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Tank 49H Solids Disturbance Analysis

M. R. Poirier

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REVIEWS AND APPROVALS

AUTHORS:

M. R. Poirier, Chemical Flowsheet Development   Date

TECHNICAL REVIEW:

C. A. Nash, Separation Sciences and Engineering, Reviewed per E7 2.60   Date

APPROVAL:

B. J. Wiedenman, Manager   Date
Separation Sciences and Engineering

F. M. Pennebaker, Director, Chemical Processing   Date

J. E. Occhipinti, SRR-Tank Farm Facility Engineering   Date

LIST OF REVISIONS		
Revision Number	**Summary of Changes**	**Date**
0	Original Issue	2/2021
1	Performed M-Star CFD simulations of the transport of disturbed solids	6/2021
	to the transfer pump. A paragraph was added to the Introduction describing	
	this approach. Four assumptions were adding describing the assumptions	
	made for these simulations. A paragraph was added to the end of Section	
	2.2 describing the simulations performed. Section 2.6 added to describe	
	the simulations performed. Additional text added to section 2.7 to	
	describe and discuss the simulation results. A paragraph was added to	
	the summary and to the conclusions describing these results.	

EXECUTIVE SUMMARY

Tank 49H will serve as the feed tank for the Salt Waste Processing Facility (SWPF). Transfers into Tank 49H may disturb solids that have settled to the bottom of the tank, resulting in feed that may exceed the insoluble solids content limit of 1,200 mg/L from the SWPF Waste Acceptance Criteria (WAC). During a transfer into Tank 49H, material that free falls into Tank 49H through a downcomer and passes through the supernate could potentially disturb the solids on the bottom of the tank and scour or suspend solids from a settled solids layer or turbid region. A previous analysis and report evaluated the potential to disturb solids when transferring into Tank 49H through the B4 riser and recommended a minimum tank level of 120 inches to prevent disturbing any solids in the bottom of the tank. The scope of this task is to perform additional fluid flow analysis to determine the impact of a "plunging jet" through the C3 downcomer on solids in Tank 49H and to determine a minimum liquid level to be maintained in Tank 49H prior to transfers that will minimize disturbing the solids and exceeding the SWPF WAC limits for insoluble solids carryover to SWPF since the C3 riser downcomer is at a lower elevation and farther away from the B5 transfer pump than the B4 downcomer.

The analysis utilized models from the technical literature to calculate the size and shape of the "plunging jet" as a function of input parameters such as initial velocity, initial jet diameter, elevation of the initial jet, liquid level in the tank, and solids depth. The analysis did not include M-Star® computational fluid dynamics (CFD) simulations of the "plunging jet" to assess whether it disturbed the solids at the bottom of the tank, and to estimate the mass of solid particles that was disturbed by the "plunging jet." Instead, it relied on the M-Star simulations performed for the previous analysis to provide bounding estimates of the amount of solid particles disturbed and used the M-Star® software to calculate the dispersion and mixing of the disturbed solids with other liquid in the tank as the solids were transported to the transfer pump.

The analysis showed that with a solid particle size of 5 micron or less, a liquid level of 115 inches should be maintained to prevent significant disturbance of the solid layer at the bottom of Tank 49H. If the particle size is 100 micron or larger, the liquid level in the tank can be reduced to as low as 80 inches. At this level, the larger particles will be disturbed, but they will settle to the tank bottom before reaching the transfer pump. Since a large fraction of the solid particles in Tank 49 are expected to be less than 5 microns based on previous analyses of SRS sludge particle size which measured median particle sizes of 2.6, 6.1, 10.8, and 15.1 microns, the 115-inch liquid level is recommended at this time.

If liquid is added to Tank 49H with a liquid level less than 115 inches, particle disturbance will occur. Once the liquid level reaches 115 inches, particle disturbance will stop and particle settling will begin. In the time that the liquid level increases from 115 inches to 290 inches (~1,000,000 gallons), significant particle settling could occur, which may prevent exceeding the SWPF WAC limits for insoluble solids, but the settling is dependent on the size of the particles at the bottom of Tank 49H.

Significant particle settling could occur during the time the disturbed particles move toward the transfer pump and between transfers to the SWPF. This settling could prevent exceeding the SWPF WAC, but it is dependent on particle size.

If the disturbed particles are 1 micron or less, the particles will follow the fluid motion in the tank. As these particles are transported to the transfer pump, they will be dispersed and blended with other liquid in the tank. The concentration of these disturbed particles in the feed to the transfer pump will likely be less than the SWPF WAC.

Considering the settling of particles 5 micron and larger during liquid addition to Tank 49H and the dispersion and mixing of particles 1 micron and smaller during transport from the disturbed region under the C3 riser to the transfer pump, it is possible that the minimum liquid level in Tank 49H could be reduced without exceeding the SWPF WAC.

If the height of the solid particles in Tank 49H is greater than 1.1 inches, the mass of suspended particles and the mass of particles reaching the transfer pump should be increased proportionally. The increased solid particle height may lead to less of a fraction of the particles being suspended, but that cannot be verified or quantified at this time.

In addition, if there are insoluble solid particles suspended in the supernate prior to the transfer or insoluble particles in the transfer, the concentration of these particles must be considered in determining whether the SWPF WAC will be met.

If Savannah River Remediation (SRR) wishes to maintain a lower level in Tank 49H, they should consider lowering the elevation at which the liquid enters the tank, adding a device to disperse the added liquid into droplets that will not penetrate deeply below the liquid surface, or adding a nozzle to the downcomer to reduce the diameter of the jet produced by the liquid entering the tank.

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LIST OF ABBREVIATIONS

ARP	Actinide Removal Process
CFD	computational fluid dynamics
CSSX	Caustic Side Solvent Extraction
D	nozzle diameter, diameter of disturbed region
D_j	plunging jet diameter at liquid surface
D_0	diameter of jet at downcomer exit
d_p	particle density
D_z	plunging jet diameter as a function of depth
DA	Design Authority
g	gravitational acceleration
g_c	gravitational constant
H	height
H_p	plunging jet penetration depth
L	distance
LWO	Liquid Waste Operations
M	mass
MCU	Modular CSSX Unit
Q	flow rate
r	radius of converging channel
s	solid-liquid density ratio
SPF	Saltstone Production Facility
SRNL	Savannah River National Laboratory
SRR	Savannah River Remediation
STP	submersible transfer pump
SWPF	Salt Waste Processing Facility
t	time
TTR	Technical Task Request
TTQAP	Task Technical and Quality Assurance Plan
v_s	settling velocity
V	volume
V_j	velocity at liquid surface
V_p	volume of a particle
V_0	downcomer discharge velocity
WAC	Waste Acceptance Criteria
x	mass fraction
z	change in elevation

Z	Plunging jet depth
ν	kinematic viscosity
ρ	density
μ	viscosity

1.0 Introduction

Tank 49H will serve as the feed tank for the Salt Waste Processing Facility (SWPF). Transfers into Tank 49H may disturb solids that have settled to the bottom of the tank, resulting in feed that may exceed the insoluble solids content limit of 1,200 mg/L from the SWPF Waste Acceptance Criteria (WAC).[1] During a transfer into Tank 49H, material that free falls from the Tank 49H C3 downcomer and passes through the supernate could potentially disturb the solids on the bottom of the tank and scour or suspend solids from a settled solids layer or turbid region. The scope of this task is to perform fluid flow analysis to determine the influence of a "plunging jet" on solids in Tank 49H and to determine a minimum liquid level to be maintained in Tank 49H prior to transfer through the C3 downcomer that will minimize disturbing the solids and exceeding the SWPF WAC limits for insoluble solids carryover to SWPF.[2]

This analysis and report builds upon a previous analysis, which assessed the disturbance of solid particles when liquid was added to Tank 49H through the B4 riser.[19] The downcomer in the C3 riser has a lower elevation (357.375 inches versus 388.125 inches) and is farther from the transfer pump (64.5 feet versus 22 feet). These differences may allow for a lower liquid level in Tank 49H to prevent solid particle disturbance, and they may reduce the impact of the disturbed solids on the feed to the SWPF.

The Design Authority (DA) for Savannah River Remediation (SRR) Tank Farm Facility Engineering provided Savannah River National Laboratory (SRNL) the information needed (inputs) to complete this task.[3] The information provided by SRR included the following.

- The location, elevation from the tank bottom, and range of flow rates of the transfer pump from Tank 49H to SWPF
- The location, vertical distance from the tank bottom, and internal diameter of the downcomer pipe used to add liquid to the tank
- The range of flow rates for the additions to the tank
- The minimum and maximum fill levels of the tank
- The thickness of the insoluble solids layer on the tank bottom

Previous SRNL analyses showed that when liquid is added to a waste tank, a "plunging jet" can form when the liquid enters the tank.[4,5,19] This "plunging jet" entrains surrounding fluid, which is mixed with the fluid added to the tank. The "plunging jet" could have sufficient momentum to disturb the solids layer on the bottom of the tank. Fluid mechanics principles were used to determine the properties of the "plunging jet" that forms as fluid is added to Tank 49H, using the geometry and operating conditions of this tank, to determine whether the jet is likely to disturb the solids layer on the bottom of Tank 49H.

The analysis utilized models from literature[6,7,8,20] to calculate the size and shape of the "plunging jet" as a function of input parameters such as initial velocity, initial jet diameter, elevation of the initial jet, liquid level in the tank, and solids depth. The input parameters were provided by SRR. The analysis varied the input parameters to determine their influence on the properties of the "plunging jet". The analysis identified conditions under which the plunging jet will not disturb the solids on the bottom of Tank 49H.

Previous work used the M-Star® Lattice-Boltzmann Computation Fluid Dynamics (CFD) software[a] to simulate the "plunging jet" behavior and estimate the amount of solids particles disturbed as a function of liquid level.[19] The simulations showed that numerical transport occurred, which may have biased the mass of solid particles disturbed high. However, the elevation of the C3 downcomer through which liquid can be added to Tank 49H is lower in this analysis than in the previous report which evaluated additions through the B4 riser downcomer. Because of the lower elevation, the jet velocity will be lower at the liquid surface, and the penetration depth of the "plunging jet" will be less. Using the mass of disturbed solids from the previous analysis will bound the mass of disturbed solids when liquid is added through the C3 riser,

[a] M-Star CFD software is licensed from M-Star Simulations, LLC. This analysis used version 2.8.

assuming the same liquid level. The mass of disturbed solids from the previous analysis will be used in some of the calculations for this report.

Because of the issues with numerical transport and the long time needed to perform the "plunging jet" simulations, an alternative approach was applied in which the M-Star® software was used to simulate the transport of the disturbed solids under the C3 riser to the transfer pump. The simulations will show the blending of the disturbed solids with the liquid in the tank as the tank contents are removed by the transfer pump. The previous document[19] provided an upper bound on the mass of solids disturbed. This work uses that mass of disturbed solids and performs M-Star® simulations to calculate the concentration of insoluble solids in a transfer from Tank 49H to SWPF.[b]

1.1 Quality Assurance

This work was performed under a Technical Task Request (TTR).[2] The recorded data, analysis, and conclusions satisfy the Safety Significant requirements in the Task Technical and Quality Assurance Plan (TTQAP) associated with this TTR.[9] The M-Star software is classified as D, and although not sufficient for Safety Significant input, it was used to complement the other analyses performed previously.

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60.[10] SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.[11]

2.0 Analysis

Inputs:

The following input parameters were provided by SRR and are used in the assessment.[3]

- Tank 49H Submersible Transfer Pump (STP)
  - Location: Riser B5
  - Position is 26.33 ft south of the tank center and 12.27 ft east of the tank center
  - Suction elevation: 16 inches above bottom of the tank
  - Flow Rate: 82 – 159 gpm
- Tank 49H C3 Downcomer
  - Position is 35.45 ft north of the tank center and 6.25 ft west of the tank center
  - Outlet elevation: 357.375 inches above the bottom of the tank[c]
  - Outlet pipe diameter: 3-inch schedule 10S pipe – ID = 3.26 inches
- Tank 49H B4 Downcomer
  - Position is 10.39 ft south of the tank center and 27.07 ft east of the tank center
- Tank 49H minimum fill level
  - Nominal fill factor is 3510 gallons per inch
  - Minimum liquid level 61 inches
- Distance between downcomer riser (B4) and STP riser (B5)
  - 22 feet
- Distance between downcomer riser (C3) and STP riser (B5)
  - 64.5 feet
- Transfer frequency to SWPF
  - 23,200 gallons every 21.6 hours

[b] This revision added the results of the M-Star® simulations of the transport of disturbed solids to the transfer pump.

[c] In a draft inputs document provided by SRR, the elevation was listed as 356 inches. The issued document specified an elevation of 357.375 inches. This increase in elevation of ~0.4% will increase the velocity of the jet at the liquid surface and the depth of the "plunging jet". Based on the analysis later in the report, this increase will be less than 0.2%. Revision 0 of this document used 356 inches as the elevation. This document uses 357.375 inches.

- Addition rate of liquid from Tank 41H to Tank 49H
    - 100 – 120 gpm
    - Maximum flow rate 200 gpm
- Addition rate of liquid from Tank 42H to Tank 49H
    - 70 – 198 gpm
    - Maximum flow rate 200 gpm
- Gibbsite density
    - 2.42 g/mL
- Sodium aluminosilicate density
    - 2.34 – 2.60 g/mL
- Tank 49H solids level
    - 1.1 inches
- Particle size
    - 1 – 100 micron

SRR provided an estimated particle size of 1 – 100 micron in the inputs document. Previous work by SRNL collected data on the particle size of simulated sludge and actual sludge. Figure 1 shows particle size data. The median particle size for the actual SRS sludge samples ranged between 2.6 micron and 15.1 micron.[17] Figure 2 shows the fraction of particles less than 10 micron measured in samples of Tank 5, Tank 13, and Tank 15 sludge. The data show that ~60% of the Tank 15 sample particles, ~45% of the Tank 13 sample particles, and ~35% of the Tank 5 sample particles were less than 5 micron. This data will be used later in the document to discuss settling of disturbed particles.

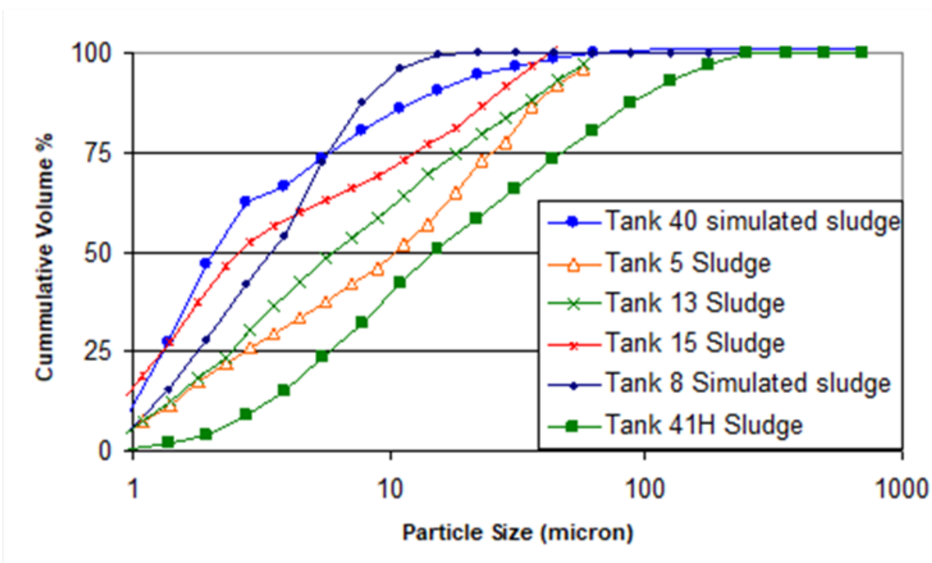

Figure 1. Particle Size of Simulated SRS Sludge and Actual SRS Sludge

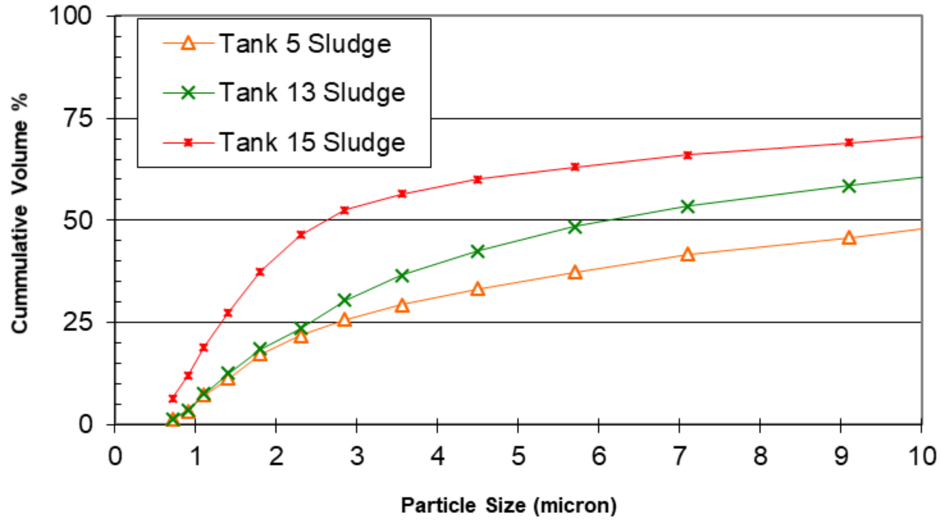

Figure 2. Fraction of Particles Less than 10 Micron in SRS Sludge Samples

In addition to the particle size data discussed above, SRNL performed a statistical analysis of sample data from Tank 48H in 1995.[21] In this study, the tank contained monosodium titanate (MST), a small concentration of entrained sludge, and no tetraphenyl borate. One of the analyses performed was titanate, which would have come from the MST. The highest sampling points were at 126 inches, and most of the solid particles dropped below 42 inches within 2 hours after stopping agitation. Based on settling data, the authors calculated a particle size of approximately 14 micron, which is approximately equal to the median particle size of 15.1 micron measured in the Tank 41H sample. The work also observed a 75 – 90% reduction in the measured insoluble solids concentration occurring over 5 hours after stopping agitation.

Analysis of the samples collected from Tank 49H to qualify Salt Batch 1 for feed to the Actinide Removal Process (ARP)/Modular Caustic Side Solvent Extraction (CSSX) Unit (MCU) after settling overnight (13.5 hours), showed a dense particle layer at the bottom of the vessel indicated that significant particle settling occurred during this time.[22]

Figure 3 shows a view of the top of Tank 49H to show the positions of the risers C3 and B5 in the tank.

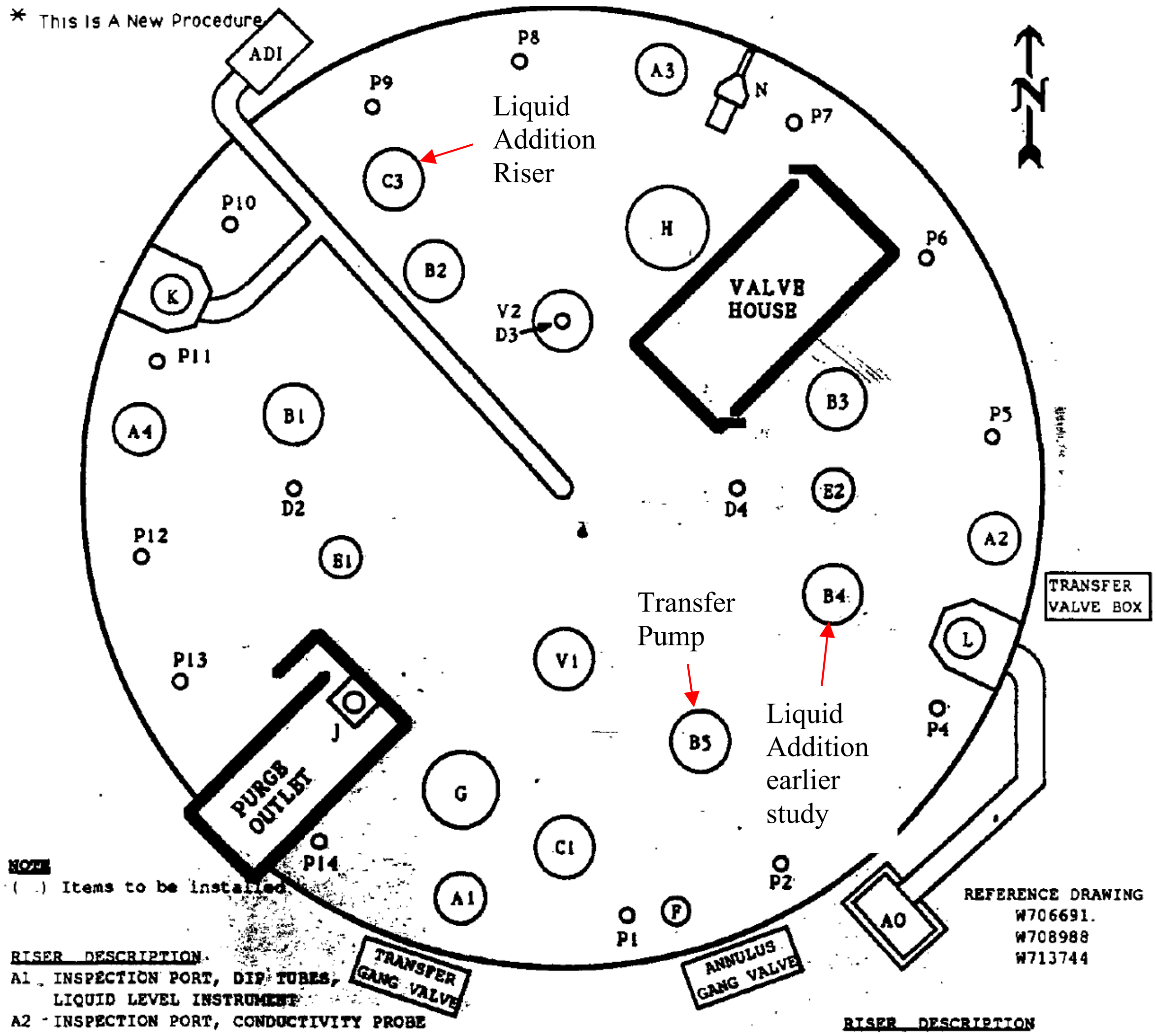

Figure 3. Tank 49H Tank Top

Assumptions:

The author made the following assumptions to perform this analysis.

- The liquid added to the tank can be modeled as a "plunging jet". The behavior of the jet entering the tank and reaching the liquid surface follows the behavior of a "plunging jet".
- The mass of solid particles disturbed from liquid addition through the C3 riser downcomer is bounded by the mass of solid particles disturbed by liquid addition through the B4 riser downcomer at the same liquid level. The downcomer in the C3 riser has a lower elevation than the downcomer in the B4 riser. Because of the lower elevation, the velocity of the liquid when it reaches the liquid surface will be less when exiting the C3 riser than when exiting the B4 riser. This lower velocity reduces the penetration depth of the "plunging jet".
- The M-Star simulation results from the previous report provide an upper bound on the mass of solids suspended by the "plunging jet". The elevation of the C3 riser downcomer is lower in this analysis than in the B4 riser downcomer analysis. Because of the lower elevation, the jet velocity will be lower at the liquid surface, and the penetration depth of the "plunging jet" will be less.

- A liquid density of 1.26 g/mL was selected based on SRS average salt solution and would be representative of the expected density of the liquid added to Tank 49H.[12]
- A liquid viscosity of 2.5 cP was selected based on SRS average salt solution and would be representative of the expected viscosity of the liquid added to Tank 49H.[12]
- There are no insoluble solid particles in the liquid added to Tank 49H or in the Tank 49H supernate prior to the addition of liquid. If insoluble solid particles are present in the liquid added to Tank 49H or in the Tank 49H supernate prior to the addition of liquid, this mass of solid particles must be included in the calculation of the insoluble solids transferred to SWPF.
- The density of the solid particles on the bottom of the tank is 2.25 g/mL or 2.6 g/mL. The 2.25 g/mL density is less than the minimum described in the inputs above, and it was selected to be conservative for calculating solid particle settling and suspension. The 2.6 g/mL is the maximum described in the inputs above, and it was selected to be conservative when calculating the mass of particles suspended in the previous analysis and in calculating the concentration of insoluble solids in the transfers from Tank 49H to the SWPF.[19]
- The solids layer on the tank bottom is 30 vol % insoluble solids. The Safety Analysis Input document specifies the maximum insoluble solids concentration in settled sludge to be 30 vol %.[18]
- The solid particles that are suspended by the "plunging jet" are assumed to be suspended into a cylindrical volume that is 10 ft in diameter and 16 inches high. The 16 inches is selected to equal the height of the transfer pump suction. This assumption provides a conservative estimate of the time needed to transport these particles to the transfer pump.
- In the M-Star® simulations of the transport of disturbed solids to the transfer pump, the solid particles are assumed to be suspended into a cylindrical volume that is 10 ft in diameter and 24 inches high. The previous simulations of the plunging jet showed the disturbed solids to be suspended to a height of approximately 24 inches.[19]
- The liquid that feeds the transfer pump comes from the bottom 16 inches of the tank. This assumption is based on the transfer pump suction being 16 inches above the tank bottom. The transfer pump suction will likely draw material from above 16 inches, making this assumption conservative. Drawing material from above 16 inches would increase the dilution of the disturbed solids as they reach the transfer pump, increase the time required for the disturbed solids to reach the transfer pump, and allow more time for particle settling before reaching the transfer pump.
- This calculation assumes the transfer pump starts as soon as all the solid particles are disturbed. There may be a delay between particles being suspended (i.e., end of transfer into the tank) and the transfer pump starting. Some particles may begin to settle once they move from the disturbed region below the downcomer.
- In the M-Star® simulations of the transport of disturbed solids to the transfer pump, there is no delay between batches. During the time between transfers, particle settling and particle dispersion will occur making the simulation results conservative.
- These calculations assume no hindered settling behavior – i.e., particle-particle interactions – which is a reasonable assumption for dilute slurries of non-cohesive particles.
- The particle size distribution of the solid particles on the bottom of Tank 49H may be represented by the particle size data collected from Tanks 5, 13, and 15. This assumption must be used with caution. Tanks 5, 13, and 15 are sludge tanks and the particle size data were collected years ago. It may not be representative of the current material in Tank 49H.

2.1 Plunging Jet

The author addressed this problem by treating the added salt solution as a "plunging liquid jet".[6,7,20] The following input parameters were used for the analysis.

- Downcomer pipe diameter = 3.26 inches
- Liquid flow rate = 95 gpm and 200 gpm

- Downcomer elevation = 357.375 inches[d]
- Liquid level = 80 - 120 inches
- Liquid density = 1.26 g/mL[12]
- Liquid viscosity = 2.5 cP[12]

The exit velocity of the downcomer is calculated with equation [1]

$$V_0 = \frac{4Q}{\pi D^2} \quad [1]$$

where Q is the flow rate and D is the downcomer internal diameter. For a flow rate of 95 gpm, the exit velocity is 3.7 ft/s. For a flow rate of 200 gpm, the exit velocity is 7.7 ft/s. Because the jet is moving vertically downward, its velocity will increase due to gravity. The velocity at the liquid surface can be calculated with equation [2]

$$V_j = \sqrt{V_0^2 + 2gL} \quad [2]$$

where V_0 is the downcomer exit velocity, g is gravitational acceleration, and L is the distance between the downcomer exit and the liquid surface (with a liquid level of 100 inches, L = 357.375 – 100 = 257.375 inches = 21.45 feet). For a downcomer exit velocity of 3.7 ft/s, the velocity at the surface is 37.3 ft/s. For a downcomer exit velocity of 7.7 ft/s, the velocity at the surface is 38.0 ft/s. Because the jet is accelerating, its diameter will decrease to conserve mass. The diameter of the jet at the surface is described by equation [3].

$$D_j = \sqrt{\frac{4Q}{\pi V_j}} \quad [3]$$

With a downcomer discharge flow rate of 95 gpm, the jet diameter at the liquid surface is 1.02 inches. With a downcomer discharge flow rate of 200 gpm, the jet diameter at the liquid surface is 1.47 inches.

The penetration depth of the jet is described by equation [4]

$$H_p = 2.1\ V_j^{0.775}\ D_0^{0.67} \quad [4]$$

where V_J is the jet velocity at the liquid surface (in m/s) and D_0 is the jet diameter at the exit of the downcomer (in m).[6,7] With a flow rate of 95 gpm out of the downcomer, the penetration depth is 102 inches. If the flow rate is increased to 200 gpm, the penetration depth is 104 inches. This distance is greater than the minimum liquid level in the tank (61 inches). Since the “plunging jet” penetration depth is greater than the liquid depth in the tank, the depth may need to be adjusted to account for the effects of the tank bottom.

After the jet enters the liquid, it will expand at an angle of ~22º. Equation [5] describes the diameter of the jet as a function of depth

$$D_z = Z \tan(\theta/2) = Z \tan(22^\circ/2) = Z \tan(11^\circ) \quad [5]$$

where Z is the depth below the liquid surface.[6,7]

Table 1 and Figure 2 summarize the results of the analysis. Table 1 shows “plunging jet” properties at four liquid levels using two flow rates. Figure 2 shows the penetration depth as a function of inlet flow rate and tank level for additional conditions. The analysis shows that between a liquid level of 100 inches and 120 inches, the penetration depth of the “plunging jet” is approximately 100 inches and that the penetration depth is a weak function of the input flow rate. Over a range of liquid levels between 60 and 170 inches, Figure 4 shows little effect of inlet flow rate on the depth of the “plunging jet”. This analysis does not allow for a determination of the mass of solid particles suspended.

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[d] In a draft inputs document provided by SRR, the elevation was listed as 356 inches. The issued document specified an elevation of 357.375 inches. This increase in elevation of ~0.4% will increase the velocity of the jet at the liquid surface and the depth of the “plunging jet”. Based on the analysis later in the report, this increase will be less than 0.2%. Revision 0 of this document used 356 inches as the elevation. This document uses 357.375 inches.

Table 1. Behavior of Plunging Jet in Tank 49H at 100, 110, and 120 inch Liquid Level

Liquid Level (inches);	100	100	110	110	115	115	120	120
Downcomer flow rate (gpm)	95	200	95	200	95	200	95	200
Downcomer exit velocity (ft/s)	3.7	7.7	3.7	7.7	3.7	7.7	3.7	7.7
Downcomer exit diameter (inches)	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26
Jet velocity at liquid surface (ft/s)	37.3	38.0	36.6	37.2	36.3	36.9	35.9	36.5
Jet diameter at liquid surface (inches)	1.02	1.47	1.03	1.48	1.03	1.49	1.04	1.50
Penetration depth (inches)	103	104	101	102	100	102	99	101
Penetration Depth with 10% conservatism (inches)	113	114	111	113	110	112	109	111
Penetration Depth with 20% conservatism (inches)	123	124	121	123	120	122	119	121

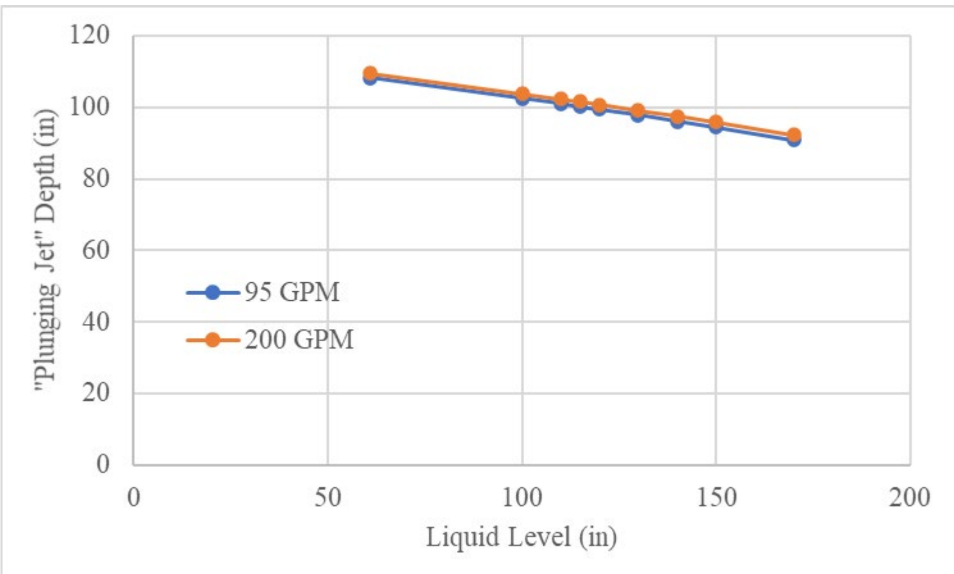

Figure 4. Influence of Inlet Flow Rate and Liquid Level on Depth of Plunging Jet

With a liquid level of 120 inches, the calculated "plunging jet" depth is 99 - 101 inches, so minimal solids disturbance should occur. With a liquid level of 115 inches, the calculated "plunging jet" depth is 100 - 102 inches, so minimal solids disturbance should occur. With a liquid level of 100 inches, the calculated "plunging jet" depth is 103 - 104 inches, so solids disturbance is likely. With a liquid level of 110 inches, the calculated "plunging jet" depth is 101 - 102 inches. While this penetration depth is less than the 110 inch liquid level, a higher liquid level should be maintained to account for uncertainty in the correlation (equation [4]), include conservatism in the recommendation, and because even if the "plunging jet" does not reach the tank bottom, it may impart a pressure force on the tank bottom, which will disturb the solid particles.

Reviewing Figure 30 from reference 20 (see Figure 5) shows only a few of the experimental data points are more than 20% above the prediction. Most of the data are not more than 10% above the prediction. Equation [4] was derived using the same data that are plotted in Figure 5. Assuming that the uncertainty in Figure 5 is valid for equation [4], it can be applied to the results in Table 1. Adding 10% uncertainty to the calculated "plunging jet" penetration depth with a liquid level of 115 inches provides a depth of 111 –

113 inches. Adding 20% uncertainty to the calculated “plunging jet” penetration depth with a liquid level of 115 inches provides a depth of 120 – 122 inches. Figure 6 shows the results for other liquid levels in Tank 49H.

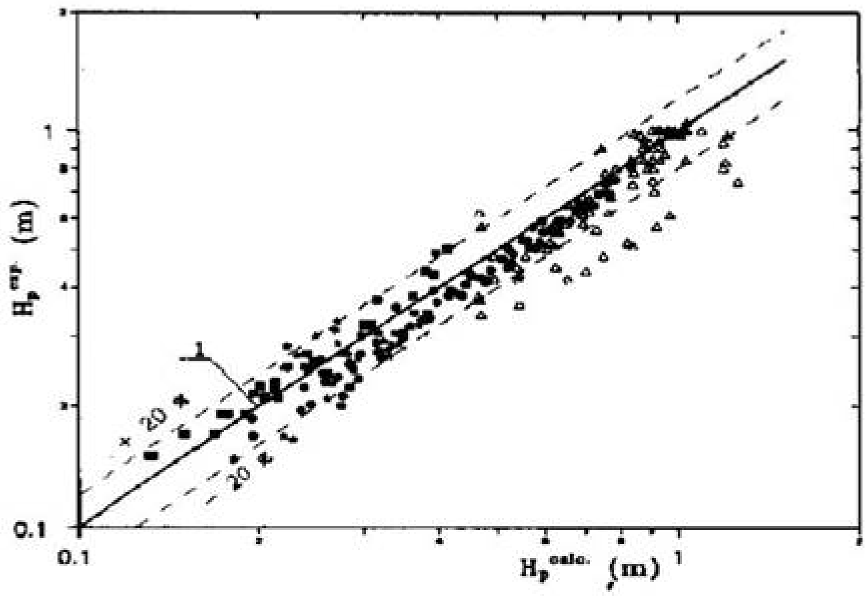

Fig. 30. Parity plot for testing eq. (55). The symbols are explained in Fig. 29: 1, line of perfect agreement.

Figure 5. Uncertainty in “Plunging Jet” depth Correlation

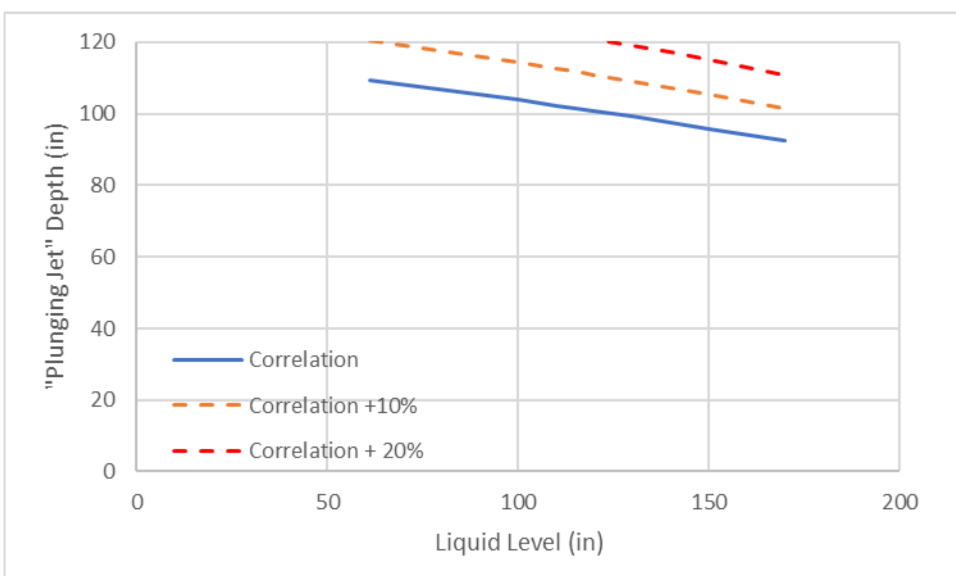

Figure 6. “Plunging Jet” Penetration Depth as a Function of Liquid Level

Based on Table 1, Figure 4, and Figure 6, a minimum liquid level of 115 inches is recommended in Tank 49H.

2.2 M-Star® CFD Simulations

To try to improve the estimate of the liquid level at which solid particles are disturbed by the "plunging jet", to attempt to quantify the mass of solids disturbed, and to examine the effect of the disturbed solids on the concentration of insoluble solids in the liquid transferred to the SWPF, computational fluid dynamics (CFD) simulations were performed using the M-Star® Lattice-Boltzmann software.

M-Star® CFD software is used at SRNL to support Liquid Waste Operations (LWO) and other projects. The software is used to model processes that involve fluid mixing, pipe flow, gas retention and release, and non-Newtonian fluids. M-Star® CFD is a multi-physics modeling package used to simulate fluid flow, heat transfer, species transport, chemical reactions, particle transport, and rigid-body dynamics. M-Star® CFD is developed, maintained, and supported by M-Star Simulations, LLC ("M-Star"), based in Maryland, USA.

The M-Star® software is not classified as Safety Significant software. It is classified as Class D software in X-SWCD-A-00011. However, its simulation results have been compared favorably with data for other SRS applications such as impeller mixing of tanks and jet mixing of miscible liquids.[13] It is a tool to complement the analysis performed in the previous section and to evaluate alternative approaches to preventing added liquid in Tank 49H from disturbing the solid particles on the bottom of the tank. In addition, the M-Star® software provides a method to quantify the mass of solid particles that are disturbed by the "plunging jet" and a method to estimate the rate at which the disturbed solids are transported to the transfer pump.

To complete the additional analysis in this report, the M-Star simulation results from a previous analysis will be used.[19] In that work, the downcomer (located in the B4 riser) elevation was 388.125 inches. In this analysis, the downcomer elevation is 357.375 inches. In addition, the inner diameter of the downcomer in this analysis is 3.26 inches compared to 3.068 inches in the previous analysis. Given the lower elevation of the downcomer in this analysis, the penetration depth of the "plunging jet" will be less (see equations [1] – [4]), and the estimates of the mass of solids disturbed will be bounded by the analysis in the previous report.[19] In addition, numerical transport occurred during the M-Star® simulations, which may have led to a bias in the results and overpredicting the mass of solid particles disturbed. Table 2 shows the results.

Table 2. Amount of Solids Disturbed by "Plunging Jet" using M-Star® Software

Liquid Level	Region Diameter (ft)	Coils	Particle Size (μm)	Fraction Disturbed	Volume Disturbed (L)	Mass Disturbed (kg)
120 in	10	N	10	0.04	7.9	6.2
100 in	10	N	10	1.00	204	159
80 in	10	N	10	1.00	204	159
80 in	10	N	100	1.00	204	159
120 in	10	Y	10	0.04	8.1	6.4
110 in	10	Y	10	0.24	49	38
100 in	10	Y	10	0.23	46.6	33.5
100 in	15	Y	10	1.00	459	358

In the M-Star® simulations, when the region diameter was increased from 10 feet to 15 feet, the mass of solid particles disturbed increased, and the bulk concentration in the transfer to SWPF exceeded the WAC. This result is unexpected and cannot be explained. It could be the result of numerical transport, which would bias the mass of disturbed solids high, or could be due to another factor that is not understood.

Because of the numerical transport observed in the previous M-Star simulations, a different approach was taken in this report. The results in Table 2 were used as an input for a simulation of transport of the disturbed solids (under the C3 riser) to the transfer pump located under the B5 riser. These simulations will be discussed in Section 2.6.

2.3 Solids Concentration in Transfer to SWPF

A previous SRNL report looked at solids disturbance from liquid being added to Tank 49H through the B4 riser located 388.125 inches above the tank bottom.[19] That report estimated the mass of solid particles disturbed as a function of liquid level. Because the elevation of the C3 downcomer is lower than the B4 downcomer, the estimates of the mass of disturbed solids in that report will bound the mass of disturbed solids from liquid entering through the C3 riser, and be used for analysis in this report.

Four approaches were employed to use this information to calculate the solid particle concentration in the liquid feed to the SWPF. These approaches are (1) performing a mass balance and calculating the bulk concentration in the entire volume of liquid transferred to the SWPF, (2) accounting for the time required for the disturbed solids to reach the transfer pump and accounting for particle settling between transfers, (3) accounting for particle settling during the addition of liquid to Tank 49H, and (4) performing M-Star® simulations of the transfer process to calculate the concentration of disturbed solid particles in the liquid that reaches the transfer pump in Tank 49H.

The first approach for calculating the solid particle concentration in the liquid transferred to the SWPF is to take the mass of solid particles suspended and divide it by the liquid volume transferred to SWPF in a batch (23,200 gallons or 87,812 L).

With a liquid level of 120 inches, no cooling coils, and a particle size of 10 micron, 6.2 kg of solid particles would be suspended (see Table 2). Given a transfer volume of 23,200 gallons (87,812 Liters) and assuming all the suspended particles are transferred to SWPF, the bulk solid particle concentration for the transfer would be 0.071 g/L (71 mg/L), which is below the SWPF WAC. When solid particles are transported in a liquid, there is often a "slip velocity" in which the solid particles move at a slower velocity than the liquid because of their higher density. This phenomenon will decrease the mass of disturbed solid particles transported to the transfer pump and make this calculation conservative. However, if there are insoluble solid particles suspended in the Tank 49H supernate prior to the transfer or insoluble particles in the transfer to Tank 49H, the concentration of these particles must be considered in determining whether the SWPF WAC will be met. The concentration of insoluble solids in the Tank 21H SWPF Batch 2 qualification was 39.3 mg/L, which is much less than the 1,200 mg/L SWPF WAC limit.[15]

With a liquid level of 80 - 100 inches (no cooling coils) and a particle size of 10 micron, 159 kg of solid particles would be suspended (see Table 2 and Table 3). Given a transfer volume of 23,200 gallons (87,812 Liters) and assuming all suspended particles are transferred to SWPF, the bulk solid particle concentration for the transfer would be 1.8 g/L (1,800 mg/L), which is above the SWPF WAC limit. This calculation was repeated for the other operating conditions, and the results are described in Table 3. The table shows that with a liquid level of 100 – 120 inches and the presence of cooling coils, the bulk concentration of insoluble solids in the entire transfer to SWPF is less than the SWPF WAC limit. However, if there are insoluble solid particles suspended in the supernate prior to the transfer or insoluble particles in the transfer, the concentration of these particles must be considered in determining whether the SWPF WAC will be met.

Table 3. Bulk Concentration of Disturbed Solids in Transfer to SWPF

Liquid Level	Region Diameter (ft)	Coils	Particle Size (μm)	Fraction Disturbed	Volume Disturbed (L)	Mass Disturbed (kg)	Bulk Concentration in Transfer to SWPF(mg/L)
120 in	10	N	10	0.04	7.9	6.2	71
100 in	10	N	10	1.00	204	159	1,800
80 in	10	N	10	1.00	204	159	1,800
80 in	10	N	100	1.00	204	159	1,800
120 in	10	Y	10	0.04	8.1	6.4	73
110 in	10	Y	10	0.24	49	38	430
100 in	10	Y	10	0.23	46.6	33.5	380
100 in	15	Y	10	1.00	459	358	4,100

2.4 Disturbed Particle Transport to Transfer Pump

This section discusses the transport of disturbed particles to the transfer pump, and the probability of the particles being transferred to the SWPF. Two particle sizes are considered: 10 micron diameter and 100 micron diameter. A particle density of 2.25 g/mL is chosen for conservatism in calculating the settling rate. The liquid density is 1.26 g/mL, and the liquid viscosity is 2.5 cP. The particle settling rate is calculated with Stokes Law, and is described by equations [8] – [11].

The particle settling velocity is calculated by the following equations[16]

$$v_s = g(s-1)d_p^2/18\nu \qquad \text{for } Re_p < 1.4 \qquad [8]$$

$$v_s = 0.13[g(s-1)]^{0.72}d_p^{1.18}\nu^{-0.45} \qquad \text{for } 1.4 < Re_p < 500 \qquad [9]$$

$$v_s = 1.74[g(s-1)\, d_p]^{0.5} \qquad \text{for } Re_p > 500 \qquad [10]$$

$$Re_p = d_p v_s/\nu \qquad [11]$$

where v_s is the settling velocity, g is the acceleration due to gravity, s is the ratio of particle and fluid densities (s = particle density/fluid density), d_p is the particle diameter, and ν is the fluid kinematic viscosity ($\nu = \mu/\rho$).

Using equation [8] with a particle size of 10 micron, the particle settling rate is 7.07×10^{-5} ft/s, and the particle Reynolds number is 1.09×10^{-4}. With a particle size of 100 micron, the particle settling rate is 7.07×10^{-3} ft/s, and the particle Reynolds number is 0.109.

Figure 7 shows the position of the transfer pump, center column, and disturbed solids in Tank 49H. Tank 49H has a radius of 42.5 feet. The horizontal distance between the C3 riser (liquid addition riser) and the B5 riser (transfer pump riser) is 64.5 feet. The common area between a circle with its center at the B5 riser and radius of 64.5 feet and a circle with its center at the Tank 49H center and radius of 42.5 feet is 5334 $ft^{2.}$ The area of a circle with radius of 42.5 feet is 5675 ft^2. Since the volume of material in Tank 49H is 3510 gallons per inch, the volume of material within 64.5 feet of the transfer pump in Tank 49H is (3510 gal/in)(5334/5675) = 3300 gallons per inch. Assuming the first material transported to the transfer pump is located in the bottom 16 inches of the tank, the volume of this material is 52,800 gallons. Since the volume of a transfer to SWPF is 23,200 gallons, the solid particles disturbed under riser C3 will not reach the transfer pump until the third transfer to the SWPF. At a flow rate of 159 gpm, the time to transfer 52,800 gallons to SWPF is 332 minutes, not including the time between transfers. Significant particle settling will occur as the disturbed solids are transferred to the SWPF. Figure 8 shows that any particles 10 micron and larger will settle at least 1.33 ft (16 inches) in the time needed to transfer 52,800 gallons of liquid to the SWPF.

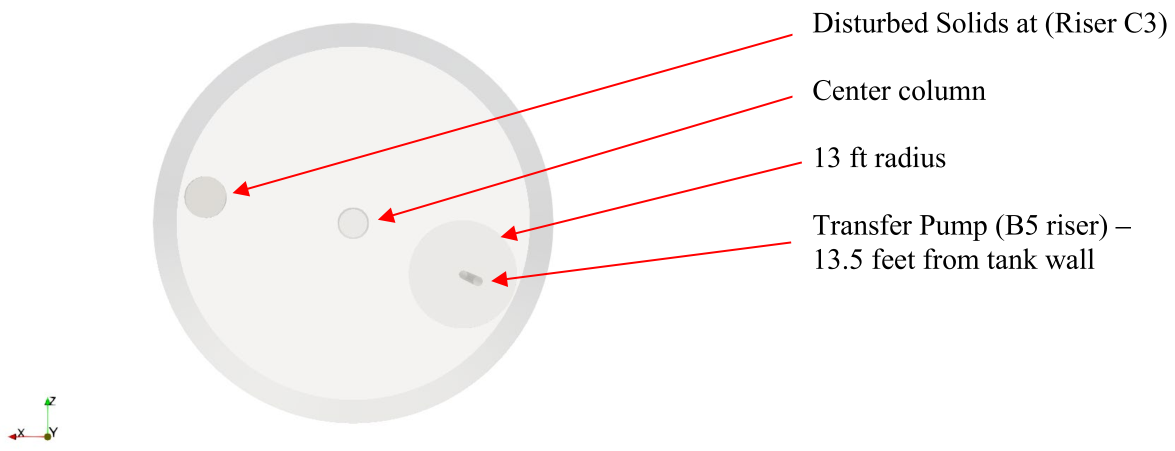

Figure 7. Location of Disturbed Solids and Transfer Pump in Tank 49H

Figure 9 shows the distance that particles will settle during the duration of the first 3 transfers from Tank 49H to SWPF after a salt batch is added to the tank. The settling time is based on the time for a transfer (146 minutes for each transfer) and the setting time between each transfer (1150 minutes). Based on the figure, a 5 micron particle will settle over 2.5 ft (30 inches) and a 3 micron particle will settle more than 1 ft (12 inches) during this time. The 5 micron particle will settle to the tank bottom before reaching the transfer pump suction. The 3 micron particle is likely to settle to the tank bottom before reaching the transfer pump.

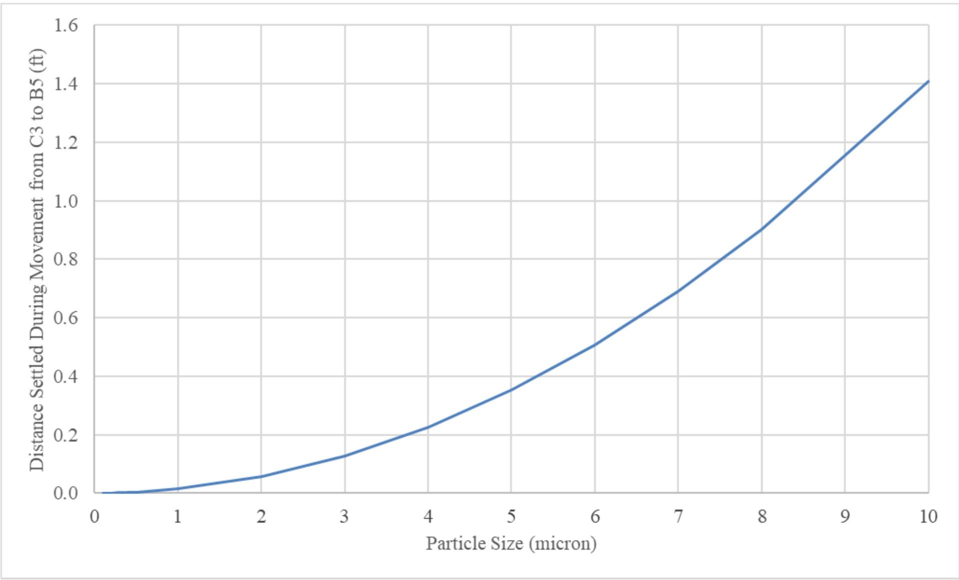

Figure 8. Distance Settled as Fluid Particle Moves from Disturbed Zone to Transfer Pump (332 minutes)

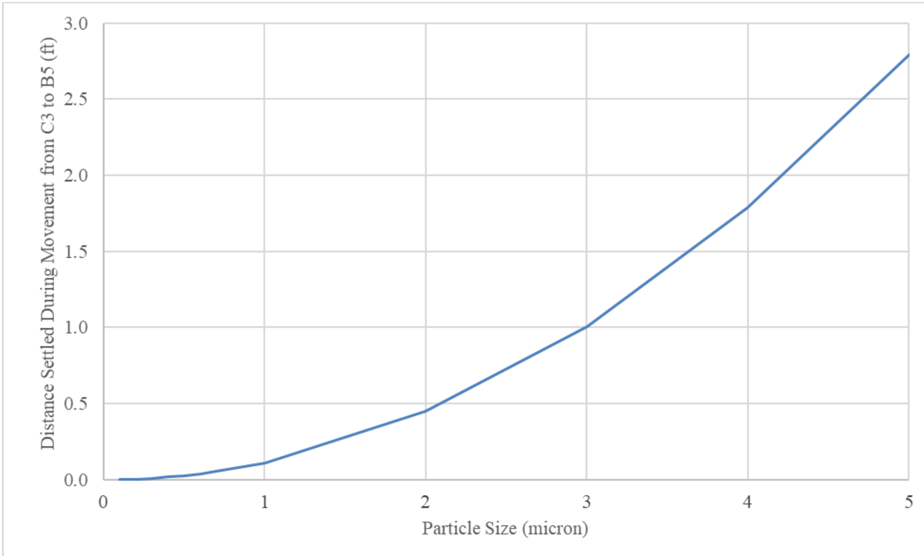

Figure 9. Particle Settling during Time to Reach Transfer Pump (2632 minutes)

2.5 Particle Settling During Transfer of Liquid into Tank 49H

Once the liquid level reaches 115 inches during addition into the tank, the plunging jet will not reach the tank bottom and disturb solids. As the liquid level increases above 115 inches, the depth and influence of the "plunging jet" will move farther away from the solid particles on the tank bottom and the disturbed solids. The disturbed solids should begin to settle.

The settling that will occur as liquid is added to Tank 49H is a function of solid particle size. Equation [8] describes the particle settling rate as a function of particle size.

At a flow rate of 200 gpm into Tank 49H, the liquid level will increase from 115 inches to 290 inches (~1,000,000 gallons) in a minimum of 2 days. The 2 day time assumes a continuous transfer into Tank 49H. If the transfer consists of multiple transfers into the tank, the time for the liquid level to increase from 115 inches to 290 inches will be longer.

Figure 10 shows the estimated distance the various particle sizes will settle as the liquid level increases above 115 inches during a transfer into Tank 49H. (These calculations assume no hindered settling behavior – i.e., particle-particle interactions – which is a reasonable assumption for dilute slurries of non-cohesive particles.) The figure shows that particles 5 micron and larger will settle at least 3 ft as the liquid level increases from 115 inches to 290 inches and should be at the tank bottom when the liquid level reaches 290 inches. The figure shows that particles 3 micron and larger will settle at least 1 ft as the liquid level increases from 115 inches to 290 inches and are likely to be at the tank bottom when the liquid level reaches 290 inches. Particles less than 3 micron may not settle to the tank bottom. These results are consistent with the results from the Tank 48H sampling analysis conducted in 1995.[21] This particle settling may prevent exceeding the SWPF WAC limits for insoluble solids but is dependent on the particle size of the particles at the bottom of Tank 49H.

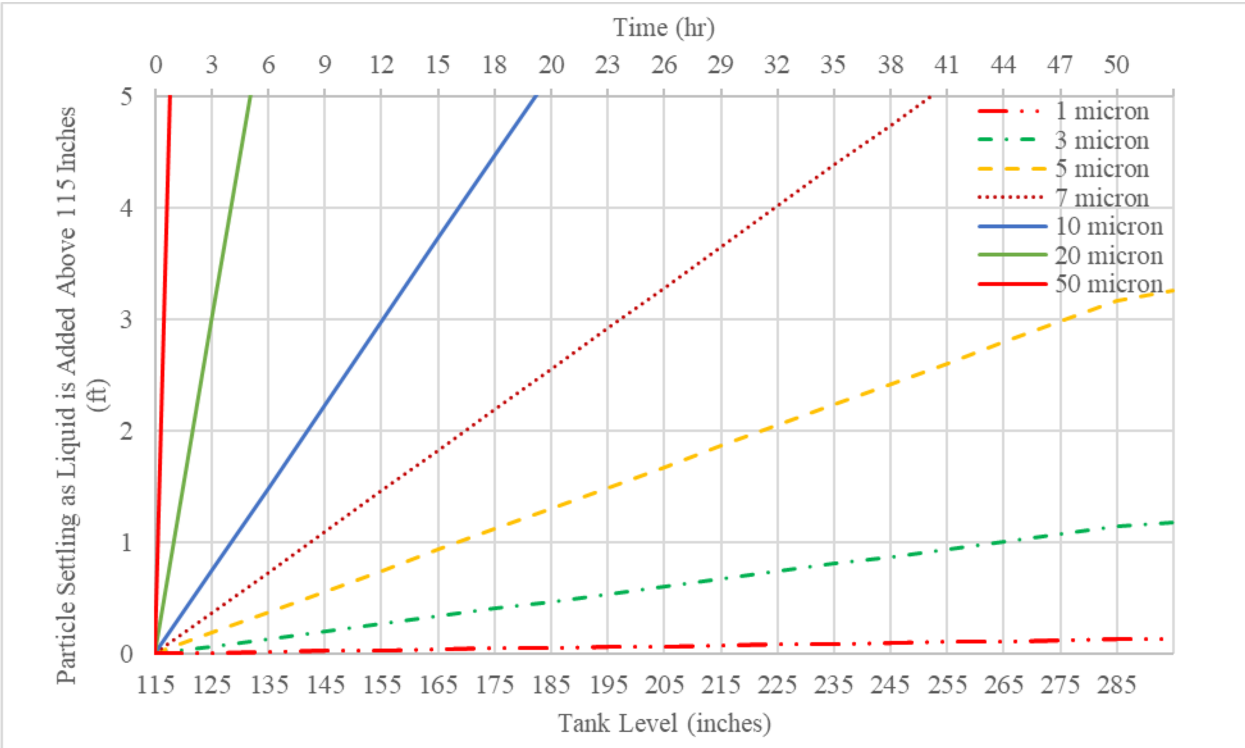

Figure 10. Particle Settling as Liquid is Added to Tank 49H

2.6 M-Star Simulations of Transport of the Disturbed Solids to the Transfer Pump

After solids are disturbed by the "plunging jet", they will either settle or be transported to the transfer pump. As discussed above, particles larger than 5 micron in diameter will settle during liquid addition to Tank 49H and during the transport of liquid to the transfer pump. Particles smaller than 1 – 3 micron in diameter are unlikely to settle, and could reach the transfer pump and be transferred to SWPF. These smaller particles are likely to follow the fluid flow and be blended/diluted by mixing with the liquid in the tank.

The following approach was employed to simulate the movement of the small, disturbed solid particles from under the C3 riser to the transfer pump:

- The transfers were continuous with no down time between transfers. The down time would allow for additional particle settling and dispersion, which makes these simulations conservative.
- All particles in a 10 foot diameter circle under the C3 riser are disturbed. This is bounding based on previous work.[19]
- The disturbed particles are contained in a 10 foot diameter, 2 foot (24 inch) high cylinder located at the tank bottom under the C3 riser.
- The particles are 1 micron in diameter. The 1 micron particles will settle minimally during liquid addition and transfer. They will follow the liquid fluid motion and represent particles 1 micron and smaller.
- Since the solids level is 1.1 inches and the volume fraction of solid particles is 0.3, the volume of solid particles is

$V = 0.3\ \pi\ D^2\ H/4 = (0.3)\ (3.14)\ (120\text{ in})^2\ (1.1\text{ in})\ (1\text{m}\ /39.37\text{ in})^3/4 = 0.0612\text{ m}^3$ of particles

The volume of a single 1 micron particle is

$V_p = (4/3)\ \pi\ (d_p/2)^3 = (4/3)\ \pi\ (0.5 \times 10^{-6}\text{ m})^3 = 5.236 \times 10^{-19}\text{ m}^3/\text{particle}$

The number of 1 micron particles occupying this volume is

$V_p/V = (0.0612\ m^3$ of particles$)/(5.236 \times 10^{-19}\ m^3$/particle$) = 1.17 \times 10^{17}$ particles

Two types of simulations were performed. In one type, the full mass of disturbed solids is added to the tank, but only 1 million particles are tracked. The particles are 1 micron in diameter and have a density of 2.25 g/mL. The forces produced by the full mass of disturbed particles are applied to the liquid and the volume occupied by the full mass of disturbed particles is included in the simulation. In the second type, 1 million tracer particles are added to the tank. The particles are 1 micron in diameter and have a density of 2.25 g/mL. These particles allow one to observe the movement of these particles throughout the tank, but the mass of particles added, the forces exerted by the particles, and the holdup volume of the particles are significantly less than those that would exist in Tank 49H.

The density of the liquid was 1.26 g/mL, and the viscosity was 2.5 cP.[12] In the simulation, the liquid removed by the transfer pump is added back at the top of the liquid in the tank. This return of liquid keeps the level in the tank constant and simulates the presence of the liquid above 40 – 120 inches in the tank.

The following cases were simulated

- 40 inch liquid level with all particles represented
- 52 inch liquid level with all particles represented
- 120 inch liquid level with all particles represented
- 40 inch liquid level with tracer particles
- 120 inch liquid level with tracer particles

2.6.1 40 inch Liquid Level with All Particles Represented

Figure 11 shows the concentration of insoluble solids in the transfer from Tank 49H to SWPF as a function of time and the normalized particle concentration in Tank 49H as a function of time. The results show that the maximum concentration in the material leaving Tank 49H is much less that the waste acceptance criteria (WAC) limit of 1.2 g/L. In addition, the results show that it takes over 72,000 seconds (20 hours) for half of the disturbed solid particles to reach the transfer pump. Since a typical transfer takes ~ 2.5 hours (23,200 gallons/159 gpm = 146 min = 2.4 hr), it would take at least 8 transfers to remove half of the disturbed particles from the tank.

Table 4 shows the average insoluble solids concentration in each of the first 11 transfers from Tank 49H to SWPF. They are all much less than the WAC limit of 1.2 g/L.

Appendix A shows screen shots from the M-Star® simulations at select times. The screen shots provide a view from the side and from the top of the tank. They show the particles accumulating near the bottom of the tank and spreading out over the entire tank cross section. The particles accumulating near the bottom of the tank is somewhat surprising given their small diameter and slow settling rate. However, because of the large number of particles (1.17×10^{17}), the total force from the particles acting on the liquid is much larger than the force of a single particle acting on the liquid and contributes to the settling.

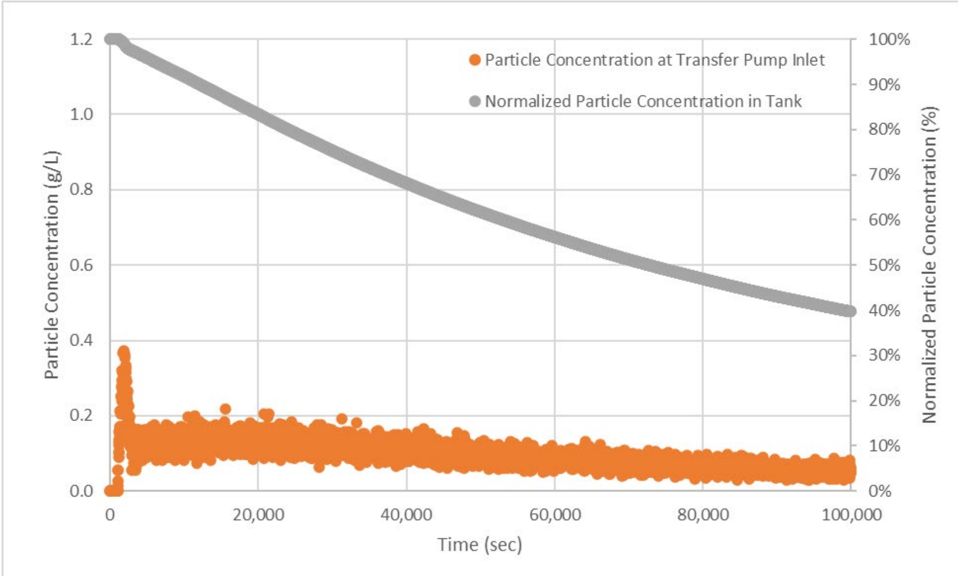

Figure 11. Particle Concentration in Transfer from Tank 49H to SWPF and in Tank 49H with 40 Inch Liquid Level

Table 4. Average Insoluble Solids Concentration in a Transfer from Tank 49H to SWPF with a 40 Inch Liquid Level

Transfer #	Particle Concentration (g/L)
1	0.13
2	0.13
3	0.13
4	0.12
5	0.11
6	0.10
7	0.09
8	0.08
9	0.07
10	0.06
11	0.05
WAC limit	1.20

2.6.2 52 inch Liquid Level with All Particles Represented

Figure 12 shows the concentration of insoluble solids in the transfer from Tank 49H to SWPF as a function of time and the normalized particle concentration in Tank 49H as a function of time. The results show that the maximum concentration in the material leaving Tank 49H is much less that the waste acceptance criteria (WAC) limit of 1.2 g/L. In addition, the results show that it takes over 72,000 seconds (20 hours) for half of the disturbed solid particles to reach the transfer pump. Since a typical transfer takes ~ 2.5 hours, it would take at least 8 transfers to remove half of the disturbed particles from the tank.

Table 5 shows the average insoluble solids concentration in each of the first 11 transfers from Tank 49H to SWPF. They are all much less than the WAC limit of 1.2 g/L.

Appendix A shows screen shots from the M-Star® simulations at select times. The screen shots provide a view from the side and from the top of the tank. They show the particles accumulating near the bottom of the tank and spreading out over the entire tank cross section.

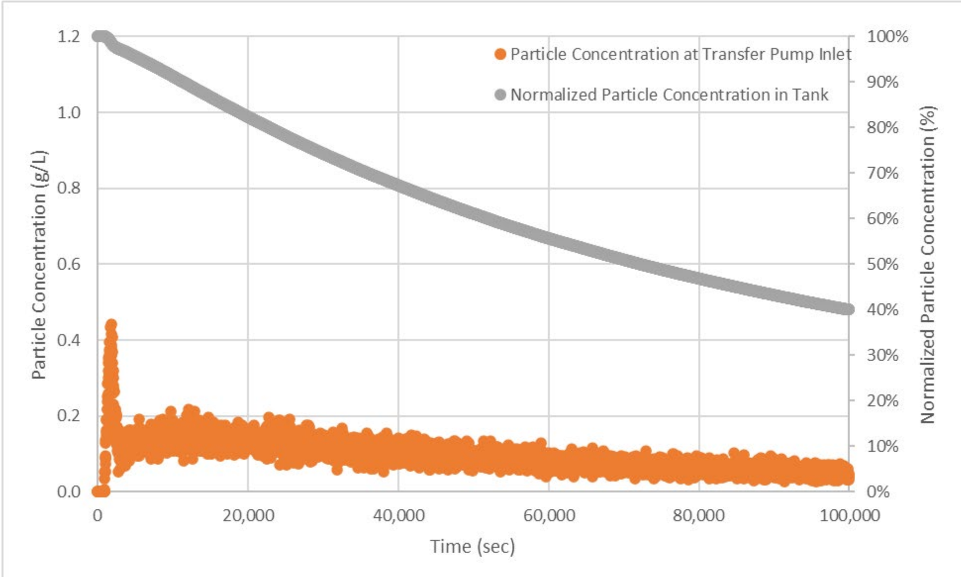

Figure 12. Particle Concentration in Transfer from Tank 49H to SWPF and in Tank 49H with a 52 Inch Liquid Level

Table 5. Average Insoluble Solids Concentration in a Transfer from Tank 49H to SWPF with a 52 Inch Liquid Level

Transfer #	Particle Concentration (g/L)
1	0.14
2	0.14
3	0.13
4	0.12
5	0.10
6	0.09
7	0.08
8	0.07
9	0.07
10	0.06
11	0.05
WAC limit	1.20

2.6.3 120 inch Liquid Level with All Particles Represented

Figure 13 shows the concentration of insoluble solids in the transfer from Tank 49H to SWPF as a function of time and the normalized particle concentration in Tank 49H as a function of time. The results show that the maximum concentration in the material leaving Tank 49H is much less that the waste acceptance criteria (WAC) limit of 1.2 g/L. In addition, the results show that it takes over 72,000 seconds (20 hours) for half of the disturbed solid particles to reach the transfer pump. Since a typical transfer takes ~ 2.5 hours, it would take at least 8 transfers to remove half of the disturbed particles from the tank.

Table 6 shows the average insoluble solids concentration in each of the first 11 transfers from Tank 49H to SWPF. They are all much less than the WAC limit of 1.2 g/L.

Appendix A shows screen shots from the M-Star® simulations at select times. The screen shots provide a view from the side and from the top of the tank. They show the particles accumulating near the bottom of the tank and spreading out over the entire tank cross section.

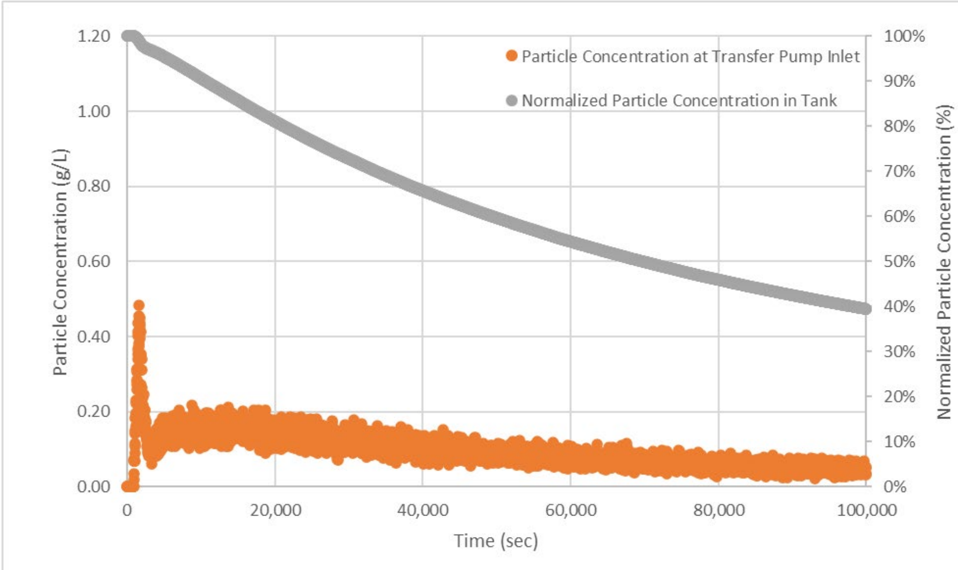

Figure 13. Particle Concentration in Transfer from Tank 49H to SWPF and in Tank 49H with a 120 Inch Liquid Level

Table 6. Average Insoluble Solids Concentration in a Transfer from Tank 49H to SWPF with a 120 Inch Liquid Level

Transfer #	Particle Concentration (g/L)
1	0.15
2	0.16
3	0.14
4	0.12
5	0.10
6	0.09
7	0.08
8	0.07
9	0.06
10	0.06
11	0.05
WAC limit	1.20

In the simulations performed that included all particles, the disturbed particles appeared to accumulate in the bottom 10 inches of the tank. Repeating the analysis from section 2.4 and using a liquid level of 10 inches rather than 16 inches, the time for the first disturbed particles to reach the transfer pump is (52,800 gal) (10 in/16 in)/(159 gal/min) = 208 min ~ 12,000 sec. While a mass of particles reached the transfer pump shortly after it started, Figures 11, 12, and 13 show that excluding this initial mass, the peak concentration of the disturbed particles reaching the transfer pump between 10,000 seconds and 15,000 seconds, which is consistent with the analysis in section 2.4 after decreasing the liquid level to 10 inches.

2.6.4 40 inch Liquid Level with Tracer Particles

Figure 14 shows the concentration of insoluble solids in the transfer from Tank 49H to SWPF as a function of time and the normalized particle concentration in Tank 49H as a function of time. The results show that the maximum concentration in the material leaving Tank 49H is less that the waste acceptance criteria (WAC) limit of 1.2 g/L. A few of the data points are close to 1.2 g/L, but most are much less than 1.2 g/L. In addition, the results show that it takes over 50,000 seconds (13 hours) for half of the disturbed solid particles to reach the transfer pump. Since a typical transfer takes ~ 2.5 hours, it would take at least 6 transfers to remove half of the disturbed particles from the tank.

Table 7 shows the average insoluble solids concentration in each of the first 11 transfers from Tank 49H to SWPF. They are all much less than the WAC limit of 1.2 g/L.

Appendix A shows screen shots from the M-Star® simulations at select times. The screen shots provide a view from the side and from the top of the tank. In this case the particles do not accumulate at the bottom of the tank like they did when all particles were simulated. In addition, they appear to move more slowly toward the transfer pump, and show less dispersion.

Repeating the analysis from section 2.4 and using a liquid level of 40 inches rather than 16 inches, the time for the first disturbed particles to reach the transfer pump is (52,800 gal) (40 in/16 in)/(159 gal/min) = 830 min ~ 50,000 sec. Figure 14 shows a large fraction of the disturbed particles reached the transfer pump between 40,000 seconds and 60,000 seconds, which is consistent with the analysis in section 2.4 after increasing the liquid level to 40 inches.

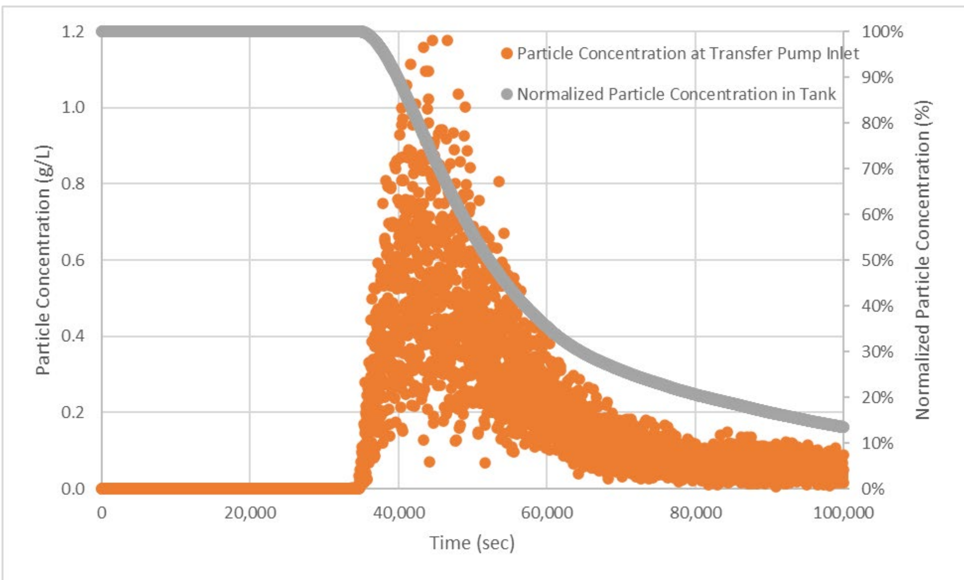

Figure 14. Particle Concentration in Transfer from Tank 49H to SWPF and in Tank 49H SWPF with a 40 Inch Liquid Level and Tracer Particles

Table 7. Average Insoluble Solids Concentration in a Transfer from Tank 49H to SWPF with a 40 Inch Liquid Level and Tracer Particles

Transfer #	Particle Concentration (g/L)
1	0.00
2	0.00
3	0.00
4	0.00
5	0.46
6	0.47
7	0.27
8	0.13
9	0.08
10	0.06
11	0.05
WAC limit	1.20

2.6.5 120 inch Liquid Level with Tracer Particles

Figure 15 shows the concentration of insoluble solids in the transfer from Tank 49H to SWPF as a function of time and the normalized particle concentration in Tank 49H as a function of time. The results show that the maximum concentration in the material leaving Tank 49H is much less that the waste acceptance criteria (WAC) limit of 1.2 g/L. In addition, the results show no significant transfer of solid particles to the transfer pump.

Table 8 shows the average insoluble solids concentration in each of the first 11 transfers from Tank 49H to SWPF. No particles reach the transfer pump inlet until 99,700 seconds after the start of the transfer (i.e., batch 11).

Appendix A shows screen shots from the M-Star® simulations at select times. The screen shots provide a view from the side and from the top of the tank. In this case the particles do not accumulate at the bottom of the tank like they did when all particles were simulated. They eventually rise to the top of the liquid level, and they do not reach the transfer pump in significant number.

Repeating the analysis from section 2.4 and using a liquid level of 120 inches rather than 16 inches, the time for the first disturbed particles to reach the transfer pump is (52,800 gal) (120 in/16 in)/(159 gal/min) = 2,490 min ~ 150,000 sec. Given a simulation time of 100,000 seconds, little or no particles are expected to reach the transfer pump, which is consistent with the analysis in section 2.4 after increasing the liquid level to 120 inches.

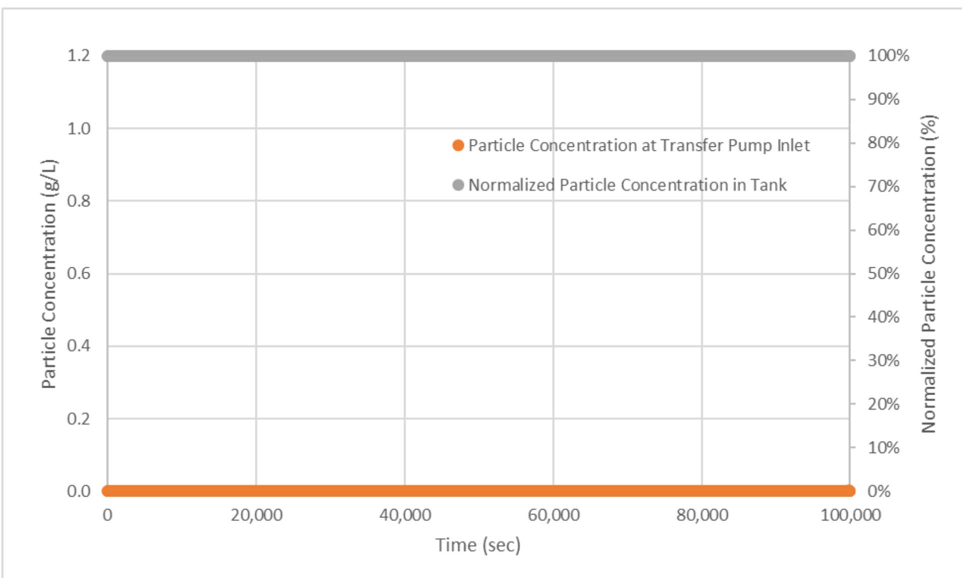

Figure 15. Particle Concentration in Transfer from Tank 49H to SWPF and in Tank 49H with a 120 Inch Liquid Level and Tracer Particles

Table 8. Average Insoluble Solids Concentration in a Transfer from Tank 49H to SWPF with a 120 Inch Liquid Level and Tracer Particles

Transfer #	Particle Concentration (g/L)
1	0.00
2	0.00
3	0.00
4	0.00
5	0.00
6	0.00
7	0.00
8	0.00
9	0.00
10	0.00
11	0.00
WAC limit	1.20

2.7 Discussion of Results

Based on the "plunging jet" analysis in Section 2.1, a minimum liquid level of 115 inches is recommended in Tank 49H. If the liquid level in Tank 49H is 115 inches or more, minimum solids disturbance will occur.

If the liquid level is less than 115 inches, significant solids disturbance could occur. Estimating the mass of solid particles disturbed, the dilution that will occur with other liquid in Tank 49H, and the settling that will occur, it may be possible to meet the SWPF WAC at a lower liquid level in Tank 49H. However, the results of the simulations performed suggest that additional work is needed to optimize the geometry of the simulation as well as the simulation parameters if the simulations are to be used to quantify the solids disturbance. If the particles are greater than 5 micron in diameter, any disturbed particles are likely to settle before being transported to the transfer pump. If the disturbed particles are less than 3 - 5 micron in diameter, a large fraction of these disturbed particles may be transported to the transfer pump, and then transferred to SWPF.

Particle settling will occur during liquid addition to Tank 49H, during transfers from Tank 49H to the SWPF, and between transfers from Tank 49H to the SWPF. At the maximum liquid addition rate to Tank 49H (200 gpm), the time for the liquid level to increase from 115 inches to 290 inches (1,000,000 gallons total) is (290 – 115 inches) (3510 gallons/inch)/200 gal/min = 3,071 minutes.

Assuming the first material transported to the transfer pump is located in the bottom 16 inches of the tank, the volume of this material is 52,800 gallons. Since the volume of a transfer to SWPF is 23,200 gallons, the solid particles disturbed under riser C3 will not reach the transfer pump until the third transfer to the SWPF. At a flow rate of 159 gpm, the time to transfer 52,800 gallons to SWPF is 332 minutes, not including the time between transfers.

The time between transfers is 1150 minutes, and the total time between transfers 1 and 2 and transfers 2 and 3 is 2,300 minutes.

Adding the time for particle settling during liquid addition (3,071 minutes), the time for settling during three transfers from Tank 49H to SWPF (332 minutes), and the time between transfers from Tank 49H to the SWPF (2,300 minutes) gives a settling time of 5,703 minutes for disturbed particles to settle before reaching the transfer pump. Figure 16 shows the volume fraction of disturbed solids that will settle a specified height during this time based on the average particle size distribution of Tanks 5, 13, and 15. Approximately 60% of the particles will settle 3 ft in this time, and approximately 65% of the particles will settle 2 ft in this time. However, Tanks 5, 13, and 15 are sludge tanks, and may not represent the particle size distribution of the particles at the bottom of Tank 49H.

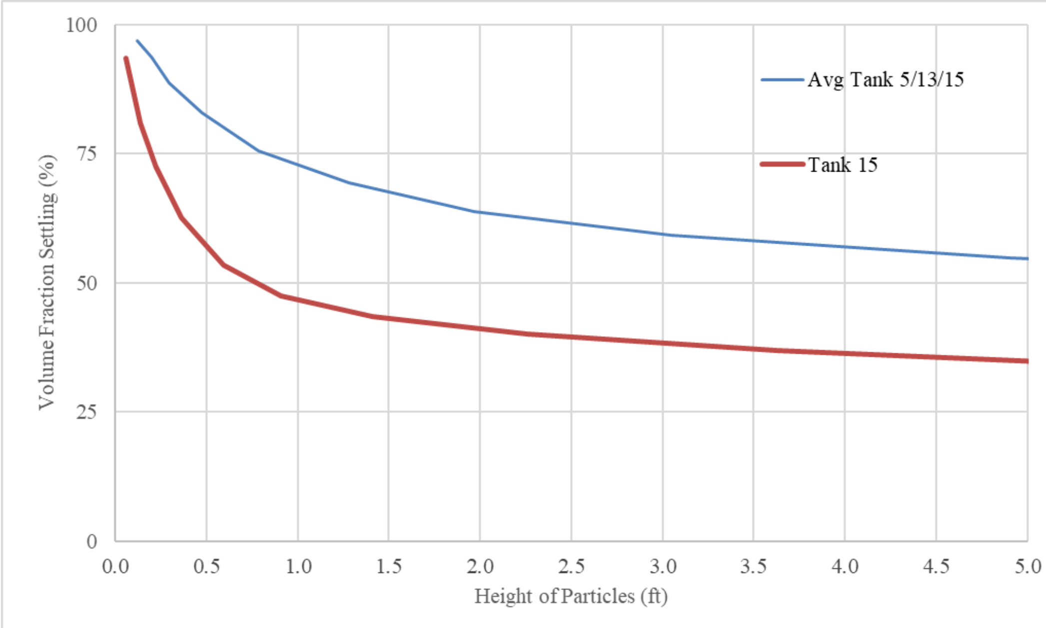

Figure 16. Volume Fraction of Disturbed Particles Settling during Liquid Addition to Tank 49H and Transfer from Tank 49H to the SWPF

In addition to looking at the behavior of the large particles (> 5 micron) disturbed during liquid addition to Tank 49H and transfer to SWPF, the author looked at the behavior of small particles (1 micron) disturbed during liquid addition to Tank 49H during the transfers to SWPF. Figure 17 and Table 9 summarize the results. Using liquid levels between 40 inches (well below the minimum in Tank 49H) and 120 inches with the all particles represented and with tracer particles represented, the concentration of insoluble solids at the transfer pump inlet is below the SWPF WAC. These calculations are likely conservative given that many of the disturbed particles are likely to be larger than 1 micron, particle settling will occur during liquid addition and between transfers.

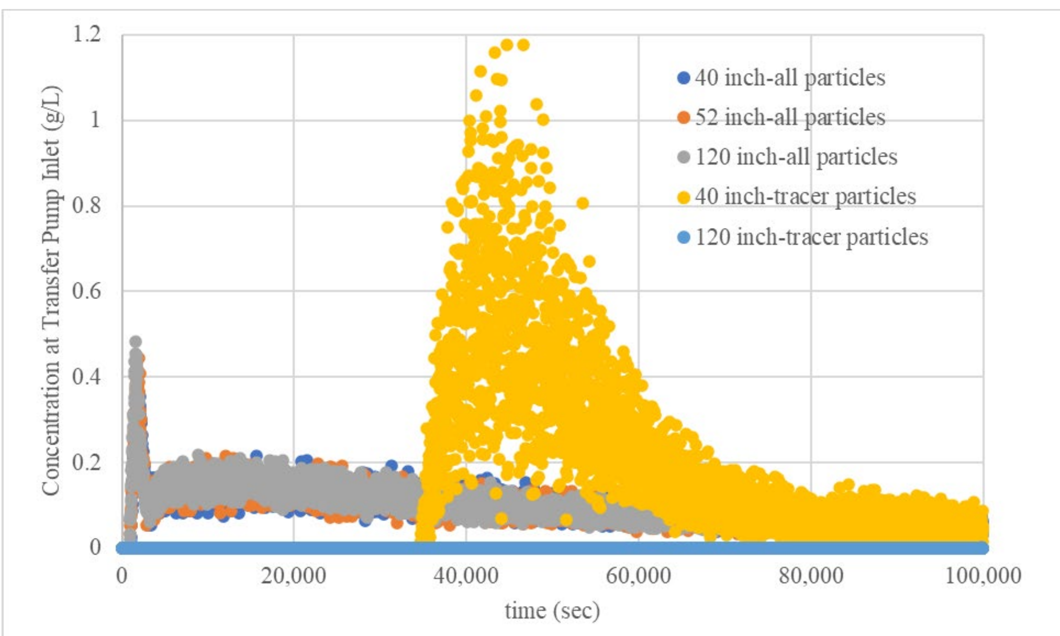

Figure 17. Particle concentration in Transfer from Tank 49H to SWPF

Table 9. Average Insoluble Solids Concentration in a Transfer from Tank 49H to SWPF

	40 inch-all particles	**52 inch-all particles**	**120 inch-all particles**	**40 inch-tracer particles**	**120 inch-tracer particles**
Transfer #	Part. Conc. (g/L)	Part. Conc. (g/L)	Part. Conc. (g/L)	Part. Conc. (g/L)	Part. Conc. (g/L)
1	**0.13**	**0.14**	0.15	0.00	0.00
2	**0.13**	**0.14**	**0.16**	0.00	0.00
3	**0.13**	0.13	0.14	0.00	0.00
4	0.12	0.12	0.12	0.00	0.00
5	0.11	0.10	0.10	0.46	0.00
6	0.10	0.09	0.09	**0.47**	0.00
7	0.09	0.08	0.08	0.27	0.00
8	0.08	0.07	0.07	0.13	0.00
9	0.07	0.07	0.06	0.08	0.00
10	0.06	0.06	0.06	0.06	0.00
11	0.05	0.05	0.05	0.05	0.00
WAC limit	1.20	1.20	1.20	1.20	1.20

^ *Highest concentrations shown in bold*

The analysis in this document shows that with a liquid level of 115 inches and higher, minimal particle disturbance will occur from adding liquid to Tank 49H through the C3 riser. If the liquid level is between 80 and 115 inches, significant particle disturbance could occur. If the disturbed particles are 5 micron and larger, they are likely to settle during liquid addition to the tank and transport to the transfer pump. Smaller particles (represented by 1 micron diameter particles) are unlikely to settle during liquid addition to the tank and transport to the transfer pump. However, during transport to the transfer pump, they will be dispersed and mix with other liquid in the tank. The concentration of disturbed solids in the feed to the transfer pump will be less than the SWPF WAC.

Other approaches that SRR should consider if they wish to maintain a lower level in Tank 49H are to lower the elevation at which the liquid enters the tank, adding a device to disperse the added liquid into droplets that will not penetrate deeply below the liquid surface, or adding a nozzle to the downcomer to reduce the diameter of the jet produced by the liquid entering the tank.

If the added liquid could be dispersed into liquid droplets rather than a jet stream with a large diameter, they are likely to penetrate less into the liquid in the tank and would be unlikely to disturb the solid particles on the tank bottom.

This analysis showed that the penetration depth of the ‘plunging jet” is a function of the diameter of the jet exiting the downcomer. If the diameter of this jet could be reduced, its penetration depth into the liquid would be reduced such that it does not disturb the solid particles on the tank bottom. Figure 18 shows a comparison of the depth of a “plunging jet” coming from a 1-inch downcomer compared with a 3-inch downcomer. The results show a significant decrease with the smaller diameter, keeping the inlet flow rate constant at 95 gpm.

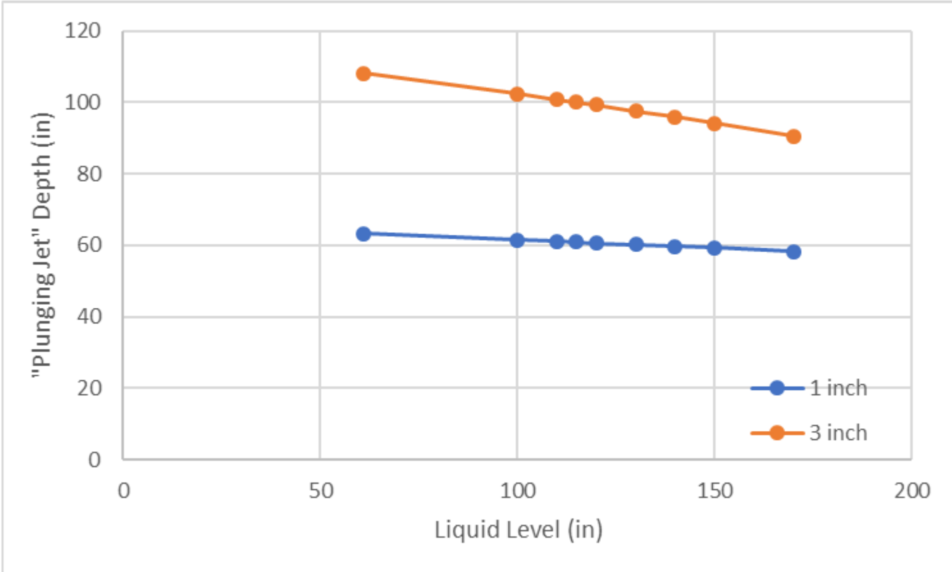

Figure 18. "Plunging Jet" Depth as a Function of Downcomer Diameter

3.0 Conclusions

The analysis showed that with a solid particle size of 5 micron or less, a liquid level of 115 inches should be maintained to prevent significant disturbance of the solid layer at the bottom of Tank 49H. If the particle size is 100 micron or larger, the liquid level in the tank can be reduced to as low as 80 inches. At this level, the larger particles will be disturbed, but they will settle to the tank bottom before reaching the transfer pump. Since a large fraction of the solid particles in Tank 49 are expected to be less than 5 microns based on previous analyses of SRS sludge particle size which measured median particle sizes of 2.6, 6.1, 10.8, and 15.1 microns, the 115-inch liquid level is recommended at this time.

If liquid is added to Tank 49H with a liquid level less than 115 inches, particle disturbance will occur. Once the liquid level reaches 115 inches, particle disturbance will stop and particle settling will begin. In the time that the liquid level increases from 115 inches to 290 inches (~1,000,000 gallons), significant particle settling could occur, which may prevent exceeding the SWPF WAC limits for insoluble solids, but the settling is dependent on the size of the particles at the bottom of Tank 49H.

Significant particle settling could occur during the time the disturbed particles move toward the transfer pump and between transfers to the SWPF. This settling could prevent exceeding the SWPF WAC, but it is dependent on particle size.

If the disturbed particles are 1 micron or less, the particles will follow the fluid motion in the tank. As these particles are transported to the transfer pump, they will be dispersed and mixed with other liquid in the tank. The concentration of these disturbed particles in the feed to the transfer pump will likely be less than the SWPF WAC.

Considering the settling of particles 5 micron and larger during liquid addition to Tank 49H and the dispersion and mixing of particles 1 micron and smaller during transport from the disturbed region under the C3 riser to the transfer pump, it is possible that the minimum liquid level in Tank 49H could be reduced without exceeding the SWPF WAC.

If the height of the solid particles in Tank 49H is greater than 1.1 inches, the mass of suspended particles and the mass of particles reaching the transfer pump should be increased proportionally. The increased solid particle height may lead to less of a fraction of the particles being suspended, but that cannot be verified or quantified at this time.

In addition, if there are insoluble solid particles suspended in the supernate prior to the transfer or insoluble particles in the transfer, the concentration of these particles must be considered in determining whether the SWPF WAC will be met.

If Savannah River Remediation (SRR) wishes to maintain a lower level in Tank 49H, they should consider lowering the elevation at which the liquid enters the tank, adding a device to disperse the added liquid into droplets that will not penetrate deeply below the liquid surface, or adding a nozzle to the downcomer to reduce the diameter of the jet produced by the liquid entering the tank.

4.0 References

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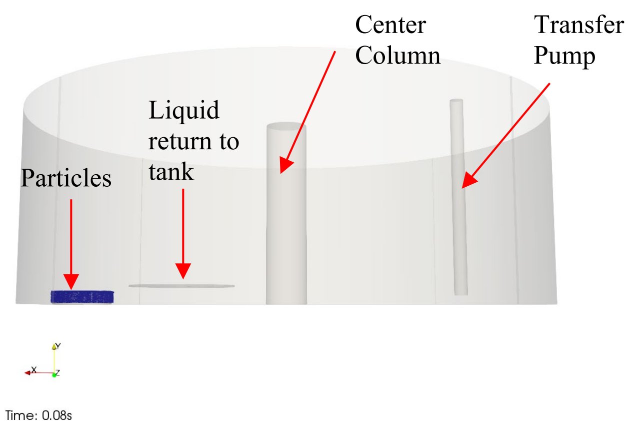
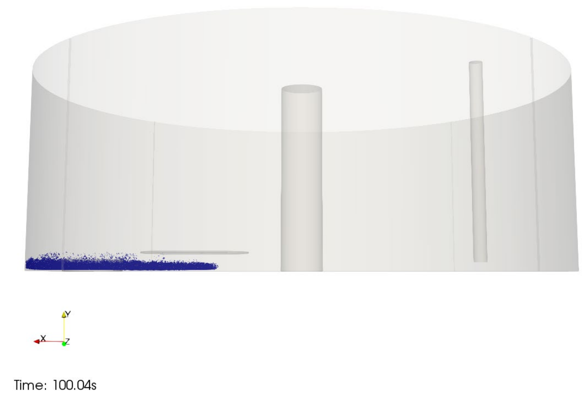
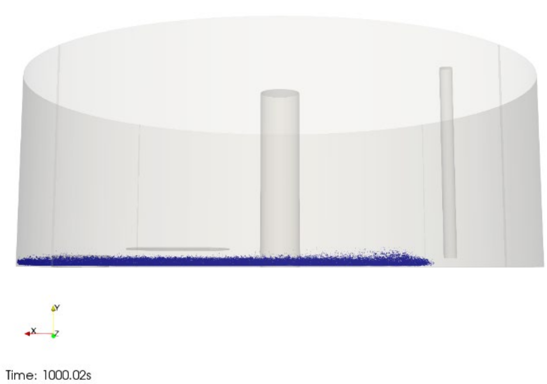
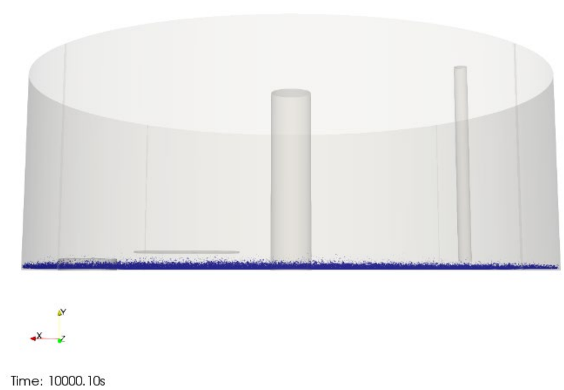
5.0 Appendix A: M-Star Simulation Screenshots

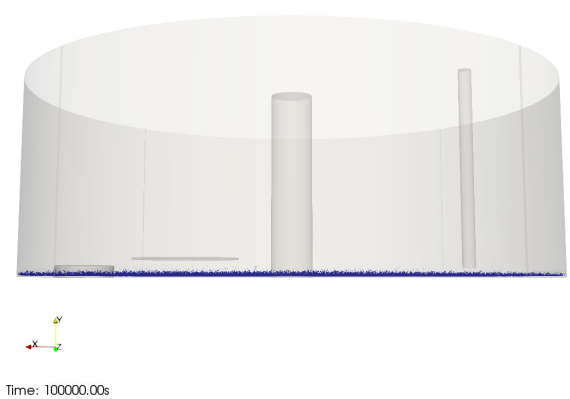
5.1 Transfer from Tank 49H to SWPF with 40 Inch Liquid Level

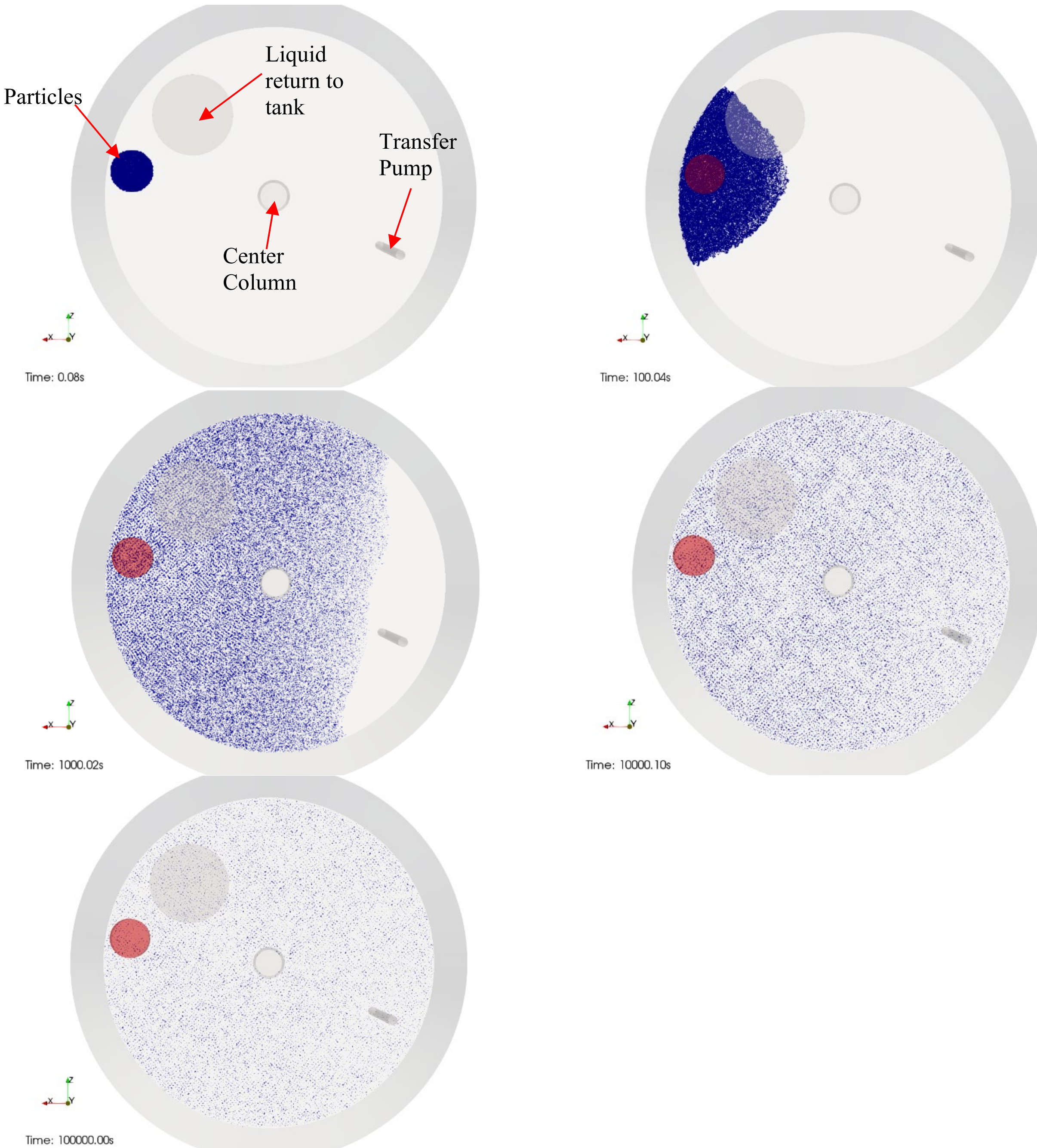











Particles
Liquid return to tank
Transfer Pump
Center Column
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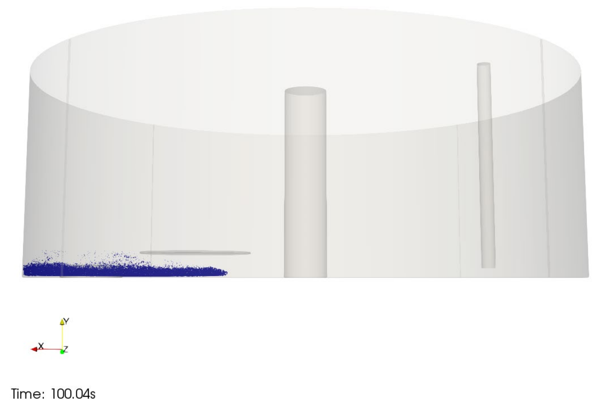
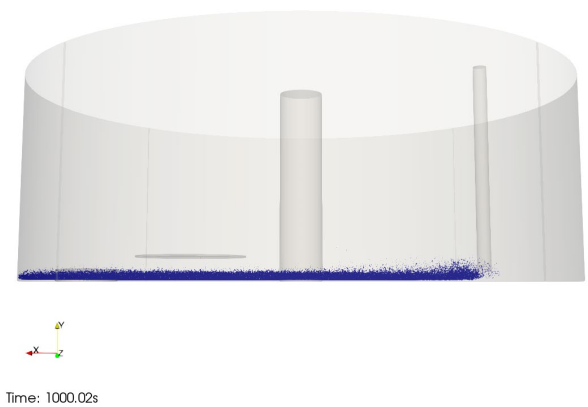
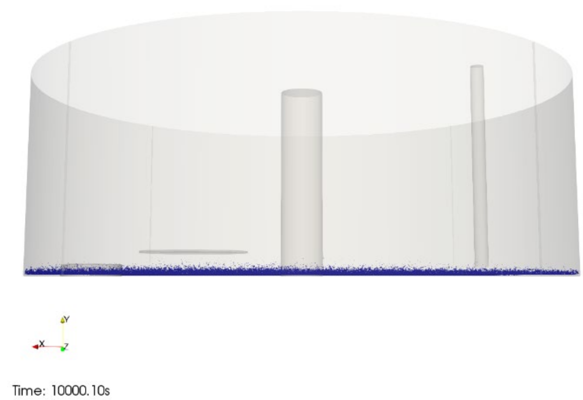
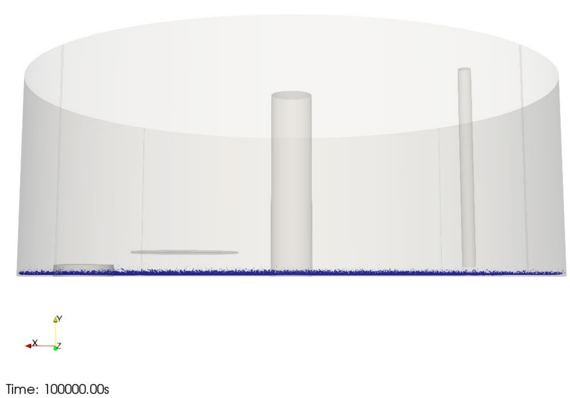
Time: 100.04s
Time: 1000.02s
Time: 10000.10s
Time: 100000.00s

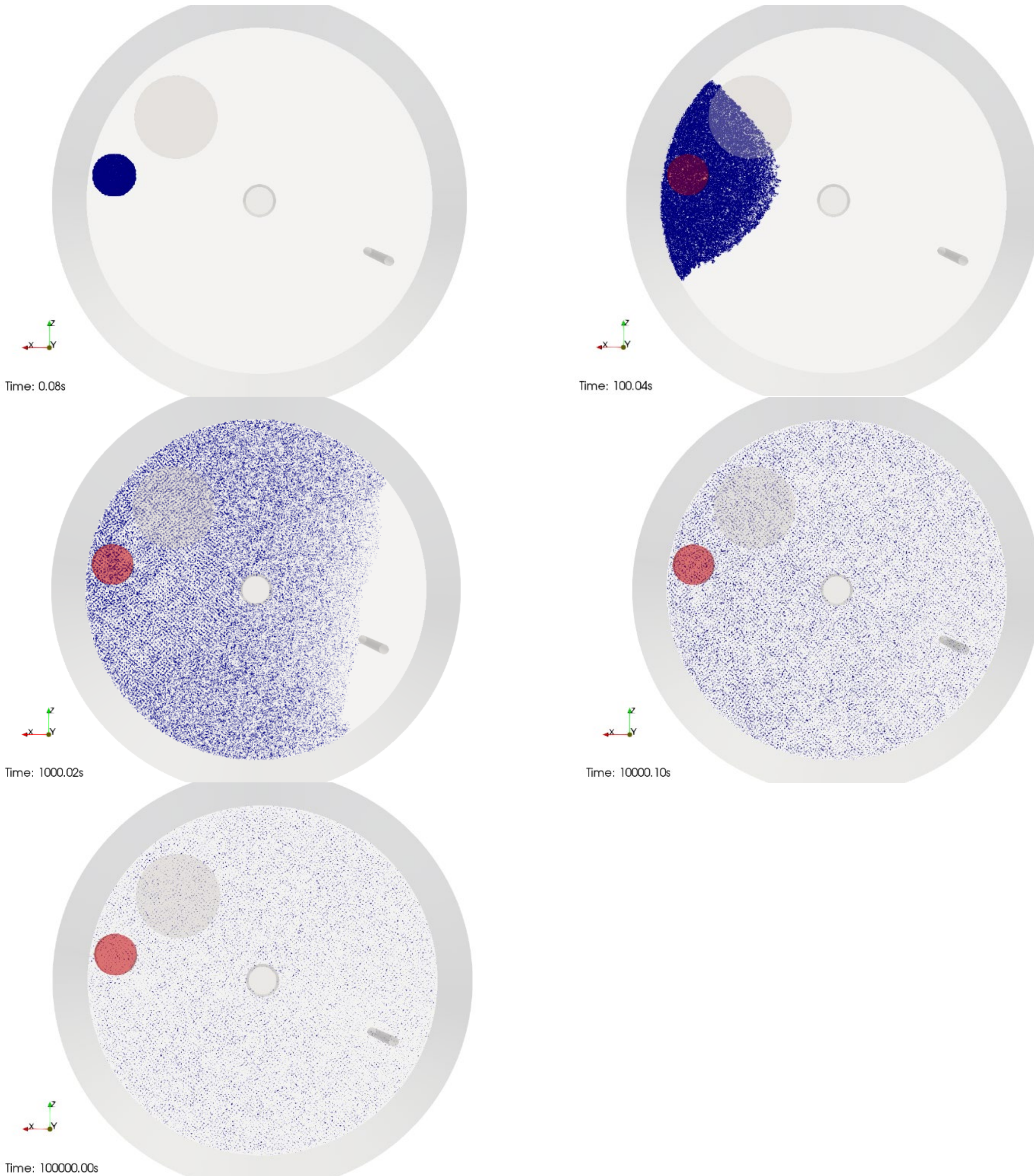
5.2 Transfer from Tank 49H to SWPF with 52 Inch Liquid Level







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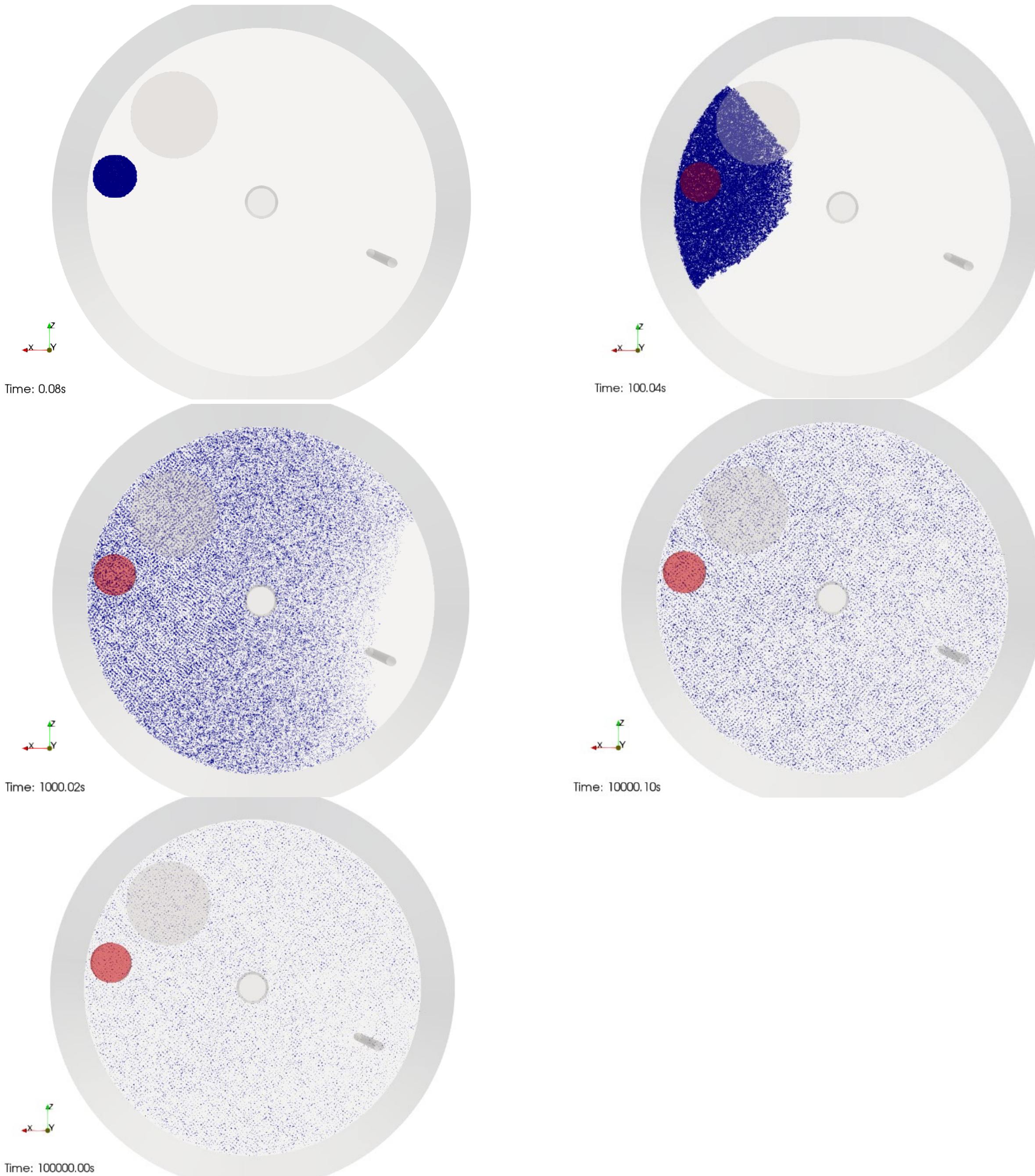
5.3 Transfer from Tank 49H to SWPF with 120 Inch Liquid Level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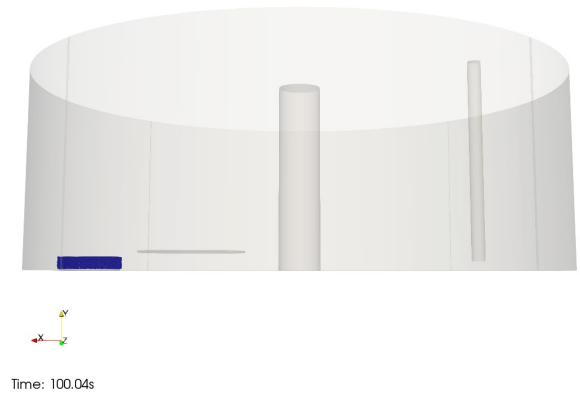
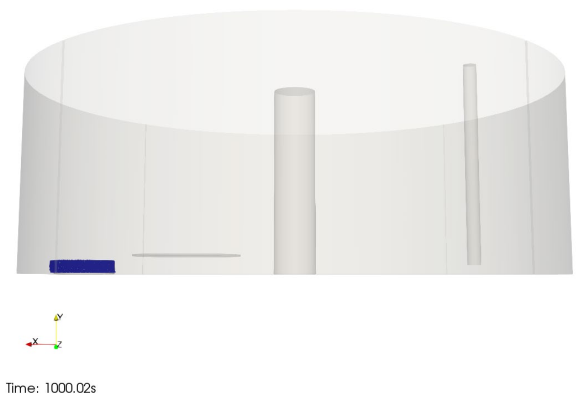
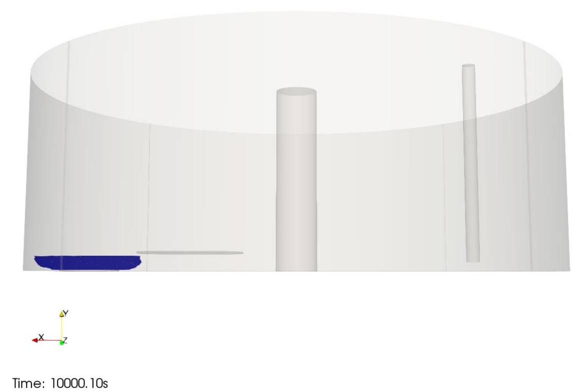
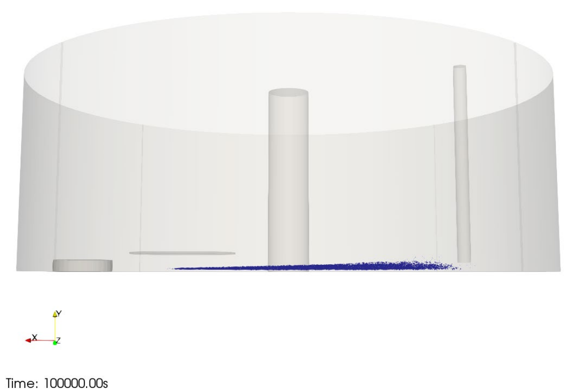
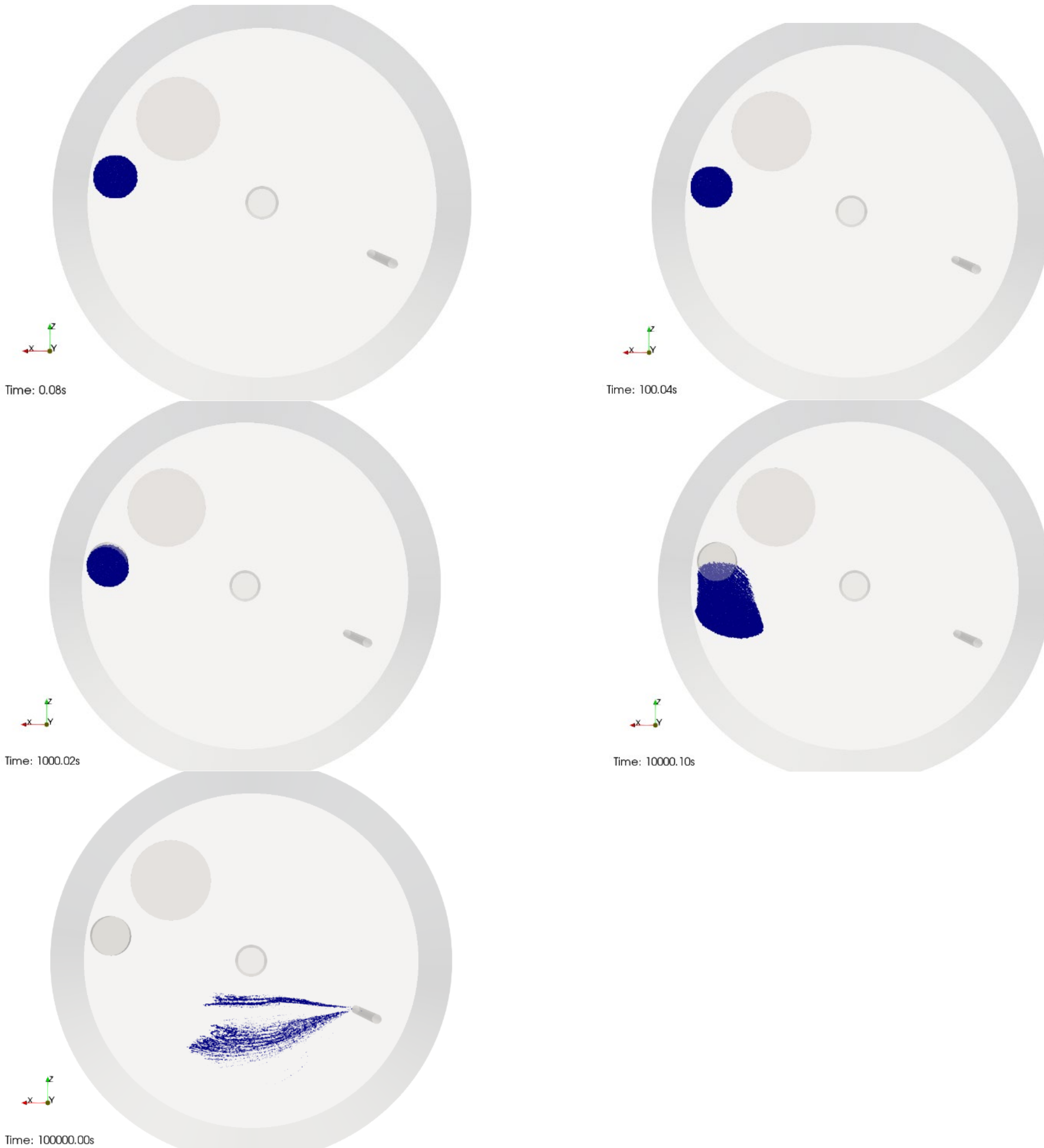
5.4 Transfer from Tank 49H to SWPF with a 40 Inch Liquid Level and Tracer Particles







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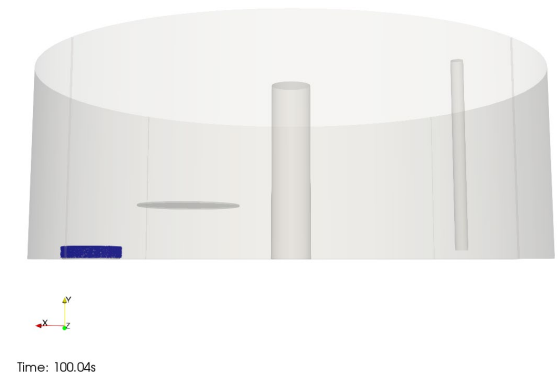
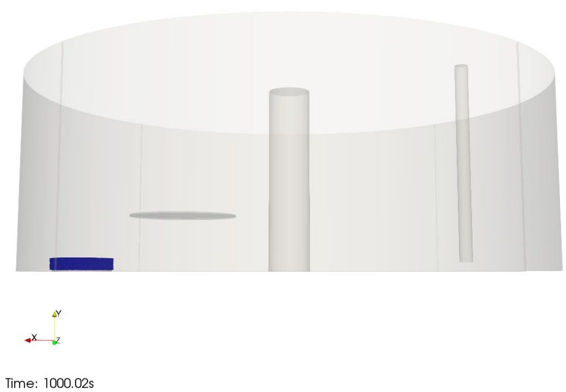
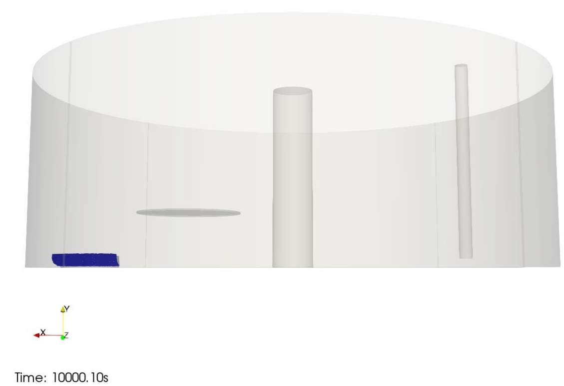
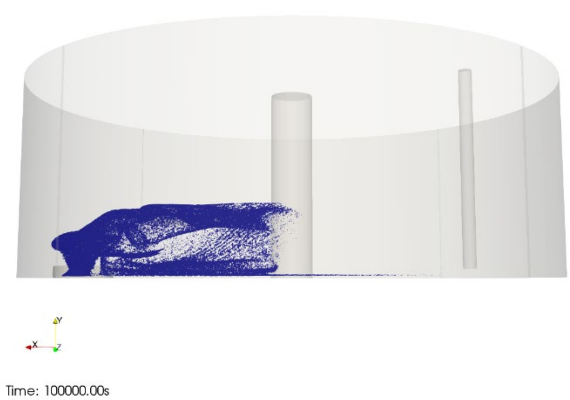
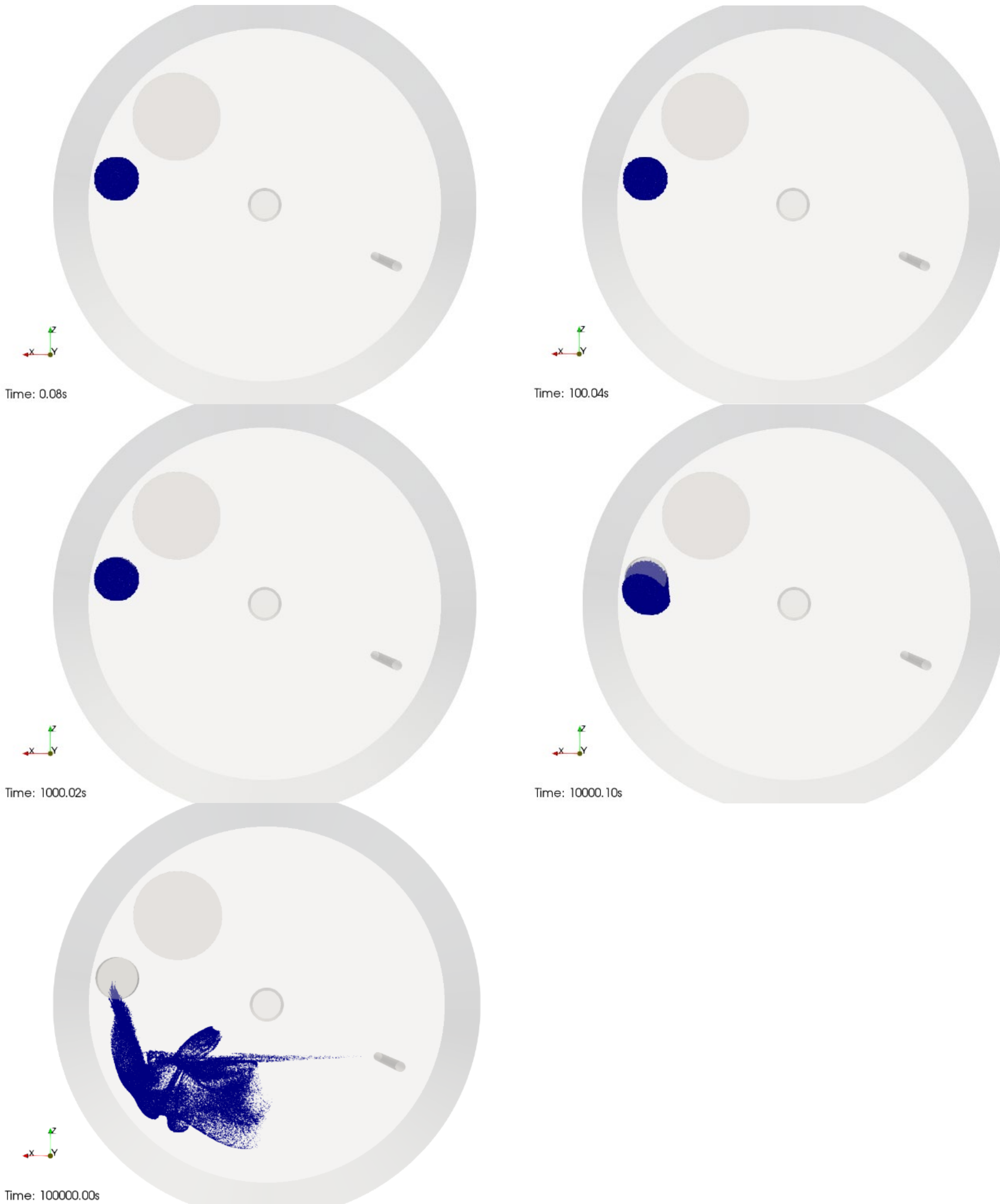
5.5 Transfer from Tank 49H to SWPF with a 120 Inch Liquid Level and Tracer Particles







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Time: 100000.00s

Distribution
cj.bannochie@srnl.doe.gov
alex.cozzi@srnl.doe.gov
a.fellinger@srnl.doe.gov
samuel.fink@srnl.doe.gov
Brenda.Garcia-Diaz@srnl.doe.gov
connie.herman@srnl.doe.gov
dennis.jackson@srnl.doe.gov
brady.lee@srnl.doe.gov
Joseph.Manna@srnl.doe.gov
daniel.mccabe@srnl.doe.gov
Gregg.Morgan@srnl.doe.gov
frank.pennebaker@srnl.doe.gov
Amy.Ramsey@srnl.doe.gov
William.Ramsey@SRNL.DOE.gov
eric.skidmore@srnl.doe.gov
michael.stone@srnl.doe.gov
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charles.nash@srnl.doe.gov
celia.aponte@srs.gov
timothy.baughman@srs.gov
Richard.Edwards@srs.gov
Azikiwe.hooker@srs.gov
lauryn.jamison@srs.gov
Ryan.McNew@srs.gov
phillip.norris@srs.gov
Christine.Ridgeway@srs.gov
Azadeh.Samadi-Dezfouli@srs.gov
Vijay.Jain@srs.gov
arthur.wiggins@srs.gov
john.occhipinti@SRS.Gov
bill.clark@srs.gov
jeffrey.crenshaw@srs.gov
james.folk@srs.gov
Curtis.Gardner@srs.gov
Pauline.hang@srs.gov
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tony.polk@srs.gov
Anthony.Robinson@srs.gov
mark-a.smith@srs.gov
patricia.suggs@srs.gov
thomas.temple@srs.gov