1 92E-02	13 8
uniform_d_pu_7_6_12_in out	150	2400	2000	651	0 9558	1 69E-02	13 8
uniform_d_pu_7_6_13_in out	175	2400	2000	741	0 9562	1 54E-02	13 8
uniform_d_pu_7_6_14_in out	200	2400	2000	825	0 9553	1 42E-02	13 8
uniform_d_pu_7_6_15_in out	225	2400	2000	904	0 9516	1 34E-02	13 8
uniform_d_pu_7_6_16_in out	250	2400	2000	980	0 9476	1 26E-02	13 8
uniform_d_pu_7_6_17_in out	275	2400	2000	1051	0 9430	1 20E-02	13 8
uniform_d_pu_7_6_18_in out	300	2400	2000	1119	0 9390	1 14E-02	13 8
uniform_d_pu_7_6_19_in out	325	2400	2000	1183	0 9338	1 10E-02	13 8
uniform_d_pu_7_6_20_in out	350	2400	2000	1245	0 9283	1 07E-02	13 8
uniform_d_pu_7_6_21_in out	375	2400	2000	1303	0 9234	1 03E-02	13 8
uniform_d_pu_7_6_22_in out	400	2400	2000	1359	0 9192	1 00E-02	13 8
uniform_d_pu_7_6_23_in out	450	2400	2000	1463	0 9106	9 53E-03	13 7
uniform_d_pu_7_6_24_in out	500	2400	2000	1559	0 9011	9 19E-03	13 7
uniform_d_pu_7_6_25_in out	600	2400	2000	1727	0 8862	8 67E-03	13 7
uniform_d_pu_9_5_10_in out	100	2600	1900	446	0 9403	2 34E-02	13 2
uniform_d_pu_9_5_11_in out	125	2600	1900	545	0 9506	2 00E-02	13 2
uniform_d_pu_9_5_12_in out	150	2600	1900	638	0 9547	1 77E-02	13 2
uniform_d_pu_9_5_13_in out	175	2600	1900	726	0 9570	1 62E-02	13 2
uniform_d_pu_9_5_14_in out	200	2600	1900	809	0 9544	1 49E-02	13 3
uniform_d_pu_9_5_15_in out	225	2600	1900	888	0 9520	1 39E-02	13 3
uniform_d_pu_9_5_16_in out	250	2600	1900	962	0 9478	1 31E-02	13 3
uniform_d_pu_9_5_17_in out	275	2600	1900	1033	0 9429	1 25E-02	13 3
uniform_d_pu_9_5_18_in out	300	2600	1900	1100	0 9379	1 18E-02	13 3
uniform_d_pu_9_5_19_in out	325	2600	1900	1164	0 9341	1 13E-02	13 3
uniform_d_pu_9_5_20_in out	350	2600	1900	1225	0 9292	1 11E-02	13 3
uniform_d_pu_9_5_21_in out	375	2600	1900	1283	0 9237	1 08E-02	13 3
uniform_d_pu_9_5_22_in out	400	2600	1900	1338	0 9193	1 05E-02	13 3
uniform_d_pu_9_5_23_in out	450	2600	1900	1442	0 9101	9 95E-03	13 3
uniform_d_pu_9_5_24_in out	500	2600	1900	1537	0 9006	9 56E-03	13 4
uniform_d_pu_9_5_25_in out	600	2600	1900	1705	0 8866	8 93E-03	13 4

The input file `uniform_d_pu_9_5_13_in` is provided in Appendix C.

6.3.2 Horizontal Tanks

When spent cleaning solutions with oxalic acid are neutralized, plutonium and uranium will typically combine with oxalates and precipitate out in chemical compounds. Similarly, when spent cleaning solutions with nitric acid are neutralized, plutonium and uranium will typically combine with nitrates and precipitate out in chemical compounds. The MCNP calculations in this subsection only credit the presence of uranium, plutonium and water in the material compositions. This is conservative due to the fact that the model excludes the additional neutron absorbing elements present in the chemical compounds.

After the acid cleaning of a CFF, the material will be in (or transferred into) the SAST. The SAST is a horizontal cylindrical tank with elliptical dish ends. The SAST was designed with a 6 foot diameter and a straight side length of 20 feet (M-CLC-J-00088)[27]. Figure 13 depicts the side view of a standard horizontal tank utilized in this analysis. Figure 14 depicts the end view of the same standard horizontal tank. This standard horizontal tank analysis bounds all the horizontal process tanks such as the SAST and ASDT that may contain CFF cleaning solution.

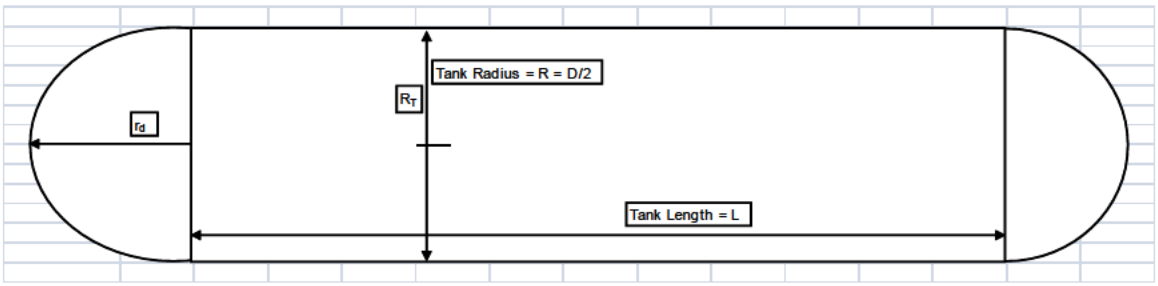


Figure 13: Horizontal Tank Side View

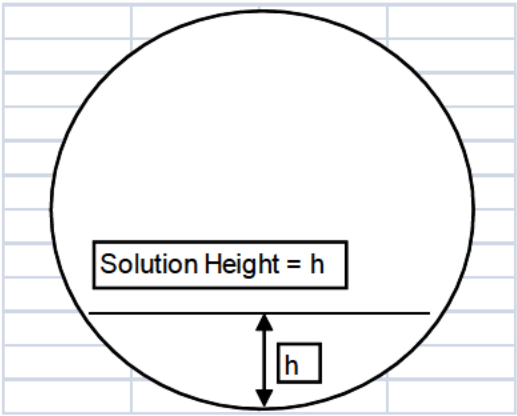


Figure 14: Horizontal Tank End View

The standard horizontal tank was modeled with a 6 foot diameter (dimension D in Figure 13) and variable straight side length (i.e., distance between flanges as noted by dimension L in Figure 13). The horizontal tank lengths investigated consisted of 44 in (3.7 ft), 50 in (4.2 ft), 90 in (7.5 ft), 143 in (11.9 ft), and 240 in (20 ft). This selection of tank lengths was determined to match or bound the tank lengths in SWPF. The radius of the dish (dimension r_d in Figure 13) was set equal to the diameter of the tank which was consistent with the design of the SAST (M-CLC-J-00088)[27].

The two ends of the tank were modeled as ellipsoids consistent with the design of the SAST (M-CLC-J-00088)[27]. Input to the model included the volume of water present in the tank and the fissile mass. The tank solution only modeled uranium oxide and water.

The height of the UO_2, PuO_2 and water solution in the horizontal tank was calculated by an iterative process. The total volume in the horizontal tank (V_t) is the sum of the volume in the cylinder (V_c) and in the elliptical ends (V_e). The volume of the horizontal cylinder and elliptical ends are represented in the following equations:

$V_e = \dfrac{\pi r h^2 (3R - h)}{3R}$	R = major ellipse radius (tank radius) r = minor ellipse radius (dish radius) h = center line height of solution in tank L = cylinder length
$V_c = L\left((h-R)\sqrt{(2R-h)h} + R^2 \cos^{-1}\left(1 - \dfrac{h}{R}\right)\right)$	

For a known total volume, it was possible to equate the ($V_t - V_e$) to the V_c to iterate on h to obtain a solution where the delta between the two sides of the equation was zero, thus indicating convergence on the value of h.

Various volumes of water (10 L – 1,000 L) were evaluated with incremental fissile mass values to produce the UO_2+PuO_2+H_2O mixture in the horizontal tank. The combined volume of UO_2, PuO_2 and water constituted the total volume in the tank. The uranium enrichment was 8% ^{235}U.

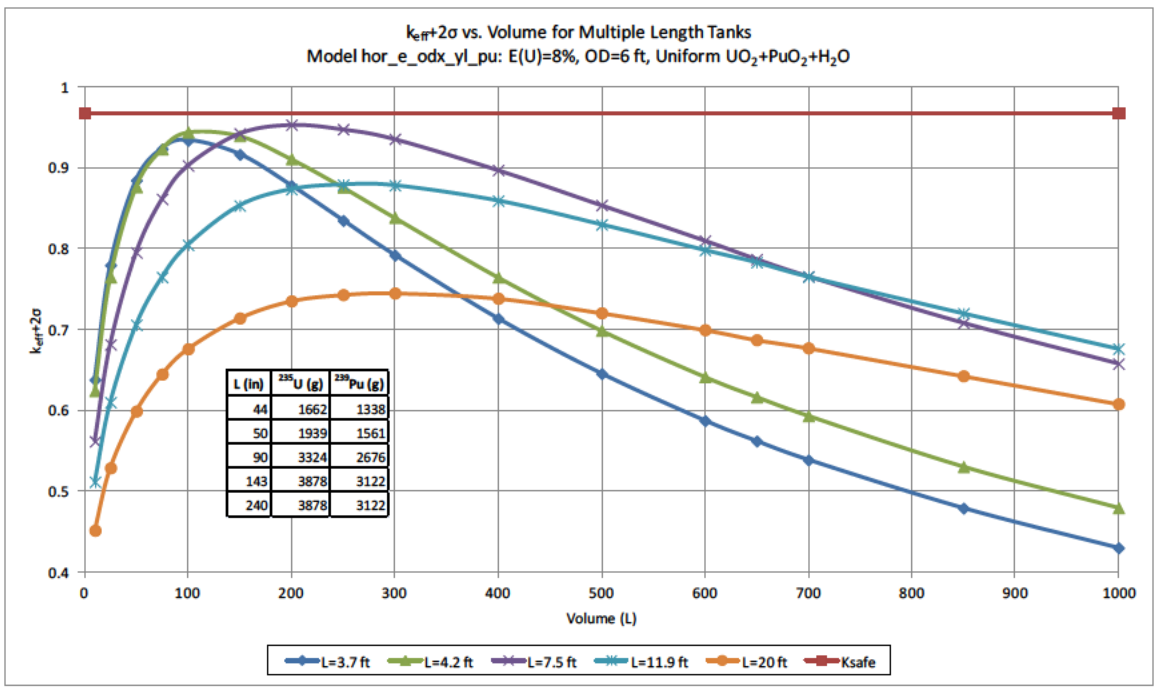


Figure 16: Horizontal Tank Results

Figure 16 presents the results of the horizontal tank analysis with the fissile contents of various fissile mass values. This figure demonstrates that the optimum concentration was analyzed and that the system remains subcritical for the lengths and mass values indicated in Figure 16. The fissile mass values were investigated in increments of CFF material at risk. Per Section 4.7 discussion, 277 g ^{235}U and 223 g ^{239}Pu was selected as the fissile material at risk due to acid cleaning CFF. Thus, the fissile mass values noted in Figure 16 were incremental multiples of these single CFF fissile mass values. The 20 ft tank length was of specific interest for the SAST and is consistent with the previous revision of this NCSE that only considered this tank length. Figure 16 indicates that 3.8 kg ^{235}U + 3.1 kg ^{239}Pu remain subcritical in that size tank. Table 18 provides the data for the results plotted in Figure 16 for the maximum curve.

Table 18: Horizontal Tank Results Data

File Name	Volume (L)	Center Line Solution Height (cm)	Density (g/cc)	H/X	$k_{eff}+2\sigma$	ANECF (MeV)	Validation X
hor_e_odx_yl_pu_20_10_5_3_in	10	1.78	5.56	24	0.5614	1.47E-01	13.6
hor_e_odx_yl_pu_20_11_5_3_in	25	3.27	2.82	90	0.6814	7.36E-02	13.6
hor_e_odx_yl_pu_20_12_5_3_in	50	5.17	1.91	199	0.7952	4.21E-02	13.6
hor_e_odx_yl_pu_20_13_5_3_in	75	6.76	1.61	308	0.8616	3.00E-02	13.6
hor_e_odx_yl_pu_20_14_5_3_in	100	8.17	1.45	418	0.9031	2.40E-02	13.6
hor_e_odx_yl_pu_20_15_5_3_in	150	10.69	1.30	636	0.9428	1.68E-02	13.6
hor_e_odx_yl_pu_20_16_5_3_in	200	12.94	1.23	855	**0.9536**	1.35E-02	13.6
hor_e_odx_yl_pu_20_17_5_3_in	250	15.01	1.18	1074	0.9480	1.15E-02	13.6
hor_e_odx_yl_pu_20_18_5_3_in	300	16.94	1.15	1292	0.9360	1.01E-02	13.6
hor_e_odx_yl_pu_20_19_5_3_in	400	20.52	1.11	1730	0.8974	8.31E-03	13.6
hor_e_odx_yl_pu_20_20_5_3_in	500	23.82	1.09	2167	0.8540	7.27E-03	13.6
hor_e_odx_yl_pu_20_21_5_3_in	600	26.92	1.07	2604	0.8101	6.72E-03	13.6
hor_e_odx_yl_pu_20_22_5_3_in	650	28.41	1.07	2823	0.7871	6.20E-03	13.6
hor_e_odx_yl_pu_20_23_5_3_in	700	29.87	1.06	3042	0.7658	6.05E-03	13.6
hor_e_odx_yl_pu_20_24_5_3_in	850	34.06	1.05	3698	0.7081	5.57E-03	13.6
hor_e_odx_yl_pu_20_25_5_3_in	1000	38.03	1.04	4354	0.6575	5.04E-03	13.6

The input file `hor_e_odx_yl_pu_20_16_5_3_in` is provided in Appendix C.

6.4 *Non-Uniform Settling*

The analysis in Sections 6.2 and 6.3 only considered uniform settling of material in a large tank. In this section, non-uniform settling analysis considered the potential for a lump of material to collect in one isolated region of the tank.

A fundamental assumption in the uniform settling analysis (Section 6.2 and 6.3) was a relatively level/flat surface of the solids layer across the tank bottom. In other words, the MST loaded with fissile material would settle out on the bottom of the tank and the top of the settling region would be relatively flat/level. The purpose of this section is to evaluate conditions in which the uniform settling assumption may not be valid.

The analysis of this section investigates the maximum subcritical mass of fissile material that may be confined within a hypothetical bounding non-uniform configuration in the bottom of a vertical processing tank (e.g., SSRT). The input provided in 00-700-20878[65] provided the following input assumption and basis:

> <u>Non-uniform accumulation in vertical process tanks</u>
>
> Assumption:
>
> Assume that potential non-uniform settling in the vertical process tanks is bounded by the geometries hypothetically associated with continuous operation a single APA pulse pot located at the outer wall of a vessel (a non-physical location). Hypothetical non-uniform geometries will be conservatively established by varying the effective cleaning radius of the pulse pot up to a

maximum of 0.5 feet less than the diameter of the vessel and assuming that all solids are simply collected into the volume outside of the cleaning radius where they settle stagnantly

Basis:

The NCSE should evaluate whether potential non-uniform distributions of settled solids on the floor of a vessel would result in a more conservative limit on the fissile contents than a uniform distribution.

Extensive testing of APAs during the various phases of this project has shown that no significant non-uniform distributions of solids will form during operation. Calculations and models have predicted and testing has demonstrated that the APAs mobilize the solids from the floor of a vessel, even after an extended period of settling.

The APA pulse pots are not physically located at the outer wall of a vessel to enable the solids movement hypothesized. This modeling selection is conservative. Extensive APA testing failed to physically produce the hypothetical solids behaviors that were conservatively assumed by modeling selections outside of the cleaning radius. Thus, the hypothetical solids geometries modeled are not considered credible. However, these provide a bounding estimate of potential non-uniform settling and should be analyzed to establish conservative limits on fissile contents.

This section utilizes a torus to produce a crescent shaped non-uniform distribution of MST and fissile solids in the bottom of a process tank per the input from 00-700-20878[65]. Per 00-700-20878[65], a bounding non-uniform distribution for MST solids in the bottom of a process tank would place the MST solids near the outer edge of the tank wall opposite some motive force. Thus, a torus was selected as a bounding approximation for the geometric distribution of solids in a process vessel.

For modeling purposes, a torus was centered at the union of the spherical dish tank bottom and the cylindrical tank wall. For the 9 foot diameter tank modeled, the vertical position of this point was z=-237.568 cm. To center the torus around the tank at this union point, the inner radius of the torus was set equal to the radius of the tank, R=137.16 cm. The radius of the torus (d) was varied from 0.5 ft to 4.0 ft. See Figure 17 for dimension references.

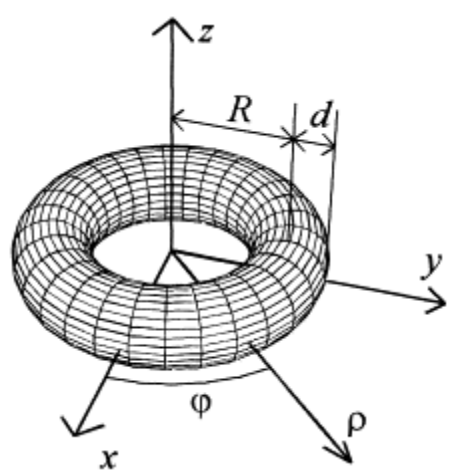


Figure 17: Torus Geometry Dimensions

A torus that fully circles the tank wall is not a reasonable model of non-uniform distribution of MST solids in the tank bottom as the motive force per 00-700-20878[65] pushes the solids toward the outer edge of the tank wall in one direction. A smaller section of a torus is required to approximate the reasonable geometric configuration. To model only a portion of the torus, a cylinder was selected to cut the torus. Modeling the solids accumulation in the positive x-direction, the cut cylinder was centered at the tank wall in the negative x-direction. The radius of the cut cylinder was varied from 50% to 98% of the tank diameter. The volume of the torus inside the cut cylinder was modeled as Nominal tank contents (per Table 10) minus the

CFF cleaning fissile mass. The volume of the torus outside the cut cylinder contained the MST solids including the precipitated fissile solids from acid cleaning the CFFs.

In Figure 18 the MCNP cell numbers are labeled. Cell 1 is the torus with the volume filled with MST solids at 0.2741 g/cc and loaded with the 5 strike data per Table 7. Incremental mass values of ^{235}U and ^{239}Pu were added to this mixture to determine the maximum fissile contribution allowed from CFF acid cleaning. Acid cleaning of the CFFs was the primary concern because this may result in the precipitation of fissile material based on process chemistry. Cell 2 is the settled MST solids collected from 7 AST-A batches of feed material. The feed material assumed was defined in the Inputs for Nominal in Table 9 except for the CFF cleaning fissile mass. Since the purpose of this analysis was to determine maximum fissile contribution allowed from CFF cleaning, the artificial addition of another CFF cleaning fissile mass was not appropriate. The height of the solution in Cell 2 was varied to account for the full volume of Cell 1 to maintain a minimum mass equal to 7 AST-A batches of feed material when the solution height covered the top of Cell 1. Cell 3 was void between the dish tank bottom and the concrete floor. Cell 4 was the 2 foot thick concrete that completely surrounded the tank. Cell 7 was the tank contents above the settled solids. This was modeled as 1 batch of AST-A feed concentration material without any MST.

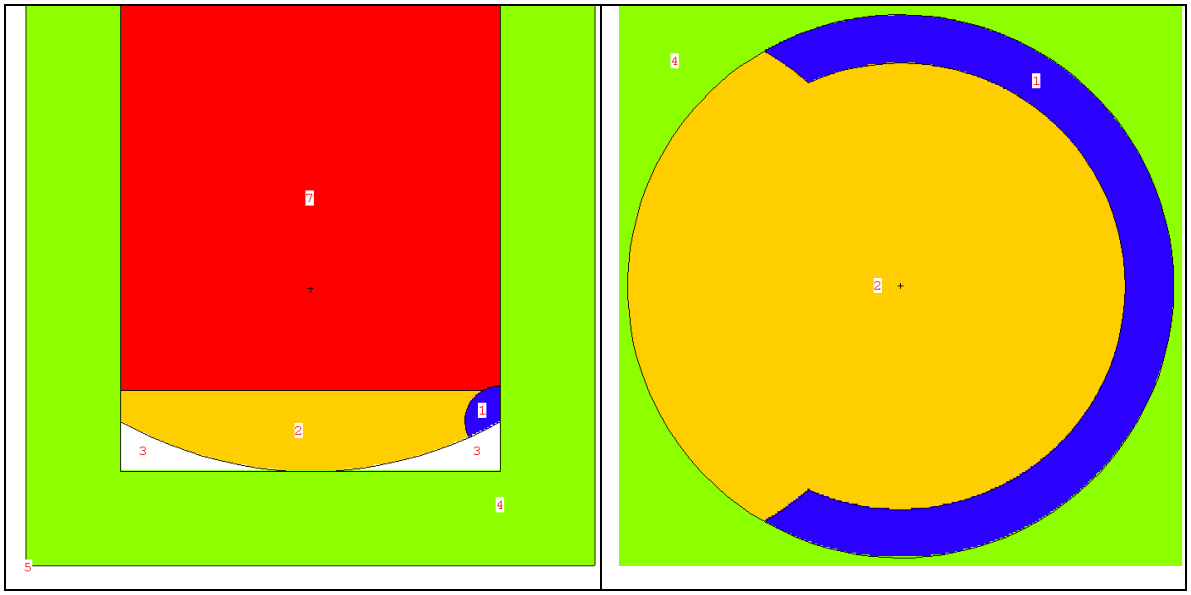


Figure 18: Torus Model by Cell

The resulting torus cut by the intersecting cylinder was a non-standard geometry. Thus, MCNP was used to calculate this volume of the torus outside the cut cylinder (Cell 1) for each torus and cut cylinder radii. Table 19 lists the volumes of the configurations evaluated.

Table 19: Non-uniform Settling Geometry Modeled Volume

Torus Radius (ft)	Cut Cylinder Fraction	Torus Volume (cc)	Torus Volume (L)	Torus Radius (ft)	Cut Cylinder Fraction	Torus Volume (cc)	Torus Volume (L)	Torus Radius (ft)	Cut Cylinder Fraction	Torus Volume (cc)	Torus Volume (L)
0 75	0 5	2 7956E+05	279 56	1 1	0 5	5 6895E+05	568 95	3	0 5	3 0562E+06	3056 20
0 75	0 6	2 4472E+05	244 72	1 1	0 6	4 9502E+05	495 02	3	0 6	2 5391E+06	2539 10
0 75	0 7	2 0596E+05	205 96	1 1	0 7	4 1222E+05	412 22	3	0 7	1 8872E+06	1887 20
0 75	0 75	1 8424E+05	184 24	1 1	0 75	3 6524E+05	365 24	3	0 75	1 4973E+06	1497 30
0 75	0 8	1 6006E+05	160 06	1 1	0 8	3 1218E+05	312 18	3	0 8	1 1076E+06	1107 60
0 75	0 85	1 3196E+05	131 96	1 1	0 85	2 4833E+05	248 33	3	0 85	7 3755E+05	737 55
0 75	0 88	1 1190E+05	111 90	1 1	0 88	1 9843E+05	198 43	3	0 88	5 3352E+05	533 52
0 75	0 89	1 0432E+05	104 32	1 1	0 89	1 7689E+05	176 89	3	0 89	4 6962E+05	469 62
0 75	0 9	9 6129E+04	96 13	1 1	0 9	1 5484E+05	154 84	3	0 9	4 0815E+05	408 15
0 75	0 91	8 7001E+04	87 00	1 1	0 91	1 3314E+05	133 14	3	0 91	3 4933E+05	349 33
0 75	0 92	7 6027E+04	76 03	1 1	0 92	1 1207E+05	112 07	3	0 92	2 9330E+05	293 30
0 75	0 93	6 3140E+04	63 14	1 1	0 93	9 1914E+04	91 91	3	0 93	2 4037E+05	240 37
0 75	0 94	5 0413E+04	50 41	1 1	0 94	7 2927E+04	72 93	3	0 94	1 9090E+05	190 90
0 75	0 96	2 7381E+04	27 38	1 1	0 96	3 9470E+04	39 47	3	0 96	1 0408E+05	104 08
0 75	0 98	9 5029E+03	9 50	1 1	0 98	1 3785E+04	13 79	3	0 98	3 6803E+04	36 80
1	0 5	4 7779E+05	477 79	1 5	0 5	9 9121E+05	991 21	4	0 5	4 5003E+06	4500 30
1	0 6	4 1644E+05	416 44	1 5	0 6	8 5584E+05	855 84	4	0 6	3 5807E+06	3580 70
1	0 7	3 4789E+05	347 89	1 5	0 7	7 0255E+05	702 55	4	0 7	2 5253E+06	2525 30
1	0 75	3 0913E+05	309 13	1 5	0 75	6 1419E+05	614 19	4	0 75	1 9867E+06	1986 70
1	0 8	2 6557E+05	265 57	1 5	0 8	5 1154E+05	511 54	4	0 8	1 4625E+06	1462 50
1	0 85	2 1381E+05	213 81	1 5	0 85	3 7335E+05	373 35	4	0 85	9 7194E+05	971 94
1	0 88	1 7506E+05	175 06	1 5	0 88	2 7364E+05	273 64	4	0 88	7 0320E+05	703 20
1	0 89	1 5916E+05	159 16	1 5	0 89	2 4139E+05	241 39	4	0 89	6 1913E+05	619 13
1	0 9	1 4040E+05	140 40	1 5	0 9	2 1008E+05	210 08	4	0 9	5 3826E+05	538 26
1	0 91	1 2108E+05	121 08	1 5	0 91	1 7991E+05	179 91	4	0 91	4 6089E+05	460 89
1	0 92	1 0211E+05	102 11	1 5	0 92	1 5101E+05	151 01	4	0 92	3 8722E+05	387 22
1	0 93	8 3852E+04	83 85	1 5	0 93	1 2364E+05	123 64	4	0 93	3 1761E+05	317 61
1	0 94	6 6579E+04	66 58	1 5	0 94	9 8036E+04	98 04	4	0 94	2 5249E+05	252 49
1	0 96	3 6040E+04	36 04	1 5	0 96	5 3150E+04	53 15	4	0 96	1 3794E+05	137 94
1	0 98	1 2561E+04	12 56	1 5	0 98	1 8648E+04	18 65	4	0 98	4 8903E+04	48 90
1 05	0 5	5 2258E+05	522 58	2	0 5	1 6200E+06	1620 00				
1 05	0 6	4 5508E+05	455 08	2	0 6	1 3835E+06	1383 50				
1 05	0 7	3 7957E+05	379 57	2	0 7	1 1113E+06	1111 30				
1 05	0 75	3 3680E+05	336 80	2	0 75	9 4874E+05	948 74				
1 05	0 8	2 8861E+05	288 61	2	0 8	7 3879E+05	738 79				
1 05	0 85	2 3101E+05	231 01	2	0 85	4 9864E+05	498 64				
1 05	0 88	1 8717E+05	187 17	2	0 88	3 6183E+05	361 83				
1 05	0 89	1 6829E+05	168 29	2	0 89	3 1860E+05	318 60				
1 05	0 9	1 4767E+05	147 67	2	0 9	2 7690E+05	276 90				
1 05	0 91	1 2713E+05	127 13	2	0 91	2 3694E+05	236 94				
1 05	0 92	1 0710E+05	107 10	2	0 92	1 9880E+05	198 80				
1 05	0 93	8 7889E+04	87 89	2	0 93	1 6279E+05	162 79				
1 05	0 94	6 9755E+04	69 76	2	0 94	1 2915E+05	129 15				
1 05	0 96	3 7756E+04	37 76	2	0 96	7 0175E+04	70 18				
1 05	0 98	1 3171E+04	13 17	2	0 98	2 4702E+04	24 70				

To aide in the visualization of the obscure geometric configuration created by cutting the torus with a cylinder, a selection of examples are provided in following figures with the elevation view on the left side and a plan view on the right.

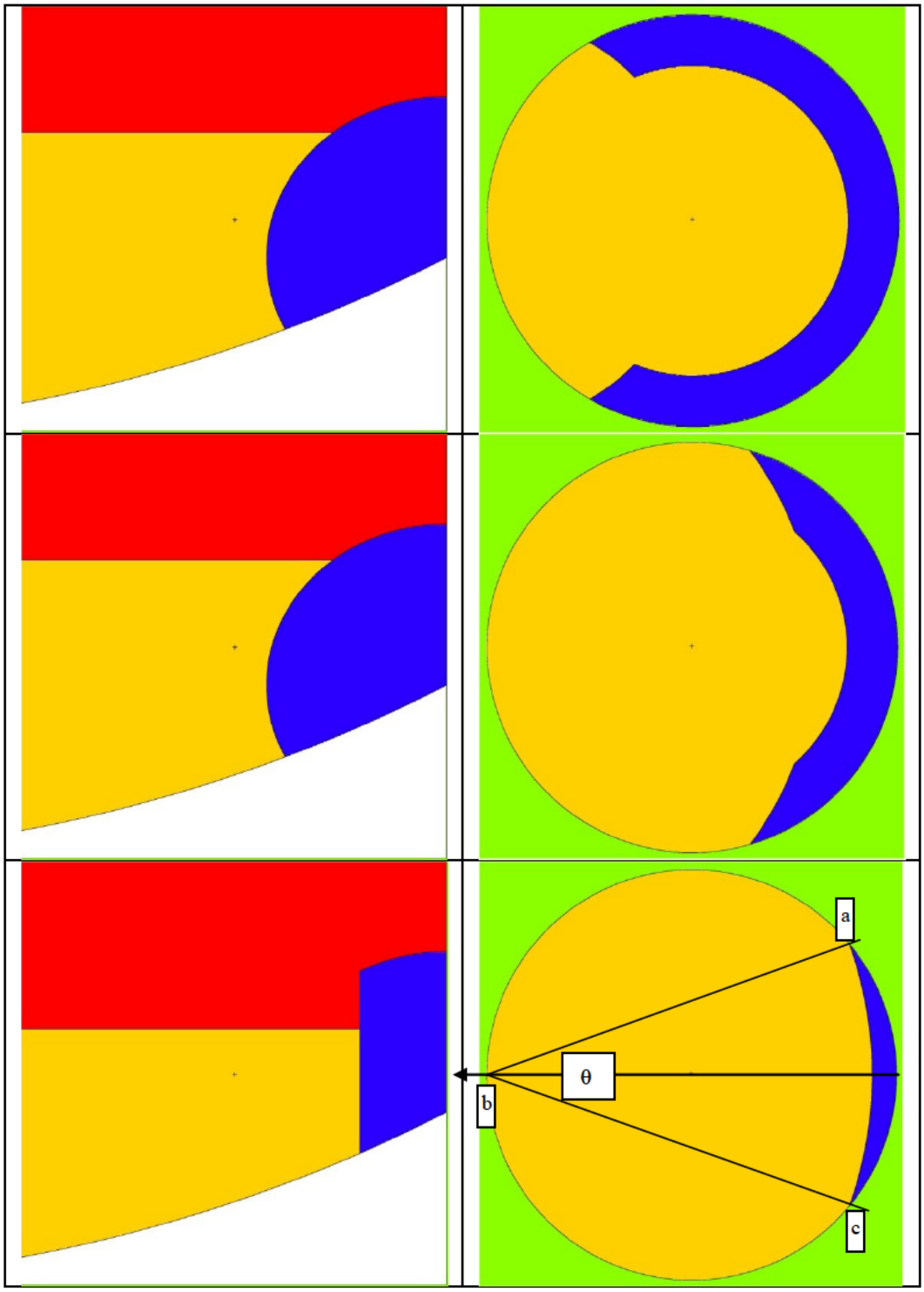


Figure 19: Torus R=1.0 ft with 50%, 80% and 94% Cut Cylinders

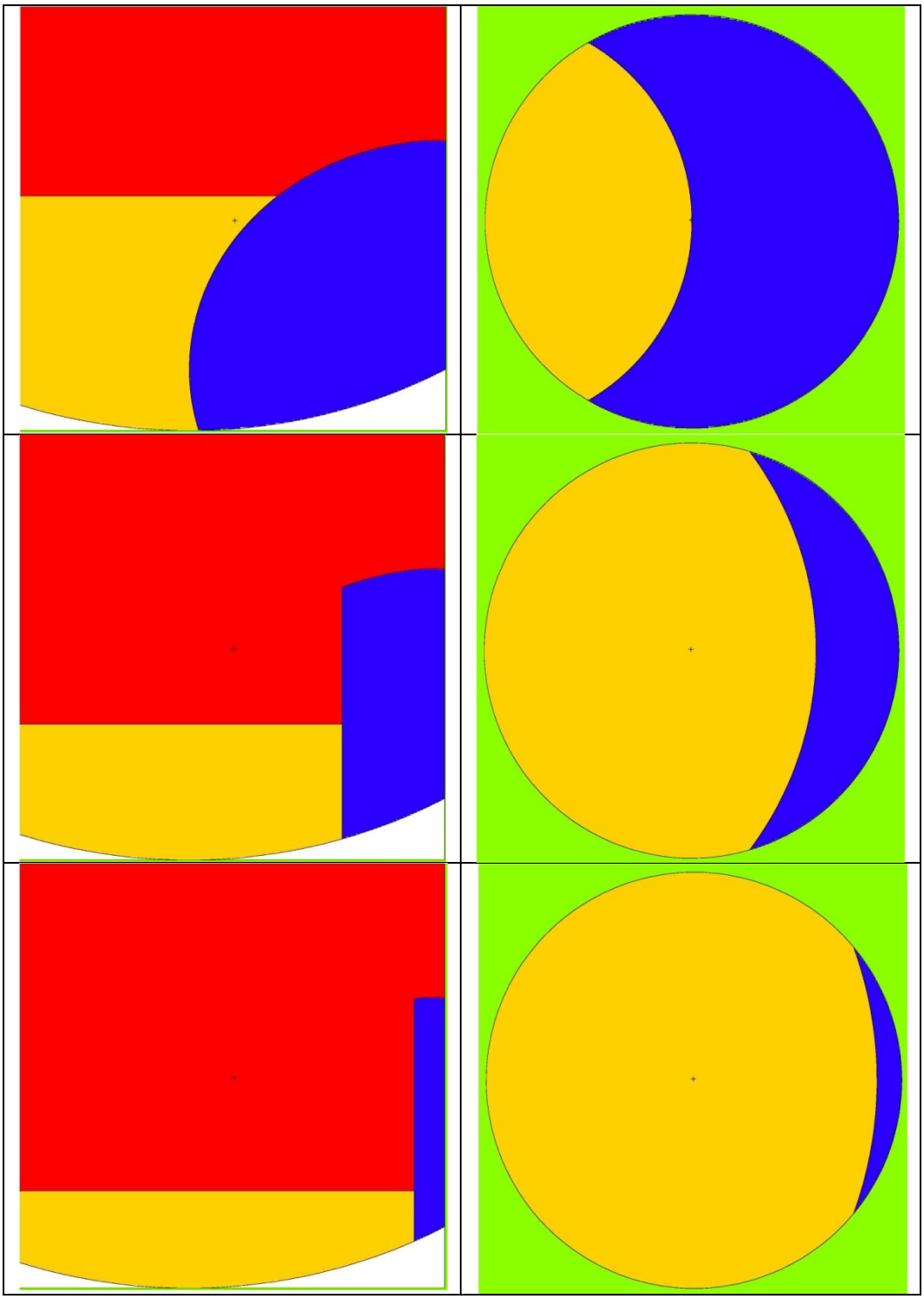


Figure 20: Torus R=4.0 ft with 50%, 80% and 94% Cut Cylinders

The fissile material placed in the volume defined by the torus cut by the cylinder (Cell 1 from Figure 18) had two components. First, the volume was assumed to be filled with MST solids at 0.2741 g/cc and loaded with the 5 strike data per Table 7. So as the volume varied, the concentration of fissile material due to MST solids remained constant. Second, a mass of ^{235}U solids was placed in the volume to account for the precipitation of fissile material due to acid cleaning of CFFs. The CFF mass was varied from 1-2 kg ^{235}U and 0.9-1.8 kg ^{239}Pu to determine the maximum mass allowed. It should be noted that the acid cleaning loop volume is between 900-1000 gallons. So for each filter cleaning operation, 900-1000 gallons

of cleaning solution will be deposited in either the ASDT or SAST. The working volume of these two tanks is approximately 4100 gallons, so the cleaning solution from only four CFFs will fit in one of the horizontal tanks thus limiting the maximum single transfer to a vertical process tank. The results are depicted in Figure 21.

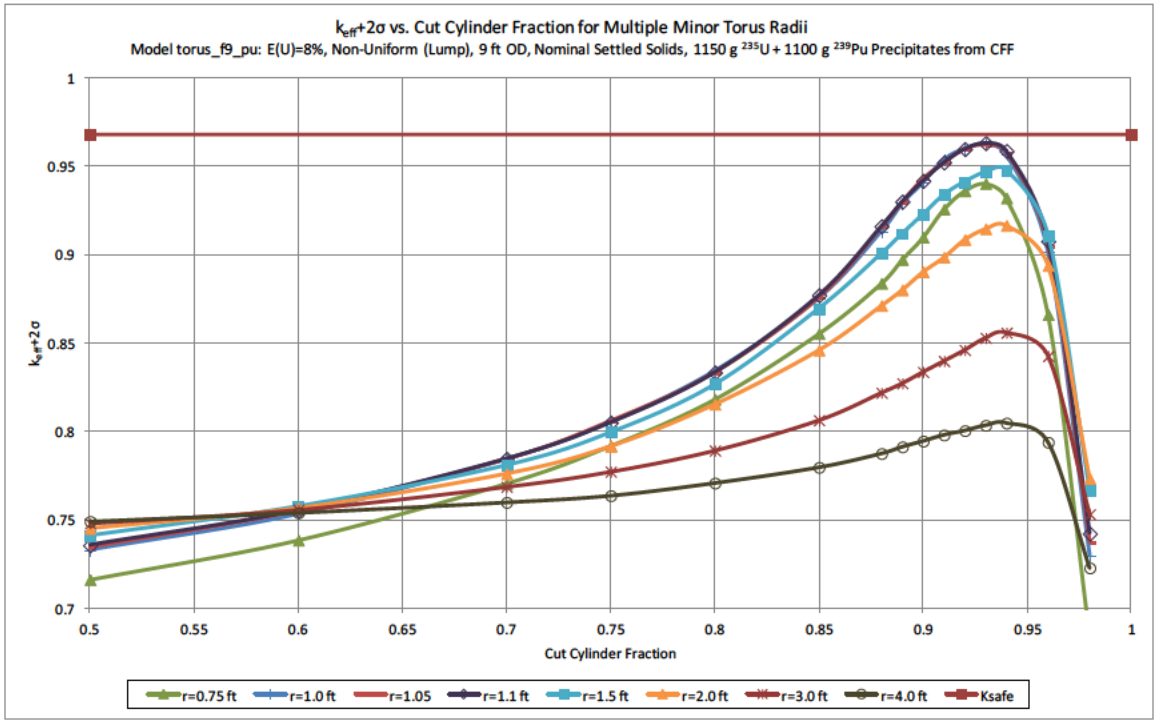


Figure 21: Torus Model Results with 1.15 kg ^{235}U plus 1.1 kg ^{239}Pu from CFF Acid Cleaning

Figure 21 depicts the model results for 1.15 kg ^{235}U plus 1.1 kg ^{239}Pu in various torus radii over the range of cut cylinder fractions analyzed. Figure 21 demonstrates that an optimum concentration exists in the 0.9 to 0.95 range of the cut cylinder fraction and that the 1 foot radius was the bounding torus dimension. Based on these results, 1.15 kg ^{235}U plus 1.1 kg ^{239}Pu from CFF cleaning and in the geometry configurations analyzed is the maximum fissile mass that has a system $k_{eff}+2\sigma$ demonstrated to remain below k_{safe}.

Table 20 provides the data for three of the torus radii results depicted in Figure 21 with the highest $k_{eff}+2\sigma$ values. The geometric parameter referenced as "θ" in Table 20 was not previously discussed, but is depicted in Figure 19 and is included for reference. The θ parameter is the angle defined by lines through the following points: a) the intersection of the cut cylinder with the tank wall in the +y direction; b) the intersection of the x-axis with the tank wall in the –x direction; and c) the intersection of the cut cylinder with the tank wall in the –y direction. Angle θ is opposite the secant line connecting points *a* and *c*. Thus, θ provides an indication of how wide spread the lump is around the tank.

Table 20: Torus Model Results Data for 1.15 kg ^{235}U plus 1.1 kg ^{239}Pu from CFF Acid Cleaning

File Name	Torus Radius (ft)	Torus Volume (L)	Cut Cylinder Fraction	Radius of Cut Cylinder (cm)	θ (deg)	H/X	Keff+2σ	ANECF	Validation X
torus_f9_pu_15_10_10_11_in out	1	477 79	0 5	137 16	120 0	2141	0 7326	7 57E-03	14 0
torus_f9_pu_15_11_10_11_in out	1	416 44	0 6	164 59	106 3	2014	0 7529	7 86E-03	14 1
torus_f9_pu_15_12_10_11_in out	1	347 89	0 7	192 02	91 1	1846	0 7841	8 17E-03	14 1
torus_f9_pu_15_13_10_11_in out	1	309 13	0 75	205 74	82 8	1735	0 8051	8 53E-03	14 1
torus_f9_pu_15_14_10_11_in out	1	265 57	0 8	219 46	73 7	1594	0 8341	8 94E-03	14 2
torus_f9_pu_15_15_10_11_in out	1	213 81	0 85	233 17	63 6	1399	0 8754	9 50E-03	14 2
torus_f9_pu_15_16_10_11_in out	1	175 06	0 88	241 40	56 7	1227	0 9132	1 04E-02	14 3
torus_f9_pu_15_17_10_11_in out	1	159 16	0 89	244 14	54 3	1149	0 9288	1 09E-02	14 3
torus_f9_pu_15_18_10_11_in out	1	140 4	0 9	246 89	51 7	1051	0 9409	1 15E-02	14 3
torus_f9_pu_15_19_10_11_in out	1	121 08	0 91	249 63	49 0	941	0 9538	1 23E-02	14 3
torus_f9_pu_15_20_10_11_in out	1	102 11	0 92	252 37	46 1	825	0 9601	1 36E-02	14 4
torus_f9_pu_15_21_10_11_in out	1	83 852	0 93	255 12	43 1	703	**0.9627**	1 53E-02	14 4
torus_f9_pu_15_22_10_11_in out	1	66 579	0 94	257 86	39 9	578	0 9565	1 79E-02	14 4
torus_f9_pu_15_23_10_11_in out	1	36 04	0 96	263 35	32 5	330	0 9014	2 78E-02	14 5
torus_f9_pu_15_24_10_11_in out	1	12 561	0 98	268 83	23 0	111	0 7295	6 43E-02	14 6
torus_f9_pu_16_10_10_11_in out	1 05	522 58	0 5	137 16	120 0	2223	0 7342	7 39E-03	14 0
torus_f9_pu_16_11_10_11_in out	1 05	455 08	0 6	164 59	106 3	2096	0 7549	7 57E-03	14 1
torus_f9_pu_16_12_10_11_in out	1 05	379 57	0 7	192 02	91 1	1928	0 7841	8 05E-03	14 1
torus_f9_pu_16_13_10_11_in out	1 05	336 8	0 75	205 74	82 8	1816	0 8057	8 35E-03	14 1
torus_f9_pu_16_14_10_11_in out	1 05	288 61	0 8	219 46	73 7	1671	0 8332	8 63E-03	14 2
torus_f9_pu_16_15_10_11_in out	1 05	231 01	0 85	233 17	63 6	1468	0 8757	9 36E-03	14 2
torus_f9_pu_16_16_10_11_in out	1 05	187 17	0 88	241 40	56 7	1284	0 9155	1 02E-02	14 3
torus_f9_pu_16_17_10_11_in out	1 05	168 29	0 89	244 14	54 3	1195	0 9296	1 07E-02	14 3
torus_f9_pu_16_18_10_11_in out	1 05	147 67	0 9	246 89	51 7	1090	0 9428	1 12E-02	14 3
torus_f9_pu_16_19_10_11_in out	1 05	127 13	0 91	249 63	49 0	977	0 9519	1 21E-02	14 3
torus_f9_pu_16_20_10_11_in out	1 05	107 1	0 92	252 37	46 1	857	0 9599	1 32E-02	14 4
torus_f9_pu_16_21_10_11_in out	1 05	87 889	0 93	255 12	43 1	731	**0.9620**	1 50E-02	14 4
torus_f9_pu_16_22_10_11_in out	1 05	69 755	0 94	257 86	39 9	602	0 9579	1 74E-02	14 4
torus_f9_pu_16_23_10_11_in out	1 05	37 756	0 96	263 35	32 5	345	0 9049	2 69E-02	14 5
torus_f9_pu_16_24_10_11_in out	1 05	13 171	0 98	268 83	23 0	117	0 7372	6 18E-02	14 6
torus_f9_pu_17_10_10_11_in out	1 1	568 95	0 5	137 16	120 0	2299	0 7355	7 29E-03	14 0
torus_f9_pu_17_11_10_11_in out	1 1	495 02	0 6	164 59	106 3	2174	0 7552	7 56E-03	14 0
torus_f9_pu_17_12_10_11_in out	1 1	412 22	0 7	192 02	91 1	2005	0 7843	7 69E-03	14 1
torus_f9_pu_17_13_10_11_in out	1 1	365 24	0 75	205 74	82 8	1892	0 8049	7 95E-03	14 1
torus_f9_pu_17_14_10_11_in out	1 1	312 18	0 8	219 46	73 7	1744	0 8333	8 39E-03	14 1
torus_f9_pu_17_15_10_11_in out	1 1	248 33	0 85	233 17	63 6	1533	0 8771	9 06E-03	14 2
torus_f9_pu_17_16_10_11_in out	1 1	198 43	0 88	241 40	56 7	1334	0 9161	9 77E-03	14 2
torus_f9_pu_17_17_10_11_in out	1 1	176 89	0 89	244 14	54 3	1236	0 9301	1 03E-02	14 3
torus_f9_pu_17_18_10_11_in out	1 1	154 84	0 9	246 89	51 7	1127	0 9418	1 09E-02	14 3
torus_f9_pu_17_19_10_11_in out	1 1	133 14	0 91	249 63	49 0	1011	0 9523	1 19E-02	14 3
torus_f9_pu_17_20_10_11_in out	1 1	112 07	0 92	252 37	46 1	887	0 9598	1 30E-02	14 4
torus_f9_pu_17_21_10_11_in out	1 1	91 914	0 93	255 12	43 1	758	**0.9632**	1 46E-02	14 4
torus_f9_pu_17_22_10_11_in out	1 1	72 927	0 94	257 86	39 9	625	0 9587	1 67E-02	14 4
torus_f9_pu_17_23_10_11_in out	1 1	39 47	0 96	263 35	32 5	360	0 9076	2 60E-02	14 5
torus_f9_pu_17_24_10_11_in out	1 1	13 785	0 98	268 83	23 0	123	0 7421	5 93E-02	14 6

The input file `torus_f9_pu_17_21_10_11_in` is provided in Appendix C.

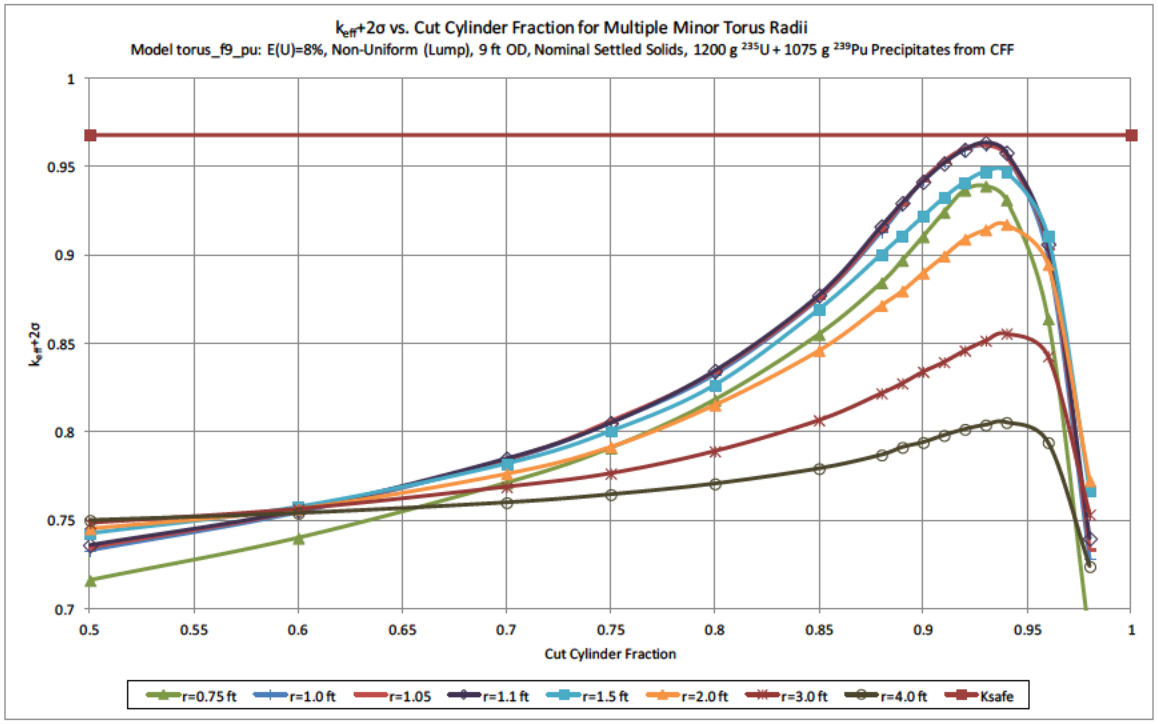


Figure 22: Torus Model Results with 1.2 kg ^{235}U plus 1.075 kg ^{239}Pu from CFF Acid Cleaning

Figure 22 depicts the model results for 1.2 kg ^{235}U plus 1.075 kg ^{239}Pu in various torus radii over the range of cut cylinder fractions analyzed. Figure 21 demonstrates that an optimum concentration exists in the 0.9 to 0.95 range of the cut cylinder fraction and that the 1 foot radius was the bounding torus dimension. Based on these results, 1.2 kg ^{235}U plus 1.075 kg ^{239}Pu from CFF cleaning and in the geometry configurations analyzed is the maximum fissile mass that has a system k_{eff}+2σ demonstrated to remain below k_{safe}. Table 21 provides the data for the bounding curve in Figure 22.

Table 21: Torus Model Results Data for 1.2 kg ^{235}U plus 1.075 kg ^{239}Pu from CFF Acid Cleaning

File Name	Torus Radius (ft)	Torus Volume (L)	Cut Cylinder Fraction	Radius of Cut Cylinder (cm)	θ (deg)	H/X	Keff+2σ	ANECF	Validation X
torus_f9_pu_17_10_11_10_in out	1 1	569	0 5	137 16	120 0	2288	0 7357	7 36E-03	13 9
torus_f9_pu_17_11_11_10_in out	1 1	495	0 6	164 59	106 3	2163	0 7555	7 54E-03	13 9
torus_f9_pu_17_12_11_10_in out	1 1	412 2	0 7	192 02	91 1	1994	0 7847	8 00E-03	13 9
torus_f9_pu_17_13_11_10_in out	1 1	365 2	0 75	205 74	82 8	1881	0 8049	8 37E-03	13 9
torus_f9_pu_17_14_11_10_in out	1 1	312 2	0 8	219 46	73 7	1734	0 8344	8 58E-03	13 9
torus_f9_pu_17_15_11_10_in out	1 1	248 3	0 85	233 17	63 6	1522	0 8772	9 18E-03	14 0
torus_f9_pu_17_16_11_10_in out	1 1	198 4	0 88	241 40	56 7	1324	0 9162	1 01E-02	14 0
torus_f9_pu_17_17_11_10_in out	1 1	176 9	0 89	244 14	54 3	1226	0 9294	1 05E-02	14 0
torus_f9_pu_17_18_11_10_in out	1 1	154 8	0 9	246 89	51 7	1118	0 9415	1 13E-02	14 0
torus_f9_pu_17_19_11_10_in out	1 1	133 1	0 91	249 63	49 0	1002	0 9518	1 20E-02	14 1
torus_f9_pu_17_20_11_10_in out	1 1	112 1	0 92	252 37	46 1	879	0 9596	1 32E-02	14 1
torus_f9_pu_17_21_11_10_in out	1 1	91 91	0 93	255 12	43 1	751	**0.9635**	1 49E-02	14 1
torus_f9_pu_17_22_11_10_in out	1 1	72 93	0 94	257 86	39 9	619	0 9579	1 73E-02	14 1
torus_f9_pu_17_23_11_10_in out	1 1	39 47	0 96	263 35	32 5	355	0 9061	2 68E-02	14 2
torus_f9_pu_17_24_11_10_in out	1 1	13 79	0 98	268 83	23 0	121	0 7395	6 09E-02	14 2

6.5 *Cross-Flow Filters*

The sintered metal CFFs separate the salt solution from the sludge and solids. The process these filters serve is described in Section 2.2.4. The filtering region of the filters is approximated by a right circular cylinder with a 23.06 cm (9.08 inch) radius that is 304.8 cm (10 ft) in length (see Drawings 1883-002-6002-04-WA-E, *Cross Flow Filter Tubesheet*[58] and 1883-002-6006-01-DD-C, *Cross flow Filter Tubesheet Filter Tube Weldment*[59]). The center of the filter was modeled with 10.8 cm (4.25 inch) radius over the entire length of the filter tube assembly that surrounds the inlet (Drawing 1883-002-6002-01-WA-E). According to drawing 1883-002-1001-01-WA-E, *Cross Flow Filters FLT-104 Filter Housing Weldment*[60] the nominal inner diameter of the shell containing the filter tube assembly is 26 inches (66.04 cm) with a 0.5 inch (1.27 cm) wall thickness. Conservatively, the wall thickness and composition was omitted from the MCNP models to remove an absorber, and 0.5 inch was added to the shell diameter to increase fissile volume resulting in a shell diameter of 67.31 cm (26.5 inches).

According to Drawing 1883-002-6003-02-DD-E, *Cross Flow Filter Tubesheet Upper Tubesheet Weldment*[61], there are 234 sintered metal tubes in each CFF. The tubes are ½" nominal outer diameter (OD). Drawing 1883-002-6006-01-DD-C[59] indicates that the wall thickness of the sintered metal tubes is 0.065". These tubes are arranged in a triangular pitch pattern with a 0.75" center-to-center (CTC) spacing. Based on the nominal OD and the CTC spacing, the nominal surface-to-surface (STS) spacing between the tubes is approximately 0.75" – 0.5" = 0.25" (0.63 cm).

The MCNP models in the following sections assume ½" OD filter tubes with half wall thickness (0.065"/2 = 0.0325") for the sintered metal tubes when analyzing material inside the tubes. The models assume the filter tubes to have an ID of 0.435" (0.5" – 2*0.0325"). The tube walls were modeled with half density (3.96 g/cc) SS 316L. Thus, the STS values specified are the distance of one tube to the surface of the closest tube(s). Due to these conservative modeling decisions, variations on the diameter of the tube were not investigated. Section 6.5.1 evaluates MCNP models of the triangular pitch tubes and developed a relationship between the STS spacing and the number of tubes in a model.

Based on the access holes in the operating deck shown in P-PA-J-00251, *SWPF Process Building Piping Central Process Area Plan at El 139'-0*[62], the CFFs are a minimum of 3.9 feet (118 cm) apart STS. The CFFs are suspended in the cell below the access holes. Nominal piping and steel supports are the only neutron reflecting materials near the installed location of the CFFs. Two CFFs were modeled side by side with close reflection from two feet of concrete on top, bottom, and two sides. As discussed in Section 6.5.4, the tubes of multiple CFFs will not completely plug, thus the external location of the two CFFs in close contact with each other was conservative.

Two basic internal material configurations were considered for the analysis of the CFFs. First, the sintered metal tubes were considered to plug such that the MST solids filled the tube volume (Section 6.5.2). This condition is not considered credible per 00-700-20878[65]. However, it is analyzed here as a hypothetical bounding condition. No credit is taken for the time (duration) of this activity so a full range of H/X values were covered by varying the volume fraction (VF) of water in the tube volume. As water was removed from the model, the volume occupied by the remaining material decreased.

The second internal material configuration considered for the analysis assumed that one or more sintered metal tubes failed, thus allowing the MST solids on the shell side of the CFF (Section 6.5.3). Furthermore, it was assumed that none of the MST solids would leave the CFF. This condition is not considered credible per 00-700-20878[65]. However, it is analyzed here as a hypothetical bounding condition. Whereas the tube side of the CFF will gravity drain out of the CFF when the pumps are turned off, the tube side was not analyzed with MST solids. No credit is taken for the time (duration) of this activity so a full range of H/X values were covered by varying the VF of water in the volume available. As water was removed from the model, the volume occupied by the remaining material decreased.

The following sections do not credit two significant conditions that each would reduce the calculated k_{eff} values. These non-credited conditions are presented here once as they may be referenced frequently by the contingency analysis in Section 5.

- Non-fissile solids are in the sludge material that passes through the filter tubes with fissile solids. A portion of the solids in the feed may be fissile material but is limited to maximum WAC values set in Section 7. The quantity of non-fissile solids is not controlled, and therefore not credited in the

following sections, however it is likely that any real accumulation of fissile material will be diluted with these solids

- Neutron absorption in the steel construction material (not including the filter tubes) of the CFF is ignored. Some credit was taken for the material composition and space occupied by the filter tubes, but none was taken for the construction material such as walls and tube supports. The iron in the steel construction material of the CFF is a neutron poison. However, the absence of this material from the models is conservative.

Therefore, any real accumulation of MST with fissile material in a CFF will have k_{eff} values less than those calculated in the following sections.

6.5.1 CFF Tubes and Spacing

Figure 23 depicts the spacing analyzed between the sintered metal tubes in the CFF. Figure 23 is not drawn to scale. Given that the tubes on the left have the same diameter as those on the right, Figure 23 shows that the various STS spacing values analyzed were achieved by varying the size of the cell containing the tube.

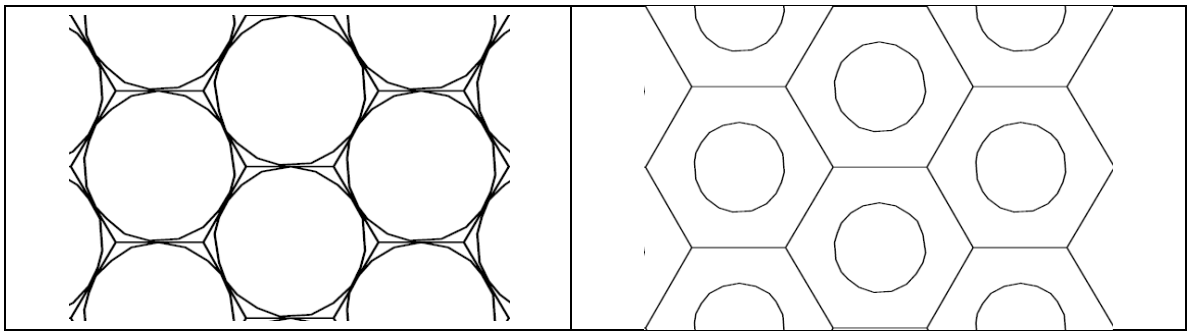


Figure 23: Tube Spacing

By varying the STS spacing between the filter tubes while maintaining the thickness of annulus and filter tube diameter as constants, the number of filter tubes in the model varied. Figure 24 provides a few examples of how the number of filter tubes in the model varied with the STS spacing based on visual inspection of the model. Figure 24 also provides a third order polynomial fit to the five data points collected so that the number of filter tubes can be estimated for any STS value in the range analyzed.

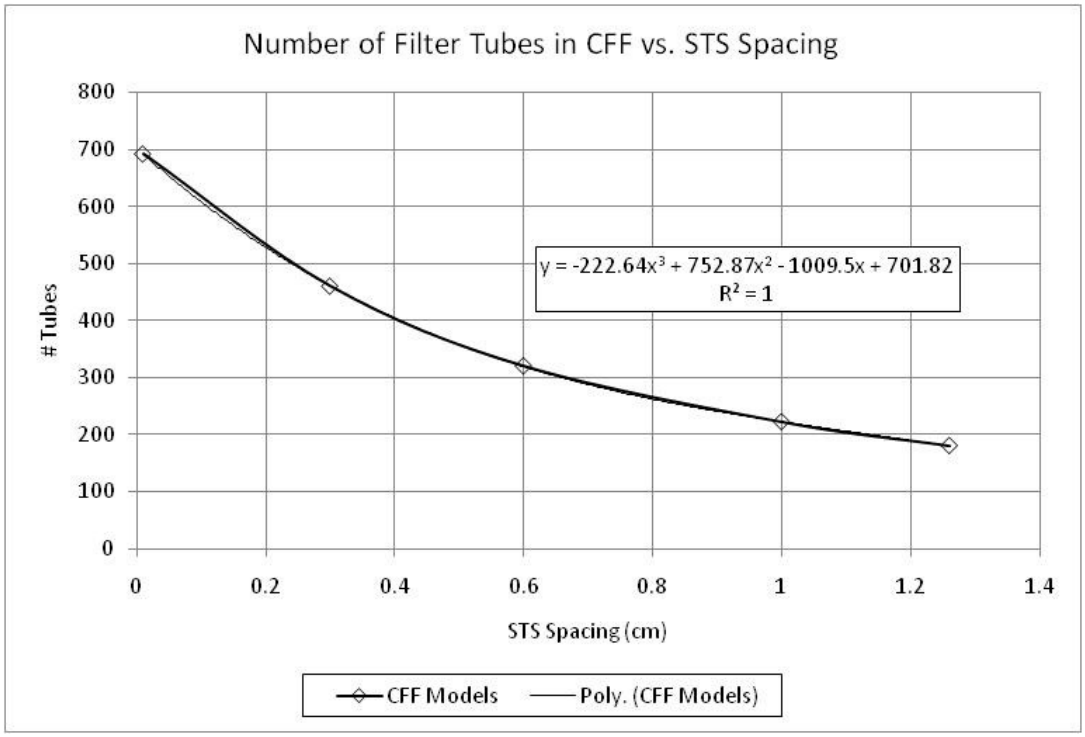


Figure 24: Number of Filter Tubes by STS Spacing

Figure 24 depicts how the number of filter tubes analyzed in a CFF vary as a function of the STS spacing between the filter tubes. Figure 24 demonstrates that the number of filter tubes analyzed in the model conservatively bounds the 234 that are in the filter by design. Table 22 provides the data depicted in Figure 24 and utilizes the curve fit equation to estimate the STS spacing when 234 tubes would be present in the model.

Table 22: Tubes Per CFF

STS (cm)	Counted Tubes	Poly Trend
0.01	692	692
0.3	460	461
0.6	320	319
1	222	223
1.26	180	180
0.9357		234

6.5.2 Tubes Filled with Solids

For this analysis two parameters were varied. First, the VF of water in the tubes was varied from 0.01 to 1.0. The volume fraction is simply a density multiplier and effectively alters the H/X in the material through a full range to account for the material drying out. The second parameter varied for this analysis was the surface-to-surface (STS) spacing between the sintered metal tubes. The STS spacing was varied from 0.01 cm to a maximum of 1.26 cm. This minimum value was selected to approximate the tubes touching each other. The maximum STS spacing value was selected as it was double the design value of 0.63 cm. This design provides for 234 tubes in the filter.

The filter model filled the sintered metal tubes with MST at a density of 0.2741 g/cc per the discussion in Section 4.6.3.

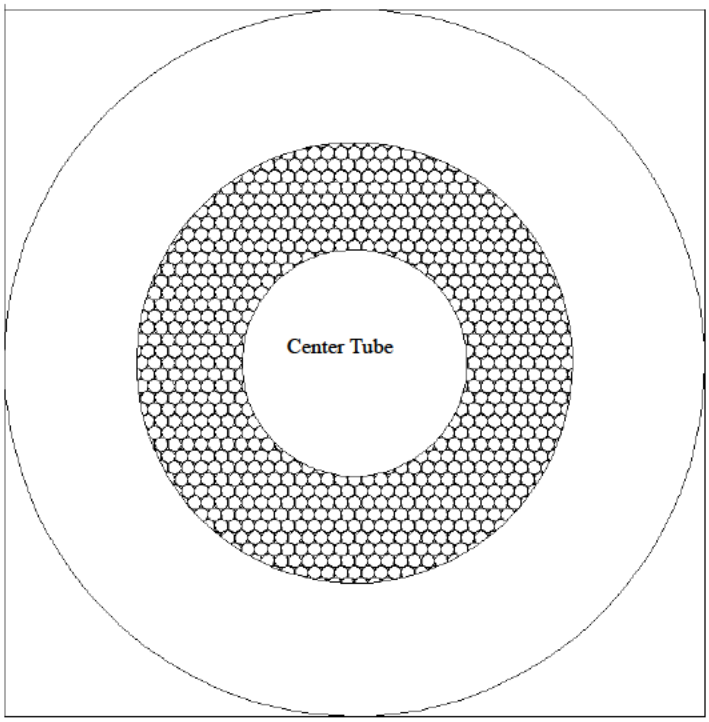


Figure 25: Cross-Section of CFF Analyzed

The model analyzed consisted of one CFF in a concrete corner where both walls were 2 feet thick and another CFF was touching it. The opposite two walls of the room were also modeled with 2 feet thick concrete. Two feet of concrete reflection was modeled above and below both filters. Figure 26 depicts the layout of the two filters in relation to the concrete reflection and their position in the room. Section 6.5.4 provides the justification that multiple CFFs will not plug simultaneously, thus the modeling of two side by side CFFs is conservative. The MST and water mixture filled all of the filter tubes in the space available to conservatively simulate plugging the filter.

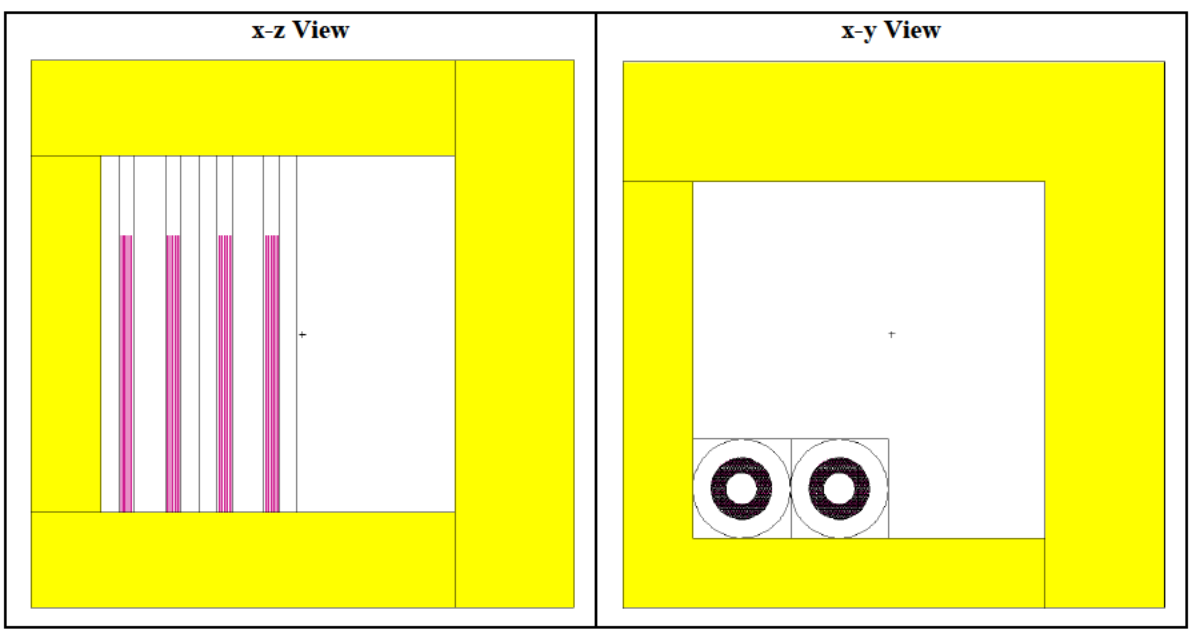


Figure 26: Filter Model Layout

Void was modeled outside the filter tubes on the shell side of the filter assembly. This configuration is appropriate because the sintered metal filter tubes are a semi-permeable membrane that allows liquid to flow in the direction of the pressure gradient. Once the pumps are turned off the primary motive force is

eliminated and the filter will begin to gravity drain. It is physically impossible for the material inside the sintered metal filter tubes to dry out until all the liquid on the shell side has drained. This may occur by liquid draining back through the sintered metal tube walls and traversing the length of the filter tube necessary to exit the filter through the bottom feed or drain line (Drawing 1883-002-6002-01-WA-E)[58] or through the drain valve on the shell side of the filter.

Void was modeled in the center tube. The center tube gravity drains out of the CFF when the motive force (pumps) is terminated.

The filter model removed water from the mixture which increased the MST and fissile concentration in the filter tubes above the starting value. As the amount of water in the mixture approached zero, the MST concentration approached its maximum theoretical density of 2.765 g/cc. As the MST concentration in the tubes increased, the volume occupied by the MST decreased. Thus, the mixture level in the filter tubes was decreased to account for the settling of MST in the tubes. Void was modeled above the MST mixture because if water were present in the tubes or in the shell, the MST could not dry out due to the tubes being made of sintered metal. Note that assuming the material slumps to the bottom is very conservative because if a filter were to plug, it is expected that the MST solids would remain adhered to the tube walls as it dried.

The filter model varied the STS spacing between the sintered metal tubes from 0.01 cm to 1.26 cm. The filter tubes were modeled as right circular cylinders with a diameter of 0.5" (1.27 cm) and half wall thickness consisting of half density SS 316L. The tubes were modeled with a length of 10 foot. The filter tube sheet design indicates the individual filter tubes have a larger diameter at the top and bottom connection points, and at the weld points along the length of the tube (Drawing 1883-002-6002-01-WA-E)[58]. This increase in OD does not affect the ID and therefore was ignored in the STS calculations.

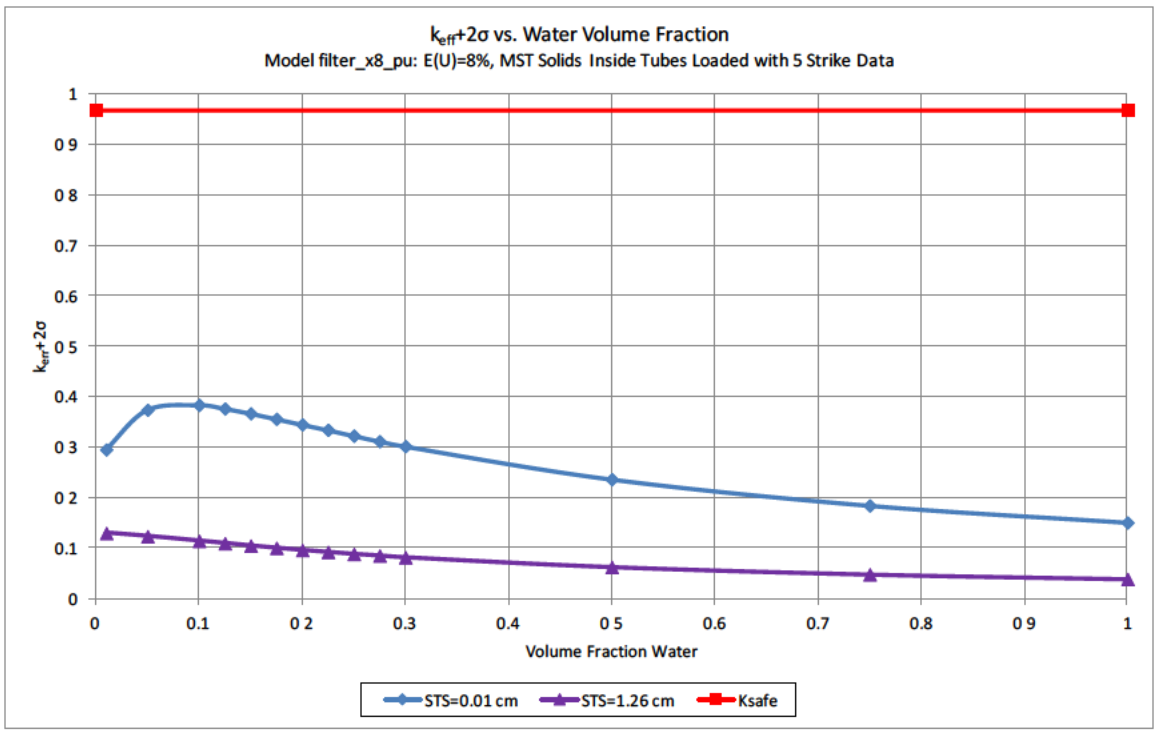


Figure 27: Results for MST in Filter Tubes with E(U)= 8%

Figure 27 presents the MCNP calculation results for 8 wt.% ^{235}U. Figure 27 demonstrates that even if the filter tubes were touching (STS=0.01 cm), the system will remain subcritical (below k_{safe}) for all material concentrations. Based on the results presented above, the 8 wt.% ^{235}U enrichment limit ensures the cross flow filter remains subcritical regardless of the STS spacing of the filter tubes or how long a (hypothetically assumed) plugged filter is allowed to dry out. Furthermore, there are no restrictions on the installed or handling spacing between cross flow filters or between cross flow filters and reflection for the installed location. The reflection conditions analyzed in the model sufficiently bound any hypothesized during operation.

Table 23 contains the results data for the 0.01 cm STS spacing series. This series is bounding for the design of the cross flow filter in this analysis because it results in the most MST and fissile material in the CFF. The data in Table 23 was plotted in Figure 27. Each filter tube contained 109.93 g MST at a density of 0.2741 g/cc per the discussion in Section 4.6.3 and the uranium enrichment was 8% ^{235}U. The resulting height of the MST solids in the tubes was reported in the Height column.

Table 23. Results Data for Material Inside CFF Tubes

File Name	VF Water	Height (cm)	H/X	$k_{eff}+2\sigma$	ANECF (MeV)	Validation X
filter_x8_pu_10_10_in.out	1	304.8	3732	0.1505	1.67E-02	13.7
filter_x8_pu_10_11_in.out	0.75	236.5	2812	0.1842	1.75E-02	13.7
filter_x8_pu_10_12_in.out	0.5	168.2	1892	0.2363	1.99E-02	13.7
filter_x8_pu_10_13_in.out	0.3	113.6	1155	0.3017	2.39E-02	13.7
filter_x8_pu_10_14_in.out	0.275	106.8	1063	0.3117	2.48E-02	13.7
filter_x8_pu_10_15_in.out	0.25	100.0	971	0.3227	2.54E-02	13.7
filter_x8_pu_10_16_in.out	0.225	93.1	879	0.3341	2.65E-02	13.7
filter_x8_pu_10_17_in.out	0.2	86.3	787	0.3449	2.85E-02	13.7
filter_x8_pu_10_18_in.out	0.175	79.5	695	0.3560	3.01E-02	13.7
filter_x8_pu_10_19_in.out	0.15	72.7	603	0.3670	3.22E-02	13.7
filter_x8_pu_10_20_in.out	0.125	65.8	511	0.3766	3.53E-02	13.7
filter_x8_pu_10_21_in.out	0.1	59.0	419	0.3837	3.96E-02	13.7
filter_x8_pu_10_22_in.out	0.05	45.3	235	0.3740	5.62E-02	13.7
filter_x8_pu_10_23_in.out	0.01	34.4	88	0.2953	1.01E-01	13.7

The input file `filter_x8_pu_10_21_in` is provided in Appendix C

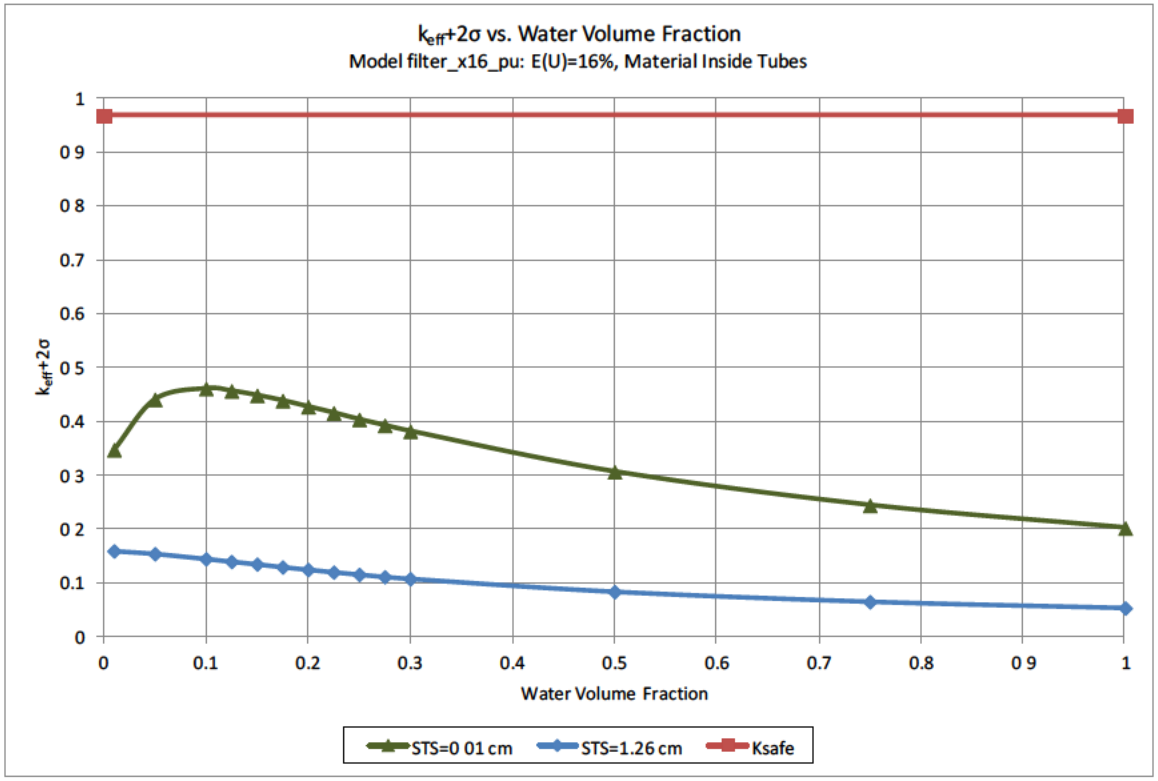


Figure 28: Results for MST in Filter Tubes with E(U)=16%

Figure 28 depicts the results for the same analysis performed for Figure 27, but the uranium enrichment was increased to 16% ^{235}U. Figure 28 demonstrates that even if enough AST-A batches were received at this high enrichment, and the material (hypothetically) plugged the filter and dried out, the system would remain subcritical.

The analysis of the CFF with tubes filled with MST solids relied on two design constraints. First, the minimum outer diameter of the center tube (depicted in Figure 25) was 21.59 cm. Based on drawing 1883-002-6003-02-DD-E[61], the STS spacing between filter tubes across the center tube is approximately 24.13 cm. This easily protects the minimum outer diameter of the center tube. Second, the filter tubes made of SS316L have a minimum density half that of SS316L (7.92/2=3.96 g/cc).

6.5.3 Shell with MST Solids

For this analysis the MST solids were placed on the shell side of the CFF and the sintered metal tubes were modeled with void. This configuration bounds the hypothesized condition that one or more tubes failed and allowed the MST solids to slowly accumulate on the shell side in the bottom of the CFF. The center feed tube was modeled as filled with void. The center feed tube gravity drains out of the CFF when the motive force (pumps) is terminated.

If one or more filter tubes were to fail and MST solids began collecting on the shell side of the CFF, at some point the pumps would be turned off and the contents of the tubes and the center feed line would gravity drain back down the inlet of the CFF. The liquid on the shell side would eventually pass back through the sintered metal tubes (if the filtrate drain line was not open) and out in the same manner, thus allowing the MST solids on the shell side to dry out.

The STS spacing between the tubes determines the amount of MST solids that could be present outside the tubes. The selection of STS spacing values analyzed for this section varied from 0.01 cm to 1.26 cm. Figure

24 indicates the number of tubes present for several selected STS spacing values. The same CFF layout as depicted in Figure 26 was used for this analysis. Note that evaluations in Section 6.6.2 conclude that this large accumulation is not a credible condition.

8% ^{235}U

For this model the height of the MST solids resulting from the analysis in Section 6.5.2 were used to define the volume containing the MST solids outside of the filter tubes. This volume decreased as the volume fraction of water decreased from the initial value of 1.0. At the initial volume fraction for water of 1.0, the MST solids were modeled to fill the shell side of the CFF the full length of the filter tubes (304.8 cm). Reducing the volume fraction of water effectively removed some volume of water from the system, thus the height of the MST solids was lowered to account for the removal of the water volume.

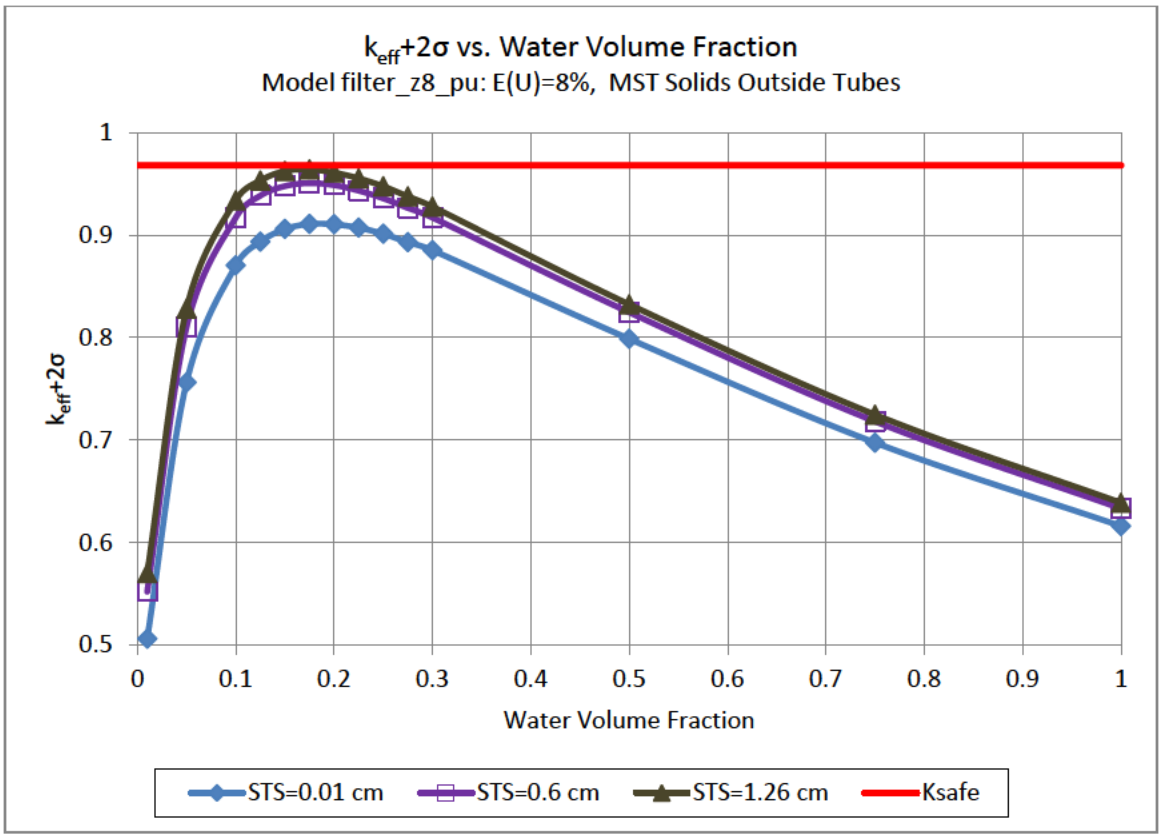


Figure 29: Results for Filled Shell Side with E(U)= 8%

Figure 29 depicts the change in k_{eff}+2σ values as a function of the volume fraction of water when the MST solids are on the shell side of the cross flow filter. The different curves represent different STS spacing for the tubes. These curves indicate that k_{eff}+2σ values increase as the STS spacing of the tubes increase. This is understandable because as the STS spacing increases, the available volume for MST material to fill on the shell side increases. Thus, the total mass of MST present (and thus uranium and plutonium) increases as the STS spacing increases.

Figure 29 also demonstrates that at the optimum volume fraction of water for each STS value depicted, the system remains subcritical. Thus, if the MST solids were allowed to completely dry out while the CFF remained installed in the facility, the system would remain subcritical. Therefore, the k_{eff}+2σ value for the hypothetical upset condition of filling the shell side of the filter with MST material will remain subcritical for all normal and credible abnormal conditions in the CFF. Table 24 provides the data for the bounding series from Figure 29 with STS=1.26 cm.

Table 24: Results Data for Filled Shell Side

File Name	VF Water	Height (cm)	H/X	$k_{eff}+2\sigma$	ANECF (MeV)	Validation X
filter_z8_pu_22_10_in.out	1	304.8	3732	0.6389	6.10E-03	13.7
filter_z8_pu_22_11_in.out	0.75	236.5	2812	0.7248	7.24E-03	13.7
filter_z8_pu_22_12_in.out	0.5	168.2	1892	0.8325	8.91E-03	13.7
filter_z8_pu_22_13_in.out	0.3	113.6	1155	0.9278	1.22E-02	13.7
filter_z8_pu_22_14_in.out	0.275	106.8	1063	0.9377	1.28E-02	13.7
filter_z8_pu_22_15_in.out	0.25	100.0	971	0.9476	1.38E-02	13.7
filter_z8_pu_22_16_in.out	0.225	93.1	879	0.9554	1.47E-02	13.7
filter_z8_pu_22_17_in.out	0.2	86.3	787	0.9610	1.59E-02	13.7
filter_z8_pu_22_18_in.out	0.175	79.5	695	0.9640	1.76E-02	13.7
filter_z8_pu_22_19_in.out	0.15	72.7	603	0.9625	1.95E-02	13.7
filter_z8_pu_22_20_in.out	0.125	65.8	511	0.9532	2.22E-02	13.7
filter_z8_pu_22_21_in.out	0.1	59.0	419	0.9339	2.57E-02	13.7
filter_z8_pu_22_22_in.out	0.05	45.3	235	0.8283	4.02E-02	13.7
filter_z8_pu_22_23_in.out	0.01	34.4	88	0.5703	8.31E-02	13.7

Table 25 provides estimates for the shell side volume and fissile mass based on dimensions modeled in MCNP. Table 25 accounts for the MST solids between the filter tubes (STS=1.26 cm) in the filter tube region plus the MST solids in the shell. For MST solids accumulation up to the top of the filter tubes (100% height), a conservative estimate for the volume on the shell side was estimated at 903 L. Assuming this volume was full of MST solids at 0.2741 g/cc and the MST was loaded with fissile material per Table 7, the total fissile mass modeled outside the filter tubes (at 304.8 cm height) was estimated at 3,190 g ^{235}U and 2,581 g ^{239}Pu. Compared to the material at risk calculations in Section 6.6.2, the MCNP models are very conservative.

Table 25: Shell Side Estimates for STS=1.26 cm

Dimension	Units	Values
Filter tube OR	in	0.25
Filter tube OR	cm	0.635
Cross Section Area of Filter Tube	cm^2	1.267
STS Spacing of tubes	cm	1.260
# Tubes in Filter Tube region	--	180
Cross Section Area of Filter Tubes	cm^2	227.692
Inner Radius of Filter Tube region	in	4.25
Inner Radius of Filter Tube region	cm	10.795
Outer Radius of Filter Tube region	in	8.25
Outer Radius of Filter Tube region	cm	20.955
Cross Section Area of Filter Tube region	cm^2	1013.415
Cross Section Area in Filter Tube region with MST solids	cm^2	785.723
Outer Radius of Shell	in	13.25
Outer Radius of Shell	cm	33.655
Cross Section Area of Shell	cm^2	2178.84
Total Cross Section Area with MST solids	cm^2	2964.56
Maximum Tube Length	in	120
Maximum Tube Length	cm	304.8
Height	cm	304.8
Height % of Tube Length	--	100%
Volume at Height	cc	903599.32
Volume at Height	L	903.60
MST concentration in volume	g/cc	0.2741
Mass MST at Height	g MST	247676.57
SRNL: U Loading on MST	gU/gMST	0.161
SRNL: Pu Loading on MST	gPu/gMST	0.010
Uranium Enrichment	g ^{235}U/ g U	0.080
Plutonium Enrichment	g ^{240}Pu/ g Pu	0.000
Mass ^{235}U	g ^{235}U	3190.1
Mass ^{239}Pu	g ^{239}Pu	2581.8

The results data for STS=1.26 cm series depicted in Figure 29 are presented in Table 26.

Table 26: Data for STS=1.26 cm, 8% ^{235}U

File Name	VF Water	Height (cm)	H/X	$k_{eff}+2\sigma$	ANECF (MeV)	Validation X
filter_z8_pu_22_10_in.out	1	304.80	3732	0.6389	6.10E-03	13.7
filter_z8_pu_22_11_in.out	0.75	236.52	2812	0.7248	7.24E-03	13.7
filter_z8_pu_22_12_in.out	0.5	168.24	1892	0.8325	8.91E-03	13.7
filter_z8_pu_22_13_in.out	0.3	113.62	1155	0.9278	1.22E-02	13.7
filter_z8_pu_22_14_in.out	0.275	106.79	1063	0.9377	1.28E-02	13.7
filter_z8_pu_22_15_in.out	0.25	99.96	971	0.9476	1.38E-02	13.7
filter_z8_pu_22_16_in.out	0.225	93.13	879	0.9554	1.47E-02	13.7
filter_z8_pu_22_17_in.out	0.2	86.31	787	0.9610	1.59E-02	13.7
filter_z8_pu_22_18_in.out	0.175	79.48	695	0.9640	1.76E-02	13.7
filter_z8_pu_22_19_in.out	0.15	72.65	603	0.9625	1.95E-02	13.7
filter_z8_pu_22_20_in.out	0.125	65.82	511	0.9532	2.22E-02	13.7
filter_z8_pu_22_21_in.out	0.1	58.99	419	0.9339	2.57E-02	13.7
filter_z8_pu_22_22_in.out	0.05	45.34	235	0.8283	4.02E-02	13.7
filter_z8_pu_22_23_in.out	0.01	34.41	88	0.5703	8.31E-02	13.7

The input file `filter_z8_pu_22_18_in` is provided in Appendix C.

The analysis of the CFF with the shell filled with MST solids relied on four design constraints. First, the minimum outer diameter of the center tube (depicted in Figure 25) was 21.59 cm. Based on drawing 1883-002-6003-02-DD-E[61], the STS spacing between filter tubes across the center tube is approximately 24.13 cm. This easily protects the minimum outer diameter of the center tube. The second design constraint was a minimum of 180 filter tubes in the CFF. This is significantly less than the 234 tubes shown with a 0.63 cm STS spacing in drawing 1883-002-6003-02-DD-E Rev. 1. Third, the maximum outer diameter of the outer shell was conservatively set to 67.31 cm (26.5 inches) based on According to drawing 1883-002-1001-01-WA-E[60]. Fourth, the filter tubes made of SS316L have a minimum density half that of SS316L (7.92/2=3.96 g/cc).

<u>16% ^{235}U</u>

It was desirable to investigate the same model described above for MST solids outside of the filter tubes when the uranium enrichment was double the nominal value. For this model the height of the MST solids resulting from the analysis in Section 6.5.2 were used to define the volume containing the MST solids outside of the filter tubes. This volume decreased as the volume fraction of water decreased from the initial value of 1.0. At the initial volume fraction for water of 1.0, the MST solids were limited to 40% of the full length of the filter tubes (304.8 cm * 40% = 122 cm) on the shell side of the CFF. Reducing the volume fraction of water effectively removed some volume of water from the system, thus the height of the MST solids was lowered to account for the removal of the water volume.

The 40% value was selected for the starting height at the initial water volume fraction of 1.0 for a couple reasons. First, there was so much more material outside the filter tubes than was analyzed inside the tubes that it was not reasonable to fill the shell side to the full length of the filter tubes (see Section 6.6.2). Second, the 40% height was sufficiently above the top of the filtrate drain. The filtrate drain was designed to be approximately 17.653 cm above the bottom of the filter tubes, Drawing 1883-002-1000-GA-E, *Washing Filter FLT-104 General Arrangement*[63]. While it is not credible that material could accumulate above the drain line height, the 40% tube height for the starting value conservatively assumed that MST solids filled the shell side of the CFF up to a height of 122 cm at the 0.2741 g/cc density and could not be removed via the filtrate drain. Thus, a bounding hypothetical condition was established.

The left side of Figure 30 depicts a partial material height on the shell side of the CFF. The right side of Figure 30 depicts the MST solids on the shell side of the filter tubes. In this figure, the STS spacing was 1.26 cm between the filter tubes and the small white dots depict the filter tubes. As shown, MST solids fill the outer ring around filter tubes and fill all the space on the shell side of the filter tubes, up to the material height analyzed based on the selected volume fraction of water.

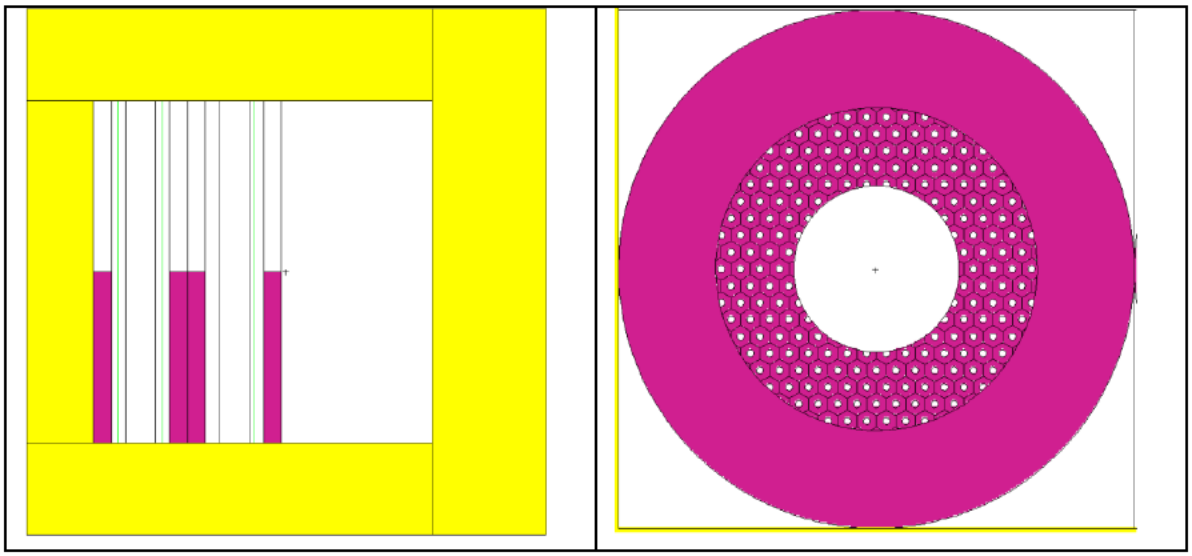


Figure 30: MST Solids on Shell Side, Partial Height

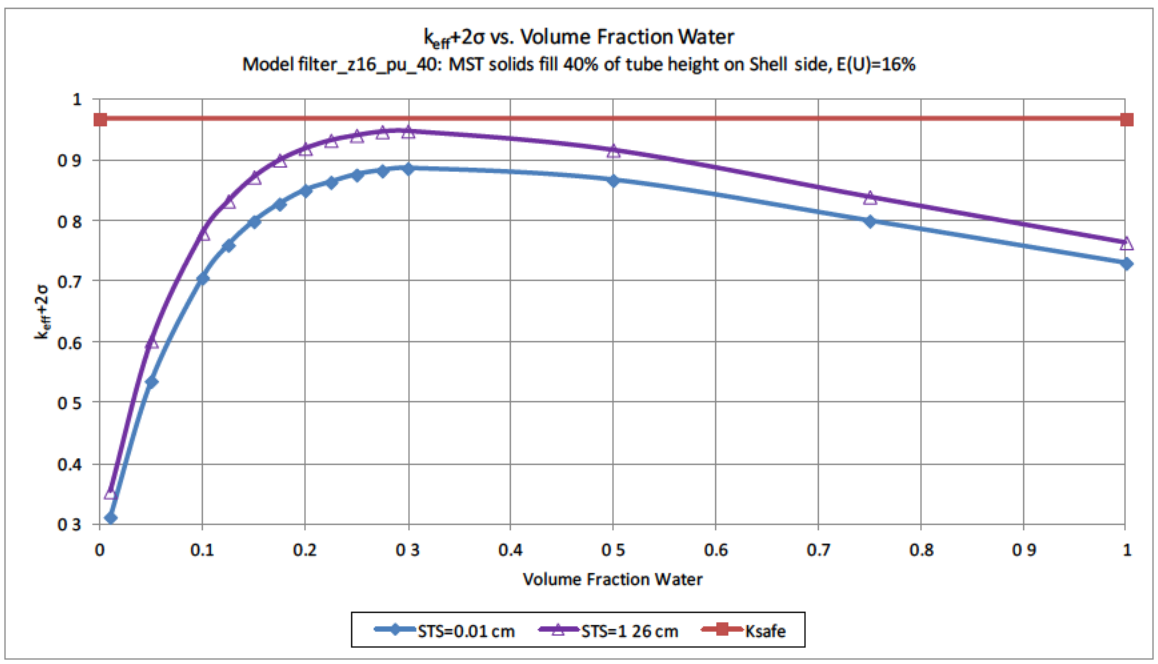


Figure 31: Results for Filled Shell Side with E(U)=16%

Figure 31 demonstrates that the highest k_{eff}+2σ values occur with the largest STS tube spacing analyzed. Figure 31 also demonstrates that at the optimum volume fraction of water for each STS value depicted, the system remains subcritical. Thus, if the MST solids were allowed to completely dry out while the CFF remained installed in the facility, the system would remain subcritical. Therefore, the k_{eff}+2σ value for the upset condition of filling the shell side of the filter with MST material will remain subcritical for all normal and credible abnormal conditions in the CFF.

Table 27 provides the data for the two extremes of the parameter investigated, STS=0.01 cm and 1.26 cm tube spacing from Figure 31.

Table 27: Results Data for Filled Shell Side with E(U)= 16%

File Name	VF Water	Height (cm)	H/X	Tube STS (cm)	$k_{eff}+2\sigma$	ANECF (MeV)
filter_z16_pu_40_10_10_in.out	1	122.0	2397	0.01	0.7300	5.40E-03
filter_z16_pu_40_10_11_in.out	0.75	94.6	1806	0.01	0.7996	6.36E-03
filter_z16_pu_40_10_12_in.out	0.5	67.3	1215	0.01	0.8669	8.16E-03
filter_z16_pu_40_10_13_in.out	0.3	45.5	742	0.01	0.8862	1.20E-02
filter_z16_pu_40_10_14_in.out	0.275	42.7	683	0.01	0.8825	1.28E-02
filter_z16_pu_40_10_15_in.out	0.25	40.0	624	0.01	0.8758	1.38E-02
filter_z16_pu_40_10_16_in.out	0.225	37.3	565	0.01	0.8636	1.50E-02
filter_z16_pu_40_10_17_in.out	0.2	34.5	506	0.01	0.8500	1.64E-02
filter_z16_pu_40_10_18_in.out	0.175	31.8	446	0.01	0.8277	1.84E-02
filter_z16_pu_40_10_19_in.out	0.15	29.1	387	0.01	0.7988	2.08E-02
filter_z16_pu_40_10_20_in.out	0.125	26.3	328	0.01	0.7598	2.40E-02
filter_z16_pu_40_10_21_in.out	0.1	23.6	269	0.01	0.7059	2.89E-02
filter_z16_pu_40_10_22_in.out	0.05	18.1	151	0.01	0.5354	4.93E-02
filter_z16_pu_40_10_23_in.out	0.01	13.8	56	0.01	0.3112	1.09E-01
filter_z16_pu_40_22_10_in.out	1	122.0	2397	1.26	0.7642	5.29E-03
filter_z16_pu_40_22_11_in.out	0.75	94.6	1806	1.26	0.8397	6.14E-03
filter_z16_pu_40_22_12_in.out	0.5	67.3	1215	1.26	0.9170	8.13E-03
filter_z16_pu_40_22_13_in.out	**0.3**	**45.5**	**742**	**1.26**	**0.9483**	**1.16E-02**
filter_z16_pu_40_22_14_in.out	0.275	42.7	683	1.26	0.9473	1.25E-02
filter_z16_pu_40_22_15_in.out	0.25	40.0	624	1.26	0.9412	1.34E-02
filter_z16_pu_40_22_16_in.out	0.225	37.3	565	1.26	0.9330	1.47E-02
filter_z16_pu_40_22_17_in.out	0.2	34.5	506	1.26	0.9195	1.59E-02
filter_z16_pu_40_22_18_in.out	0.175	31.8	446	1.26	0.9003	1.77E-02
filter_z16_pu_40_22_19_in.out	0.15	29.1	387	1.26	0.8726	2.01E-02
filter_z16_pu_40_22_20_in.out	0.125	26.3	328	1.26	0.8329	2.31E-02
filter_z16_pu_40_22_21_in.out	0.1	23.6	269	1.26	0.7803	2.75E-02
filter_z16_pu_40_22_22_in.out	0.05	18.1	151	1.26	0.6023	4.66E-02
filter_z16_pu_40_22_23_in.out	0.01	13.8	56	1.26	0.3535	1.03E-01

The input file `filter_z16_pu_40_22_13_in` is provided in Appendix C.

6.5.4 Potential for CFF Pluggage

This section provides additional information supporting the physical inability of a CFF to plug. Although not used to demonstrate a sub-critical configuration or compliance with a calculated limit, this additional information provides supplemental support to the arguments in Section 5, the modeling selections in Section 6, and the conclusions provided in *Process Inputs to the Nuclear Criticality Safety Evaluation*, 00-700-20878[65].

Section 6.5.2 analyzed a configuration of two CFFs with fully plugged tubes. This hypothetical configuration of full tube pluggage represents an extreme bounding condition of tube fouling. This section justifies why it is not possible for the tubes of one (or multiple) CFFs to completely plug as modeled in Section 6.5.2. Section 6.6.1 uses the conclusion that tube pluggage does not occur for the purpose of estimating the maximum fissile mass of concern for the acid cleaning of multiple CFFs in the ASP.

As discussed in Section 2.2.4 and *Process Inputs to the Nuclear Criticality Safety Evaluation*, 00-700-20878[65], the filtration slurry passes through the CFF tubes at high velocity. This high velocity acts to limit the quantity of material that could adhere to the inside surface of the CFF tubes. Excessive concentration of solids within the slurry in the filter loops has been postulated as a mechanism leading to CFF tube pluggage. The SWPF ASP process targets a nominal 5-7 wt.% solids slurry both in FFT-A after accumulation of seven AST-A batches of solids, and in the SSRT during the subsequent washing step. During testing, the response of a cross-flow filter to a high-solids slurry was investigated, and up to 20 wt.% slurries showed little impact on filter performance, and no indication of tube pluggage[54].

For the ASP process in SWPF, the extent of concentration that is physically possible in the cross-flow filter systems is determined by three parameters: the mass of solids present, the volume of the circulating path for the slurry in the filter loop, and the minimum volume in the associated source tank necessary to support filter loop operation. The mass of solids present is dependent on the concentration of solids in the feed to SWPF, which was set to the maximum allowed value as opposed to a lower but bounding expected value. The volume of the filter loop depends on the facility design and the loop volume varies for each loop. The following discussions utilized the minimum calculated loop volumes. The minimum volume in the source tank varies by tank as the tank heel volume changes based on multiple design variables.

S-CLC-J-00029, *Radionuclide Concentrations in Process Vessels*[64], evaluated minimum loop and tank heel volumes for the purpose of supporting accident analysis calculations. According to Appendix 6 of S-CLC-J-00029[64], the smallest volume cross-flow filter loop in ASP is at least 690 gallons. Section 6.8.2.1 of S-CLC-J-00029[64] indicates that the lowest tank level that can support filter loop operations is 8 inches of level (274 gallons). So the smallest system volume that can be achieved for 1-loop filter operations is 964 gallons. Given the mass of solids accumulated from the processing of 7 batches of AST-A material (assuming 1200 mg/liter solids from the Tank Farm), the highest slurry concentration achievable in 1-loop filter operations is 17.9 wt.% solids (see Figure 33).

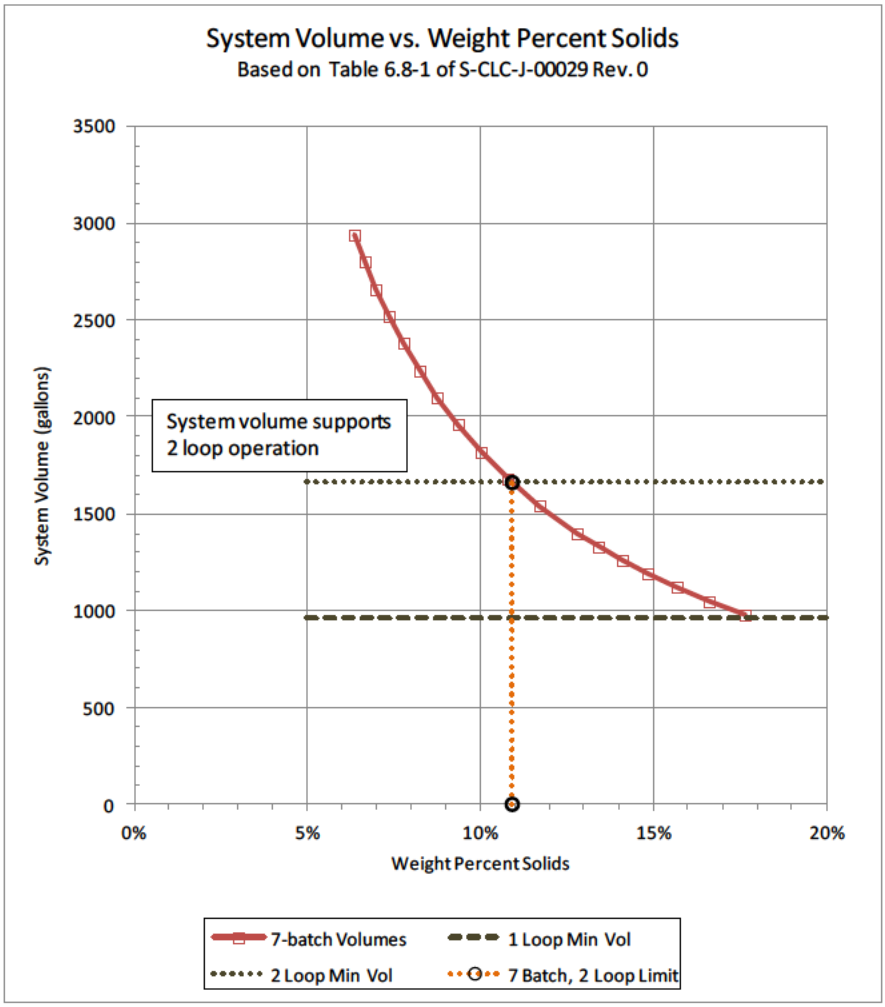


Figure 33: Tank Volume vs. Weight Percent Solids

The results depicted in Figure 33 were based on maximum solids content and minimum volumes. Thus, all other combinations of variables are bounded by the curve presented. On Figure 33 a vertical dotted line is drawn at 10.9 wt.% solids to mark the solids concentration point at which the system volume could no longer support 2-loop CFF operations. At this concentration point, the liquid in one loop must be allowed to drain back into the process tank to support continued operation. The curve intersects the minimum 1-loop operation volume at 17.9 wt.%. Thus, it is not possible for normal operations (which are bounded by these very conservative calculations) to achieve 20 wt.% solids in one filter. Based on P-RPT-J-0000758, testing data with sludge and solids simulant indicate that the filter still functioned without pluggage when the feed contained 20 wt.% solids. Therefore, tube pluggage in the CFF is not considered credible.

6.6 *Material at Risk from Cross-Flow Filter Acid Cleaning*

The purpose of this section is to calculate estimates of the fissile material present in a CFF prior to acid cleaning. This material is at risk for precipitation during CFF acid cleaning. These estimates of precipitated fissile mass are used in accident scenarios for comparison to sub-critical mass limits derived for the applicable location of concern.

As discussed in Section 2.2.6, it is expected that the filters will need to be acid cleaned on some frequency. The acid solution used during the cleaning process would be transferred into a caustic environment in the large tanks (e.g., SSRT). The same condition exists if the acid were neutralized before transferring the filter cleaning solution to the SSRT, but that condition would exist in a different tank (e.g., the SAST). It was hypothesized that the neutralization of spent acid could cause the precipitation of uranium and plutonium when the SAST is transferred into the SSRT. Thus, the 5 strike MST material compositions utilized in the previous sections of this analysis may not be valid for these precipitates because the MST will be separated from the uranium and plutonium.

The evaluation in this section differs from that in Section 6.5 in that Section 6.5 assumed hypothetical amounts of material beyond that considered credible remained inside the CFF and was allowed to dry out. This section estimates bounding quantities of material that could be credibly removed from the CFF by the filter cleaning (caustic or acid). Section 6.3 then evaluates configurations where the uranium and plutonium have been separated from the MST and potentially precipitated in the tanks.

As CFF tube fouling and cleaning is a normal condition, Section 6.6.1 calculates the mass of ^{235}U that can credibly accumulate in the CFF tubes. Additionally, Section 6.6.1 calculates a bounding mass of ^{235}U that can credibly accumulate in the tubes of multiple CFFs.

A hole or tear in a tube would allow material to pass to the shell side. As these tubes were designed as Safety Significant (SS) for preventing solids break-through they are very robust and this would be an upset configuration. Section 6.6.2 calculates a bounding mass of ^{235}U that can credibly accumulate in the shell side of CFFs prior to cleaning. Section 6.3.2 calculates these masses of ^{235}U as precipitate in the horizontal tanks used to collect the used acid cleaning solution, and Section 6.4 calculates these masses of ^{235}U as precipitate in the non-uniform settling in the vertical process tanks.

6.6.1 Inside Tubes

To account for fissile material addition to the SSRT due to cleaning the CFFs, it was necessary to estimate the amount of uranium and plutonium that may be present in the tubes of a CFF prior to acid cleaning. From a processing perspective, the filters will not be cleaned unless processing efficiency is reduced to a point that warrants such action. Thus, it is expected that some amount of uranium and plutonium will be present in a CFF when it is cleaned.

The *Process Inputs to the Nuclear Criticality Safety Evaluation*, 00-700-20878[65], provided the following assumption and basis for tube side material accumulation:

> Cross-Flow Filter – Tube Side
>
> A conservative upper bound for solids material accumulation in the filter tubes and on the tubes inner surface of a Cross Flow Filter prior to cleaning would be to assume that the entire porosity volume of all the sintered metal filter tubes is filled with accumulated solid material.
>
> Basis
>
> The cross flow filter tubes are oriented vertically and operate at a high downward axial velocity to preclude any solid material accumulations within the ID of the tubes. Testing at nearly three (3) times the nominal solids loading (i.e.; 20 wt.%) did not introduce any solid material accumulations within the ID of the filter tubes. Thus, solid material accumulation on the ID of the filter tubes is not expected.
>
> Although solid material accumulation within the ID of the filter tubes is not expected, solid material accumulation within the pores of the sintered metal filter tubes will occur over time due to trans-membrane flow during the filtration process. The gradual decrease in trans-membrane filtrate flow rate due to the accumulation of solid material within the sintered metal pores is known as “filter fouling.”

If complete "filter fouling" were to occur, then all trans-membrane flow (and additional solid material accumulation within the pores of the sintered metal tubes) would cease and only axial flow would be present as is the case in a standard pipe. Complete "filter fouling" has not been encountered during testing even under grossly non-prototypic conditions that were intended to optimize "filter fouling". Complete "filter fouling" would be expected to occur well before all of the pores in the sintered metal tubes were filled with accumulated solid material.

The assumption that the entire porosity volume of all sintered metal filter tubes is filled with accumulated solid material is sufficiently conservative to provide adequate margin accounting for any slight accumulation of solids on the ID of the filter tubes.

The porosity of the sintered metal filter tubes was reported in S-RPT-J-00006, *Cross Flow Filter Tube Porosity and Porous Volume*[66], as 0.244 volume fraction. S-RPT-J-00006 also reported the appropriate dimensions (with uncertainty included) values for the filter tube OD and wall thickness. According to Table 5-1 of S-RPT-J-00006, the OD was taken as 0.52 inches and the wall thickness was taken as 0.0831 inches. These values were used in the following calculations to estimate the fissile mass filling the pores of the 234 sintered metal filter tubes in one CFF.

To bound the mass of uranium and plutonium present, some additional assumptions were required for the calculations presented in Table 28.

1. The MST solids that plug the CFF were the same MST solids analyzed on the bottom of the large tanks (see Sections 6.2 and 6.4). Thus, the MST concentration at the point processing stops and filter cleaning begins is the same as in the large tanks. The MST concentration utilized was 0.2741 g/cc (see Section 4.6.3).
2. The MST in the CFF was loaded with the five strike data from Table 7.
3. The Nominal uranium enrichment of 8 wt.% ^{235}U was used to calculate the fissile portion of the uranium on the MST.

Table 28 utilized the assumptions above and calculated the fissile mass on the MST embedded in the walls of the sintered metal CFF tubes.

Table 28: Fissile Mass Estimate Tube Side in CFF

Dimension	Units	Value
Filter tube length	cm	304.8
Filter tube OD	in	0.52
Filter tube OD	cm	1.321
Filter tube wall thickness	in	0.0831
Filter tube wall thickness	cm	0.211
Filter tube ID	cm	0.899
Filter tube wall volume	cc	224.3
Filter tube wall porosity	cc Void / cc Total	0.244
Filter tube wall void volume	cc	54.7
MST mass per unit volume	g/cc	0.2741
MST mass per filter tube in void volume	g	15.0
Number filter tubes per CFF	--	234
MST mass per CFF	g MST	3510.2
5 Strike U loading on MST	g U / g MST	0.161
5 Strike Pu loading on MST	g Pu / g MST	0.0104
Uranium mass per CFF	g U	565.1
Plutonium mass per CFF	g Pu	36.6
E(U)	g ^{235}U / g U	0.08
E(Pu)	g ^{240}Pu / g Pu	1.0E-06
Mass ^{235}U per CFF	g ^{235}U	45.2
Mass ^{239}Pu per CFF	g ^{239}Pu	36.6

Based on the conservative assumptions and calculations presented in Table 28, 45.2 g ^{235}U and 36.6 g ^{239}Pu was used as the fissile contribution to large tanks from acid cleaning one CFF with plugged pores. If all four CFFs in the ASP had their pores plugged, the total fissile material that may become precipitate in a process tank is 180.8 g ^{235}U and 146.3 g ^{239}Pu. Including an approximate 53% margin, 277 g ^{235}U and 223 g ^{239}Pu were selected as the standard fissile contribution from four CFFs that was collected in seven AST-A batches for most MCNP models herein.

6.6.2 Shell Side of CFFs

To account for fissile material addition to the SSRT due to cleaning the CFFs, it was necessary to estimate the amount of uranium and plutonium that may be present on the shell side of a CFF prior to acid cleaning.

The *Process Inputs to the Nuclear Criticality Safety Evaluation*, 00-700-20878[65], provided the following assumptions for shell side material accumulation:

> Cross-Flow Filter – Shell Side
>
> The Cross Flow Filter tubes are robust Safety Significant (SS) components whose function is to prevent significant transfer of solids material to the shell side of the filter. If one of the SS filter tubes were compromised, then solids material could be transferred to and accumulate in the shell side of the filter.
>
> Credible mechanisms by which the SS filter tubes would allow particles to pass to the shell side can be categorized as chronic penetration (e.g., where a few small channels through the tube wall allow a small fraction of the MST fines to pass during filter operation) or acute failures (e.g., where either a tube suddenly shears or a crack propagates over a period hours/days).
>
> Assumption 1:
>
> The amount of solids that would remain in the shell side of the filter (and undergo acid cleaning) due to chronic penetration is bounded by the amount of settled solids it would take to fill the shell side of the filter up to the bottom of the filter shell's 2-inch drain line.
>
> Basis:
>
> The size of the MST particles that pass through the channels in the tube walls will be smaller than the average MST particle size in the recirculation filter loop. These relatively small particles will be mobile and the majority will exit the shell of the cross-flow filter and be transferred to the downstream vessel.
>
> Prior to the acid cleaning step for a cross-flow filter, the shell side will be drained, the entire filter loop will be filled with filter cleaning caustic and circulated, and the filter loop and the shell of the filter will be drained again based on DCS control and normal operating practices.
>
> The assumption that the entire volume of the shell side of the filter is filled with settled solids up to the 2-inch drain line prior to filter cleaning is extremely conservative and bounds any credible potential solids accumulations on the shell side of the filter due to chronic penetration.
>
> Assumption 2:
>
> The amount of solids that would remain in the shell side of the filter (and undergo acid cleaning) following an acute failure is bounded by the amount of slurried solids it would take to fill the shell side of the filter at a concentration of 7 wt.% solids. It is conservative to calculate the weight percent solids based on a mixture of only MST and water.
>
> Basis:
>
> 7 wt.% total solids represents the upper end of normal operating envelope for the Alpha Strike Process. The solids concentration on the shell side is not expected to exceed the solids concentration in the FFT-A/SSRT at the time of the filter tube failure because of the dilutive effects of the filtrate initially on the shell side. An acute failure of filter tube(s) will result in a rapid rate of rise in detected downstream turbidity, which should increase the speed of operator diagnosis and response.

Prior to the acid cleaning step for a cross-flow filter, the shell side will be drained, the entire filter loop will be filled with filter cleaning caustic and circulated, and the filter loop and the shell of the filter will be drained again based on DCS control and normal operating practices. This sequence of draining and flushing will cause a reduction in the amount of solids that remain on the shell side of the filter and undergo acid cleaning.

Calculating the weight percent solids based on a mixture of only MST and water inserts a significant conservatism since the process mass balance supporting the facility design includes both sludge solids in the waste feed as well as MST in the determination of solids concentrations (i.e. the MST solids comprise only a fraction of the total weight percent solids). The presence of sludge solids in the waste feed is confirmed by the operating experience of the ARP/MCU pilot CSSX facility. Furthermore, it may not be practical with only MST solids to achieve 7 wt.% solids in ASP after accumulating the solids from 7 AST-A batches based on the need to fill the complete volume of a filter loop during concentration and the minimum tank level needed to support pump operation in the filter loop.

The assumption that the entire volume of the shell side of the filter is filled with MST only solids at 7 wt.% prior to acid cleaning of the filters is extremely conservative and bounds any credible potential solids accumulations on the shell side of the filter due to an acute filter failure.

Table 29 utilized the assumptions above and calculated the fissile mass on the MST on the shell side of one CFF. The 12.57 cm height for the bottom of the drain line was calculated from dimensions provided in drawing 1883-002-1000-01-GA-E, Washing Filter[67].

Table 29: CFF Shell Side Fissile Mass Below Drain Line

Dimension	Units	Values
Outer Radius of Filter Tube region	in	9.08
Outer Radius of Filter Tube region	cm	23.06
Outer Radius of Shell	in	13.25
Outer Radius of Shell	cm	33.655
Cross Section Area of Shell	cm^2	1887.30
Maximum Tube Length	in	120
Maximum Tube Length	cm	304.8
Shell Drain Line Top Height	cm	12.57
Shell Drain Line Top Height % of Tube Length	--	4.125%
Volume of Shell side at Height	cc	23729.09
MST concentration in volume	g/cc	0.2741
Mass MST at top of Drain Line	g MST	6504.14
SRNL: U Loading on MST	gU/gMST	0.161
SRNL: Pu Loading on MST	gPu/gMST	0.0104
Uranium Enrichment	g ^{235}U/ gU	0.080
Plutonium Enrichment	g ^{240}Pu/ g Pu	1.0E-06
Mass ^{235}U	g ^{235}U	83.8
Mass ^{239}Pu	g ^{239}Pu	67.8

Based on the conservative assumptions and calculations presented in Table 29, 83.8 g ^{235}U and 67.8 g ^{239}Pu was used as the fissile contribution to large tanks from acid cleaning one CFF with material accumulation up to the bottom of the drain line. If the shell side of all four CFFs in the ASP were filled up to the bottom of the drain line, the total fissile material that may become precipitate in a process tank would be 335.1 g ^{235}U and 271.2 g ^{239}Pu.

Another possible accumulation on the shell side is for 7 wt.% MST solids to fill the shell side of the CFF. As discussed previously, this is very conservative considering the dilution that would occur due to the presence of filtrate on the shell side prior to a hypothesized acute tube failure and the assumption that all solids present are MST. Table 30 summarizes the calculation of equivalent fissile material present on the CFF shell side prior to acid cleaning as a result of an acute tube failure. Uranium and plutonium loadings on the MST were five strike data as specified in Table 7.

Table 30: Shell Side with 7 wt.% Solids

Dimension	Units	Values
Outer Radius of Filter Tube region	in	9.08
Outer Radius of Filter Tube region	cm	23.0632
Outer Radius of Shell	in	13.25
Outer Radius of Shell	cm	33.655
Cross Section Area of Shell	cm^2	1887.30
Maximum Tube Length	in	120
Maximum Tube Length	cm	304.8
Height % of Tube Length	--	100.0%
Volume of Shell side at Height	cc	575250.56
Weight % MST Solids	g MST / g mix	**7.00%**
Density of Water	g/cc	0.9982
Density of MST solids	g/cc	2.7650
Density of Mixture	g/cc	1.0449
Mass of Mixture	g	601101.9
Mass of MST Solids	g	42077.1
SRNL: U Loading on MST	gU/gMST	0.161
SRNL: Pu Loading on MST	gPu/gMST	0.010
Uranium Enrichment	g ^{235}U/ gU	0.080
Plutonium Enrichment	g ^{240}Pu/ g Pu	1.0E-06
Mass ^{235}U	g ^{235}U	542.0
Mass ^{239}Pu	g ^{239}Pu	438.6

Table 30 demonstrates that MST containing 542 g ^{235}U and 438.6 g ^{239}Pu would fill the shell side of one CFF. This calculation bounds the Table 29 result and eliminates any need to credit controls that protect or prevent material from accumulating above the two inch drain line on the shell side.

6.6.3 Material At Risk from CFF Acid Cleaning Summary

The purpose of this section is to compile the conditions of concern in an easy to reference table with the associated material at risk based on calculations in previous sections.

There are two time-frames of concern for material at risk in a CFF. An acute failure indicates the sudden loss of containment. A chronic failure indicates a build-up of material over a lengthy time period. The fissile mass result from each of the following conditions is assumed to all be transferred to a large vertical process tank, precipitate/separate from the MST, and collect in the bottom of the tank mixed with the MST solids present. The geometry assumed for the collection of the MST solids (e.g., uniform settling, torus lump) dictates the maximum subcritical mass allowed from acid cleaning the CFFs.

According to 00-700-20878[65], the chronic conditions are related to MST solids filling the CFF shell up to the bottom of the 2-inch drain line, and the acute conditions are related to 7 wt.% solids filling the shell side.

Acute-1 reflects the upset condition of a major break in the filter tubes resulting 7 wt.% solids filling the shell side of the CFF. The filter loops will contain 5-7 wt.% solids at various times in the filtering process, but not continually, prior to transferring the solution to the next tank or facility. One CFF is assumed to fail in this manner.

Acute-2 reflects the upset condition of a major break in the filter tubes resulting 7 wt.% solids filling the shell side of the CFF. The filter loops will contain 5-7 wt.% solids at various times in the filtering process, but not continually, prior to transferring the solution to the next tank or facility. Two CFFs are assumed to fail simultaneously in this manner (e.g., one CFF on FFT-A and the one on the SSRT). No common mode failure mechanism has been identified. Thus, two CFFs with 7 wt.% solids filling the shell side that are acid cleaned and the full contents collected in one large vertical process tank is the bounding upset condition of concern.

Acute-3 reflects a gradual build-up of MST solids in the pores of the 234 filter tubes in all four CFFs in ASP plus one CFF with a major break in the filter tubes resulting 7 wt.% solids filling the shell side of the CFF.

Acute-4 reflects a gradual build-up of MST solids in the pores of the 234 filter tubes in all four CFFs in ASP plus all three CFFs in AFF, plus one CFF with a major break in the filter tubes resulting 7 wt.% solids filling the shell side of the CFF.

Chronic-1 reflects a gradual build-up of MST solids in the pores of the 234 filter tubes in all four CFFs in ASP. The pore volume is filled with MST at the settled density of 0.2741 g/cc (see Section 4.6.3) and loaded with the five strike data per Table 7. This condition implies that the pores in all four CFFs in ASP became filled with MST solids, were acid cleaned, and collected in one vertical process tank.

Chronic-2 reflects a gradual build-up of MST solids in the pores of the 234 filter tubes in all four CFFs in ASP. The pore volume is filled with MST at the settled density of 0.2741 g/cc (see Section 4.6.3) and loaded with the five strike data per Table 7. This condition implies that the pores in all four CFFs in ASP became filled with MST solids, were acid cleaned, and collected in one vertical process tank. In addition the upset condition of a break in the filter tubes resulting in MST solids on the shell side. The MST solids settle to the bottom and those below the drain line are not removed from the shell side when the drain line valve is opened. This volume is filled with MST solids at the settled density of 0.2741 g/cc (see Section 4.6.3) and loaded with the five strike data per Table 7. Four CFFs are assumed to fail simultaneously in this manner.

Chronic-3 reflects a gradual build-up of MST solids in the pores of the 234 filter tubes in all four CFFs in ASP. The pore volume is filled with MST at the settled density of 0.2741 g/cc (see Section 4.6.3) and loaded with the five strike data per Table 7. This condition implies that the pores in all four CFFs in ASP and all three CFFs in AFF became filled with MST solids, were acid cleaned, and collected in one vertical process tank.

Chronic-4 reflects a gradual build-up of MST solids in the pores of the 234 filter tubes in all four CFFs in ASP plus all three CFFs in AFF, for a total of seven CFFs. The pore volume is filled with MST at the settled density of 0.2741 g/cc (see Section 4.6.3) and loaded with the five strike data per Table 7. This condition implies that the pores in all four CFFs in ASP plus all three in AFF became filled with MST solids, were acid cleaned, and collected in one vertical process tank. In addition the upset condition of a break in the filter tubes resulting in MST solids on the shell side. The MST solids settle to the bottom and those below the drain line are not removed from the shell side when the drain line valve is opened. This volume is filled with MST solids at the settled density of 0.2741 g/cc (see Section 4.6.3) and loaded with the five strike data per Table 7. Seven CFFs are assumed to fail simultaneously in this manner.

Table 31 provides a summary of acute and chronic upset conditions discussed above with references to the previous table(s) used to calculate the mass values presented.

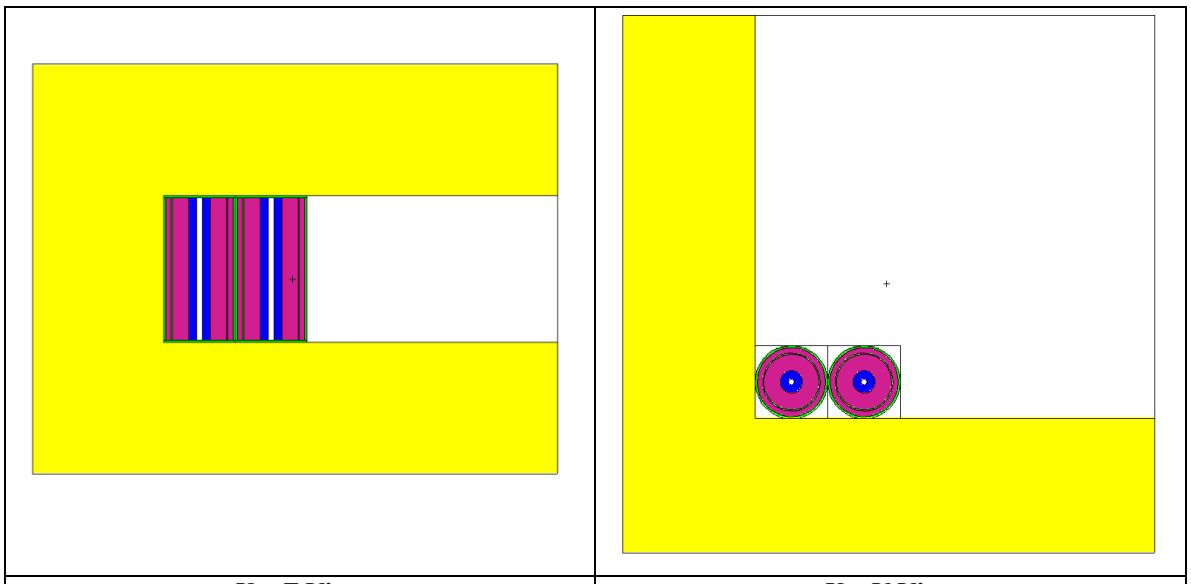
Table 31: CFF Material At Risk Summary

		Material at Risk		
Label	**Condition**	**(g ^{235}U)**	**(g ^{239}Pu)**	**References**
Acute-1	One CFF has shell side filled with 7 wt.% solids.	542.0	438.6	Table 30
Acute-2	Two CFFs have shell side filled with 7 wt.% solids.	1083.9	877.2	Table 30
Acute-3	Four CFFs with filter tube pores filled with MST solids, plus one CFF with shell side filled with 7 wt.% solids.	722.8	585.0	Table 28 Table 30
Acute-4	Seven CFFs with filter tube pores filled with MST solids, plus one CFF with shell side filled with 7 wt.% solids.	858.4	694.7	Table 28 Table 30
Chronic-1	Four CFFs with filter tube pores filled with MST solids.	180.8	146.4	Table 28
Chronic-2	Four CFFs with filter tube pores filled with MST solids. Four CFFs with centrifuged density on shell side, accumulation up to bottom of 2-inch drain line.	515.9	417.6	Table 28 Table 29
Chronic-3	Seven CFFs with filter tube pores filled with MST solids.	316.5	256.1	Table 28 Table 30
Chronic -4	Seven CFFs with filter tube pores filled with MST solids. Seven CFFs with centrifuged density on shell side, accumulation up to bottom of 2-inch drain line.	902.9	730.7	Table 28 Table 30

6.7 Contactors

According to Drawing 10A0505-CRIT in *Contactor Housing Dimensions Reference* [68], the outer radius of the V10 contactor housing is approximately 6.38 inches and the height is approximately 21.64 inches. These dimensions result in a volume of approximately 51.3 liters.

For the contactor model, two contactors were placed side by side with tight fitting concrete that was two feet thick on top, bottom and two sides. This amount of reflection was determined to bound normal and credible abnormal conditions common to maintenance and normal operations. Figure 35 depicts the layout for this model.



X – Z View	X – Y View

Figure 35: Contactor Model Layout

Figure 36 depicts the model of a single contactor. The center was modeled as void in place of the rotor shaft. A layer of water was modeled between the rotor shaft and the MST solids. The layer of MST solids was varied in thickness ranging from 0.5 to 7.62 cm thick. Even though the contactors will likely fail to function with a 0.5” layer of MST solids on the inner wall, a wide range of thicknesses were selected.

The rotor shaft, water layer, and MST solids were the three parts that filled the mixing region of the contactor. MST solids were also modeled to fill the contactor inlet and outlet regions. All metal wall thicknesses were modeled as 0.19” (0.482 cm) thick SS316L with a density of 7.92 g/cc, which was consistent with dimensions and materials specified in the design (Drawing 10A0505-CRIT)[68]. The design also specified the center rotor region to have a 1.25” radius with the rotor shaft itself having a radius of 0.5”.

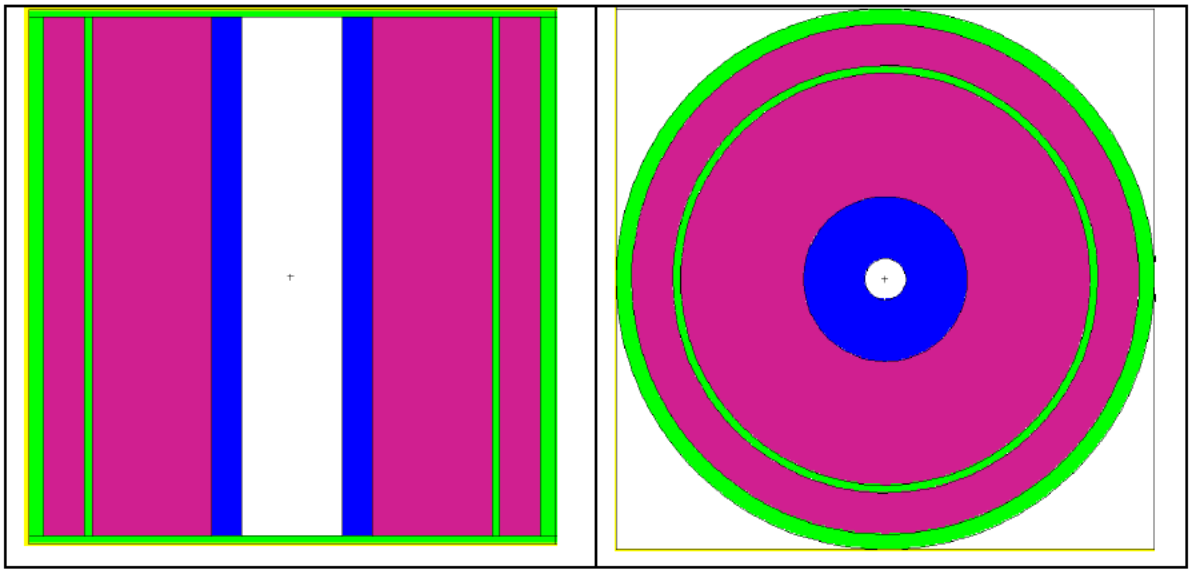


Figure 36: Contactor Model

The rotor radius was varied from 0.5" (1.27 cm) to 1.25" (3.175 cm) to determine if this was a significant factor in the results. It was determined that this variable was insignificant because k_{eff}+2σ values varied much less with changing the rotor radius than change the MST density, and consequently the 1.25" rotor was selected for further discussion purposes.

Table 8 indicated three different MST densities might be obtained based on the parameters of the testing performed. All three MST densities were investigated for the contactors because of their high rotation speeds.

For each MST density analyzed, the MST loadings for uranium and plutonium (see Table 7) were used to compute the material composition atom densities for the defined volume as in previous sections (e.g., see Section 6.3). Two different uranium enrichments were investigated (8% and 16%) and the results for the enrichment with the highest resulting k_{eff}+2σ are provided below.

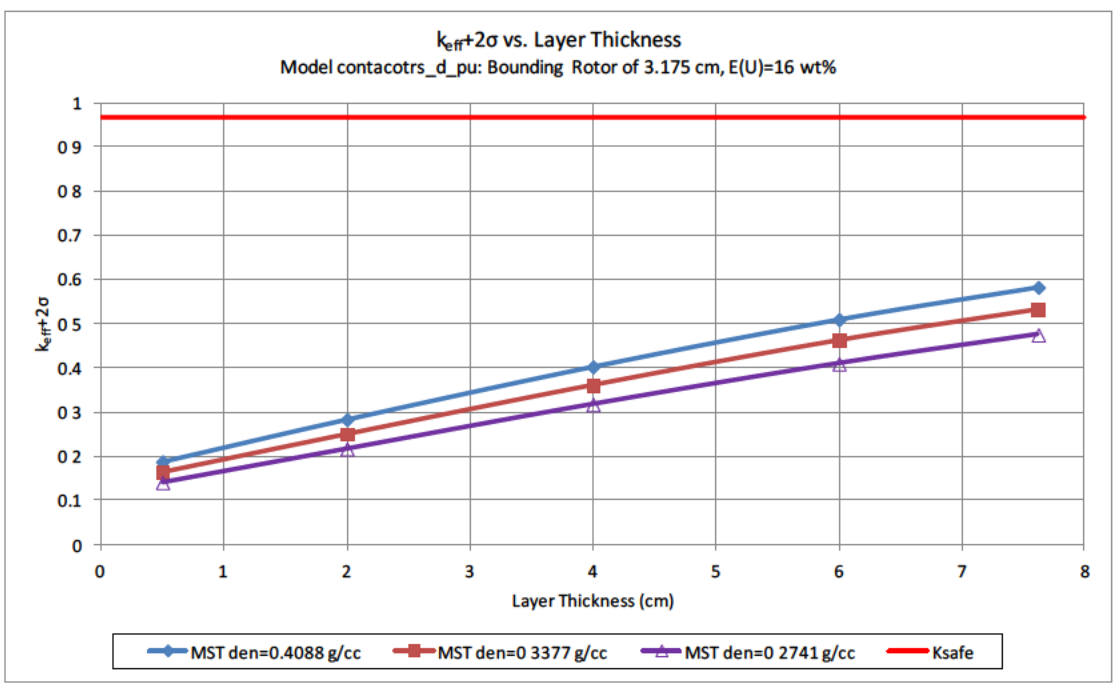


Figure 37: Contactor Results

Figure 38 depicts the k_{eff}+2σ results for all three MST densities over the range of layer thicknesses investigated, for a uranium enrichment of 16% ^{235}U. Figure 38 demonstrates that even at double the nominal uranium enrichment, at the maximum MST density, for the largest layer thickness investigated, the system remains subcritical.

Table 32 provides the data depicted in Figure 38.

Table 32: Contactor Results Data

File Name	Layer Thick (cm)	Centrifuge MST Density (g/cc)	H/X	k_{eff}+2σ	ANECF (MeV)
contactors_d_pu_1_1_1_in.out	0.5	0.2741	2397	0.1406	1.21E-02
contactors_d_pu_2_1_1_in.out	2	0.2741	2397	0.2166	9.59E-03
contactors_d_pu_3_1_1_in.out	4	0.2741	2397	0.3172	7.84E-03
contactors_d_pu_4_1_1_in.out	6	0.2741	2397	0.4093	6.86E-03
contactors_d_pu_5_1_1_in.out	7.62	0.2741	2397	0.4749	6.60E-03
contactors_d_pu_1_1_2_in.out	0.5	0.3377	1900	0.1645	1.29E-02
contactors_d_pu_2_1_2_in.out	2	0.3377	1900	0.2502	1.03E-02
contactors_d_pu_3_1_2_in.out	4	0.3377	1900	0.3608	8.87E-03
contactors_d_pu_4_1_2_in.out	6	0.3377	1900	0.4617	7.75E-03
contactors_d_pu_5_1_2_in.out	7.62	0.3377	1900	0.5313	7.37E-03
contactors_d_pu_1_1_3_in.out	0.5	0.4088	1528	0.1874	1.41E-02
contactors_d_pu_2_1_3_in.out	2	0.4088	1528	0.2830	1.11E-02
contactors_d_pu_3_1_3_in.out	4	0.4088	1528	0.4024	9.58E-03
contactors_d_pu_4_1_3_in.out	6	0.4088	1528	0.5092	8.63E-03
contactors_d_pu_5_1_3_in.out	7.62	0.4088	1528	0.5823	8.21E-03

The input file `contactors_d_pu_5_1_3_in` is provided in Appendix C.

6.8 *Sumps*

The previous sections of this NCSE have considered the fissile material inside the various process tanks and equipment found in the SWPF. The purpose of this section is to consider the concentration of MST solids when the normal material that was in the process vessels becomes relocated to a sump. As discussed in previous sections, the bounding process material is found in the SSRT. A relocation event may include, but is not limited to, seismic event, pipe leaks, tank leaks, or miss-directed transfers.

The following analysis takes the Nominal SSRT contents as presented in Table 10 and places that material in a typical SWPF sump, then incrementally removes water to simulate the evaporation process. The result was a sump full of the MST solids that were present in the SSRT.

The typical SWPF process sump has a 4 foot diameter and 3 foot straight wall before the dish bottom. The radius of the dish is equal to the diameter of the sump. Table 33 presents these standard process sump dimensions and utilizes the equations at the end of Section 6.1 to calculate the depth of the dish and volume of the dish. The volume in the sump above the dish was calculated with the standard formula of a cylinder.

Table 33: Sump Dimensions and Calculations

Description	Value	Units
Sump Diameter	4	ft
Sump Diameter	121.92	cm
Radius of Dish	4	ft
Radius of Dish	121.92	cm
Sump Straight Wall	3	ft
Sump Straight Wall	91.44	cm
Depth of Dish	16.33	cm
Volume of Dish	97628.91	cc
Volume of Dish	97.63	L
Volume of Cylinder	1067519.97	cc
Volume of Cylinder	1067.52	L
Total Sump Volume	1165.15	L

The sump was modeled to be completely surrounded in 2 foot thick concrete and no credit was taken for the sump construction steel or the space occupied by the steel. Figure 39 depicts the typical process sump with a dish bottom and modeled with concrete completely surrounding it.

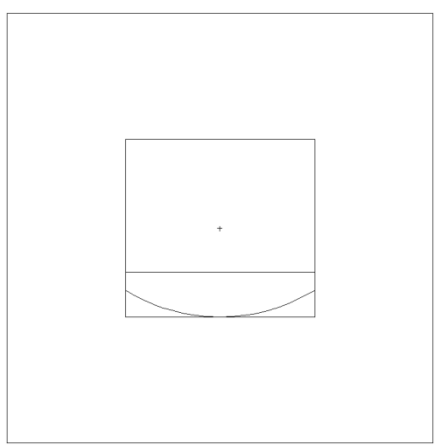


Figure 39: Sump Model

This evaluations starts with the Nominal contents as defined in Table 10. Note that the volume of the settled solids (Row 30 of Table 10) is approximately 1,469 L while the sump volume is only 1,165 L.

Therefore, the water mass is reduced from approximately 1,318 kg (Row 51 of Table 10) to 1,014 kg to allow the volumes to match. The water mass is further reduced as the volume of the MST solids is varied from 1,165 L to 150 L. The mass of MST and fissile materials remain constant at their Table 10 values. This simulates long term drying of the material. Due to varying the water mass, the H/X and fissile concentrations varied over a sufficiently wide range to demonstrate that optimum moderation conditions have been analyzed. Figure 40 depicts the MCNP results.

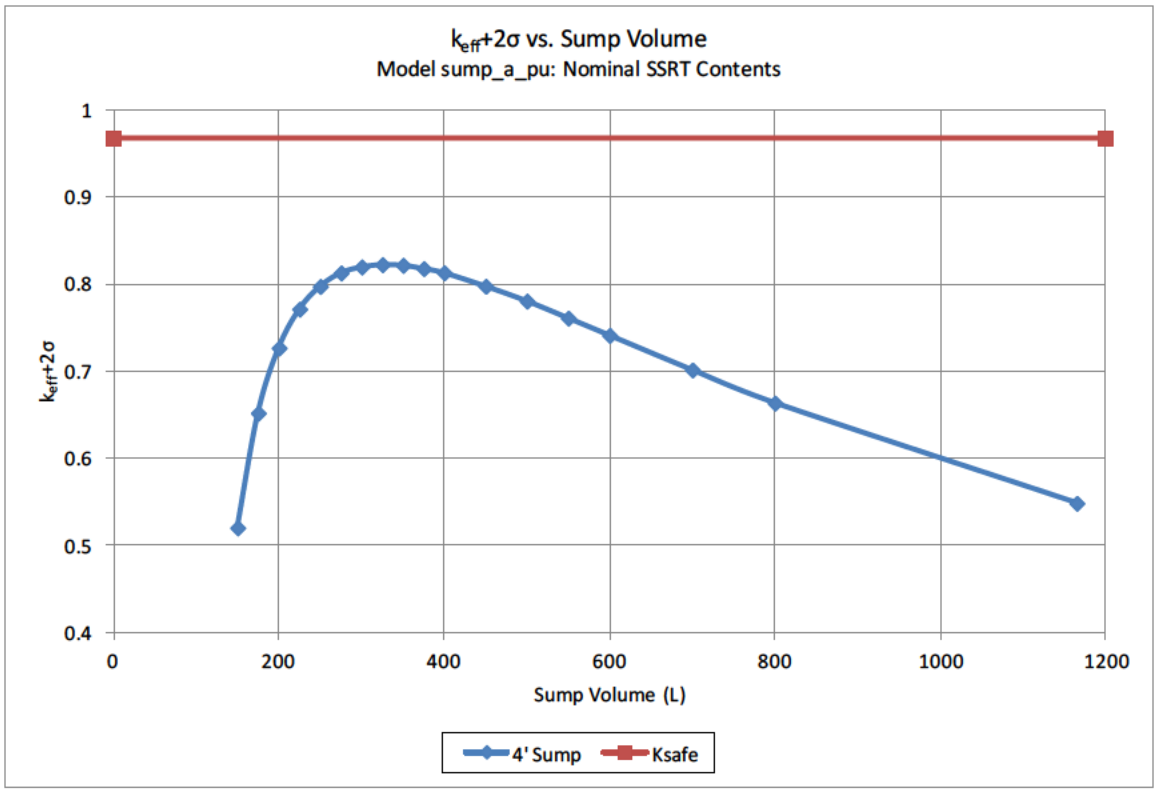


Figure 40: Sump Analysis Results

Figure 40 demonstrates that optimum moderation conditions for the fissile material nominally present in the SSRT remains subcritical ($k_{eff}+2\sigma < k_{safe}$) regardless the sump volume. Table 34 provides the data plotted in Figure 40.

Table 34: Sump Analysis Results Data

File Name	Sump Volume (L)	H/X	$k_{eff}+2\sigma$	ANECF (MeV)
sumps_a_pu_3_12_in	150	101	0.5199	4.67E-02
sumps_a_pu_3_13_in	175	232	0.6517	3.09E-02
sumps_a_pu_3_14_in	200	362	0.7266	2.35E-02
sumps_a_pu_3_15_in	225	493	0.7713	1.91E-02
sumps_a_pu_3_16_in	250	623	0.7974	1.65E-02
sumps_a_pu_3_17_in	275	754	0.8129	1.46E-02
sumps_a_pu_3_18_in	300	885	0.8197	1.31E-02
sumps_a_pu_3_19_in	325	1015	0.8224	1.20E-02
sumps_a_pu_3_20_in	350	1146	0.8217	1.10E-02
sumps_a_pu_3_21_in	375	1277	0.8179	1.04E-02
sumps_a_pu_3_22_in	400	1407	0.8130	9.78E-03
sumps_a_pu_3_23_in	450	1668	0.7976	8.60E-03
sumps_a_pu_3_24_in	500	1930	0.7805	7.96E-03
sumps_a_pu_3_25_in	550	2191	0.7610	7.44E-03
sumps_a_pu_3_26_in	600	2452	0.7411	6.87E-03
sumps_a_pu_3_27_in	700	2975	0.7013	6.16E-03
sumps_a_pu_3_28_in	800	3497	0.6633	5.78E-03
sumps_a_pu_3_29_in	1165	5404	0.5481	4.67E-03

The input file `sumps_a_pu_3_19_in` is provided in Appendix C.

6.9 *Implementation Equivalency Factor*

Per Section 14 of N-NCS-J-00004[5], a bounding Equivalency Factor (EF) may be selected for implementation using the optimum H/X of the configuration modeled and the equations provided. Table 35 provides the optimum H/X value for the bounding case in each series, along with the associated $k_{eff}+2\sigma$ value. Provided the optimum H/X value is less than 1500, two EFs were calculated for each series. One EF is for calculating the equivalent ^{239}Pu mass based on a given ^{235}U mass. The other one is for calculating the equivalent ^{235}U mass based on a given ^{239}Pu mass. This last EF is only provided for reference because N-NCS-J-00004[5] recommends converting into ^{239}Pu.

Table 35: Equivalency Factors

Series	Optimum H/X	$k_{eff}+2\sigma$ at Optimum H/X	EF(H/X) for ^{235}U to ^{239}Pu	EF(H/X) for ^{239}Pu to ^{235}U
contactors_d_pu	1528	0.5823		
filter_x8_pu	419	0.3837	**0.701**	1.473
filter_z8_pu	695	0.9640	0.531	1.842
hor_c_pu	945	0.9133	0.427	2.280
lump_q_pu	564	0.7571	0.598	1.671
torus_d_pu	653	0.9629	0.551	1.785
uniform_d_pu	726	0.9570	0.517	1.885
MSTConc3_pu	3186	0.6238		
Num_batch3_pu	7519	0.4631		
Pu_conc2_pu	5174	0.5690		
U_conc2_pu	4209	0.5758		
U_enrich2_pu	3134	0.6896		
sumps_a_pu	993	0.8186	0.408	2.398

Table 35 indicates that for the MCNP case series analyzed in this NCSE, the maximum $k_{eff}+2\sigma$ value did not challenge k_{safe} when the optimum H/X value is above 1500. Thus the integrity of the equivalency factor equations was not challenged.

Based on the guidance provided in N-NCS-J-00004[5], it is conservative to select the maximum EF value for converting from ^{235}U to ^{239}Pu. Based on the results summary provided in Table 35, this maximum EF value that is applicable to all the operations analyzed herein is EF=0.701 [g ^{239}Pu / g ^{235}U]. Note that each NCSE may present a different bounding EF and all NCSEs should be referenced before selecting one EF for implementation.

7 Assumptions, Limits, Controls, and Design Features

In accordance with the guidance in Section 4.3.7 of N-NCS-J-00004[5], which implements requirements from the appropriate Standards, this section summarizes the requirements necessary to ensure that the conclusions of this NCSE remain valid.

7.1 *Assumptions*

Section 4.3.7 of N-NCS-J-00004[5] acknowledges four different types of assumptions. Each assumption from this NCSE is categorized according to those four types in the following subsections. The subsections for restricted assumptions provide additional detail on how each assumption will be protected and maintained. This detail is not applicable for unrestricted assumptions.

7.1.1 Restricted Bounding Assumptions

Per Section 4.3.7 of N-NCS-J-00004[5], a Restricted Bounding Assumption represents the bounds of the analysis, and for a process condition to exceed a specified value is to be in unanalyzed space. This means the current NCSE does not demonstrate that the facility/process is subcritical when any aspect of a Restricted Bounding Assumption is exceeded.

1. The maximum uranium enrichment allowed is 8% ^{235}U. (All scenarios).

   Basis

   The analysis presented in Section 6 demonstrated that uranium loading on MST for the SWPF process remained subcritical, provided the uranium enrichment was limited to a maximum of 8% ^{235}U. The SWPF process will not affect the uranium enrichment, so the feed to SWPF is required to meet this specification.

   Protection and Control

   The SWPF WAC shall specify this maximum value.

2. The maximum uranium concentration in the feed to SWPF is 0.025 g/L (including solids). [Scenarios 5.1.1 - 5.1.6]

   Basis

   The SRNL report (WSRC-STI-2006-00012[49]) was based on a maximum feed of 25 mg/L uranium. This report provided the wt.% loading values for uranium and plutonium on MST. These loading values were used in the calculation of the material compositions for all MCNP calculations presented in Section 6.

   Protection and Control

   The SWPF WAC shall specify this maximum value.

3. The maximum plutonium and equivalent trace actinide concentration in the feed to SWPF is 0.0025 g/L (including solids). [Scenarios 5.1.1 - 5.1.6]

   Basis

   This value was selected and used to bound all expected plutonium and equivalent trace actinide concentrations.

   Protection and Control

   The SWPF WAC shall specify this maximum value.

7.1.2 Restricted Process Assumptions

Per Section 4.3.7 of N-NCS-J-00004[5], a Restricted Process Assumption is to protect something in the facility from changing, or prevent something from being done, without evaluating its impact on the NCSE, due to it being relied on in the analysis.

1. MST is the only chemical added to a SWPF tank (see Table 1) that may behave as a concentrating mechanism for fissile material within the Scope of this NCSE (see Section 1.1).

   Protection and Control

   SWPF Operating procedures shall not allow chemical additions (i.e., other than MST) that may concentrate (e.g., collect or precipitate) fissile material.

2. The MST used in the SWPF is that analyzed in WSRC-STI-2006-00012[49]. See Section 4.5.

   Protection and Control

   The MST that was analyzed in WSRC-STI-2006-00012[49] is part of the design basis for the facility. Any other variety of MST may impact the results of the analysis. Any change to the variety of MST used will require a Design Change Notice (DCN) to be processed which will receive Nuclear Safety review.

7.2 *Design Features*

The analysis of the CFF with MST solids relied on three design constraints.

1. The minimum outer diameter of the center tube (depicted in Figure 25) was 21.59 cm. See Section 6.5.2.
2. A minimum of 180 filter tubes in the CFF. See Section 6.5.3.
3. The maximum outer diameter of the outer shell was 67.31 cm. See Section 6.5.
4. The sintered metal tubes in the CFF were made of SS316L with a minimum density of 3.96 g/cc. See Section 6.5.
5. The sintered metal tubes in the CFF are designated as Safety Significant (SS) for preventing solids break-through. See Section 6.6.2.

7.3 *Limits and Controls*

There are no administrative controls relied on to ensure the analyzed scenarios remain incredible beyond those presented above.

8 Summary

This NCSE demonstrated that, for all normal and credible abnormal conditions, the material in the SWPF process will remain subcritical due to MST concentration of fissile material. The contingency analysis concluded that none of the hypothetical accident conditions were considered credible to result in a criticality, based on the credited assumptions and controls that are summarized in Section 7.

Because the contingency analysis did not identify any credible criticality scenarios for the ASP tanks, and all the ASP tanks are in "dark cells" that are not expected to require the need for personnel entrance for the life of the facility, there is no justification or need for criticality accident alarm system coverage (a k.a., nuclear incident monitors).

Therefore, it is recommended that adequate protection of the assumptions, limits, controls, and design features specified in Section 7 be implemented in appropriate design documents, operating procedures, and WAC.

Per Section 6.9, it is permissible to implement an EF of 0.701 [g ^{239}Pu / g ^{235}U] when calculating an equivalent ^{239}Pu mass based on a given ^{235}U mass for the scope of the analysis contained herein. Otherwise the individual ^{239}Pu and ^{235}U mass limits are applicable.

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Appendix A

Spreadsheet Cell Formulas

The following table shows the cell formulas for the Nominal case as shown in Table 10. All the upset conditions presented in Table 10 utilize the same formulas for the different input parameter values.

A	B	C	D
1	**Input Parameters**	**Units**	**Nominal**
2	AST-A Batch Volume	gal	38000
3	Target MST Concentration	g/L	0.4
4	Uranium Feed Concentration	mgU/L	25
5	Uranium (^{235}U) Enrichment	g^{235}U/gU	0.08
6	Plutonium Feed Concentration	mgPu/L	2 5
7	Plutonium (^{240}Pu) Enrichment	g^{240}Pu/gPu	0.0000001
8	# AST-A Batches in one tank (SSRT)	#	7
9	# MST Strike for loading in settled region	#	5
10	^{235}U mass from acid cleaning CFF	g ^{235}U	277
11	^{239}Pu mass from acid cleaning CFF	g ^{239}Pu	223
12	**Calculated Parameters**		
13	AST-A Batch Volume	L	=3.78541178*D2
14	Mass U per batch	gU	=D13*D4/1000
15	Mass ^{235}U per batch	g^{235}U	=D14*D5
16	Mass Pu per batch	gPu	=D13*D6/1000
17	Mass ^{239}Pu per batch	g^{239}Pu	=D16*(1-D7)
18	Mass MST per batch	g	=D3*D13
19	Mass U per SSRT tank	gU	=D14*D8
20	Mass ^{235}U per SSRT tank	g^{235}U	=D15*D8
21	Mass Pu per SSRT tank	gPu	=D16*D8
22	Mass ^{239}Pu per SSRT tank	g^{239}Pu	=D8*D17
23	Mass MST per SSRT tank	gMST	=D18*D8
24	Mass of U+Pu+MST per SSRT tank	g	=D19+D21+D23
25	Mass UO_2 from CFF	g	=(D10/D5)/D80
26	Mass PuO_2 from CFF	g	=(D11/(1-D7))/D82
27	Volume UO_2 from CFF	cc	=D25/D61
28	Volume PuO_2 from CFF	cc	=D26/D63
29	MST concentration in settled region	gMST/cc	0 2741
30	Volume of settled region	L	=(D23/D29/1000)+((D27+D28)/1000)
31	SRNL: U Loading on MST	gU/gMST	=0.14+2*0.0105
32	SRNL: Pu Loading on MST	gPu/gMST	=0.0102+2*0.000112
33	Possible Mass U on MST (in settled region) per tank	gU	=D31*D23
34	Possible Mass ^{235}U on MST (in settled region) per tank	g^{235}U	=D33*D5
35	Possible Mass Pu on MST (in settled region) per tank	gPu	=D32*D23
36	Possible Mass ^{239}Pu on MST (in settled region) per tank	g^{239}Pu	=D35*(1-D7)
37	Mass ^{235}U in settled region	g^{235}U	=MIN(D34,D20)+D10
38	Mass ^{239}Pu in settled region	g^{239}Pu	=MIN(D36,D22)+D11
39	^{235}U delta	g^{235}U	=D37-D20
40	^{239}Pu delta	g^{239}Pu	=D38-D22
41	^{235}U Concentration in settled region	g^{235}U/L	=D37/D30

A	B	C	D
42	^{239}Pu Concentration in settled region	g^{239}Pu/L	=D38/D30
43	Mass U in settled region	gU	=D37/D5
44	Mass UO_2 in settled region	gUO_2	=D43/D80
45	Volume UO_2 in settled region	cc	=D44/D61
46	Mass Pu in settled region	gPu	=D38/(1-D7)
47	Mass PuO_2 in settled region	gPuO_2	=D46/D82
48	Volume PuO_2 in settled region	cc	=D47/D63
49	Volume of MST in settled region	cc	=D23/D64
50	Volume of Water in settled region	cc	=(1000*D30)-D49-D48-D45
51	Mass of Water in settled region	g	=D50*D65
52	Mass of settled region	g	=D51+D47+D44+D23
53	Density of settled region	g/cc	=D52/(D30*1000)
54	wt% UO_2 in settled region	%	=D44/D52
55	wt% PuO_2 in settled region	%	=D47/D52
56	wt% U in settled region	%	=D43/D52
57	wt% Pu in settled region	%	=D46/D52
58	wt% MST in settled region	%	=D23/D52
59	wt% water in settled region	%	=D51/D52
60	density of U	g/cc	19.05
61	density of UO_2	g/cc	=11.05*(D72/D71)
62	density of Pu	g/cc	19.84
63	density of PuO_2	g/cc	11.46
64	density of MST	g/cc	2.765
65	density of H_2O	g/cc	0.9982
66	mole wt. H	g/mole	1.00794
67	mole wt. O	g/mole	15.9994
68	mole wt. Na	g/mole	22.98977
69	mole wt. Ti	g/mole	47.867
70	mole wt. ^{235}U	g/mole	235.043922
71	mole wt. ^{238}U	g/mole	238.050785
72	mole wt. U	g/mole	=(1/((D5/D70)+((1-D5)/D71)))
73	mole wt. ^{239}Pu	g/mole	239.0521636
74	mole wt. ^{240}Pu	g/mole	240.0538138
75	mole wt. Pu	g/mole	=(1/((D7/D74)+((1-D7)/D73)))
76	mole wt. $NaTi_2O_5H$ (MST)	g/mole	=D68+2*D69+5*D67+D66
77	mole wt. UO_2	g/mole	=D72+2*D67
78	mole wt. PuO_2	g/mole	=D75+2*D67
79	mole wt. H_2O	g/mole	=2*D66+D67
80	wt% U in UO_2	%	=D72/D77
81	wt% O in UO_2	%	=2*D67/D77
82	wt% Pu in PuO_2	%	=D75/D78
83	wt% O in PuO_2	%	=2*D67/D78
84	wt% H in H_2O	%	=2*D66/D79
85	wt% O in H_2O	%	=D67/D79
86	wt% H in $NaTi_2O_5H$ (MST)	%	=D66/D76
87	wt% O in $NaTi_2O_5H$ (MST)	%	=5*D67/D76
88	wt% Ti in $NaTi_2O_5H$ (MST)	%	=2*D69/D76
89	wt% Na in $NaTi_2O_5H$ (MST)	%	=D68/D76
90	b Na	#/b-cm	0.6022045
91	atom density H from water	#/b-cm	=D53*D59*D84*D90/D66
92	atom density H from MST	#/b-cm	=D53*D58*D86*D90/D66

A	B	C	D
93	Total H		=SUM(D91:D92)
94	atom density ^{235}U	#/b-cm	=D53*D56*D5*D90/D70
95	atom density ^{238}U	#/b-cm	=D53*D56*(1-D5)*D90/D71
96	atom density ^{239}Pu	#/b-cm	=D53*D57*(1-D7)*D90/D73
97	atom density ^{240}Pu	#/b-cm	=D53*D57*D7*D90/D74
98	atom density Ti	#/b-cm	=D53*D58*D88*D90/D69
99	Ti: atom density ^{54}Fe	#/b-cm	=0.059006*D98
100	Ti: atom density ^{56}Fe	#/b-cm	=0.917181*D98
101	Ti: atom density ^{57}Fe	#/b-cm	=0.021007*D98
102	Ti: atom density ^{58}Fe	#/b-cm	=0.002806*D98
103	atom density Na (modeled as Al)	#/b-cm	=D53*D58*D89*D90/D68
104	atom density O from MST	#/b-cm	=D53*D58*D87*D90/D67
105	atom density O from UO_2	#/b-cm	=D53*D54*D81*D90/D67
106	atom density O from PuO_2	#/b-cm	=D53*D55*D83*D90/D67
107	atom density O from water	#/b-cm	=D53*D59*D85*D90/D67
108	Total O		=SUM(D104:D107)
109	**Total**	#/b-cm	=D93+D108+D94+D95+D96+D97+D98+D103

Appendix B

The following table is an atom density calculation example for Torus D model case `torus_e_pu_22_17_11_10_in` which was reported in Section 6.4.

Calculations for concentration in Torus E

Input values		
Torus Volume (V_t)	**88096**	cc
Centrifuge MST concentration	**0.2741**	g/cc
^{235}U Enrichment for MST Solids	**8.0%**	g U-235 / g U
^{235}U Enrichment for CFF	**8.0%**	g U-235 / g U
Volume Fraction H_2O	**1.00E+00**	density multiplier
wt% Pu-240	**1.00E-06**	g Pu-240 / g Pu
Mass ^{235}U from CFF	**1200.0**	g ^{235}U
Mass ^{239}Pu from CFF	**900.0**	g ^{239}Pu
U & Pu Loading on MST		
nominal Pu loading on MST	0.0102	g Pu / g MST
1*σ Pu loading on MST	0.000112	σ
Pu loading on MST	0.010424	g Pu / g MST
nominal U loading on MST	0.14	g U / g MST
1*σ U loading on MST	0.0105	σ
U loading on MST	0.161	g U / g MST
Densities		
Uranium density	19.05	g/cc
UO_2 density	11.05	g/cc
Plutonium density	19.84	g/cc
PuO_2 density	11.46	g/cc
dry MST density	2.765	g/cc
H_2O density	0.9982	g/cc
b Na	0.6022045	#/b-cm
Distribution of natural Fe from NSA-TR-07-11, Rev. 0		
Isotope	Atom Fraction	
Fe 26054	0.059006	
Fe 26056	0.917181	
Fe 26057	0.021007	
Fe 26058	0.002806	
Isotope / Compound		
U-235	235.043922	g/mole
U-238	238.050785	g/mole
U total	237.8074077	g/mole
O (from UO_2)	15.9994	g/mole
UO_2	269.8062077	g/mole
Pu-239	239.052156	g/mole
Pu-240	240.053808	g/mole
Pu total	239.052157	g/mole
O (from PuO_2)	15.9994	g/mole
PuO_2	271.050957	g/mole
Na	22.98977	g/mole
Ti	47.867	g/mole
O	15.9994	g/mole
H	1.00794	g/mole
$NaTi_2O_5H$ (MST)	199.72871	g/mole
H from water	1.00794	g/mole
O from water	15.9994	g/mole
H_2O	18.01528	g/mole
Weight Fractions of elements in compounds		
H in H_2O	0.1119	g H / g H_2O
O in H_2O	0.8881	g O / g H_2O
U in UO_2	0.8814	g U / g UO_2
O in UO_2	0.1186	g O / g UO_2
Pu in PuO_2	0.8819	g Pu / g PuO_2
O in PuO_2	0.1181	g O / g PuO_2

Na in $NaTi_2O_5H$ (MST)	0.1151	g Na / g $NaTi_2O_5H$
Ti in $NaTi_2O_5H$ (MST)	0.4793	g Ti / g $NaTi_2O_5H$
O in $NaTi_2O_5H$ (MST)	0.4005	g O / g $NaTi_2O_5H$
H in $NaTi_2O_5H$ (MST)	0.0050	g H / g $NaTi_2O_5H$
Mass & volume of U & Pu on MST		
Mass MST	24147.11	g
Volume of MST	8733.13	cc
Mass U on MST	3887.69	g U
Mass UO_2 on MST	4410.80	g UO_2
Mass ^{235}U on MST	311.01	g ^{235}U
Mass ^{238}U on MST	3576.67	g ^{238}U
Mass ^{235}U from CFF	1200.00	g ^{235}U
Mass ^{238}U on CFF	13800.00	g ^{238}U
Mass U from CFF	15000.00	g U
Mass UO_2 from CFF	17018.36	g UO_2
Mass Pu on MST	251.71	g Pu
Mass ^{239}Pu on MST	251.71	g ^{239}Pu
Mass ^{240}Pu on MST	0.00	g ^{240}Pu
Mass PuO_2 on MST	285.40	g PuO_2
Mass ^{239}Pu from CFF	900.00	g ^{239}Pu
Mass ^{240}Pu from CFF	0.00	g ^{240}Pu
Mass Pu from CFF	900.00	g Pu
Mass PuO_2 from CFF	1020.47	g PuO_2
Mass & volume of compounds & mixture		
Mass UO_2	21429.17	g UO_2
Volume UO_2	1939.29	cc UO_2
Mass PuO_2	1305.87	g PuO_2
Volume PuO_2	113.95	cc PuO_2
Mass H_2O	77170.47	g H_2O
Volume H_2O	77309.62	cc H_2O
Total mixture mass	124052.62	g
Mixture Density	1.4082	g/cc
Mass of elements		
Mass H in H_2O	8635.25	g H
Mass O in H_2O	68535.22	g O
Mass Na in MST	2779.45	g Na
Mass Ti in MST	11574.20	g Ti
Mass O in MST	9671.60	g O
Mass H in MST	121.86	g H
Mass O in UO_2	2541.48	g O
Mass O in PuO_2	154.16	g O
Weight fraction in mixture calculations		
WF of MST in mixture	0.1947	g MST / g mix
WF of H_2O in mixture	0.6221	g H_2O / g mix
WF of UO_2 in mixture	0.1727	g UO_2 / g mix
WF of PuO_2 in mixture	0.0105	g PuO_2 / g mix
WF of ^{235}U from UO_2 in mixture	0.0122	g ^{235}U / g mix
WF of ^{238}U from UO_2 in mixture	0.1401	g ^{238}U / g mix
WF of ^{239}Pu from PuO_2 in mixture	0.0093	g ^{239}Pu / g mix
WF of ^{240}Pu from PuO_2 in mixture	0.0000	g ^{240}Pu / g mix
WF of O in mixture	0.6522	g O / g mix
WF of Na in mixture	0.0224	g Na / g mix
WF of Ti in mixture	0.0933	g Ti / g mix
WF of H in mixture	0.0706	g H / g mix
Atom density calculations		
Atom density ^{235}U	4.3945E-05	#/(b-cm)
Atom density ^{238}U	4.9898E-04	#/(b-cm)
Atom density ^{239}Pu	3.2934E-05	#/(b-cm)
Atom density ^{240}Pu	3.2796E-11	#/(b-cm)
Atom density Na	8.2644E-04	#/(b-cm)
Atom density O	3.4566E-02	#/(b-cm)
Atom density H	5.9390E-02	#/(b-cm)

Atom density Ti	1.6529E-03	#/(b-cm)
Atom density Fe 26054	9.7530E-05	#/(b-cm)
Atom density Fe 26056	1.5160E-03	#/(b-cm)
Atom density Fe 26057	3.4722E-05	#/(b-cm)
Atom density Fe 26058	4.6380E-06	#/(b-cm)
Total mixture atom density	9.7011E-02	#/(b-cm)
Other Information		
Validation X	13.4	
Total H/X	773	

The following table shows the cell formulas used in the previous table.

A	B	C	D
2	Input values		
3	Torus Volume (Vt)	=1000*88.096	cc
4	Centrifuge MST concentration	0.2741	g/cc
5	235U Enrichment for MST Solids	0.08	g U-235 / g U
6	235U Enrichment for CFF	0.08	g U-235 / g U
7	Volume Fraction H2O	1	density multiplier
8	wt% Pu-240	0.000001	g Pu-240 / g Pu
9	Mass 235U from CFF	1200	g 235U
10	Mass 239Pu from CFF	900	g 239Pu
11	U & Pu Loading on MST		
12	nominal Pu loading on MST	0.0102	g Pu / g MST
13	1*σ Pu loading on MST	0.000112	σ
14	Pu loading on MST	=C12+2*C13	g Pu / g MST
15	nominal U loading on MST	0.14	g U / g MST
16	1*σ U loading on MST	0.0105	σ
17	U loading on MST	=C15+2*C16	g U / g MST
18	Densities		
19	Uranium density	19.05	g/cc
20	UO2 density	11.05	g/cc
21	Plutonium density	19.84	g/cc
22	PuO2 density	11.46	g/cc
23	dry MST density	2.765	g/cc
24	H2O density	=0.9982*C7	g/cc
25	b Na	0.6022045	#/b-cm
26	Distribution of natural Fe from NSA-TR-07-11, Rev. 0		
27	Isotope	Atom Fraction	
28	Fe 26054	0.059006	
29	Fe 26056	0.917181	
30	Fe 26057	0.021007	
31	Fe 26058	0.002806	
32	Isotope / Compound		
33	U-235	235.043922	g/mole
34	U-238	238.050785	g/mole
35	U total	=1/((C5/C33) + ((1-C5)/C34))	g/mole
36	O (from UO2)	15.9994	g/mole
37	UO2	=C35+2*C36	g/mole
38	Pu-239	239.052156	g/mole
39	Pu-240	240.053808	g/mole
40	Pu total	=1/((C8/C39) + ((1-C8)/C38))	g/mole
41	O (from PuO2)	=C36	g/mole
42	PuO2	=C40+2*C41	g/mole
43	Na	22.98977	g/mole
44	Ti	47.867	g/mole
45	O	=C36	g/mole

46	H	=C48	g/mole
47	NaTi2O5H (MST)	=C43+2*C44+5*C45+C46	g/mole
48	H from water	1.00794	g/mole
49	O from water	=C36	g/mole
50	H2O	=2*C48+C49	g/mole
51	Weight Fractions of elements in compounds		
52	H in H2O	=2*C48/C50	g H / g H2O
53	O in H2O	=C49/C50	g O / g H2O
54	U in UO2	=C35/C37	g U / g UO2
55	O in UO2	=2*C36/C37	g O / g UO2
56	Pu in PuO2	=C40/C42	g Pu / g PuO2
57	O in PuO2	=2*C41/C42	g O / g PuO2
58	Na in NaTi2O5H (MST)	=C43/C47	g Na / g NaTi2O5H
59	Ti in NaTi2O5H (MST)	=2*C44/C47	g Ti / g NaTi2O5H
60	O in NaTi2O5H (MST)	=5*C45/C47	g O / g NaTi2O5H
61	H in NaTi2O5H (MST)	=C46/C47	g H / g NaTi2O5H
62	Mass & volume of U & Pu on MST		
63	Mass MST	=C3*C4	g
64	Volume of MST	=C63/C23	cc
65	Mass U on MST	=C63*C17	g U
66	Mass UO2 on MST	=C65/C54	g UO2
67	Mass 235U on MST	=C65*C5	g 235U
68	Mass 238U on MST	=(1-C5)*C65	g 238U
69	Mass 235U from CFF	=C9	g 235U
70	Mass 238U on CFF	=C71-C69	g 238U
71	Mass U from CFF	=C69/C6	g U
72	Mass UO2 from CFF	=C71/C54	g UO2
73	Mass Pu on MST	=C63*C14	g Pu
74	Mass 239Pu on MST	=C73*(1-C8)	g 239Pu
75	Mass 240Pu on MST	=C73*C8	g 240Pu
76	Mass PuO2 on MST	=C73/C56	g PuO2
77	Mass 239Pu from CFF	=C10	g 239Pu
78	Mass 240Pu from CFF	=C79*C8	g 240Pu
79	Mass Pu from CFF	=C77/(1-C8)	g Pu
80	Mass PuO2 from CFF	=C79/C56	g PuO2
81	Mass & volume of compounds & mixture		
82	Mass UO2	=C66+C72	g UO2
83	Volume UO2	=C82/C20	cc UO2
84	Mass PuO2	=C76+C80	g PuO2
85	Volume PuO2	=C84/C22	cc PuO2
86	Mass H2O	=C87*C24	g H2O
87	Volume H2O	=C3-C64-C83-C85	cc H2O
88	Total mixture mass	=C82+C84+C86+C63	g
89	Mixture Density	=C88/C3	g/cc

90	Mass of elements		
91	Mass H in H2O	=C86*C52	g H
92	Mass O in H2O	=C86*C53	g O
93	Mass Na in MST	=C63*C58	g Na
94	Mass Ti in MST	=C63*C59	g Ti
95	Mass O in MST	=C63*C60	g O
96	Mass H in MST	=C63*C61	g H
97	Mass O in UO2	=C82*C55	g O
98	Mass O in PuO2	=C84*C57	g O
99	Weight fraction in mixture calculations		
100	WF of MST in mixture	=C63/C88	g MST / g mix
101	WF of H2O in mixture	=C86/C88	g H2O / g mix
102	WF of UO2 in mixture	=C82/C88	g UO2 / g mix
103	WF of PuO2 in mixture	=C84/C88	g PuO2 / g mix
104	WF of 235U from UO2 in mixture	=(C67+C69)/C88	g 235U / g mix
105	WF of 238U from UO2 in mixture	=(C68+C70)/C88	g 238U / g mix
106	WF of 239Pu from PuO2 in mixture	=(C74+C77)/C88	g 239Pu / g mix
107	WF of 240Pu from PuO2 in mixture	=(C78+C75)/C88	g 240Pu / g mix
108	WF of O in mixture	=(C92+C95+C97+C98)/C88	g O / g mix
109	WF of Na in mixture	=C93/C88	g Na / g mix
110	WF of Ti in mixture	=C94/C88	g Ti / g mix
111	WF of H in mixture	=(C96+C91)/C88	g H / g mix
112	Atom density calculations		
113	Atom density 235U	=C104*C89*C25/C33	#/(b-cm)
114	Atom density 238U	=C105*C89*C25/C34	#/(b-cm)
115	Atom density 239Pu	=C106*C89*C25/C38	#/(b-cm)
116	Atom density 240Pu	=C107*C89*C25/C39	#/(b-cm)
117	Atom density Na	=C109*C89*C25/C43	#/(b-cm)
118	Atom density O	=C108*C89*C25/C49	#/(b-cm)
119	Atom density H	=C111*C89*C25/C48	#/(b-cm)
120	Atom density Ti	=C110*C89*C25/C44	#/(b-cm)
121	Atom density Fe 26054	=$C$120*C28	#/(b-cm)
122	Atom density Fe 26056	=$C$120*C29	#/(b-cm)
123	Atom density Fe 26057	=$C$120*C30	#/(b-cm)
124	Atom density Fe 26058	=$C$120*C31	#/(b-cm)
125	Total mixture atom density	=C113+C114+C115+C116+C117+C118+C119+C120	#/(b-cm)
126	Other Information		
127	Validation X	=100*(C113+C115)/(C113+C114+C115+C116)	
128	Total H/X	=C119/(C113+C115)	

Appendix C

Selected Input Files

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Case uniform_d_pu_9_5_13_in

```
MCNP calc of uniform_d_pu_9_5_13_in
C  Cell cards
1   1  9.69681e-2   (-1 -2 -4):(1 -2 -4 6)     imp n=1 $ settled region
3   5  1.00102e-1    -1 -2 -3 4  imp:n=1 $ low concentration U/Pu above settled region
10  0   -10 #1 #3   imp:n=1
11  3  8.17775e-2   -11 10 imp n=1
99  0           11    imp:n=0

C  Surface cards
1  so  243.84
2  cz  121.92
3  pz  93.628365
4  pz  -228.5652
6  pz  -211.1716
10  rpp -121.9201  121.9201  -121.9201  121.9201  -243.84    93.628365
11  rpp -198.12    198.12    -198.12    198.12    -320.04    169.82836

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 0 0 -236.20
si1 0 121.92
si2 -236.20
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+PuO2+UO2
c      Mixture 1 Volume  = 1.75000e5   cc
c      Mixture 1 Density = 1.42475 g/cc
m1     92235.80c  4.71106e-5
      92238.80c  5.34929e-4
      94239.80c  3.45483e-5
      94240.80c  3.44042e-11
      13027.80c  8.26442e-4    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 1.65288e-3
      26054.80c  9.75301e-5
      26056.80c  1.51599e-3
      26057.80c  3.47221e-5
      26058.80c  4.63799e-6
       8016.80c  3.45922e-2
       1001.80c  5.92800e-2
mt1  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
       8016.80c  4.60557e-2
      11023.80c  1.74719e-3
      13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
      14028.80c  1.53283e-2
      14029.80c  7.78334e-4
```

```
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5     92235.80c  5.12419e-9
      92238.80c  5.81838e-8
      94239.80c  6.29783e-9
      94240.80c  6.27156e-15
       1001.80c  6.67343e-2
       8016.80c  3.33673e-2
mt5  lwtr.20c
```

Case MSTconc3_pu_5_3 _in

```
MCNP calc of MSTconc3_pu_5 _3 _in
C  Cell cards
1   1  9.74755e-2   (-1 -2 -4):(1 -2 -4 6)     imp n=1 $ settled region
3   5  1.00102e-1    -1 -2 -3 4  imp n=1 $ low concentration U/Pu above settled region
10  0   -10 #1 #3   imp:n=1
11  3  8.17775e-2   -11 10 imp n=1
99  0           11    imp:n=0

C  Surface cards
1  so  243.84
2  cz  121.92
3  pz  93.628365
4  pz  -216.4946
6  pz  -211.1716
10  rpp -121.9201  121.9201  -121.9201  121.9201  -243.84    93.628365
11  rpp -198.12    198.12    -198.12    198.12    -320.04    169.82836

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 0 0 -230.16
si1 0 121.92
si2 -230.16
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+Eq.U-235+U-238
c      Mixture 1 Volume  = 5.51410e2   cc
c      Mixture 1 Density = 1.22859 g/cc
m1     92235.80c  1.03261e-5
      92238.80c  1.17250e-4
      94239.80c  8.21157e-6
      94240.80c  8.17731e-13
      13027.80c  8.25876e-4    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 1.65175e-3
      26054.80c  9.74633e-5
      26056.80c  1.51496e-3
      26057.80c  3.46984e-5
      26058.80c  4.63482e-6
       8016.80c  3.42794e-2
       1001.80c  6.05827e-2
mt1  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
       8016.80c  4.60557e-2
      11023.80c  1.74719e-3
      13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
      14028.80c  1.53283e-2
      14029.80c  7.78334e-4
```

```
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5     92235.80c  5.12419e-9
      92238.80c  5.81838e-8
      94239.80c  6.29783e-9
      94240.80c  6.27156e-15
       1001.80c  6.67343e-2
       8016.80c  3.33673e-2
mt5  lwtr.20c
```

Case U_con2_pu_3_1_in

```
MCNP calc of U_conc2_pu_3 _1 _in
C  Cell cards
1   1  9.74902e-2   (-1 -2 -4):(1 -2 -4 6)     imp n=1 $ settled region
3   5  1.00102e-1    -1 -2 -3 4  imp n=1 $ low concentration U/Pu above settled region
10  0   -10 #1 #3   imp:n=1
11  3  8.17775e-2   -11 10 imp n=1
99  0           11    imp:n=0

C  Surface cards
1  so  243.84
2  cz  121.92
3  pz  93.628365
4  pz  -196.4251
6  pz  -211.1716
10  rpp -121.9201  121.9201  -121.9201  121.9201  -243.84    93.628365
11  rpp -198.12    198.12    -198.12    198.12    -320.04    169.82836

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 0 0 -220.13
si1 0 121.92
si2 -220.13
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+Eq.U-235+U-238
c      Mixture 1 Volume  = 1.46967e3   cc
c      Mixture 1 Density = 1.22231 g/cc
m1     92235.80c  9.35891e-6
       92238.80c  1.06268e-4
       94239.80c  4.56564e-6
       94240.80c  4.54659e-13
       13027.80c  8.26304e-4    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 1.65261e-3
       26054.80c  9.75137e-5
       26056.80c  1.51574e-3
       26057.80c  3.47163e-5
       26058.80c  4.63722e-6
        8016.80c  3.42695e-2
        1001.80c  6.06216e-2
mt1  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
        8016.80c  4.60557e-2
       11023.80c  1.74719e-3
       13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
       14028.80c  1.53283e-2
       14029.80c  7.78334e-4
```

```
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5     92235.80c  5.12419e-9
      92238.80c  5.81838e-8
      94239.80c  6.29783e-9
      94240.80c  6.27156e-15
       1001.80c  6.67343e-2
       8016.80c  3.33673e-2
mt5  lwtr.20c
```

Case Uenrich2_pu_2_3_in

```
MCNP calc of U_enrich2_pu_2 _3 _in
C  Cell cards
1   1  9.75635e-2   (-1 -2 -4):(1 -2 -4 6)     imp n=1 $ settled region
3   5  1.00102e-1    -1 -2 -3 4  imp n=1 $ low concentration U/Pu above settled region
10  0   -10 #1 #3   imp:n=1
11  3  8.17775e-2   -11 10 imp n=1
99  0           11    imp:n=0

C  Surface cards
1  so  243.84
2  cz  121.92
3  pz  93.628365
4  pz  -196.4261
6  pz  -211.1716
10  rpp -121.9201  121.9201  -121.9201  121.9201  -243.84    93.628365
11  rpp -198.12    198.12    -198.12    198.12    -320.04    169.82836

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 0 0 -220.13
si1 0 121.92
si2 -220.13
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+Eq.U-235+U-238
c      Mixture 1 Volume  = 1.46962e3   cc
c      Mixture 1 Density = 1.19414 g/cc
m1     92235.80c  7.50466e-6
       92238.80c  3.89018e-5
       94239.80c  4.69726e-6
       94240.80c  4.67766e-13
       13027.80c  8.26330e-4    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 1.65266e-3
       26054.80c  9.75168e-5
       26056.80c  1.51579e-3
       26057.80c  3.47174e-5
       26058.80c  4.63736e-6
        8016.80c  3.42249e-2
        1001.80c  6.08085e-2
mt1  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
        8016.80c  4.60557e-2
       11023.80c  1.74719e-3
       13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
       14028.80c  1.53283e-2
       14029.80c  7.78334e-4
```

```
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5     92235.80c  5.12419e-9
      92238.80c  5.81838e-8
      94239.80c  6.29783e-9
      94240.80c  6.27156e-15
       1001.80c  6.67343e-2
       8016.80c  3.33673e-2
mt5  lwtr.20c
```

Case Pu_conc2_2_3_in

```
MCNP calc of Pu_conc2_pu_2 _3 _in
C  Cell cards
1   1  9.75578e-2   (-1 -2 -4):(1 -2 -4 6)     imp n=1 $ settled region
3   5  1.00102e-1    -1 -2 -3 4  imp n=1 $ low concentration U/Pu above settled region
10  0   -10 #1 #3   imp:n=1
11  3  8.17775e-2   -11 10 imp n=1
99  0            11    imp:n=0

C  Surface cards
1  so  243.84
2  cz  121.92
3  pz  93.628365
4  pz  -196.4223
6  pz  -211.1716
10  rpp -121.9201  121.9201  -121.9201  121.9201  -243.84    93.628365
11  rpp -198.12    198.12    -198.12    198.12    -320.04    169.82836

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 0 0 -220.13
si1 0 121.92
si2 -220.13
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+Eq.U-235+U-238
c      Mixture 1 Volume  = 1.46980e3   cc
c      Mixture 1 Density = 1.19652 g/cc
m1     92235.80c  3.99330e-6
       92238.80c  4.53429e-5
       94239.80c  7.57807e-6
       94240.80c  7.54645e-13
       13027.80c  8.26230e-4    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 1.65246e-3
       26054.80c  9.75051e-5
       26056.80c  1.51560e-3
       26057.80c  3.47132e-5
       26058.80c  4.63680e-6
        8016.80c  3.42286e-2
        1001.80c  6.07936e-2
mt1  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
        8016.80c  4.60557e-2
       11023.80c  1.74719e-3
       13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
       14028.80c  1.53283e-2
       14029.80c  7.78334e-4
```

```
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5     92235.80c  5.12419e-9
      92238.80c  5.81838e-8
      94239.80c  6.29783e-9
      94240.80c  6.27156e-15
       1001.80c  6.67343e-2
       8016.80c  3.33673e-2
mt5  lwtr.20c
```

Case Num_batch2_pu_2_3_in

```
MCNP calc of Num_batch2_pu_2 _3 _in
C  Cell cards
1   1  9.75605e-2   (-1 -2 -4):(1 -2 -4 6)     imp n=1 $ settled region
3   5  1.00102e-1    -1 -2 -3 4  imp n=1 $ low concentration U/Pu above settled region
10  0   -10 #1 #3   imp:n=1
11  3  8.17775e-2   -11 10 imp n=1
99  0           11    imp:n=0

C  Surface cards
1  so  243.84
2  cz  121.92
3  pz  93.628365
4  pz  -164.9479
6  pz  -211.1716
10  rpp -121.9201  121.9201  -121.9201  121.9201  -243.84    93.628365
11  rpp -198.12    198.12    -198.12    198.12    -320.04    169.82836

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 0 0 -204.39
si1 0 121.92
si2 -204.39
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+Eq.U-235+U-238
c      Mixture 1 Volume  = 2.93959e3   cc
c      Mixture 1 Density = 1.19533 g/cc
m1     92235.80c  3.99330e-6
      92238.80c  4.53429e-5
      94239.80c  4.69669e-6
      94240.80c  4.67709e-13
      13027.80c  8.26230e-4    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 1.65246e-3
      26054.80c  9.75051e-5
      26056.80c  1.51560e-3
      26057.80c  3.47132e-5
      26058.80c  4.63680e-6
       8016.80c  3.42267e-2
       1001.80c  6.08011e-2
mt1  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
       8016.80c  4.60557e-2
      11023.80c  1.74719e-3
      13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
      14028.80c  1.53283e-2
      14029.80c  7.78334e-4
```

```
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5     92235.80c  5.12419e-9
      92238.80c  5.81838e-8
      94239.80c  6.29783e-9
      94240.80c  6.27156e-15
       1001.80c  6.67343e-2
       8016.80c  3.33673e-2
mt5  lwtr.20c
```

Case filter_x8_pu_10_21_in

```
MCNP calc of filter_x8_pu_10_21_in
c This is a TUBE model. No material outside the filter tubes.
C  Cell cards
1   1   8.66153e-2   -1  u=10  imp:n=1  $ m1 inside tubes
51  4   8.59637e-2    -51 1 u=10  imp:n=1  $ 316L sindered metal tube
91  0     (51 -2):(51 3)                    u=10  imp:n=1  $ void on shell side above & below mixture
2   0     51  2 -3                          u=10  imp n=1  $ void in the tube
3   0   -31 36 -32 34 -35 33     lat=2 fill=10  u=20  imp:n=1  $ Unit cell for hexagonal STS spacing
4   0    31:-36:32:-34:35:-33                u=20  imp:n=1  $ rest of u=20
5   0      -9  8 2 -4                fill=20  u=30  imp:n=1  $ create annulus and fill with unit cells
6   0  -8 2 -4                            u=30  imp:n=1  $ fill center region with void
94  0    -91 2 -3 #5 #6                    u=30  imp:n=1  $ fill shell side of filter with void
92  0    #5 #6 #94                         u=30  imp:n=1  $ rest of u=30
7   0   10 -11 12 -13 22 -23     lat=1 fill=30  u=40  imp:n=1  $ filter 1 & 2
8   0   -10:11:-12:13:-22:23                u=40  imp:n=1  $ rest of u=40
9   0   -40                        fill=40  u=0   imp:n=1  $ fill u=0 with 2 filters
10  0        10 -20  12 -21  2 -4 40        u=0   imp:n=1  $ void room region
11  3  8.17775e-2   16 -20  17 -21 -2  14          u=0   imp:n=1  $ concrete bottom reflector
12  3  8.17775e-2   16 -20  17 -21  4 -15          u=0   imp:n=1  $ concrete top reflector
13  3  8.17775e-2   16 -20  17 -21  2 -4 #9 #10      u=0   imp:n=1  $ concrete corner
14  3  8.17775e-2   16 -19  17 -18  14 -15 #9 #10 #11 #12 #13    u=0   imp:n=1  $ concrete reflector on
other side of room
93  0       #9 #10 #11 #12 #13 #14              u=0   imp:n=0  $ rest of universe

C  Surface cards
c tube inner radius
1   cz  0.55245
51  cz  0.635
c tube length
2   pz  0
3   pz  58.994399       $ height of m1 in tube
4   pz  304.8       $ length of tube
c Center Void of filter
8   cz  10.795
c Outer radius of filter section
9   cz  20.955
c Outer radius of filter shell
91  cz  33.655
c u=30 boundaries
10  px  -33.6551
11  px   33.6551
12  py  -33.6551
13  py   33.6551
22  pz  -0.0001
23  pz   304.8001
c Reflector surfaces
14  pz  -81.915
15  pz   386.715
16  px  -81.915
17  py  -81.915
18  py  291.465
```

```
19  px  291.465
c Room boundaries
20  px   209.55
21  py   209.55
c Hexagonal Lattice cell boundaries
31  px   0.64                  $ surface e
32  p    1  1.73205  0   1.28     $ surface a
33  p   -1  1.73205  0  -1.28     $ surface b
34  p    1  1.73205  0  -1.28     $ surface c
35  p   -1  1.73205  0   1.28     $ surface d
36  px  -0.64                  $ surface f
c volume for placing 2 filters
40  rpp  -33.655    100.965    -33.655    33.655     0 304.8

C  Data cards
C  Criticality control cards
kcode  6000  1.0  75  575
sdef  sur=0 rad=d1 ext=d2 pos=d3 axs= 0 0 1
si1   11.295       33.155
sp1   -21  2
si2   0 58.994399
sp2   0  1
si3  L 0 0 0   67.31     0  0
sp3   1  1
print 40 50 128 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+UO2+PuO2
c      Mixture 1 Density = 2.15370 g/cc
m1     92235.80c  4.67330e-5
      92238.80c  5.30642e-4
      94239.80c  3.71877e-5
      94240.80c  3.70325e-12
      13027.80c  4.26989e-3    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 8.53978e-3
      26054.80c  5.03898e-4
      26056.80c  7.83252e-3
      26057.80c  1.79395e-4
      26058.80c  2.39626e-5
       8016.80c  3.80261e-2
       1001.80c  3.51649e-2
mt1  lwtr.20c
c  Material 2 == Water
m2      1001.80c   0.066735
       8016.80c   0.033368
mt2     lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
       8016.80c  4.60557e-2
      11023.80c  1.74719e-3
      13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
      14028.80c  1.53283e-2
      14029.80c  7.78334e-4
```

```
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 4 == SS316L, den= 7.92         g/cc
c  Composition taken from Methods Manual.
c  Per NSA-TR-07-11 must break iron into individual isotopes.
m4     26054.80c   3.30085e-3
      26056.80c   5.13080e-2
      26057.80c   1.17515e-3
      26058.80c   1.56970e-4
c  Total Cr atom density = 1.5594e-2
      24050.80c   6.7756e-4
      24052.80c   1.3066e-2
      24053.80c   1.4816e-3
      24054.80c   3.6880e-4
c  Total Ni atom density = 9.7514e-3
      28058.80c   6.6385e-3
      28060.80c   2.5571e-3
      28061.80c   1.1116e-4
      28062.80c   3.5441e-4
      28064.80c   9.0269e-5
c  Total Mo atom density = 1.2428e-3
      42092.80c   1.8443e-4
      42094.80c   1.1372e-4
      42095.80c   1.9686e-4
      42096.80c   2.0717e-4
      42097.80c   1.1931e-4
      42098.80c   3.0312e-4
      42100.80c   1.2204e-4
      25055.80c   1.7363e-3
c    Silicon total =  1.69821e-3
      14028.80c   1.56625e-3
      14029.80c   7.95306e-5
      14030.80c   5.24271e-5
```

Case filter_z8_pu_22_18_in

```
MCNP calc of filter_z8_pu_22_18_in
c This is a SHELL side model. No material inside the filter tubes.
C  Cell cards
1   0       -1                          u=10  imp:n=1  $ void in the tube
91  0     (1 -2):(1 3)                    u=10  imp:n=1  $ void on shell side above & below mixture
2   1   9.00911e-2                1  2 -3    u=10  imp n=1  $ m1 on shell side, between voids
3   0   -31 36 -32 34 -35 33     lat=2 fill=10  u=20  imp:n=1  $ Unit cell for hexagonal STS spacing
4   0    31:-36:32:-34:35:-33                u=20  imp:n=1  $ rest of u=20
5   0      -9  8 2 -4                fill=20  u=30  imp n=1  $ create annulus and fill with unit cells
6   0  -8 2 -4                          u=30  imp:n=1  $ fill center region with void
94  1   9.00911e-2                -91 2 -3 #5 #6 u=30  imp:n=1  $ fill shell side of filter with m1
92  0    #5 #6 #94                        u=30  imp:n=1  $ rest of u=30
7   0   10 -11 12 -13 22 -23     lat=1 fill=30  u=40  imp:n=1  $ filter 1 & 2
8   0   -10:11:-12:13:-22:23                u=40  imp:n=1  $ rest of u=40
9   0   -40                       fill=40  u=0   imp:n=1  $ fill u=0 with 2 filters
10  0        10 -20  12 -21  2 -4 40          u=0   imp:n=1  $ void room region
11  3  8.17775e-2    16 -20  17 -21 -2  14            u=0   imp n=1  $ concrete bottom reflector
12  3  8.17775e-2    16 -20  17 -21  4 -15            u=0   imp:n=1  $ concrete top reflector
13  3  8.17775e-2    16 -20  17 -21  2 -4 #9 #10       u=0   imp:n=1  $ concrete corner
14  3  8.17775e-2    16 -19  17 -18  14 -15 #9 #10 #11 #12 #13    u=0   imp n=1  $ concrete reflector on
other side of room
93  0       #9 #10 #11 #12 #13 #14               u=0   imp:n=0  $ rest of universe

C  Surface cards
c tube inner radius
1   cz  0.4699
c tube length
2   pz  0
3   pz  79.478199        $ height of m1 in tube
4   pz  304.8       $ length of tube
c Center Void of filter
8   cz  10.795
c Outer radius of filter section
9   cz  20.955
c Outer radius of filter shell
91  cz  33.655
c u=30 boundaries
10  px  -33.6551
11  px   33.6551
12  py  -33.6551
13  py   33.6551
22  pz  -0.0001
23  pz   304.8001
c Reflector surfaces
14  pz  -81.915
15  pz   386.715
16  px  -81.915
17  py  -81.915
18  py  291.465
19  px  291.465
c Room boundaries
20  px   209.55
```

```
21  py   209.55
c Hexagonal Lattice cell boundaries
31  px   1.265                $ surface e
32  p    1  1.73205  0   2.53     $ surface a
33  p   -1  1.73205  0  -2.53     $ surface b
34  p    1  1.73205  0  -2.53     $ surface c
35  p   -1  1.73205  0   2.53     $ surface d
36  px  -1.265                $ surface f
c volume for placing 2 filters
40  rpp  -33.655    100.965    -33.655    33.655     0 304.8

C  Data cards
C  Criticality control cards
kcode  7000  1.0  75  575
sdef  sur=0 rad=d1 ext=d2 pos=d3 axs= 0 0 1
si1   11.295       33.155
sp1   -21  2
si2   0 79.478199
sp2   0  1
si3  L 0 0 0   67.31     0  0
sp3   1  1
print 40 50 128 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+UO2+PuO2
c      Mixture 1 Density = 1.85589 g/cc
m1     92235.80c  3.46886e-5
      92238.80c  3.93880e-4
      94239.80c  2.76033e-5
      94240.80c  2.74882e-12
      13027.80c  3.16942e-3    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 6.33884e-3
      26054.80c  3.74029e-4
      26056.80c  5.81386e-3
      26057.80c  1.33160e-4
      26058.80c  1.77868e-5
       8016.80c  3.68254e-2
       1001.80c  4.33013e-2
mt1  lwtr.20c
c  Material 2 == Water
m2      1001.80c   0.066735
       8016.80c   0.033368
mt2     lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
       8016.80c  4.60557e-2
      11023.80c  1.74719e-3
      13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
      14028.80c  1.53283e-2
      14029.80c  7.78334e-4
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
```

```
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
```

Case filter_z16_pu_40_22_13_in

```
MCNP calc of filter_z16_pu_40_22_13_in
c This is a SHELL side model. No material inside the filter tubes.
C  Cell cards
1   0       -1                          u=10  imp:n=1  $ void in the tube
91  0     (1 -2):(1 3)                    u=10  imp:n=1  $ void on shell side above & below mixture
2   1   9.30999e-2                1  2 -3    u=10  imp n=1  $ m1 on shell side, between voids
3   0   -31 36 -32 34 -35 33     lat=2 fill=10  u=20  imp:n=1  $ Unit cell for hexagonal STS spacing
4   0    31:-36:32:-34:35:-33                u=20  imp:n=1  $ rest of u=20
5   0      -9  8 2 -4                fill=20  u=30  imp:n=1  $ create annulus and fill with unit cells
6   0  -8 2 -4                          u=30  imp:n=1  $ fill center region with void
94  1   9.30999e-2                -91 2 -3 #5 #6 u=30  imp:n=1  $ fill shell side of filter with m1
92  0    #5 #6 #94                        u=30  imp:n=1  $ rest of u=30
7   0   10 -11 12 -13 22 -23     lat=1 fill=30  u=40  imp:n=1  $ filter 1 & 2
8   0   -10:11:-12:13:-22:23                u=40  imp:n=1  $ rest of u=40
9   0   -40                       fill=40  u=0   imp:n=1  $ fill u=0 with 2 filters
10  0        10 -20  12 -21  2 -4 40          u=0   imp:n=1  $ void room region
11  3  8.17775e-2    16 -20  17 -21 -2  14            u=0   imp n=1  $ concrete bottom reflector
12  3  8.17775e-2    16 -20  17 -21  4 -15            u=0   imp:n=1  $ concrete top reflector
13  3  8.17775e-2    16 -20  17 -21  2 -4 #9 #10       u=0   imp:n=1  $ concrete corner
14  3  8.17775e-2    16 -19  17 -18  14 -15 #9 #10 #11 #12 #13    u=0   imp n=1  $ concrete reflector on
other side of room
93  0       #9 #10 #11 #12 #13 #14               u=0   imp:n=0  $ rest of universe

C  Surface cards
c tube inner radius
1   cz  0.4699
c tube length
2   pz  0
3   pz  45.4575         $ height of m1 in tube
4   pz  304.8       $ length of tube
c Center Void of filter
8   cz  10.795
c Outer radius of filter section
9   cz  20.955
c Outer radius of filter shell
91  cz  33.655
c u=30 boundaries
10  px  -33.6551
11  px   33.6551
12  py  -33.6551
13  py   33.6551
22  pz  -0.0001
23  pz   304.8001
c Reflector surfaces
14  pz  -81.915
15  pz   386.715
16  px  -81.915
17  py  -81.915
18  py  291.465
19  px  291.465
c Room boundaries
20  px   209.55
```

```
21  py   209.55
c Hexagonal Lattice cell boundaries
31  px   1.265                $ surface e
32  p    1  1.73205  0   2.53     $ surface a
33  p   -1  1.73205  0  -2.53     $ surface b
34  p    1  1.73205  0  -2.53     $ surface c
35  p   -1  1.73205  0   2.53     $ surface d
36  px  -1.265                $ surface f
c volume for placing 2 filters
40  rpp  -33.655    100.965    -33.655    33.655     0 304.8

C  Data cards
C  Criticality control cards
kcode  7000  1.0  75  575
sdef  sur=0 rad=d1 ext=d2 pos=d3 axs= 0 0 1
si1   11.295       33.155
sp1   -21  2
si2   0 45.4575
sp2   0  1
si3  L 0 0 0   67.31     0  0
sp3   1  1
print 40 50 128 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+UO2+PuO2
c      Mixture 1 Density = 1.59819 g/cc
m1     92235.80c  4.85308e-5
      92238.80c  2.51569e-4
      94239.80c  1.93091e-5
      94240.80c  1.92286e-12
      13027.80c  2.21708e-3    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 4.43415e-3
      26054.80c  2.61641e-4
      26056.80c  4.06692e-3
      26057.80c  9.31482e-5
      26058.80c  1.24422e-5
       8016.80c  3.57869e-2
       1001.80c  5.03424e-2
mt1  lwtr.20c
c  Material 2 == Water
m2      1001.80c   0.066735
       8016.80c   0.033368
mt2     lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
       8016.80c  4.60557e-2
      11023.80c  1.74719e-3
      13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
      14028.80c  1.53283e-2
      14029.80c  7.78334e-4
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
```

```
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
```

Case hor_e_odx_yl_pu_20_16_5_3_in

```
MCNP calc of hor_e_odx_yl_pu_20_16_5_3_in
C  Cell cards
10  2  1.00103e-1  (-101 -102 103 106):(-104 -101 106):
      (-105 -101 106)  u=1  imp:n=1  $ horizontal tank with spherical dish ends
20  1  9.95134e-2  (-101 -102 103 -106):(-104 -101 -106):
      (-105 -101 -106) u=1 imp:n=1 $ m1 solution in tank
80  3  8.17775e-2    #10 #20     u=1 imp n=1  $ concrete reflection around tank
90  0  -201 202 -203 204 -205 206 fill=1 u=0 imp:n=1
99  0           #90      u=0 imp:n=0

C  Surface cards
101  cx   91.44      $ horizontal cylinder
102  px   114.3       $ plane at right end
103  px  -114.3       $ plane at left end
104  ell   114.3   0  0    24.501 0  0    -91.44       $ sphere to intersect cylinder at right end
105  ell  -114.3   0  0    24.501 0  0    -91.44       $ sphere to intersect cylinder at left end
c
106  pz  -78.50092    $ solution level
200  cx  167.64
201  px  215.00127
202  px -215.00127
203  py  167.64
204  py -167.64
205  pz  167.64
206  pz -167.64

C  Data cards
C  Criticality control cards
kcode  2500  1.0  75  575
sdef  sur=0  par=n  axs= 1 0 0  x=d1 y=d2 z=d3
si1  -114.3      114.3
sp1   0 1
si2  -46.89219  46.89219
sp2   0 1
si3  -91.44     -78.5009
sp3   0 1
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of H2O+UO2+PuO2
c      Mixture 1 Volume  = 2.00000e5   cc
c      Mixture 1 Density = 1.22646 g/cc
m1     92235.80c  4.25820e-5
      92238.80c  4.83508e-4
      94239.80c  3.37060e-5
      94240.80c  3.35654e-11
       8016.80c  3.37309e-2
       1001.80c  6.52227e-2
mt1  lwtr.20c
c  Material 2 == Water (mass den = 0.9982 g/cc)
m2      1001.80c   0.066735
      8016.80c   0.033368
mt2  lwtr.20c
```

```
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
       8016.80c  4.60557e-2
      11023.80c  1.74719e-3
      13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
      14028.80c  1.53283e-2
      14029.80c  7.78334e-4
      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
```

Case torus_f9_pu_17_21_10_11_in

```
MCNP calc of torus_f9_pu_17_21_10_11_in
c  Cell Cards
c  Radius of torus = 1.1          ft
c  Volume of torus = 91.914       L
1   1  9.70441e-2   -1 -2 -3 5 imp n=1   $ torus lump
2   4  9.75569e-2  (-1 -2 -3 -5 -20):(-1 -2  3 -5 -20):(-1 -2 3 5 -20)
                imp n=1  $ Settled solids outside torus
7   5  1.00102e-1  (-1 -2 -3 -5 20):(-1 -2 3 20):(1 -2 -4 6)  imp:n=1  $ Feed concentration
3    0        (1 -2 -6 14)  imp:n=1 $ void under and around tank
4   3  8.17775e-2   (2 -10 11 12 -13 14 -4):(-10 11 12 -13 -14 15):
                              (-10 11 12 -13 4 -16) imp:n=1  $ concrete reflection all around tank
5    0        -99 (-11 :10 :-12 :13 :16 :-15)  imp:n=1  $ surface 98 used for volume calc
6    0         99  imp:n=0   $ rest of the universe

c  Surface Cards
1       so 274.32     $ dish tank bottom
2       cz 137.16     $ tank radius
3       tz 0 0 -237.56808 137.16    33.528 33.528 $ torus for settled solids
4       pz 762          $ top of tank
5       c/z  -137.16    0 255.117   $ cut Cylinder
6       pz 0  $ reference plane
10        px  213.36       $ concrete reflection
11        px -213.36       $ concrete reflection
12        py -213.36       $ concrete reflection
13        py  213.36       $ concrete reflection
14        pz -274.32
15        pz -350.52
16        pz  838.2
20        pz  -229.9663
98 so  900.0    $ Boundary/surface for volume calc (not used for anything else)
99 so  901.0    $ Boundary/surface for volume calc (not used for anything else)

C  Data cards
C  Criticality control cards
 kcode  5000  1.0  75  575
  sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 127.5588 0 -226.392 axs= 0 1 0
  si1  0 9.601199
  si2  -127.5588 127.5588
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+UO2+PuO2
c      Mixture 1 Volume  = 9.19140e4   cc
c      Mixture 1 Density = 1.39564 g/cc
m1     92235.80c  4.11014e-5
      92238.80c  4.66695e-4
      94239.80c  3.73460e-5
      94240.80c  3.71902e-11
      13027.80c  8.26442e-4    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 1.65288e-3
      26054.80c  9.75301e-5
      26056.80c  1.51599e-3
      26057.80c  3.47221e-5
      26058.80c  4.63799e-6
       8016.80c  3.45461e-2
       1001.80c  5.94736e-2
mt1  lwtr.20c
```

```
c  Material 2 == Water (mass den = 0.9982 g/cc)
m2      1001.80c   0.066735
        8016.80c   0.033368
mt2  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
        8016.80c  4.60557e-2
       11023.80c  1.74719e-3
       13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
       14028.80c  1.53283e-2
       14029.80c  7.78334e-4
       14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
       20040.80c  1.47411e-3
       20042.80c  9.83848e-6
       20043.80c  2.05285e-6
       20044.80c  3.17203e-5
       20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
       26054.80c  2.04888e-5
       26056.80c  3.18475e-4
       26057.80c  7.29430e-6
       26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 4 == Bulk solution in tank is Nominal per NCSE table.
m4      92235.80c  4.46480e-6
       92238.80c  5.06970e-5
       94239.80c  4.40250e-6
       94240.80c  4.38410e-13
        1001.80c  6.07870e-2
        8016.80c  3.42300e-2
       13027.80c  8.26040e-4   $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 0.0016521
       26054.80c  9.74838e-5
       26056.80c  1.51527e-3
       26057.80c  3.47057e-5
       26058.80c  4.63579e-6
mt4  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5      92235.80c  5.12419e-9
       92238.80c  5.81838e-8
       94239.80c  6.29783e-9
       94240.80c  6.27156e-15
        1001.80c  6.67343e-2
        8016.80c  3.33673e-2
mt5  lwtr.20c
```

Case contactors_d_pu_5_1_3_in

```
MCNP calc of contactors_d_pu_5_1_3_in
C  Cell cards -- Build from inside out
51   0   -1 4 -5  u=10 imp:n=1  $ rotor shaft region Vapor Space
52   2   1.00103e-1    1 -9 4 -5 u=10 imp n=1 $ water between rotor shaft and MST solids on inner wall
53   1   9.62141e-2  9 -2 4 -5 u=10 imp n=1 $ solids on wall of contactor
54   4   8.59637e-2   2 -3 4 -5 u=10 imp:n=1 $ steel wall
55   1   9.62141e-2  3 -7 4 -5 u=10 imp n=1  $ MST solids in both inlets
56   4   8.59637e-2   7 -8  4 -5     u=10 imp:n=1  $ outer steel wall of contactor
57   4   8.59637e-2   -8  5 -11    u=10 imp:n=1  $ top steel wall of contactor
58   4   8.59637e-2   -8 10 -4     u=10 imp n=1  $ bottom steel wall of contactor
59   0    (8):(-8 -10):(-8 11)          u=10 imp:n=1  $ rest of u=10
60   0    21 -22 23 -24 10 -11 lat=1 fill=10  u=20 imp:n=1  $ one contactor per lattice cell in u=20
61   0    #60  u=20 imp:n=1  $ rest of u=20
70   0    21 -25 23 -24 10 -11 fill=20  u=21 imp:n=1  $ two contactors in u=20
71   0    #70 u=21 imp n=1  $rest of u=21
62   0    21 -31 23 -33 10 -11  fill=21  u=30 imp:n=1  $ air in room outside contactor
63   3   8.17775e-2  #62  u=30 imp:n=1  $ concrete fills rest of u=30
64   0   -31 32 -33 34 35 -36  fill=30 u=0 imp:n=1 $ concrete reflection by truncation
99   0    #64 u=0 imp n=0 $ rest of u=0

C  Surface cards
c rotor radius
1   cz  3.175
c inner radius
2   cz  12.7
c outer radius (liquid reflection)
3   cz  13.1826
c contactor height
4   pz  0
5   pz  65.8622
c thickness of material in bottom of contactor above z=0  ** Not used
6   pz  7.62
c annular region
7   cz  15.7226
c contactor outer radius
8   cz  16.6878
c water between rotor shaft and MST solids on inner wall
9   cz  5.08
c plane for steel on bottom of contactor
10  pz  -0.9652
c plane for steel on top of contactor
11  pz  66.8274
c planes to define one lattice cell in u=20
21  px  -16.6878
22  px   16.6878
23  py  -16.6878
24  py   16.6878
c planes need for two lattice cell in u=21
25  px   50.0634
c planes for concrete reflection
31  px   166.878
```

```
32  px  -77.6478
33  py   166.878
34  py  -77.6478
35  pz  -61.9252
36  pz   127.787

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef   sur=0  rad=d1  ext=d2  pos=d3  axs= 0 0 1
si1    3.175     16.6878
sp1    -21  2
si2    0  65.8622
sp2    -21  1
si3    L 0 0 0   33.3756 0 0
sp3    1  1
print 40 50 128 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O + UO2 + PuO2
c      Mixture 1 Density = 1.33181 g/cc
m1     92235.80c  2.69806e-5
       92238.80c  1.39859e-4
       94239.80c  1.07349e-5
       94240.80c  1.06901e-11
       13027.80c  1.23258e-3    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 2.46516e-3
       26054.80c  1.45459e-4
       26056.80c  2.26099e-3
       26057.80c  5.17855e-5
       26058.80c  6.91723e-6
        8016.80c  3.47141e-2
        1001.80c  5.76247e-2
mt1  lwtr.20c
c  Material 2 == Water
m2      1001.80c   0.066735
       8016.80c   0.033368
mt2     lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
        8016.80c  4.60557e-2
       11023.80c  1.74719e-3
       13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
       14028.80c  1.53283e-2
       14029.80c  7.78334e-4
       14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
       20040.80c  1.47411e-3
       20042.80c  9.83848e-6
       20043.80c  2.05285e-6
       20044.80c  3.17203e-5
       20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
```

```
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 4 == SS316L, den= 7.92         g/cc, half density is used
c  Composition taken from Methods Manual.
c  Per NSA-TR-07-11 must break iron into individual isotopes.
m4     26054.80c   3.30085e-3
      26056.80c   5.13080e-2
      26057.80c   1.17515e-3
      26058.80c   1.56970e-4
c  Total Cr atom density = 1.5594e-2
      24050.80c   6.7756e-4
      24052.80c   1.3066e-2
      24053.80c   1.4816e-3
      24054.80c   3.6880e-4
c  Total Ni atom density = 9.7514e-3
      28058.80c   6.6385e-3
      28060.80c   2.5571e-3
      28061.80c   1.1116e-4
      28062.80c   3.5441e-4
      28064.80c   9.0269e-5
c  Total Mo atom density = 1.2428e-3
      42092.80c   1.8443e-4
      42094.80c   1.1372e-4
      42095.80c   1.9686e-4
      42096.80c   2.0717e-4
      42097.80c   1.1931e-4
      42098.80c   3.0312e-4
      42100.80c   1.2204e-4
      25055.80c   1.7363e-3
c    Silicon total =  1.69821e-3
      14028.80c   1.53283e-2
      14029.80c   7.78334e-4
      14030.80c   5.13083e-4
```

Case sumps_a_pu_3_19_in

```
MCNP calc of sumps_a_pu_3_19_in
C  Cell cards
1   1  8.86080e-2   (-1 -2 -4):(1 -2 -4 6)     imp n=1 $ settled region
3   5  1.00102e-1    -1 -2 -3 4  imp n=1 $ low concentration U/Pu above settled region
10  3  8.17775e-2   -10 #1 #3   imp:n=1  $ region below tank/sump
11  3  8.17775e-2   -11 10      imp:n=1  $ regular reflection around tank/sump
99  0            11    imp:n=0

C  Surface cards
1  so  121.92
2  cz  60.96
3  pz  -14.14581
4  pz  -86.11001
6  pz  -105.5858
10  rpp -60.9601   60.9601   -60.9601   60.9601   -121.92    -14.14581
11  rpp -137.16    137.16    -137.16    137.16    -198.12    62.054182

C  Data cards
C  Criticality control cards
kcode  5000  1.0  75  575
sdef  cel=1 sur=0 par=n rad=d1 ext=d2 pos= 0 0 -104.01
si1 0 60.96
si2 -104.01
print 40 50 -175
C  Material cards
c  Material 1 == Mixture of MST+H2O+UO2+PuO2
c      Mixture 1 Volume  = 3.25000e5   cc
c      Mixture 1 Density = 1.88974 g/cc
m1     92235.80c  1.80595e-5
       92238.80c  2.05061e-4
       94239.80c  2.12405e-5
       94240.80c  2.11519e-11
       13027.80c  3.73659e-3    $Na modeled as Al when in fissile
c  Sub Fe for Ti atom-for-atom. Per NSA-TR-07-11 must break iron into individual isotopes.
c  Total atom density for Ti (replaced by Fe) is 7.47317e-3
       26054.80c  4.40962e-4
       26056.80c  6.85425e-3
       26057.80c  1.56989e-4
       26058.80c  2.09697e-5
        8016.80c  3.72535e-2
        1001.80c  3.99004e-2
mt1  lwtr.20c
c  Material 3 == Regulatory Concrete, den=2.30 g/cc
c  Composition taken from Methods Manual.
m3      1001.80c  1.37417e-2
        8016.80c  4.60557e-2
       11023.80c  1.74719e-3
       13027.80c  1.74537e-3
c    Silicon total =  1.66197e-2
       14028.80c  1.53283e-2
       14029.80c  7.78334e-4
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      14030.80c  5.13083e-4
c    Calcium total =  1.52063e-3
      20040.80c  1.47411e-3
      20042.80c  9.83848e-6
      20043.80c  2.05285e-6
      20044.80c  3.17203e-5
      20048.80c  2.84358e-6
c  Total Fe atom density = 0.00034723
      26054.80c  2.04888e-5
      26056.80c  3.18475e-4
      26057.80c  7.29430e-6
      26058.80c  9.74333e-7
mt3  lwtr.20c
c  Material 5 == Bulk solution in tank is 25 mgU/L and 2.5 mgPu/L, rest is water. PuO2+UO2+H2O
m5     92235.80c  5.12419e-9
      92238.80c  5.81838e-8
      94239.80c  6.29783e-9
      94240.80c  6.27156e-15
       1001.80c  6.67343e-2
       8016.80c  3.33673e-2
mt5  lwtr.20c
```