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Baseline Process Description for Simulating Plutonium Oxide Production for PreCalc Project

J. A. Pike

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EXECUTIVE SUMMARY

Savannah River National Laboratory (SRNL) started a multi-year project, the PreCalc Project, to develop a computational simulation of a plutonium oxide (PuO_2) production facility with the objective to study the fundamental relationships between morphological and physicochemical properties. This report provides a detailed baseline process description to be used by SRNL personnel and collaborators to facilitate the initial design and construction of the simulation. The PreCalc Project team selected the HB-Line Plutonium Finishing Facility as the basis for a nominal baseline process since the facility is operational and significant model validation data can be obtained. The process boundary as well as process and facility design details necessary for multi-scale, multi-physics models are provided.

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LIST OF ABBREVIATIONS

COTS	commercial off-the-shelf
FAFOF	Flush After Flush on the Fly
FOF	Flush on the Fly
SRNL	Savannah River National Laboratory
SRS	Savannah River Site

1.0 Introduction

Savannah River National Laboratory (SRNL) started a multi-year project, the PreCalc Project, to develop a computational simulation of a plutonium oxide (PuO_2) production facility with the objective to study the fundamental relationships between morphological and physicochemical properties. Laboratory-scale phenomena do not translate linearly because inhomogeneous temperature and pressure gradients dramatically complicate the macroscopic prediction of global kinetics. Multi-scale, multi-physics models will provide a basis for the prediction of specific properties. The approach will capture the atomistic features of non-equilibrium, dynamic phenomena at finite temperatures while maintaining relevance at the process scale. The PreCalc Project will develop a simulation system that will integrate multiple models at various time and length scales to provide a description of the crystallization and calcination dynamics of PuO_2 from a production facility.

2.0 Objective

This report provides a detailed baseline process description to be used by SRNL personnel and collaborators to facilitate the initial design and construction of the simulation. The PreCalc Project team selected the HB-Line Plutonium Finishing Facility as the basis for a nominal baseline process since the facility is operational and significant model validation data is available. The process boundary as well as nominal process and facility design details necessary for the simulation are provided. The simulation system will be constructed to allow user selection or input for all facility design and process parameters.

3.0 Background

The fundamental relationships between morphological and physicochemical properties from a plutonium oxide (PuO_2) production facility are understood only at an empirical level. Laboratory-scale phenomena do not translate linearly because inhomogeneous temperature and pressure gradients dramatically complicate the macroscopic prediction of global kinetics. Multi-scale, multi-physics models will provide a basis for the prediction of specific properties, but the approach must capture the atomistic features of non-equilibrium dynamic phenomena at finite temperatures while maintaining relevance at the process scale.

Computationally coupling different types of physical and chemical models is a significantly challenging aspect of a complete production model. These models will include not only physics and chemistry-based models but also discrete event models for simulating the start-and-stop aspects of process control, procedures, and human factors. The models will be built from commercial off-the-shelf (COTS) software or by adapting code from existing models. The initial version of the PreCalc software will focus upon 2 key process steps: precipitation and calcination. The PreCalc framework will be designed such that additional process steps can be added later. In the precipitation process step, micro- and meso-scale modeling protocols will be developed from COTS software and capture the kinetic rate constants of crystal growth. The resulting data will be coupled to macro-scale models capturing the effects of non-ideal mixing in industrial-scale process equipment. In calcination, micro-scale models will determine the mechanism for thermal decomposition of plutonium oxalate and macro-scale models will then describe the heat transfer equations.

4.0 Approach

The process flowsheet is developed using the Savannah River Site (SRS) HB-Line Plutonium Finishing Facility as a subject model. Design details necessary to establish a nominal process simulation are provided here as a nominal representation of a process flowsheet such that, once the simulation is fully developed, parameter specification in the model can be modified to suit a specific process facility and batch run. The PreCalc project team plans to use data from specific HB-Line facility batch runs to provide adequate validation data for the simulation.

Dynamic process simulation requires compositions, process/procedural steps, and macro scale unit operation design details, whereas fluid dynamic and thermal simulation of individual key process equipment requires dimensional design details in addition to thermodynamic and physical properties. The latter are determined from the composition and conditions from the process simulation. Thermodynamic and kinetic parameters will be determined from both literature data and atomistic scale models. Atomistic scale simulation primarily requires component composition and environmental factors. Process information and initial simulation conditions are provided such that the sub-models or separately developed simulation fragments share a common basis. As the project develops, this document will be revised to update or elaborate on process details if discovered to be insufficient.

5.0 Description of the Plutonium Oxide Production Process via Oxalate Precipitation

The following sections first describe the process from the highest level, i.e. flowsheet configurations, followed by intermediate level process descriptions of the chemistry and processes. The process description is followed by detailed descriptions of the hardware in order to provide adequate information necessary for simulating initial or default conditions. Appendix A provides a detailed process flowsheet diagram and material balance based on simplifying assumptions to provide initial simulation conditions.

5.1 Overall Flowsheet

Plutonium(IV) dissolved in nitric acid is mixed with oxalic acid in a precipitator to produce a plutonium(IV) oxalate precipitate. The precipitate solids are filtered from the slurry. Filtration is followed by calcination by heating in a furnace to at least 650°C for greater than 4.5 hours. The calcined solids, plutonium(IV) oxide, are then packaged in storage cans. Figure 5-1 shows the simplified flowsheet and the process boundary that will be simulated in the initial PreCalc simulation.

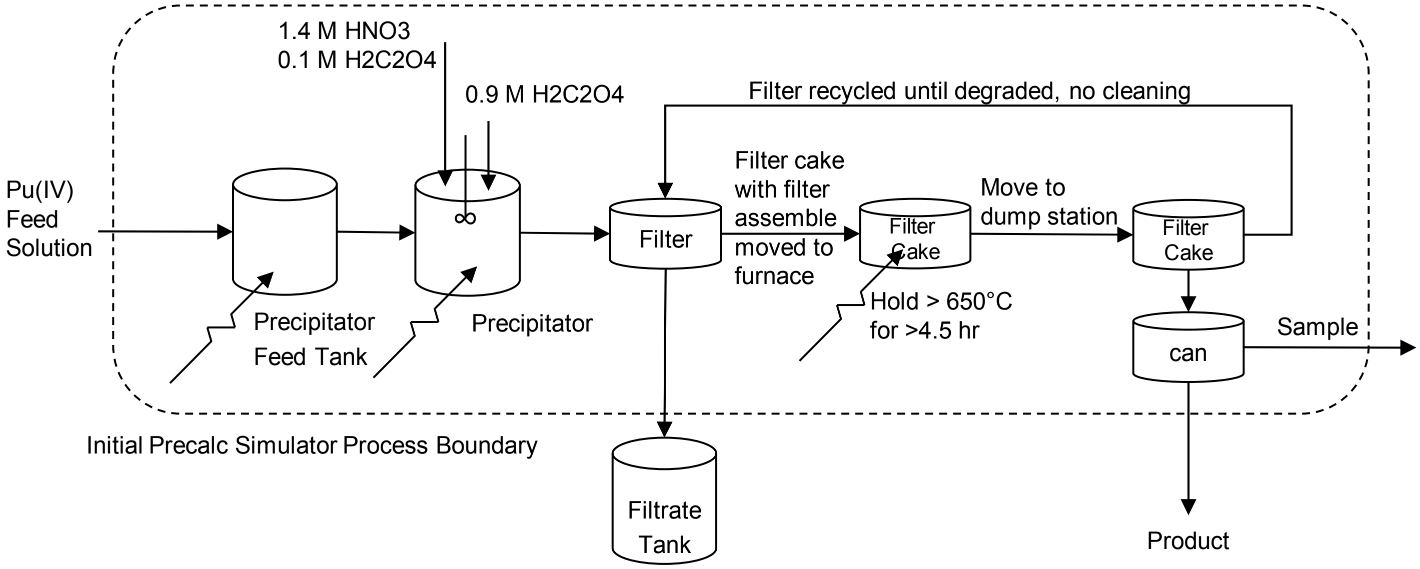


Figure 5-1: Simplified Process Flowsheet

5.1.1 Pu(IV) Feed Solution

The feed solution is prepared and received at the rate of 3 L/min into the Precipitator Feed Tank in 26 L batches at a concentration of 40 g/L plutonium as $Pu(NO_3)_4$ in 2.5 M nitric acid. Each batch contains nominally about 1 kg of plutonium as plutonium nitrate in 2.5 M nitric acid. Trace components are neglected for the initial simulation development.

5.1.2 Precipitator Feed Prep

Submersible electric heaters in the Precipitator Feed Tank will heat the solution to 56°C prior to transfer to the precipitator. Heating the tank to the high end of the operating temperature range of the precipitator minimizes the energy needed to maintain the precipitator at operating conditions after addition of the relatively cool oxalic acid.

5.1.3 Oxalate Precipitation

The simulation will allow selection of oxalate precipitation methods such as direct-strike and reverse-strike methods to convert plutonium nitrate solutions to a plutonium oxalate solid using aqueous oxalic acid. The term "direct-strike" describes precipitation by adding oxalic acid into plutonium nitrate solution. Reverse-strike method adds plutonium nitrate solution into oxalic acid. The baseline method will be the direct-strike precipitation method.

The plutonium(IV) oxalate precipitation equation is written as:

$$Pu(NO_3)_4 + 2H_2C_2O_4 + 6H_2O \rightarrow Pu(C_2O_4)_2 \cdot 6H_2O \downarrow + 4HNO_3$$

Precipitation performance is highly sensitive to processing conditions and equipment. The important process parameters provided in this flowsheet are precipitation temperature, agitator speed, reaction time, nitric acid concentration of the feed, plutonium concentration of the feed, oxalic acid concentration, and oxalic acid feed rate.

The plutonium nitrate solution is transferred by gravity via a bottom outlet in the feed tank to the precipitator at a rate of about 1 L/min. In this case, the residual heel is assumed to be zero. The Pu solution in the precipitator is maintained at 50 ± 5 °C. The baseline agitator speed is 650 rpm.

5.1.3.1 Oxalic Acid Addition

Excess volume of 0.9 M oxalic acid to achieve a final 0.1 M oxalic acid concentration is fed at a rate such that the addition time is nominally 30 min. For baseline conditions, this amounts to 14.4 L @ 0.48 L/min. The digestion hold time is 10 minutes after completion of the oxalic acid addition.

5.1.4 Precipitate Slurry Filtration, Precipitator Flush, and Filter Cake Wash

Slurry is transferred from the precipitator to the filter via vacuum transfer. The outlet suction tube extends to the bottom of the low point in the precipitator, which minimizes the residual heel. The vacuum is created in the filtrate tank, thus, creating a pressure differential from the precipitator, through the filter station, to the filtrate tank. A vacuum of at least 18 in. of Hg is created prior to starting the transfer. Once the transfer begins, the slurry will pass through a filter boat with a 10-micron stainless steel filter to catch the plutonium oxalate solids. The filtrate supernatant passes through to the Filtrate Tank. The vacuum transfer rate of the plutonium oxalate slurry is about 1 L/min. The material balance provided in Appendix A is based on the assumption of 2.0 L residual heel in the Precipitator Tank.

To minimize residual solids in the heel, two precipitator flush steps occur simultaneously and continuously with the filtration transfer, a "Flush on the Fly" (FOF) and "Flush After Flush on the Fly" (FAFOF). The simulation may also include an optional sequential batch flush after the slurry transfer is complete. Flush methods should be user selectable to allow simulation of several variations.

The slurry transfer and flush occur as follows:

Initiate slurry transfer to filter at 1 L/min.

After 19 L of slurry transfers, start FOF, i.e. add 16 L of flush solution @ 9 L/min simultaneously with continuing the slurry transfer.

Continue slurry transfer after FOF addition.

After 33 L of slurry has transferred from the initiation of the FOF addition, start FAFOF, i.e., add 6 L of flush solution @ 1 L/min simultaneously with continuing the slurry transfer.

Continue slurry transfer after FAFOF addition until vacuum suction sucks air rather than slurry.

Continue sucking air through the filter cake to “air dry” the filter cake.

Flush solution consists of 2.0 M nitric acid and 0.1 M oxalic acid.

Some plutonium will pass through the filter to the filtrate hold tank in the form of soluble plutonium oxalate and solid fines. The simulation will model the thermodynamic equilibrium of soluble species, thus, accounting for the effect of the soluble portion passing through the filter. Solid particle generation and growth will also be simulated and potentially provide a reasonable estimate of the particle size distribution and propensity to pass the filter. The material balance in Appendix A uses simplifying assumptions of complete conversion of plutonium nitrate to plutonium oxalate and 100% retention in the filter cake.

In addition, the material balance assumes a simple additive slurry dilution from the successive flushes with continuous perfect mixing. The simulation will capture more realistic hydro-dynamic conditions during the flushing operation.

The bulk density of the plutonium oxalate solids is assumed to contain 460 g of Pu/L based on test data (Crowder, et. al., June 2012, p. 9); whereas, the crystalline density has a placeholder value of 5 kg/L.

The material balance in Appendix A assumes that the filter cake retains 40 volume% liquid at the end of filtering and 20% after air drying. The composition of the retained liquid matches the composition of the last liquid passed through the filter cake. The simulation should include a user adjustable parameter for liquid retention. Models for porous flow and retention in the filter cake may be added to the simulation later.

5.1.4.1 Cake Wash (optional step)

The PreCalc simulator should include a user selectable cake wash using variable volume of flush solution.

5.1.5 Precipitate Calcination

The filter cake of Pu oxalate that collects on the filter boat will be air dried for a minimum of 60 min by pulling air through the filter cake. Afterwards, the filter boat will be moved into a bottom-loaded furnace and heated to a target cake temperature of greater than 650°C (nominal average) for at least 4 ½ hours. Once the target calcination temperature is achieved, calcination will run continuously for at least four hours. Air flows into the furnace chamber from channels under the filter boat and around the filter boat. The air is heated as it flows between the filter boat and the furnace wall. Air is pulled down through the filter and out the ventilation at the nominal rate of 1 scfm.

The material balance in Appendix A assumes no Pu losses during calcination and complete conversion of all the plutonium oxalate to plutonium oxide according to the following reaction:

$$Pu(C_2O_4)_2 \cdot 6H_2O \rightarrow PuO_2 + 2CO\uparrow + 2CO_2\uparrow + 6H_2O$$

The simulation will include the heat transfer and dynamics of the calcination reactions.

Once calcination is complete, the furnace and product oxide will be allowed to cool. The furnace may be maintained at elevated temperatures to minimize moisture adsorption after calcination until ready to package, sample, and seal the product. During cooling, the airflow will be discontinued to help minimize moisture adsorption. Moisture adsorption during cooling is expected to be minimal and is assumed to be 0.34 mass% in the material balance (Crowder and Pierce, August 2012, p. A-4).

The product bulk density is assumed to be 1550 g plutonium/L based on test data (Crowder, et. al., June 2012, p. 22). The plutonium density is equivalent to a solid precipitate bulk density of 3980 g $Pu(C_2O_4)_2 \cdot 6H_2O$/L, ignoring the slight effect of retained moisture.

5.1.6 Product Packaging and Sample

After cooling to less the 100° C, the product is dumped into a storage can where a sample of the solids is taken by core sampling the solids. For the baseline simulation, the dumping action is assumed to perfectly mix the particles in the product. The material balance assumes a small ~6-gram sample, but this should be a user selected variable. Although trivial for the process simulation, the sample is the actual point of measurement and should be reflected in the mass balance.

5.2 Equipment Descriptions

The following sections describe baseline design parameters to be used for modeling the key process equipment. Primarily, the information provided includes data on nominal internal tank dimensions, heating or cooling details, inlets, outlets, and any detail necessary to complete a simulation. Where necessary, assume all materials of construction are 304L stainless steel with the ability to modify any material parameters.

5.2.1 Precipitator Feed Tank

The Feed Tank is a 77 L slab tank, 3 1/4" between tank walls. The entire perimeter of the tank ends and bottom are rounded such that there are no square corners. The tank is heated by tubular submersible heaters. Each heater has three 0.490" diameter tubular heater elements that are arranged at three elevations in U-shaped loops. Each element activates when it is completely submerged as follows:

Element	Power (watts)	Surface Area (in^2)	Bottom Elevation (inches)	Activation Elevation (inches)
1	400	17.3	2	13 ¼
2	800	20.0	3	16
3	1400	40.0	4	29

Note: Elevation is from tank bottom.

The tank outlet drains by gravity from the low point. Figure 5-2 shows interior dimensions, inlet and outlet locations, and other details for a baseline simulation case.

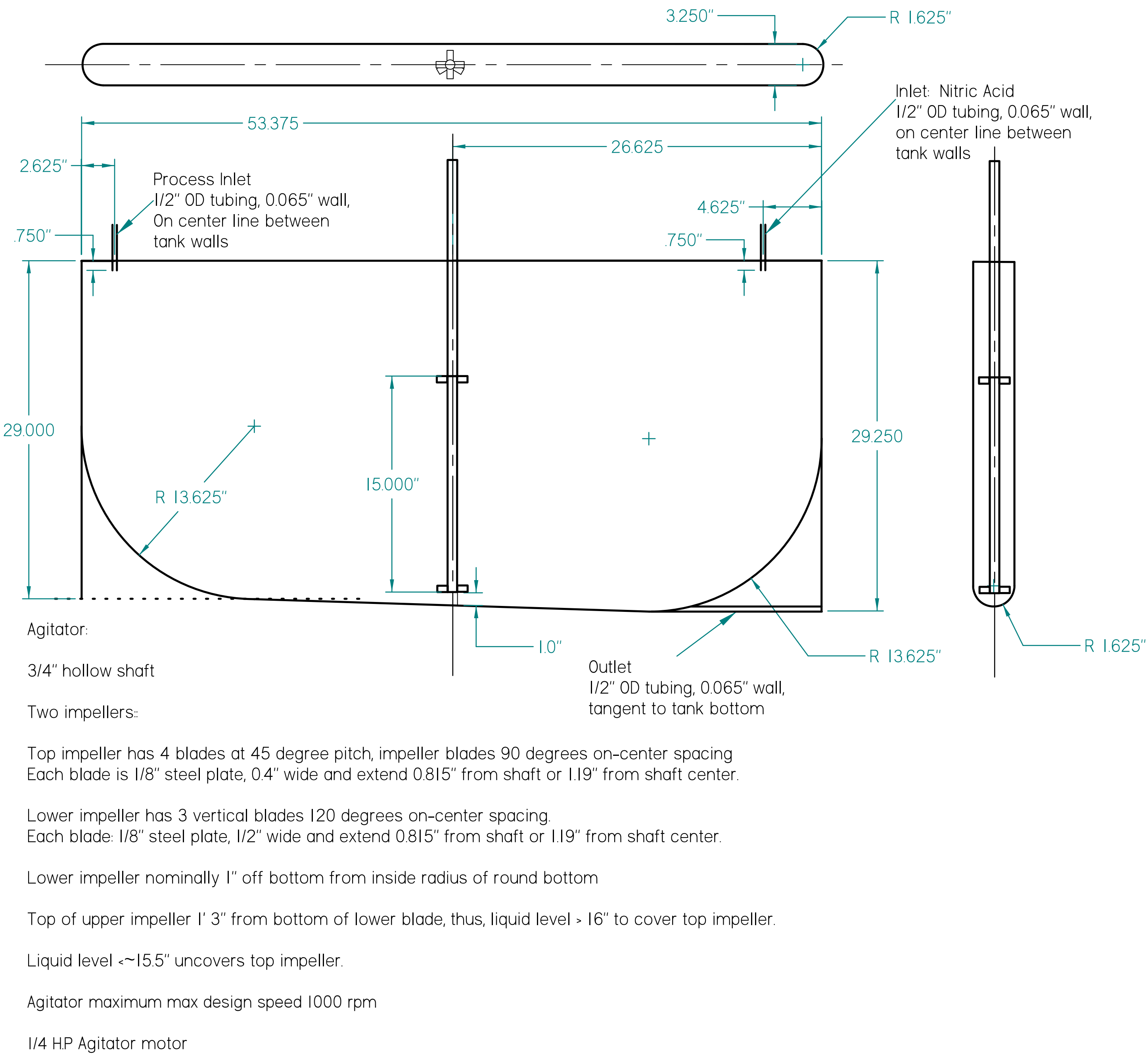
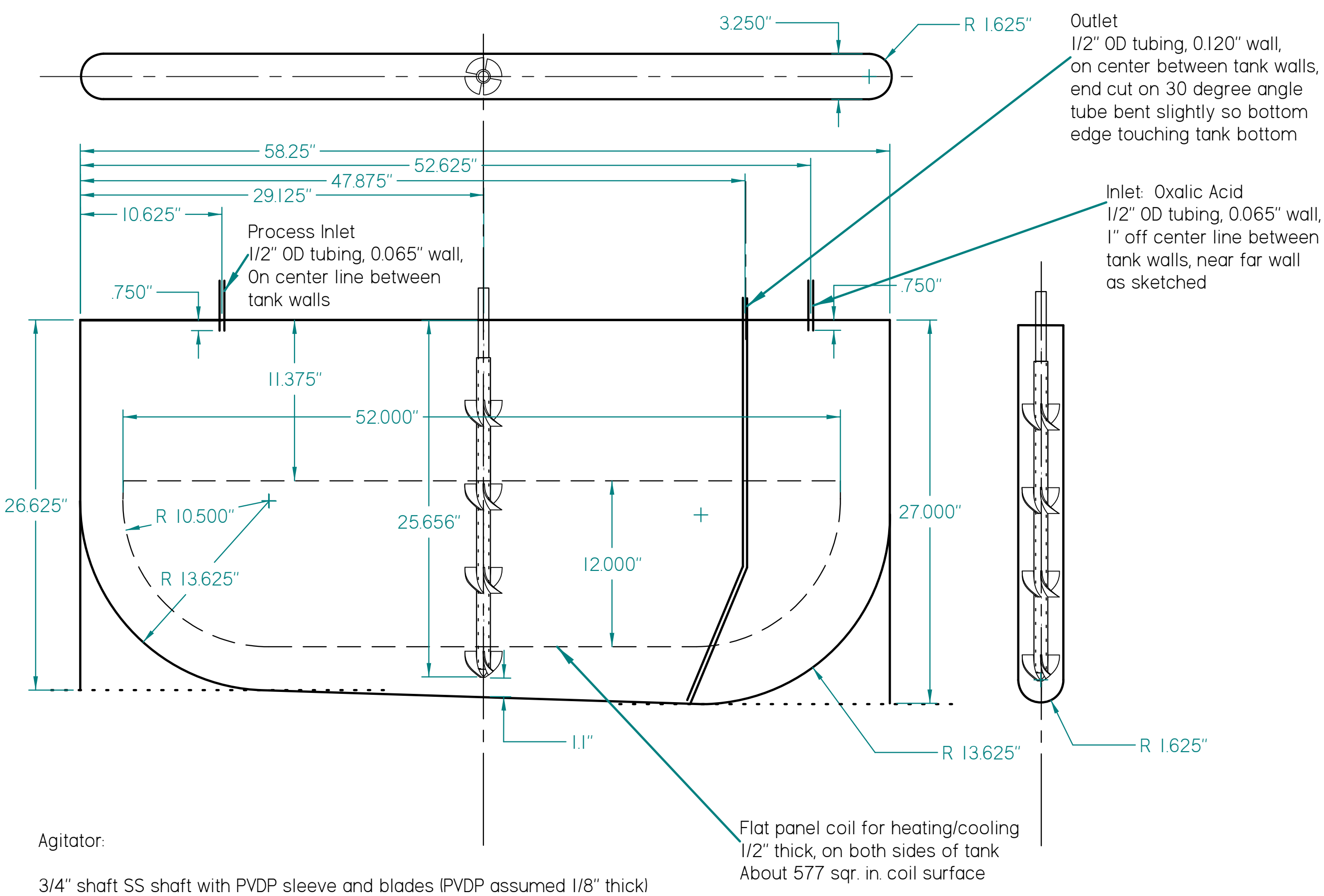


Figure 5-2: Feed Tank Diagram

Note: All dimensions relative to interior surfaces.

5.2.2 Precipitator

The precipitator is a 77 L slab tank, 3 1/4” between tank walls. The entire perimeter of the tank ends and bottom are rounded such that there are no square corners. Flat panel coils on each side of the tank provide heating and cooling. Figure 5-3 shows interior dimensions, inlet and outlet locations, and other details for a baseline simulation case.



Agitator:

3/4” shaft SS shaft with PVDP sleeve and blades (PVDP assumed 1/8” thick)

4 identical impellers with 4 blades each
Blades are helical on 45 degree pitch and 90 degree on-center radial spacing
6” separation between Impellers.
Each impeller blade of top is in line with blades at the bottom location
Each blade: 1/8” plate, 1 7/8” long and extend 13/16” from shaft or 1.31” from shaft center.

Lower impeller nominally 1” off bottom from inside radius of round bottom
blades are cut to 1 1/4” radious

Liquid level <~19” is below top impeller.

Agitator maximum max design speed 700 rpm

1/2 H.P. Agitator motor: 1750 R.P.M. 240V 3 phase motor on VFD

Figure 5-3: Precipitator Tank Diagram

Note: All dimensions relative to interior surfaces.

5.2.3 Filter

The baseline simulation will need enough detail to simulate heat transfer to the filter cake during the calcination process. Figure 5-4 shows the shape of the upper portion of the filter boat in position in the furnace. The 1 ½” thick base plate with filter media is not shown in Figure 5-4 for clarity.

5.2.4 Furnace

The calcination furnace is bottom-loading and dome shaped with 10 kw heaters. The filter boat is lifted into the furnace by a lifting device that includes an insulated furnace bottom plate. The filter cake temperature is raised to 650°C for about 4 ½ hours. During heating, air enters the furnace through vents in the furnace closure plate and flows up between the filter boat and furnace wall. The air will heat up as it reaches the top edge of the filter boat where it changes direction, flows down into the filter cake, and exits through the filter to the furnace exhaust ventilation. Figure 5-4 shows the general arrangement of the filter boat in the furnace. The filter boat base is not shown.

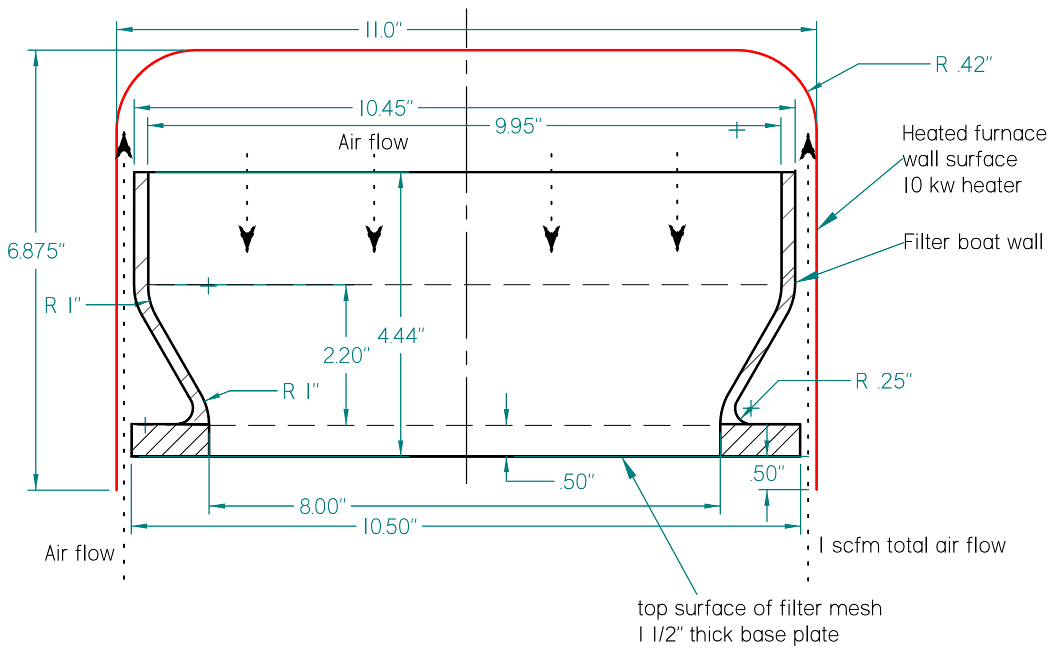


Figure 5-4: Diagram of the Filter Boat Arrangement in the Furnace

Note: All dimensions relative to interior surfaces.

One may note that the plutonium oxalate calcination reaction releases 4 moles of gas and 6 moles of water for every mole of plutonium in the filter cake. At the baseline flowsheet quantities, this amounts to nearly 70 scf of generated gas and vapor. The time to heat the filter cake from ambient to 650°C is estimated to take about 80 minutes. With the additional vapor load from the retained solution whetting the filter cake, the gas and vapor generation rate may be greater than the 1 scfm of the furnace ventilation. If this occurs, generated gas and vapor could flow out the bottom furnace chamber vents. The simulation will need to allow for adjustment of the ventilation rate and/or initial heat up rate in order to simulate the effect of the ventilation system capacity.

5.2.5 Filtrate Tank

For the baseline simulation, the filtrate tank will be modeled as an accumulator in order to complete the material balance. As such, no additional design details are needed.

6.0 References

Crowder, M. L., and Pierce, R. A., "Lab-Scale Demonstration of Plutonium Purification by Anion Exchange, Plutonium(IV) Oxalate Precipitation, and Calcination to Plutonium Oxide to Support the MOX Feed Mission", SRNL-STI-2012-00422, Rev. 0, Savannah River Site, August 2012.

Crowder, M. L.; Pierce, R. A.; Scogin, J. H.; Daniel, W. E.; and King, W. D.; "Small-Scale Testing of Plutonium(IV) Oxalate Precipitation and Calcination to Plutonium Oxide to Support the MOX Feed Mission", SRNL-STI-2012-00338, Rev. 0, Savannah River Site, June 2012.

Appendix A: Detailed Plutonium Oxide Production via Oxalate Precipitation Process Flowsheet

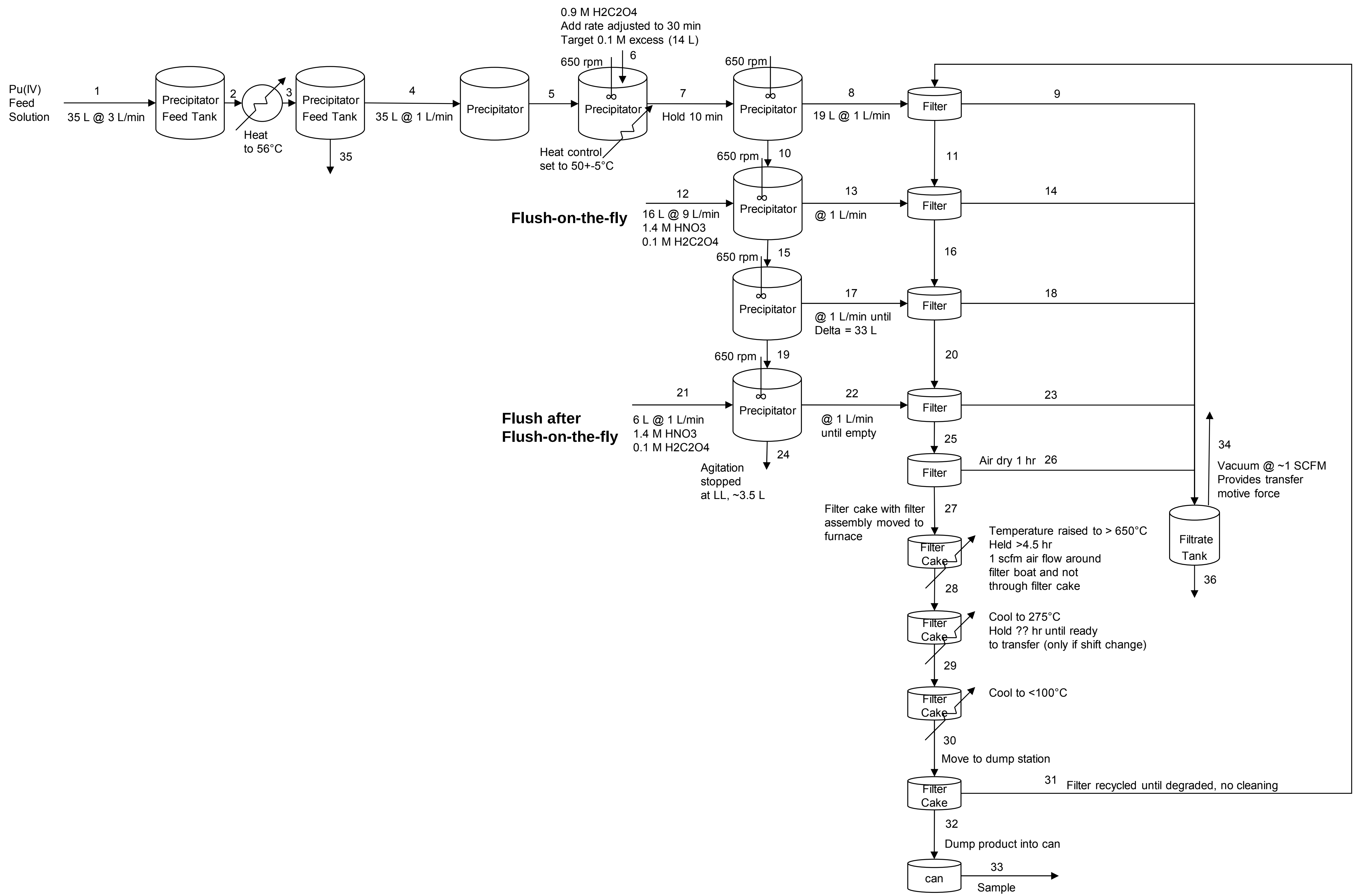


Table A-1: Flowsheet Material Balance

	Stream Number		1	2	3	4	35	5	6	7	8	9	10	11	12	13	14	15	16a	16	17
		Units	Pu(IV) Feed Solution	Feed Tank	Heat solution	Transfer to Precipitator	Feed Tank Heel	Heat Precipitator	Oxalic acid solution	Precipitation Complete	Slurry to Filter	Filtrate	Precipitator Heel	Filter Cake	Flush-on-the-Fly (FOF)	Slurry to Filter	Filtrate	Precipitator Heel	to Filter Cake	Filter Cake	Slurry to Filter
Stream Parameters	Temperature	C	25	25	56	55	55	50	50	50	50	50	50			50	50	50			50
	Total Volume	L	26.0	26.0	26.0	26.0	0.0	28.0	14.4	42.4	19.0	18.3	23.4	1.03	16.0	1.8	1.7	37.6	0.10	1.12	33.0
	Total Mass	Kg																			
	Liquid Volume	L						27.99		41.8	18.8	18.3	23.1	0.41	16	1.8	1.7	37.3	0.04	0.45	32.8
	Liquid Mass	Kg																			
	Bulk Solids Volume	L												1.03					0.10	1.12	
	Solids Mass	Kg						0.0318		2.70	1.21	0.00	1.49	1.21		0.11	0.00	1.38	0.11	1.32	1.21
Mass Transfer	Transfer Device		pump			gravity			pump		vaccum transfer				pump	vaccum transfer					vaccum transfer
	Transfer Rate	L/min	3.0			1.0			0.48		1.0				9.0	1.0					1.0
	Transfer/Hold Time	min	8.7			26			30	10	19				1.8	1.8					33
	Transfer/Hold Time	hr	0.14			0.43			0.50	0.17	0.32				0.03	0.03					0.55
Heat Transfer	Heater/Cooler type				Submersible Electric			Hot/Cold Water flat panel coil on side wall	Hot/Cold Water flat panel coil on side wall	Hot/Cold Water flat panel coil on side wall			Hot/Cold Water flat panel coil on side wall		Hot/Cold Water flat panel coil on side wall	Hot/Cold Water flat panel coil on side wall		Hot/Cold Water flat panel coil on side wall			Hot/Cold Water flat panel coil on side wall
	Water Temperature	C						TBD	TBD	TBD			TBD		TBD	TBD		TBD			TBD
	Max. flow	L/min						TBD	TBD	TBD			TBD		TBD	TBD		TBD			TBD
	Heat Transfer Area	in^2			>13 ¼": 17.3 >16": 37.3 >29": 77.3			577	577	577			577		577	577		577			577
	Electric Heat	Watts			>13 ¼": 400 >16": 1200 >29": 2600																
Composition	HNO3	M	2.50	2.50	2.50	2.50	2.50	2.46		2.04	2.04	2.04	2.04	2.04	2.00	2.04	2.04	2.02	2.04	2.04	2.02
	Total NO3	M	3.17	3.17	3.17	3.17	3.17	3.09		2.04	2.04	2.04	2.04	2.04		2.04	2.04	2.02	2.04	2.04	2.02
	H2C2O4	M							0.90	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Pu as Pu(NO3)4	g/L	40	40	40	40	40	37.1		0.0											
	Pu	M	0.167	0.167	0.167	0.167	0.167	0.155		0.000											
	Total Pu as Pu(NO3)4	Kg	1.04	1.04	1.04	1.04	0	1.04		0.0											
	Pu as Pu(C2O4)2·6H2O	g/L						4.42E-01		24.8	24.8	0.0	24.8	460		24.8	0.0	14.3	460	460	14.3
	Pu	M						1.85E-03		0.104	0.104	0.00	0.104	1.925		0.104	0.000	0.060	1.92	1.92	0.060
	Total Pu as Pu(C2O4)2·6H2O	Kg						1.24E-02		1.05	0.47	0.00	0.58	0.47		0.04	0.00	0.54	0.04	0.52	0.47
	Pu as PuO2	g/L																			
	Pu	M																			
	Total Pu as PuO2	Kg																			
	Total Pu	M	0.167	0.167	0.167	0.167	0.167	0.157		0.104	0.104	0.000	0.104	1.92		0.104	0.000	0.060	1.92	1.92	0.060
Properties	Heat Capacity	cal/(L*C)																			
	Solids Density	Kg/L						5		5	5	5	5	5		5	5	5	5	5	5
	Solids Bulk Density	Kg/L												1.18					1.18	1.18	
	Liquid Density	Kg/L																			

Note that shaded table entries are placeholder values.

Table A-1: Flowsheet Material Balance Continued

Stream Number			18	19	20a	20	21	22	23	24	25a	25	26	27	28	29	30	31	32	33	34	34
		Units	Filtrate	Precipitator Heel	to Filter Cake	Filter Cake	Flush after Flush-on-the-Fly (FAFOF)	Slurry to Filter	Filtrate	Precipitator Heel	to Filter Cake	Filter Cake	Air dry	Filter cake moved to furnace	Raise temperature	lower temperature	lower temperature	Move cake to Dump Station	Dump cake into can	Sample solids in can	Filtrate Tank Vent	Filtrate Tank Total
Stream Parameters	Temperature	C	50	50					50	50					> 650	275	< 100	< 100	< 100	< 100		
	Total Volume	L	31.7	4.60	1.02	2.15	6.0	8.6	8.5	2.0	0.05	2.26	2.26	2.26	0.30	0.30	0.30	0.30	0.30	0.0015		60.8
	Total Mass	Kg																				
	Liquid Volume	L	31.7	4.57	0.41	0.86	6	8.6	8.5	1.99	0.05	0.90	0.45	0.45	0.0040	0.0040	0.0040	0.0040	0.0040	2.0E-05		60.8
	Liquid Mass	Kg													0.0040	0.0040	0.0040	0.0040	0.0040	2.0E-05		
	Bulk Solids Volume	L			1.02	2.15					0.12	2.26	2.26	2.26	0.30	0.30	0.30	0.30	0.30	0.0015		0
	Solids Mass	Kg	0.00	0.17	1.21	2.53		0.14	0.00	0.032	0.14	2.67	2.67	2.67	1.18	1.18	1.18	1.18	1.18	0.0060		0
Mass Transfer	Transfer Device						pump	vaccum transfer														
	Transfer Rate	L/min					1.0	1.0					1 scfm		1 scfm air	1 scfm air	1 scfm air				1 scfm air	
	Transfer/Hold Time	min					6.0	8.6					60									
	Transfer/Hold Time	hr					0.10	0.14					1.00		> 4.5	TBD	TBD	TBD	TBD	TBD		
Heat Transfer	Heater/Cooler type		Hot/Cold Water flat panel coil on side wall	Hot/Cold Water flat panel coil on side wall			Hot/Cold Water flat panel coil on side wall	Hot/Cold Water flat panel coil on side wall							Electric							
	Water Temperature	C	TBD	TBD			TBD	TBD														
	Max. flow	L/min	TBD	TBD			TBD	TBD														
	Heat Transfer Area	in^2	577	577			577	577														
	Electric Heat	Watts													10,000							
Composition	HNO3	M	2.02	2.02	2.02	2.02	2.00	2.01	2.01	2.01	2.01	2.01	2.01	2.01								2.03
	Total NO3	M	2.02	2.02	2.02	2.02		2.01	2.01	2.01	2.01	2.01	2.01	2.01								2.03
	H2C2O4	M	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10								0.10
	Pu as Pu(NO3)4	g/L																				
	Pu	M																				
	Total Pu as Pu(NO3)4	Kg																				
	Pu as Pu(C2O4)2·6H2O	g/L	0.0	14.3	460	460		6.2	0.0	6.2	460	460	460	460	0.0							
	Pu	M	0.000	0.060	1.92	1.92		0.026	0.00	0.026	1.92	1.92	1.92	1.92	0.000							
	Total Pu as Pu(C2O4)2·6H2O	Kg	0.00	0.066	0.47	0.99		0.053	0.00	0.012	0.053	1.04	1.04	1.04	0.000							
	Pu as PuO2	g/L													1550	1550	1550	1550	1550	1550		
	Pu	M													6.49	6.49	6.49	6.49	6.49	6.49		
	Total Pu as PuO2	Kg													1.04	1.04	1.04	1.04	1.04	0.0053		
	Total Pu	M	0.000	0.060	1.92	1.92		0.026	0.00	0.026	1.92	1.92	1.92	1.92	6.49	6.49	6.49	6.49	6.49	6.49		
Properties	Heat Capacity	cal/(L*C)																				
	Solids Density	Kg/L	5	5	5	5		5	5	5	5	5	5	5	11.46	11.46	11.46	11.46	11.46	11.46		
	Solids Bulk Density	Kg/L			1.18	1.18					1.18	1.18	1.18	1.18	3.98	3.98	3.98	3.98	3.98	3.98		0
	Liquid Density	Kg/L																				

Distribution:

L. E. Roy, 773-41A
C. J. South, 773-41A
S. Y. Lee, 773-41A
A. T. Masterson, 704-2H
S. L. Garrison, 704-2H
T. B. Brown, 773-A
L. T. Reid, 773-A
D. A. Crowley,773-42A