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Project Title/Work Order Preliminary Flowsheet for Plasma Arc Calcination of Selected Hanford Tank Waste, Revision 1		EDT No. ECN No. 608657

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12. Description of Change Document revised to include recent plasma arc calcination testing results and process improvements.		
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FSAR/SAR	<input type="checkbox"/>	IEFD Drawing	<input type="checkbox"/>	Process Control Manual/Plan	<input type="checkbox"/>
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Environmental Report	<input type="checkbox"/>	Inspection Plan	<input type="checkbox"/>		<input type="checkbox"/>
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Cog. Mgr.	J. A. Hunter <i>[Signature]</i>	<u>9/19/94</u>		QA	_____
QA				Safety	_____
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Document Number: WHC-SD-WM-TI-577, Rev.1

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7. Abstract

This preliminary flowsheet document was developed for the Initial Pretreatment Module (IPM). This flowsheet documents the calcination technology that can be used to accomplish the destruction of organics, ferrocyanide, and nitrate/nitrite salts in addition to solubilizing aluminum compounds in selected waste tanks at the Hanford Site. The flow sheet conditions are 76 L/min diluted waste feed rate at 800°C, atmospheric pressure, and 100 millisecond residence time in the calciner. Preliminary flow diagrams, material balances, and energy requirements are presented.

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**PRELIMINARY FLOWSHEET FOR PLASMA ARC CALCINATION
OF SELECTED HANFORD SITE TANK WASTES**

D. W. Hendrickson

September 1994

Westinghouse Hanford Company
Richland, Washington

WHC-SD-WM-TI-577, Rev. 1

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PRELIMINARY FLOWSHEET FOR PLASMA ARC CALCINATION
OF SELECTED HANFORD SITE TANK WASTES

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PRELIMINARY FLOWSHEET FOR PLASMA ARC CALCINATION
OF SELECTED HANFORD SITE TANK WASTES

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to provide a preliminary flowsheet that uses a plasma arc heat source to calcine retrieved Hanford Site tank wastes. Thermal treatment (calcination) is used to destroy the organic molecules contained in the waste, to destroy nitrite and nitrate compounds, to destroy ferrocyanide, and to form soluble aluminum and chromium compounds. The formation of soluble aluminum and chromium among other reactions in this thermal process is termed 'thermal reconstitution.' The flowsheet may serve as a basis for comparing different technologies under consideration and for information for conceptual design of the Initial Pretreatment Module (IPM). This document completes Westinghouse Hanford Company fiscal year (FY) 1994 Work Breakdown Structure 1.1.2.3.2.1.2 milestone entitled "Issue Revision 1 of a Preliminary Flowsheet for Calcine/Dissolution of Tank Waste."

1.2 BACKGROUND

The Tank Waste Remediation System (TWRS) Process Technology has been evaluating organic destruction technologies that may be incorporated into the IPM to treat the radioactive Hanford Site tank waste and resolve tank safety issues. Since the initiation of this work, the issues of organic destruction and ferrocyanide destruction have ceased to be driving forces in tank safety resolution. Calcination of the waste has been one of the technologies being evaluated to accomplish the destruction of organics, ferrocyanide, and nitrate/nitrite salts, and resolubilization of aluminum and chromium.

An extensive body of information related to radioactive waste calcination exists. This information was developed through hot and cold testing at the Hanford Site (Larson 1980), other DOE sites, other U.S. sites, and in full-scale operations in other countries. However, most of these tests used an acidic, low sodium feed stream and were designed to produce a product suitable for vitrification. Some of this work has been summarized in Appendix C.

This flowsheet is modeled to process complexant concentrate (CC) waste. Complexant concentrate waste contains a high concentration of organic complexants (e.g., ethylenediaminetetraacetate [EDTA], N-2-hydroxyethyl ethylenediaminetriacetate [HEDTA]; and pH buffering agents, such as citrate, glycolate) and the resulting organic degradation products. The EDTA and HEDTA are assumed to be largely degraded to oxalate and formate (Babad *et al.* 1993 and Campbell *et al.* 1994). Tank 241-SY-101 contains CC waste and is currently designated as the first tank for organic destruction, if required.

1.3 SCOPE

The flowsheet is preliminary due to the limited testing and process development of the chemistry and equipment for plasma arc calcination. Flowsheet assumptions are based on testing done in FY 1993 and FY 1994 at Westinghouse Science and Technology Center (WSTC) (Gass *et al.* 1993 and McLaughlin *et al.* 1994), laboratory testing at Westinghouse Hanford Company (WHC), and literature reviews, as referenced. The primary goal of calcination/dissolution for program development was organic destruction. In addition, decomposition of nitrate and nitrite compounds, and resolubilization of aluminum and chromium is desirable, and expected, at the process temperatures.

A plasma torch fired cupola test system has been used to calcine simulated tank 101-SY material (Gass *et al.* 1993 and McLaughlin *et al.* 1994). Operating parameters and product compositions from these experiments, where applicable, have been used for this flowsheet document. In addition to actual process data, information from industrial applications have been used to modify the flowsheet and provide equipment not currently represented by the test system at the WSTC. The proposed equipment design will reduce the amount of sodium, cesium, and other volatile components entering the offgas stream and provides an integral quench water bath to modify product handling (liquid slurry versus a molten 'slag').

Chemistry development of the calcination technology, by laboratory and literature studies, is currently underway. Results of additional laboratory testing, as well as material balance data collected from a system similar to the proposed flowsheet, may be incorporated in a revision of this flowsheet document.

2.0 PROCESS SUMMARY

The major process steps consist of feed receipt, feed concentration, waste calcination, product handling, and offgas treatment. As the core activities of this process are the calcination and dissolution steps, a summary material balance is provided with Figure 2-1 and Table 2-1. A summary of the process and material balance is shown in Figure 2-2. A more detailed flowsheet and associated material balance is described in Section 3.1, Process Description, while complete analyses are contained in the appendices.

The diluted and retrieved waste is received into one of two 190,000-L (50,000-gal) sample tanks, processed through the evaporator at 76 L/minute (20 gal/minute) to provide an evaporated feed of 15.1 L/minute (4 gal/minute) to the calciner. Based on preliminary tests at the Westinghouse Science and Technology Center (WSTC) (Colby *et al.* 1994 and McLaughlin *et al.* 1994) an operating temperature range of 750-850°C (1380-1560°F) for the plasma arc calciner operation is indicated. Further temperature optimization for processing is desirable and may be acquired with ongoing kinetics studies.

The flowsheet equipment assumes a 0.1-second residence time, 800°C (1470°F) and atmospheric pressures, to provide 99 percent organic decomposition, 91/86 percent nitrate/nitrite decomposition, 70 percent aluminum solubility as sodium aluminate, and 99 percent chromium solubility. Residence time considerations are described in Section 3.1, below. Decomposition percentages are based on preliminary tests at WSTC and information presented in Colby *et al.* (1994) and McLaughlin *et al.* (1994). The proposed equipment design may need to be evaluated further if a much higher (e.g. 98 percent) nitrate/nitrite destruction is required; however, ongoing kinetics evaluations indicate that destruction efficiencies exceeding 99% are achievable.

The high operating temperatures oxidize the waste resulting in the destruction of organics and oxidization of metals to produce a fluid molten salt which is primarily sodium hydroxide (NaOH). The oxidation produces the gaseous decomposition products which are primarily N₂, O₂, and water vapor, with small amounts of NO₂, NO, CO₂, and CO. The molten salt, carried by the gas stream, is redissolved in an integral water quench. Originally, the water-insoluble stream was expected to contain a majority of the transuranic (TRU) isotopes, the multivalent metal oxides and hydroxides, as well as the aluminates. Preliminary data from a literature review (Delegard *et al.* 1993) and laboratory analysis suggest the TRU compounds may become soluble under process conditions.

Additional chemistry development tasks are planned to determine actinide behavior in the dissolution step. The anticipated oxidation states and solubility of the neptunium, plutonium, and americium is discussed by Delegard *et al.* (1993). The actinides of neptunium, plutonium, and americium are expected to be oxidized to (V), or greater, oxidation states and form ternary oxides with sodium. In the oxidizing, aqueous quench solution, the oxidized actinides are expected to remain in the solution phase.

The offgas treatment system and particulate filtration system must be designed to assure that effluent releases meet all regulatory requirements. The offgas system will remove heat, condense water, absorb gases, remove particles, and reduce entrained radionuclide particles. Equipment for the offgas system consists of a liquid/vapor separator, venturi scrubber, NO_x reactor, condensers, heaters, two stages of high-efficiency particulate air (HEPA) filters, and stack. The offgas equipment is considered to be readily available and does not require significant equipment development.

Figure 2-1 Plasma Arc Calciner with Integral Quench

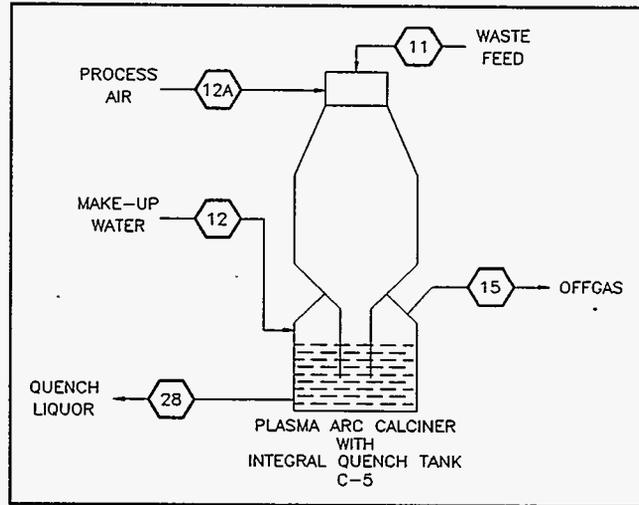
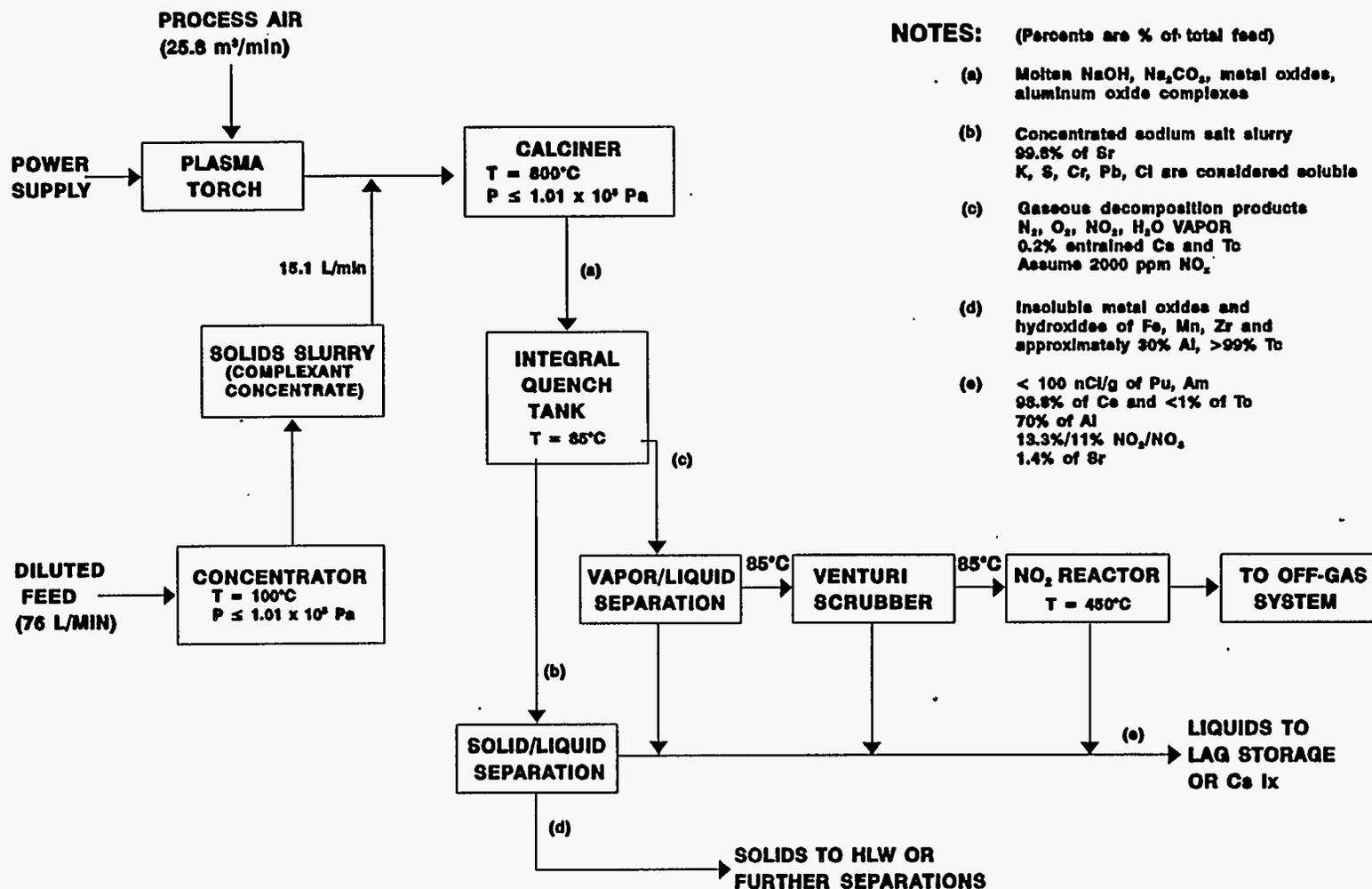


Table 2-1 Summary Material Balance of Plasma Arc Calciner with Integral Quench

LIQUID COMPONENTS					SOLID COMPONENTS				
STREAM NAME	11	12a	12	15	28	STREAM NAME	11	15	28
Total Flow (Kg/D)	3.80 E+04	4.46 E+04	6.55 E+04	1.01 E+05	4.60 E+04	Total Flow (Kg/D)	3.87 E+02	2.99 E+00	6.72 E+02
N ₂		3.42 E+04		3.56 E+04		Al ₂ O ₃	3.55 E+01		
O ₂		1.04 E+04		1.27 E+04		Na ₂ O	5.75 E+01		
Na ₂ O	5.69 E+03				5.69 E+03	SiO ₂	3.94 E+01		
CO ₂ -2	9.65 E+02				3.64 E+03	CH ₄	2.03 E+02		
NO ₂ -	1.05 E+03			9.75 E+01	4.39 E+01	Organic Carbon	3.04 E+01	1.35 E+03	3.03 E+01
NO ₂ -	5.28 E+03			3.26 E+02	1.47 E+02	Al ₂ O ₃		1.78 E+00	4.00 E+02
CH ₄	2.97 E+03				2.11 E+03	Cr ₂ O ₃		2.12 E+03	4.75 E+01
H ₂ O	1.92 E+04		6.55 E+04	5.18 E+04	3.34 E+04	Fe ₂ O ₃		2.33 E+01	5.24 E+01
						Na ₂ O		3.43 E+01	7.71 E+01
						SiO ₂		3.74 E+01	8.40 E+01
Cs-Ba 137 (Bq/D)	6.07 E+14				6.66 E+14	Cs-Ba 137 (Bq/D)	6.70 E+13	2.98 E+10	6.70 E+12
Sr-Y 90 (Bq/D)	1.69 E+14					Sr-Y 90 (Bq/D)	8.92 E+12	7.88 E+11	1.77 E+14
Tc 99 (Bq/D)	4.51 E+11					Tc 99 (Bq/D)	2.37 E+10	2.11 E+09	4.74 E+11
Pu (Bq/D)	1.75 E+11					Pu (Bq/D)	9.21 E+09	8.14 E+08	1.83 E+11
Am (Bq/D)	5.85 E+11					Am (Bq/D)	3.03 E+10	2.72 E+09	6.11 E+11

PROCESS SUMMARY OF PLASMA ARC CALCINATION



- NOTES:** (Percent are % of total feed)
- (a) Molten NaOH, Na₂CO₃, metal oxides, aluminum oxide complexes
 - (b) Concentrated sodium salt slurry
99.6% of Sr
K, S, Cr, Pb, Cl are considered soluble
 - (c) Gaseous decomposition products
N₂, O₂, NO₂, H₂O VAPOR
0.2% entrained Cs and Tc
Assume 2000 ppm NO_x
 - (d) Insoluble metal oxides and hydroxides of Fe, Mn, Zr and approximately 30% Al, >99% Tc
 - (e) < 100 nCi/g of Pu, Am
98.8% of Cs and <1% of Tc
70% of Al
13.3%/11% NO₂/NO
1.4% of Sr

Figure 2-2 Process Summary of Plasma Arc Calcination

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3.0 PROCESS DESIGN

The calcination process destroys the organics, complexants, and ferrocyanides contained in the feed. For this flowsheet, the organic decomposition results in a concentrated sodium salt solution containing the cesium, technetium, strontium, transuranics (americium, plutonium, neptunium, curium), and small amounts of insoluble oxides (Fe, Zr, Bi, Al, Lanthanides). Oxides and hydroxides expected to be mostly soluble in the quench solution following calcination are sodium, potassium, sulfur, chromium, lead, and chlorine. Aluminum is solubilized as sodium aluminate. The chemistry of the quench solution can be better defined upon completion of the chemistry development tasks, but preliminary quench solution chemistry was evaluated in WSTC tests (McLaughlin *et al.* 1994). The calciner offgas contains mostly nitrogen, oxygen, water vapor, small amounts of nitrogen oxides, and low levels of particles and volatile radioactive materials.

The following sections provide a description of the plasma arc calcination process.

3.1 PROCESS DESCRIPTION

The proposed process assumes a 99 percent organic destruction. The calcination test conducted at WSTC used 3,900 kg of tank 101-SY simulated waste to obtain greater than 99 percent thermal oxidation of the feed organics. A prior demonstration demonstrated 98 percent destruction (Gass *et al.* 1993).

The WSTC plasma arc calcination test results also provide estimates of the expected nitrate/nitrite destruction. A 91%/85% nitrate/nitrite destruction is assumed based on the 6.8 L/minute (1.8 gal/minute) WSTC plasma arc calcination of 3,900 kg of tank 101-SY simulated waste. However, the residence time for this destruction efficiency was relatively long because of the cupola nature of the WSTC calcination equipment. Ongoing work with plasma torch chemistry kinetics at the University of Idaho yields promise of extensive destruction and reconstitution in the range of 100 milliseconds, the basis for residence time for this flowsheet.

Thermal analyses of simulated and genuine high-level radioactive waste (HLW) show that decomposition of the nitrate/nitrite salts occurs slowly at 600-800°C (932-1,472°F) (Colby *et al.* 1994). For this process, roughly ten percent of the nitrate and nitrite does not decompose with half carried into the gas stream exiting the calcination equipment and half remaining in the product solution (i.e. quench).

3.2 THROUGHPUT CAPACITY AND FEED COMPOSITION

The processing rate for the organic destruction process is 76 L/minute (20 gal/minute) as defined by the previous IPM functions and operating requirements (WHC 1993). This rate reflects the dilution of tank waste during retrieval activities of 3 parts water to 1 part tank waste. This throughput rate allows processing of all of the waste in tank 101-SY in one year at a 50 percent operating efficiency, assuming 24 hours per day, 7 days per week operation. The annual plant capacity is about $2.0 \times 10^4 \text{ m}^3$ (5.3 million gallons) of feed. More recent preliminary evaluations yield expectations of flowrate needs of up to three times those described herein.

The waste stream for flowsheet processing is based on the most current information for the overall composition of complex concentrate waste presented in Table 3-1 (Boomer *et al.* 1993). A comparison of the CC composition and tank 101-SY composition samples taken during the Window E event was presented in Delegard *et al.* (1993) and is reproduced in Table 3-2¹. This table indicates, for most components, that the concentrations are comparable.

The feed material used for the continuous bench scale plasma calcination experiments (Colby *et al.* 1994, and McLaughlin *et al.* 1994) was an undiluted and slightly diluted tank 101-SY simulant recipe which is slightly different than the recent WHC approved simulant (Hohl 1993). The tank 101-SY simulant (see Table 3-3²) is based on analyses of Window E core samples and characterization data taken during December 1991 (Herting 1992).

The waste is concentrated in a low temperature forced convection evaporator similar to the 242-S evaporator-crystallizer to approximately 11.35 M Na. The purpose of the concentration step is to remove as much water as possible to reduce the load and energy requirements for the calciner. The dilute retrieved waste volume is thus reduced by a factor of five (5) and the concentrated waste stream is fed to the calciner at a feed rate of 15.1 L/minute (4 gal/minute).

3.3 OXIDATION CHAMBER OR CALCINER

The concentrated aqueous waste slurry is injected into the hot working gases which have been preheated in the plasma arc torch. The effective operating temperature is about 800°C (1470°F) and an operating pressure slightly above (or below, depending on equipment design) atmospheric pressure. The high operating temperature oxidizes the waste and results in the destruction of organics, ferrocyanide, nitrates, and nitrites, and produces the gaseous decomposition products N_2 , O_2 , CO_2 , CO, NO_2 , NO, and water vapor.

¹Delegard and Hey (1993).

²Table obtained from *Synthetic Waste Formulations for Representing Hanford Tank Waste Contents*, WHC-SD-WM-TI-549, Rev. 0 (Hohl 1993).

Preliminary testing produced approximately 95 percent nitrate/nitrite destruction, but had a residence time in the calciner for several hours (Colby *et al.* 1994). Shorter residence occurred with secondary tests (McLaughlin *et al.* 1994) yielding approximately 90 percent destruction. Residence time for this flowsheet is assumed to be 100 milliseconds as a more reasonable residence time for the gas phase reaction equipment design. However, much longer residence times may be required to achieve 95 percent nitrate/nitrite decomposition. Further testing is required to provide better information on the nitrate/nitrite decomposition and resolubilization of aluminum as they relate to equipment development and waste form needs (see Section 4.4).

The molten salts and hot gases from the oxidation process pass through a downcomer tube which is partially filled with an alkaline solution contained in the bottom of the calciner. The alkaline solution quenches the molten waste and cools the hot gases. All the soluble solids are redissolved in the quench solution in the form of oxides, hydroxides, and carbonates. Materials of construction of the quench portion of the calciner will be developed in future testing; however, preliminary process and vendor data (Delegard *et al.* 1994) indicate that material selection need not be stringent (see Table 7-1).

The quench solution is about 85°C (185°F) and removes particles two microns or larger from the gas stream, some of the soluble gases, and greater than 99% of the total cesium and technetium, respectively. If necessary for process design, the quench solution can overflow to the calciner product tank. The solution could also be pumped from the quench tank to the product tank.

Future chemistry development activities planned for the near term (FY 1995) will provide additional data on calcination. This testing is expected to provide improved material balance data, determine TRU/non-TRU split, determine additional data on nitrate/nitrite decomposition, and identify insoluble residue phases after quenching.

3.4 CALCINER PRODUCT

The calciner product consists of an alkaline solution containing insoluble and soluble fractions. The insoluble fraction contains the multivalent metal oxides and hydroxides (i.e. iron, nickel, zirconium), strontium, the long-lived transuranic (TRU) isotopes [plutonium-239,240 ($^{239,240}\text{Pu}$), americium-241 (^{241}Am), and neptunium-237 (^{237}Np)], and small quantities of aluminum. This insoluble fraction is expected to require immobilization in a durable waste form such as glass canisters.

The soluble fraction contains the cesium-137 (^{137}Cs), technetium-99 (^{99}Tc), iodine-129 (^{129}I), Cl, N₂, O₂, and alkali metal salts (sodium and potassium, e.g. sodium aluminate). The carbon dioxide produced from the decomposition of the organics will form carbonate in the quench. Additional chemistry development studies, to confirm the behavior of the TRU elements in the dissolution step, will be performed in the near term (FY 1995). This information may provide the basis for subsequent flowsheet revisions.

Table 3-1 Composition of Complexant Concentrate Waste

Input Chemical	CC	
	Solid (kg)	Liquid (kg)
Al+3	2.78 E+04	5.28 E+05
B+3	3.69 E+01	7.00 E+02
Ba+2	5.40 E+01	4.86 E+02
Ca+2	7.71 E+02	6.94 E+03
Cr+3,+6	1.28 E+03	2.43 E+04
Fe+3	1.44 E+03	2.74 E+04
K+	3.13 E+02	3.10 E+04
Mg+2	3.28 E+02	2.95 E+03
Mo+6	2.52 E+02	4.79 E+03
Na+	4.51 E+04	4.46 E+06
Ni+3	2.95 E+02	5.60 E+03
Rare Earths+3	4.43 E+02	3.99 E+03
Si+4	3.09 E+04	
UO2+2	3.20 E+00	6.08 E+01

Input Chemical	CC	
	Solid (kg)	Liquid (kg)
Zn+2	1.05 E+02	9.42 E+02
Cl-	1.10 E+02	1.10 E+05
CO3-2	7.57 E+02	7.56 E+05
F-	3.89 E+01	3.88 E+04
NO2-	8.27 E+02	8.27 E+05
NO3-	4.15 E+03	4.14 E+06
OH-	1.63 E+05	2.33 E+06
PO4-3	1.08 E+02	1.08 E+05
SO4-2	1.32 E+02	1.32 E+05
TOC	9.00 E+03	4.41 E+05
H2O		1.26 E+07
MnO2	5.83 E+02	1.11 E+04
ZrO2:2H2O	1.83 E+02	1.65 E+03
Total (kg)	2.88 E+05	2.66 E+07
Volume (m ³)	3.45 E+02	1.80 E+04

Input Radionuclides	CC (Bq)
C-14	3.70 E+13
Cs,Ba-137	5.25 E+17
I-129	2.59 E+11
Sr,Y-90	1.40 E+17
Waste Density (kg/L)	1.46

Input Radionuclides	CC (Bq)
Tc-99	3.70 E+14
Am-241	4.81 E+14
Pu-239,240	1.44 E+14
Total (Bq)	6.66 E+17

Radionuclides decayed to 1991.

Solubility data from testing performed at Los Alamos National Laboratories (LANL) indicates that 30 wt% of a test calcine product is insoluble. More recent analysis by LANL on plasma arc calcined synthetic waste received from WHC shows 75 percent of solids dissolved (in water) and 25 percent remained undissolved. Particle size of the solids was 1-8 microns. Given the current uncertainty related to the aluminum solubility, 30 wt% minimum insoluble aluminum is used for the flowsheet material balance with calculated solubilities of 70%.

3.5 OFFGAS TREATMENT

The offgas treatment system is used to remove all of the particles generated by the calcination system and assure the radioactive gaseous effluent streams are below regulatory requirements. Elements and compounds in the waste expected to have significant volatility include Cs, Na, K, Cl, F, Zn, and entrained particulate SO₄ and PO₄. The quench system will remove a majority of these components. However, some entrainment (0.2%) of cesium and technetium is expected in the offgas from the quench tank.

The gas stream exits the quench tank at approximately 93 m³/minute (3,272 ft³/min) and flows into a vapor-liquid separator where particles (>1 micron) and some water can be separated from the gas stream. From the

Table 3-2 Comparison of Undiluted Complexant Concentrate Waste and Tank 101-SY Sample Data.

Component	Composition 101-SY (wt%) (Herting <i>et al.</i> 1992)	Composition CC Waste (wt%) (Boomer <i>et al.</i> 1993)
Al	3.2	4.4
Ca	0.023	0.028
Cr	0.041	0.092
Fe	0.028	0.10
K	0.326	0.11
Na	20.7	16.3
Ni	0.015	0.021
Zn	0.002	0.004
Cl ⁻	0.79	0.40
F ⁻	0.03	0.14
NO ₂ ⁻	10.5	3.0
NO ₃ ⁻	11.7	15.0
PO ₄ ³⁻	0.64	0.39
SO ₄ ²⁻	0.40	0.48
CO ₃ ²⁻	3.15	2.74
OH ⁻	2.47	9.0
NH ₃	0.19	--
TOC	1.53	1.6
H ₂ O	35.5	45.9

vapor-liquid separator, the gas stream flows through a venturi scrubber for additional vapor-liquid separation. The venturi scrubber provides further cooling, condensation, and particle removal. The liquid bottoms are expected to contain the entrained Cs, Tc, Na, solid oxides, etc.

The remaining saturated gases are sent to a NO₂ reactor to remove NO₂ and NO. Any CO₂ or CO that may be carried into the offgas (<1 percent) is expected to pass through the reactor, along with approximately 2000 ppm NO_x developed thermally (McLaughlin *et al.* 1994) and any remaining NO_x not removed in the

Table 3-3 Composition of Tank 101-SY Simulant

Component ^a	Weight percent undiluted ^b	Weight percent SY1-SIM-93A	Concentration SY1-SIM-93A (M)
Na	20.7	7.05	3.69
Al	3.2	1.12	0.50
Cr ^c	0.41	0.14	0.033
Ca	0.023	0.0080	0.0024
Fe	0.028	0.0097	0.0021
K	0.326	0.11	0.035
Ni	0.015	0.0052	0.0011
Zn	0.002	0.00071	0.00013
Cs	0.00145 ^d	0.00049	0.000044
Sr	0.000058 ^d	0.000021	0.0000029
NO ₃	11.7	4.07	0.79
NO ₂	10.5	3.65	0.96
OH ^e	2.47	1.02	0.72
TIC ^f	0.63	0.22	0.22
PO ₄	0.64	0.22	0.028
SO ₄	0.4	0.14	0.017
Cl	0.79	0.27	0.093
F	0.03	0.010	0.0067
TOC ^f	1.53	0.53	0.53
H ₂ O	35.5	78.46	--

NOTE:

^aNon-sodium metals added as nitrate salts (excluding ZnCl₂). Anions added as sodium salts.

^bBased on information in WHC-SD-WM-DTR-026, Rev. 0, Table 5-4.

^cCr(VI) is small compared to total Cr and is not added.

^dConcentrations of Cs & Sr are based on data from WHC-SD-WM-DTR-026, Rev. 0, Tables 5-7 & 5-8. These concentrations were adjusted to add in the more stable forms of these two elements. Based on ORIGEN2 model data and 35 years of decay, the ¹³⁷Cs & ⁹⁰Sr concentrations were multiplied by factors of 4.01 & 2.46, respectively to arrive at total Cs and Sr.

^eTo neutralize acidic hydrolyzable metal salts of Cr, Ca, Fe, Ni, Zn, Cs and Sr; 0.443M "extra" NaOH added per liter of undiluted simulant.

^fTIC, TOC wt.% reported as C. Carbonate is used for TIC. TOC is made up using EDTA, the baseline organic.

reactor. The scrubbed gas stream exits the reactor at approximately 450°C (842°F). The stream passes through a condenser where the condensate is collected for recycle or sent to lag storage for final disposal. The final gas stream will be heated, filtered, and discharged through a stack.

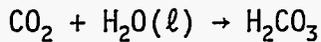
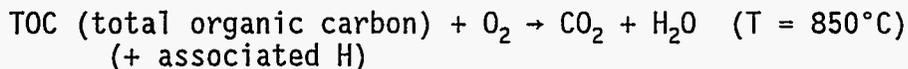
4.0 PROCESS TECHNOLOGY

4.1 CHEMISTRY

The purpose of plasma arc calcination is to destroy the organic compounds, ferrocyanide, and nitrite and nitrate in the waste while converting aluminum to soluble sodium aluminate and insoluble chromium (III) to soluble chromate (VI). At the nominal operating temperature of the flame, the organics and ferrocyanide readily decompose. The temperature is also high enough to decompose most of the nitrates and nitrites. The principal chemical reactions and estimates of product compositions are discussed below.

4.1.1 Organic Decomposition

Organic destruction values typically use EDTA as the primary source of TOC. Based on recent studies (Babad *et al.* 1993 and Campbell *et al.* 1994), it is more likely that the organic material in the tanks is no longer EDTA, but a combination of sodium acetate, oxalate, formate, and citrate. The organic decomposition results in the generation of carbonates which are soluble in the water quench. The major reactions assumed for this flowsheet are as follows:



To accomplish the precipitation of transuranics, the pH must be kept near 12. Therefore, for every mole of TOC oxidized to CO_2 , 2 moles of NaOH are necessary. The molarity of the NaOH in the quench bath can be adjusted by chemical addition, if necessary. A discussion (Delegard *et al.* 1993) of the stoichiometry of the organic oxidation reactions estimates 1.25 moles of hydroxide will be consumed per mole of organic carbon oxidized.

The required level of organic destruction to resolve tank safety issues is not well defined. Following the preparation of Delegard *et al.* (1994) for the purpose of technology selection, the pretreatment program deemed tank safety resolution to no longer be a driver for organic destruction. The existing grout specification is 1,556 ppm TOC (1.5 g/L) and was used as the criterion for this flowsheet (Hendrickson 1991).

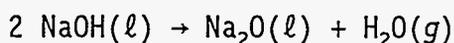
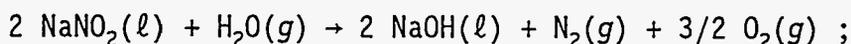
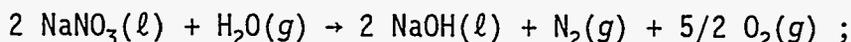
4.1.2 Nitrate/Nitrite Decomposition

The temperature range where the thermal decomposition of pure compounds of sodium nitrate and sodium nitrite begins is 320-380°C (608-716°F) (Weast

1982). This decomposition proceeds rapidly at temperatures above 750°C (1380°F).

However, other data collected from nitrate/nitrite kinetic tests show a much higher temperature for thermal decomposition. These tests indicate an optimum temperature between of 700–800°C (1290–1470°F), with reactions increasing at 900–1000°C (1650–1830°F) (Colby *et al.* 1994). Other lab-scale calcining studies (Burger *et al.* 1973) provide data that show the thermal decomposition of NaNO₃ and NaNO₂ is not as fast or complete as indicated in literature data. Calcination at 850°C (1560°F) for 105 minutes left about 28 percent of the sodium nitrate as NaNO_x (Burger *et al.* 1973). Ongoing work at the University of Idaho indicates extensive destruction in 40 to 100 milliseconds at modest plasma torch power.

The following major reactions describe the calcination of sodium nitrate and sodium nitrite. These reactions occur in the calciner at 750–900°C (1380–1650°F):



Formation of small amounts of sodium peroxide (Na₂O₂) is also expected (Delegard *et al.* 1993). The decomposition of the waste compounds provides excess oxygen to support oxidation of the waste.

It will be assumed that half of the unreacted nitrite/nitrate is carried into the initial offgas from the quench bath and the other half remains in the quench bath. Fourteen percent and nine percent of the incoming nitrite/nitrate, respectively, is assumed to be unreacted. The offgas from the quench contains the more volatile elements and compounds. Offgas products generated from the WSTC plasma arc calcination test consisted primarily of nitrogen and oxygen with low concentrations of NO₂, NO, CO₂, and CO.

For the purposes of this flow sheet, air is assumed as the arc gas. The flow rate of air to calcine 15.1 L/minute (4 gal/minute) of waste is calculated to be 25.8 m³/minute (911 ft³/minute) (see Appendix B). At this time no extensive review has been conducted of alternative gases, although thermodynamic analyses have conducted preliminary reviews (McLaughlin 1994). It will be assumed that the air in the arc gas does not significantly affect the calcination products.

4.1.3 Aluminum

The following reactions are assumed to occur for the aluminum in the feed:

Reaction in the calciner at T = 850°C (1560°F):



Reaction in the quench solution at $T = 85^\circ\text{C}$ (185°F):



If insufficient NaOH is present, excess aluminum hydroxide will be converted to insoluble Al_2O_3 . For this flowsheet, it is assumed some of the $\text{Al}(\text{OH})_3$ is converted to insoluble Al_2O_3 at the given process temperature and pressure and a portion of the Al_2O_3 remains as an insoluble precipitate.

4.1.4 Sodium Carbonates

The formation and accumulation of sodium carbonate solids may be of concern for downstream processing. The total sodium (both Na_2CO_3 and NaOH) in the quench solution, and the affect on sodium salt solubilities, will be important.

Figure 4-1 (Delegard *et al.* 1993)³ shows that increasing NaOH concentration decreases the solubility of Na_2CO_3 . This is due to the "common ion effect" of the sodium ion from NaOH and Na_2CO_3 . Trisodium phosphate, Na_3PO_4 , is also present in tank waste and will further impact sodium salt solubilities. From the data in Figure 4-1, if the resulting salt solution is maintained as a solution of approximately 7 M Na^+ , the solubility in the quench appears adequate. Further analysis is contained in Appendix B (Calciner, Quench Mass Requirement).

4.1.5 NO_x Removal

The NO_2 reactor uses ammonia over zeolite catalysts to convert the NO_2 to nitrogen and water. In 1974, tests were run on simulated calciner offgas with a dew point of 70°C (158°F) (conceptual design report for NO_x Abatement System Project). Greater than 99 percent reduction efficiencies were obtained for both NO and NO_2 species with bed temperatures between 380°C and 550°C (716°F and 1020°F). The following reactions and 99 percent conversion are assumed:



³ Derived from Linke (1965). Line corresponds to $\text{OH}^-/\text{CO}_3^{2-} = 6$ mole ratio.

4.1.6 Transuranics and Other Oxides

The behavior of the neptunium, plutonium, and americium in the dissolution of the calcined waste is not yet determined. Ternary sodium actinide oxides, in which the actinides neptunium, plutonium and americium are in oxidation states ranging from (V) to (VII) may be expected to form during the calcination process (Delegard et al. 1993). Data on the solubility limits of the TRU in the quench bath or dissolution step will be evaluated in planned chemistry development activities. Such solubility evaluations must also be geared to prevent precipitation of chromium.

The current limits for radionuclide activity in low level waste is specified at <100 nCi/g (e.g. Class C Low Level Waste) corresponding to about 0.17g ²³⁷Np/L, 0.001g ^{239,240}Pu/L or 0.000035g ²⁴¹Am/L. Flowsheet calculations and tables assume ²⁴⁰Pu and ²⁴¹Am in activity calculations.

4.2 ENGINEERING

The continuous mode plasma arc calcination of undiluted tank 101-SY simulant waste has been demonstrated by testing performed at the WSTC. A molten salt product was collected and analyzed to determine the destruction efficiencies of organics and nitrates/nitrites. The molten salt mixture consisted of sodium hydroxide, sodium carbonate, aluminum oxide complex, and trace amounts of heavy metal oxides and phosphates. Equipment modification and/or vendor testing will be required to simulate the calcination process proposed in the preliminary flowsheet.

Small scale crucible tests have been performed by Westinghouse Hanford, but can not accurately simulate the temperature gradients that would be expected in a system with integral quench and water cooled refractory wall. Additional chemistry analyses are planned to demonstrate the chemistry of a direct quench.

4.3 ASSUMPTIONS AND LIMITATIONS

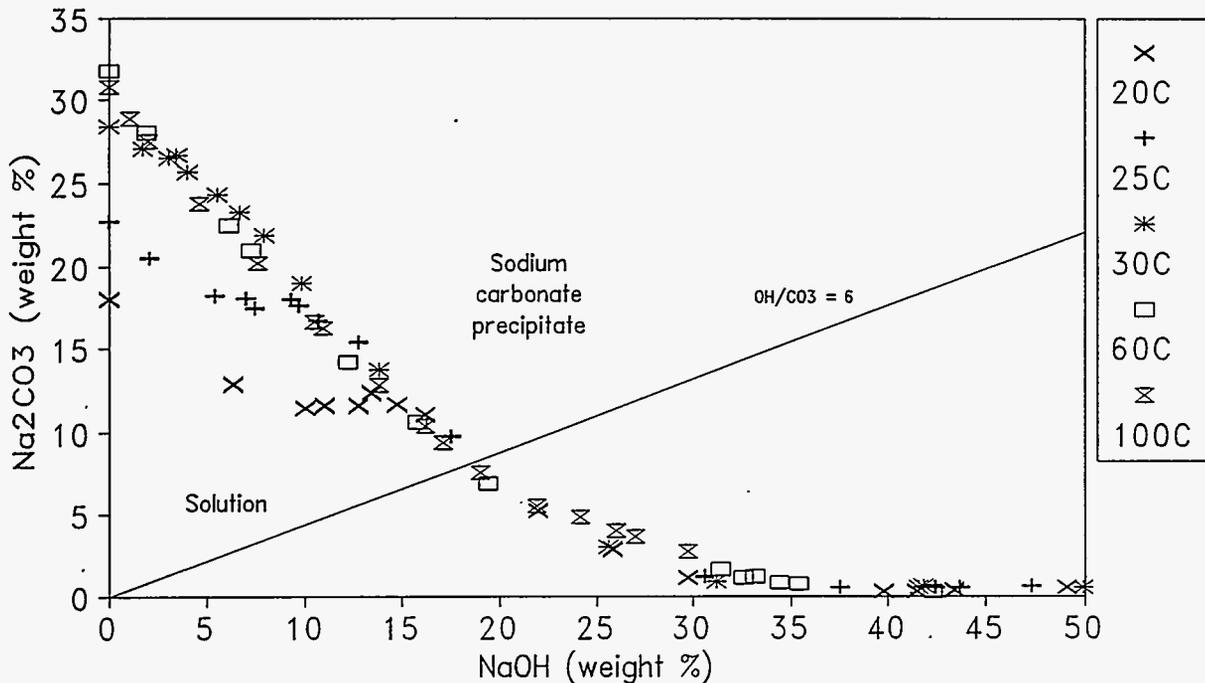
The following sections describe the significant assumptions and limitations of the proposed flowsheet.

4.3.1 Assumptions

The final organic concentration (total organic carbon) is intended to meet grout feed criteria. This limit is 1,556 ppm (Hendrickson 1991). Organic destruction is assumed to be 99 percent. Carbon dioxide generated by the organic decomposition is assumed to form carbonate in the quench and any carbonate carried into the offgas is removed by the venturi scrubber system. Carbonate in the waste is considered to be inorganic carbon. The current grout specifications limit the amount of OH and CO₃ to less than 25 percent of the total anions. Although the grout program is not anticipated to proceed,

Figure 4-1 Sodium Carbonate Solubility in Sodium Hydroxide Solution

Sodium Carbonate Solubility in Sodium Hydroxide Solution



such specifications remain the only extant basis for several IPM requirements.

Nitrate/nitrite destruction is assumed to be 91%/86% at 800°C (1470°F) following a one hundred millisecond residence time.

The insoluble aluminum in the quench is assumed to be a minimum of 30 percent of the original aluminum. A small percentage of components are assumed to be entrained or volatilized in the offgas system and include Na, K, Fe, Pb, Zr, Cs, Tc, and Sr. The integral quench unit, supplemented with additional makeup water, is assumed to reduce entrained solids to 0.2% of feed.

Ion exchange processes will be used to remove cesium from waste processed through the IPM. The calcination flowsheet assumes that the ion exchange process follows organic destruction.

Energy requirements for the plasma arc are assumed to be directly scalable from the WSTC tests.

4.3.2 Limitations

The molten sodium hydroxide is extremely corrosive. If operating with molten caustic at the described operating conditions, rapid corrosion of Type 304L stainless steel is expected to occur. Corrosion tests of salt mixtures and metal alloys are underway at Pacific Northwest Laboratory (PNL). Dissolution testing of the calcine product provided the following information: (1) the alumina (Al_2O_3) crucible cracked, (2) the zirconia ceramic broke, and (3) a nickel crucible had severe interfacial corrosion. Thermal stress is a factor in the results of these crucible tests as well as corrosion. Demonstrated within some commercial applications, a 'cold skull' may inhibit significant corrosion of the calciner; however, maintenance of such an operation can become exceedingly difficult with radioactive waste. Calcination "on-the-fly" with direct quench is seen as the only serviceable assembly of this nature.

4.4 RECOMMENDATIONS

Continued laboratory pilot scale testing is appropriate to provide necessary information and data on component (particularly aluminum, carbonate, phosphate, plutonium, neptunium, and americium) solubilities and the composition of the solid and gaseous waste streams from the process. This information is necessary to allow investigation of the compatibility of the liquid waste with the low level waste disposal process and the solids waste for HLW disposal.

A hot test facility for pilot scale tests with actual waste will not be available until FY 1998 and would be expected to be performed by the IPM under alternate separations activities. Vendor testing with a 'calciner' similar in design to the flowsheet calcination will be necessary if an integral quench bath is desired. Residence time in the calciner must be resolved to continue with the proposed flowsheet equipment. Such vendor testing and kinetics research at the University of Idaho were described in Delegard *et al.* (1994).

5.0 PROCESS FLOWSHEET

Figure 5-1 shows the flow diagram for the Plasma Arc Calcination Process. The mass balance (calculated using the ASPEN computer code) for the process is found in Appendix A. The stream numbers correspond to those shown in Figure 5-1. The assumptions for determining material balance splits and energy requirements are given in Appendix B. Detailed unit operation material balances are provided in Appendix D.

5.1 ENERGY BALANCES

The plasma arc calcination demonstration performed by WSTC operated the torch at approximately 1 megawatt (MW) with an average throughput of 6.8 L/minute (1.8 gal/minute) feed diluted forty-one percent (McLaughlin et al. 1994). The power requirement for the calciner is scaled up from 6.8 L/minute and 1 MW to 15.1 L/minute (4 gal/minute) and a requirement of 2.3 MW (see Appendix B).

A thermodynamic simulation of the calcination of a simulant waste feed composition was performed by WSTC using the simulation code CET89. The CET89 code computes a detailed free energy minimization calculation for a given input composition at final conditions of temperature, pressure, enthalpy, and entropy. The code output is the composition and thermodynamic properties of the equilibrium product mixture. Additional thermodynamic studies have been conducted to demonstrate the feasibility of the operation by McLaughlin and Peterson (1993) and McLaughlin (1994).

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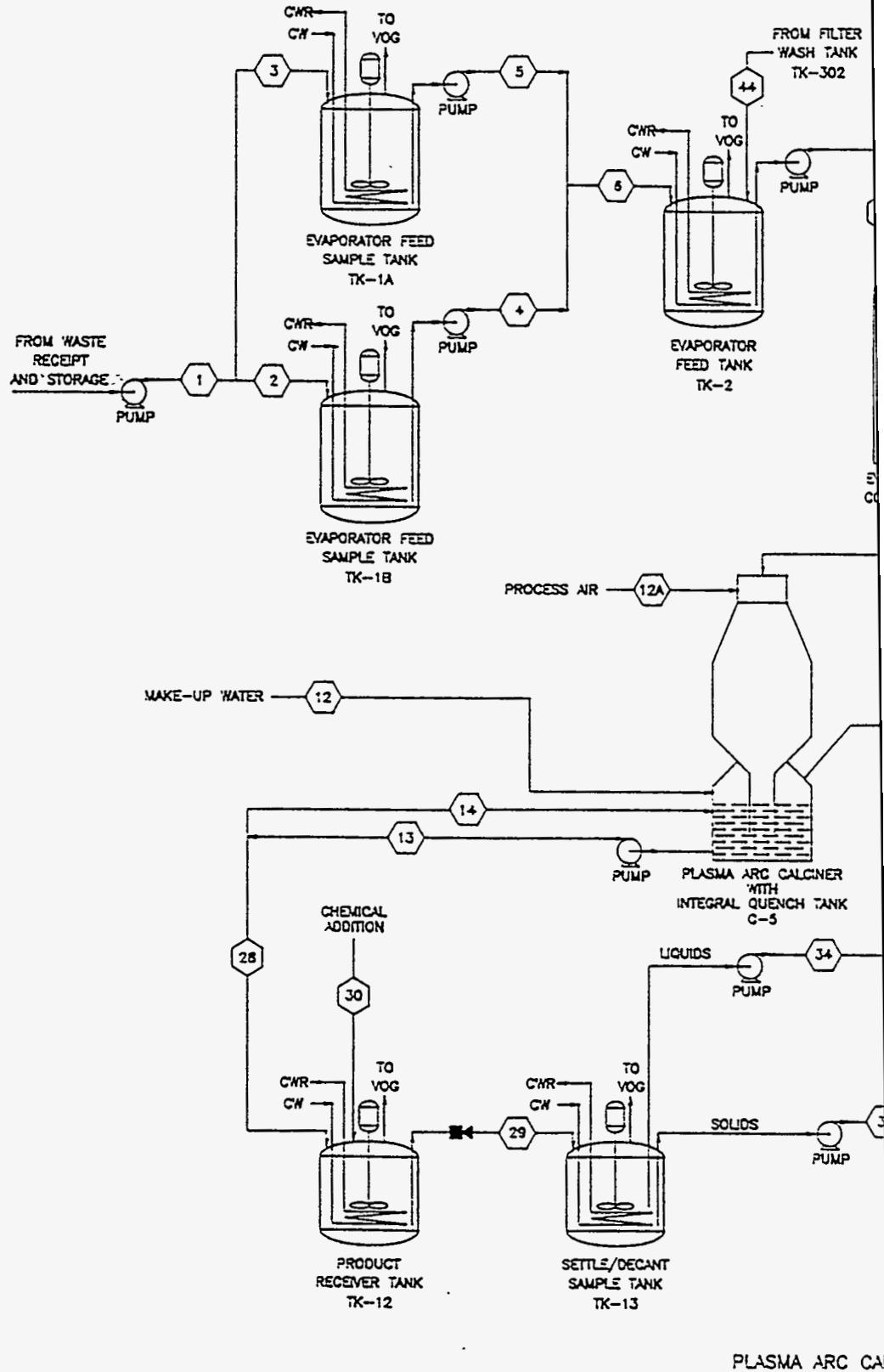
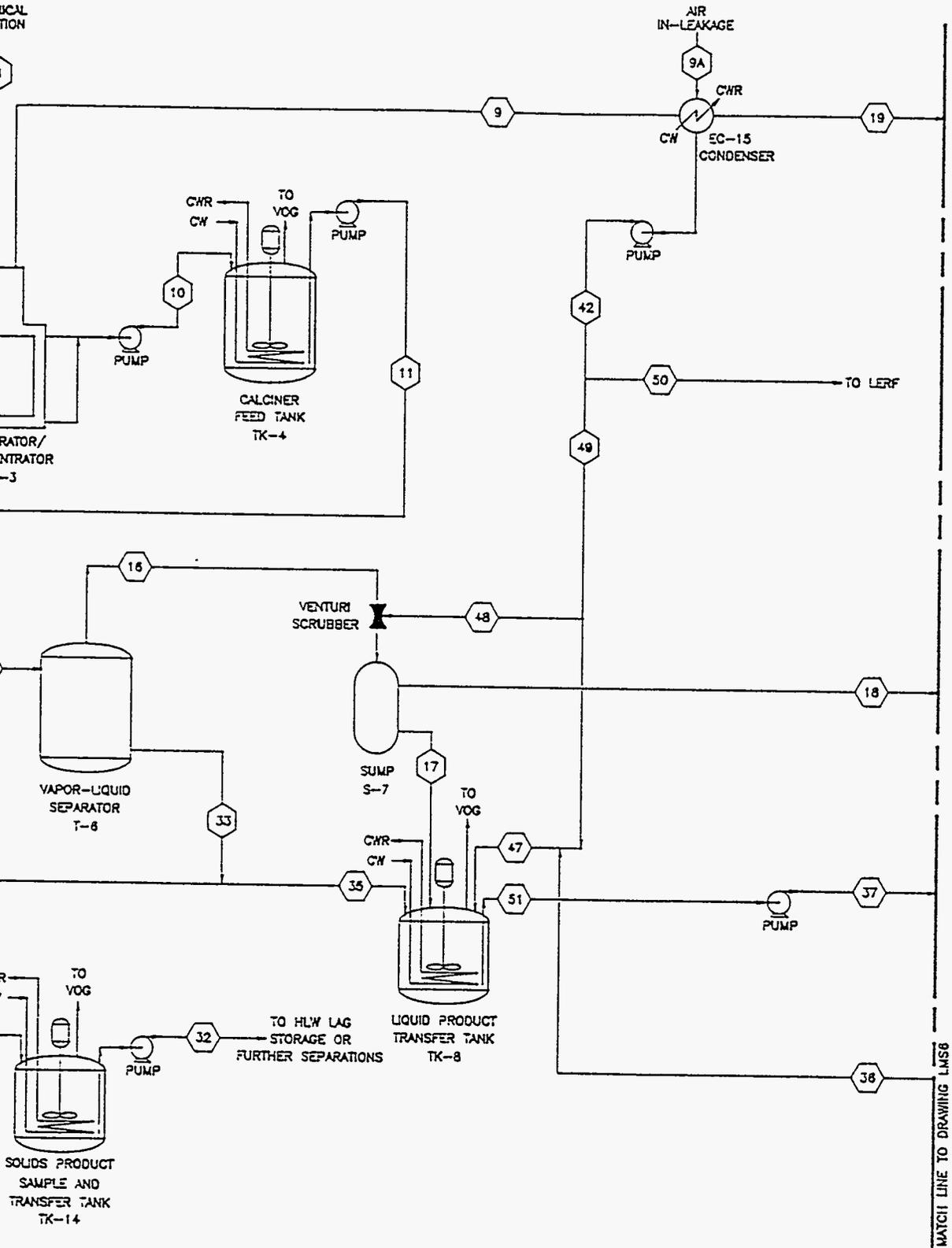
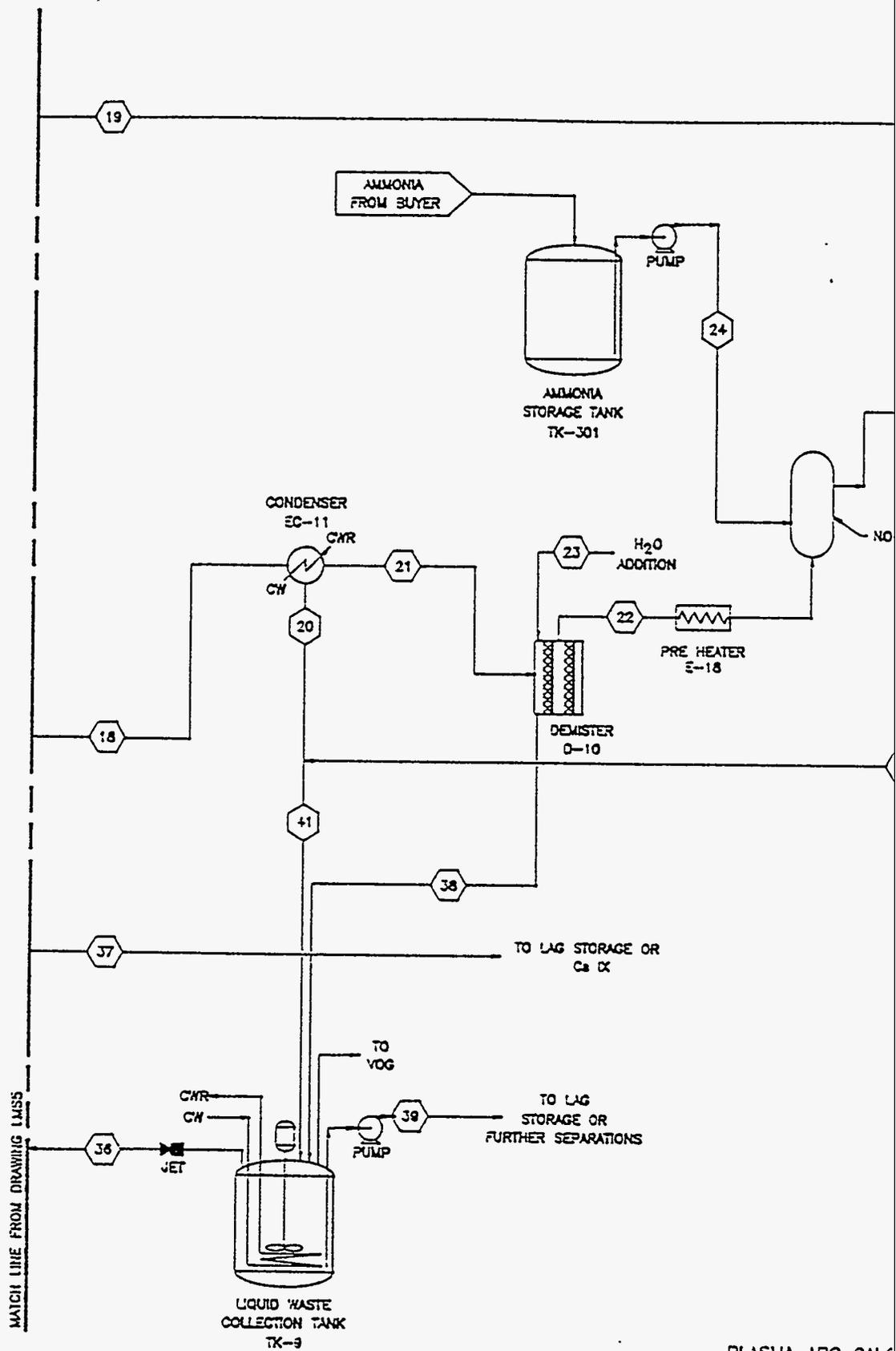


Figure 5-1 Plasma Arc Calcination Process Flow Diagram

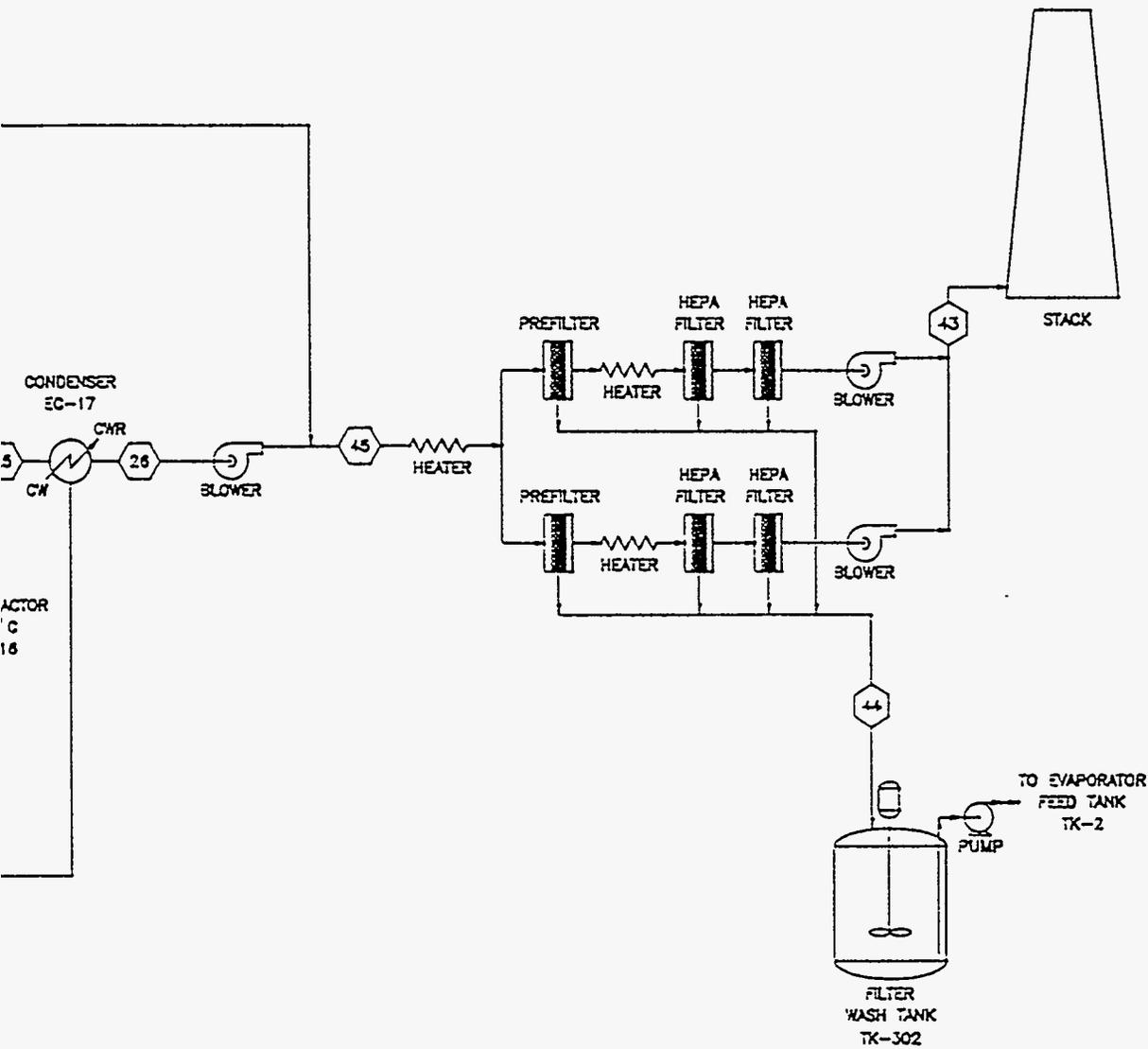
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PLASMA ARC CALC



6.0 PROCESS CONTROL

The plasma arc calciner and upstream equipment are operated on a continuous basis. Downstream of the calciner, the equipment is operated on a batch or semi-batch basis. The tank waste feed to the IPM is received in one of two feed sample tanks. After sampling and adjustment, the feed is added to the evaporator feed tank as space becomes available. The feed is continuously pumped to the evaporator and the concentrated waste is pumped to the feed tank for the calciner. From the feed tank, the waste is continuously fed to the calciner.

The quench solution is continuously removed from the quench tank to the product receiver tank. The product is periodically moved in a batch to the settle/decant tank. After settling (or other appropriate liquid/solids separation), the solution is moved to the liquid product sample tank. The solution in the liquid product tank is fed to the cesium ion exchange system. The solids are slurried from the settle/decant tank to the solids product sample tank for sampling. The solids are transferred to HLW storage or to further downstream processing [e.g. acid dissolution and transuranic extraction (TRUEX)/strontium extraction (SREX) or carbonylation (Delegard et al. 1994)].

The offgas from the calciner goes through a dedicated treatment system that is operated continuously. The offgas system consists of a vapor/liquid separator to remove large droplets of water and entrained particles; a venturi scrubber for particulate and atomized solution separation; a condenser for removal of water vapor; a demister for removal of submicron entrained particles; a preheater and NO_x reactor for destruction of nitrogen oxides; a condenser to lower the vapor stream temperature; a reheater for dehumidification; and HEPA filters. In the calculations applied in this flowsheet, final particulate matter removal is incurred in passing condenser EC-11; in reality, the subsequent demisting, condensation, and the HEPA filters would contact trace contaminants.

6.1 PROCESS CONTROL PHILOSOPHY

Figure 6-1, Process Control Diagram, shows the process control instrumentation for the calcination process. The instruments shown in Figure 6-1 are also listed in Table 7-1, Plasma Arc Calcination Equipment List.

The evaporator feed tanks receive tank farm waste which has been diluted 3:1 for retrieval. The waste is sampled to confirm the characteristics of interest for process control. The percent solids, the density of the waste, the sodium and aluminum concentration, and ^{137}Cs are examples of analyses run on the sample to support process control and material balance needs. Selected equipment for sampling points are discussed in Section 6.2, Sampling and Monitoring.

The waste slurry will be transferred as a batch into the evaporator feed tank. The transfer into the feed tank begins when the liquid level in the tank has dropped to a preselected low level (generally 10 percent to 20 percent of the operating volume). The transfer continues until the liquid level in the feed tank reaches a predetermined level (generally 80 percent of the operating volume).

The evaporator is fed continuously at a rate of about 76 L/minute (20 gal/minute). The feed flow is at a constant rate. The product discharge rate from the evaporator and the heating rate of the evaporator are used to control the conditions in the evaporator. Vacuum evaporation will be used in the evaporator to minimize the operating temperature and control the amount of organics vaporized into the evaporator offgas. Heat is supplied by steam or electrical elements.

The continuous concentrate rate from the evaporator is about 15.1 L/minute (4 gal/minute). The rate is adjusted as required to control the amount of solids going to the calciner feed tank. Solids will be present in the feed to the evaporator and the percentage of solids will increase in the concentrate going to the calciner feed tank. The temperature in the calciner feed tank will be maintained as high as possible to minimize additional solids formation and prevent pump cavitation. The addition of retrieved, undissolved solids to the evaporator may result in fouling and operational problems.

The volume of feed in the calciner feed tank is maintained near the minimum operating level to provide some lag in the process in case of process upsets downstream. Make-up chemicals are added to the feed tank if necessary to maintain continuity of operations if process upsets upstream result in an operating volume that goes below the normal minimum level.

Concentrated waste is fed continuously to the calciner at about 15.1 L/minute (4 gal/minute). The feed rate and torch power must be optimized and adjusted to control the amount of solids in the quench tank. The feed is sprayed or injected into the hot gases from the plasma torch in the calciner. The temperature in the calciner is controlled by adjusting the power to the plasma torch and/or the feed rate.

The integral quench is an important operation for the calcination process. Several parameters are controlled to assure continuity of operation, an acceptable product, and a controlled offgas stream. The temperature and chemical concentration in the quench tank is used to control solids formation and prevent solids buildup (see Appendix B, Calciner, Quench Mass Requirement). The liquid level is controlled by continuously removing the slurry from the quench tank. Makeup water is added as required to maintain the volume of liquid in the quench tank.

Maintaining the temperature and the liquid level at specified levels is essential to providing an initial scrub of the vapor and atomized solution generated by the high temperature of the torch. In the quench, the vapor-liquid separator, and then the venturi scrubber, the vapor is cooled and most

of the entrained liquid and particles are removed. The temperature of the quench is maintained at approximately 85°C (185°F) to control scrubbing and solids formation.

The vapor passes from the venturi scrubber to the first condenser. Cooling water to the condenser is used to maintain the temperature of the vapor outlet near 45°C (113°F). The vapor passes through the demister before being preheated to more than 250°C (482°F) to feed into the nitrogen oxide reactor. The nitrogen oxide reactor is operated at 450°C (842°F).

From the reactor, the offgas passes through a condenser and heater before filtering for release via the stack. The condenser and heater remove residual water to protect the filters. Cooling water to the condenser is used to maintain the temperature of the vapor outlet near 45°C (113°F).

The quench solution is continuously removed from the quench tank to the product receiver tank. The quench solution is a solids slurry. Control of solids to limit settling is essential to the continuity of operations. All of the tanks will have mixing systems to maintain solids in suspension. The slurry is transferred to the settle/decant tank on a batch basis.

In the settle/decant tank, the solids are settled. Flocculating (or other) agents, to assist settling, are added as required (see Section 10.0). The solution is decanted to the liquid product transfer tank. The solids are slurried to the solids product tank for sampling. The laboratory analysis of the solids will provide data to assess process performance and to assist in maintaining the material balance.

The liquid product transfer tank also receives batches of solution from the liquid waste collection tank. The liquid waste collection tank collects condensate from the condensers and other solutions from the offgas treatment systems. The contents of the liquid product transfer tank are sampled before transfer to the cesium ion exchange process. The analysis provides process and material balance data.

6.2 SAMPLING AND MONITORING

Sampling of the waste feed and product for chemical and radionuclide analyses must be performed to characterize and schedule feed to the process, for optimizing feed to the calciner, and to characterize liquid and solid products for subsequent processing. Offgas sampling must be performed to satisfy regulatory requirements.

Samples are taken from the contents of the following tanks and delivered to the laboratory for analysis:

- TK-1A; TK-1B, Evaporator feed sample tank
- TK-4, Calciner feed tank
- TK-13, Settle/Decant sample tank

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- TK-14, Solids product sample and transfer tank
- TK-8, Liquid product transfer tank

Online samples are also taken from the following streams:

- Condensate from the EC-15 condenser
- Condensate from the EC-11 condenser
- Condensate from the EC-17 condenser
- Offgas before and after the nitrogen oxide reactor
- Offgas downstream from the HEPA filters.

Instrumentation is used to provide online data for process control. Liquid level, density, pressure, and temperature measurements are needed for all of the tanks and the evaporator. In-line monitors are on the offgas system to provide data on radionuclide content and other constituents such as nitrogen oxides.

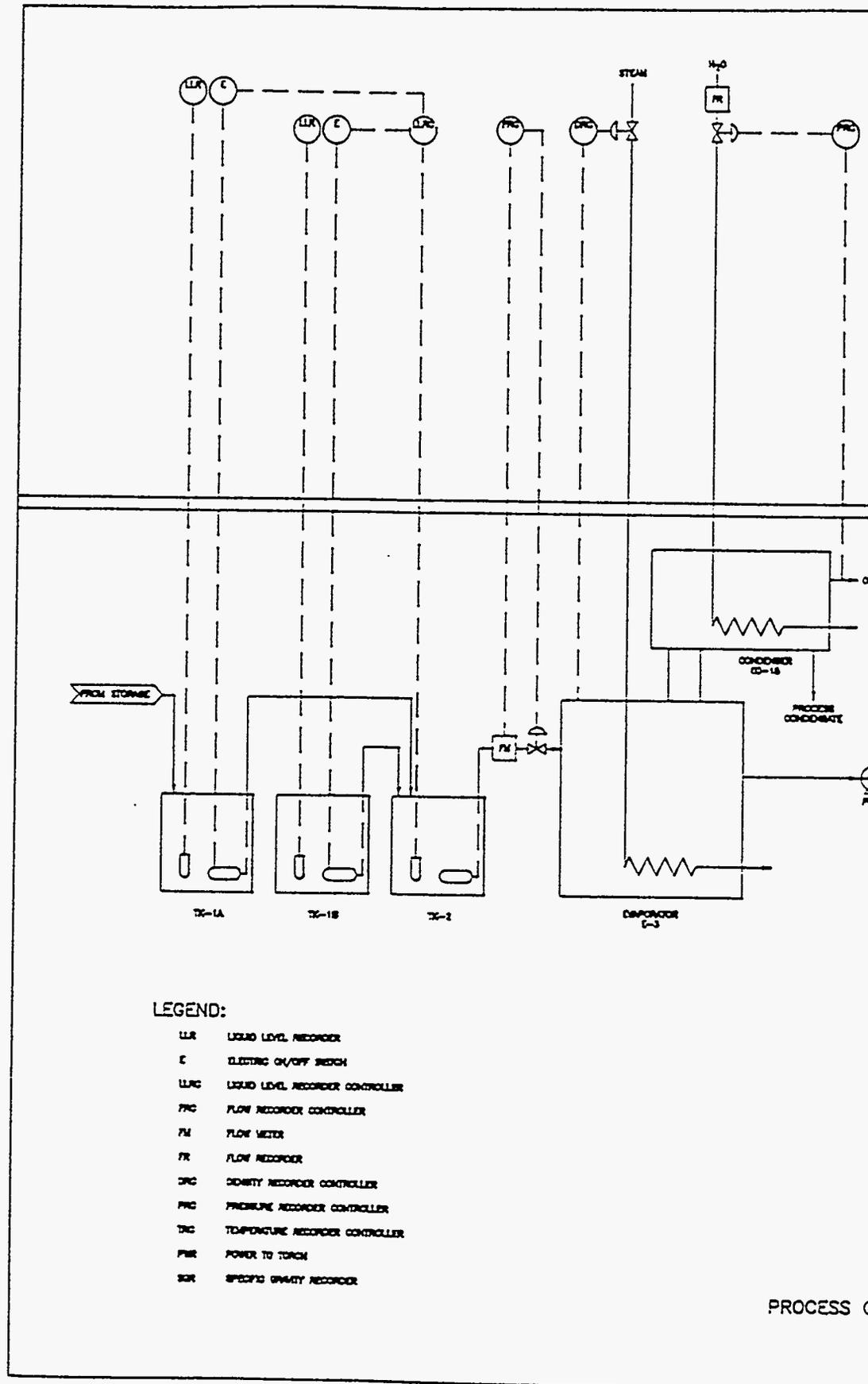
6.3 ANALYSES, DATA, AND CONTROL

The control of the calcination process will be dependent on the operating conditions of the calciner and the accuracy of the analytical data obtained from samples. The system will be primarily controlled by time and temperature process parameters. Analyses of process constituents such as organic carbon, carbonate, nitrates, nitrites, and sodium hydroxide will be needed to determine the effectiveness of the calcination/dissolution process. The solids will also be sampled and quantified to determine product quality and the effectiveness of the calcination process.

Retrieved waste will be added to the evaporator feed sample tanks in batches. Solid and liquid products from the calciner are also transferred in batches. These batch transfers will provide the necessary data to prepare process control material balances.

Density and liquid level measurement is needed to control batch sizes during transfers from tank to tank. Temperature control is important in all of the tanks due to the concentrated solutions being handled. All tanks and vessels will have temperature elements and appropriate heating and cooling capability to maintain temperatures within the normal process control range. All of the tanks and vessels which handle process solutions and slurries will have agitators. The heating and cooling systems and agitation systems are not shown on the simplified process control diagrams.

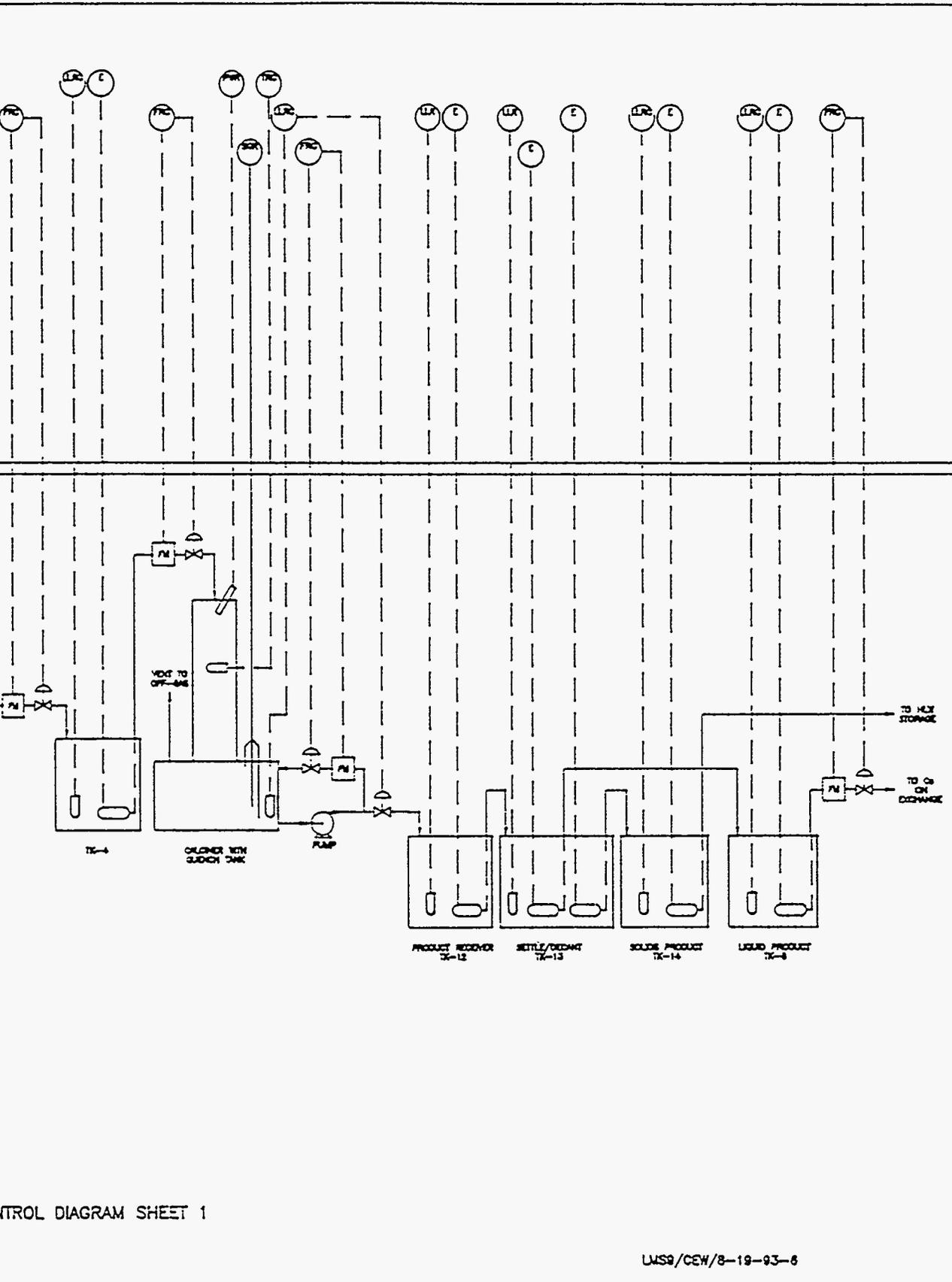
Flow rates are measured on process streams that are continuously operated. Flow rate measurements are used on batch transfers only if needed as backup control.



LEGEND:

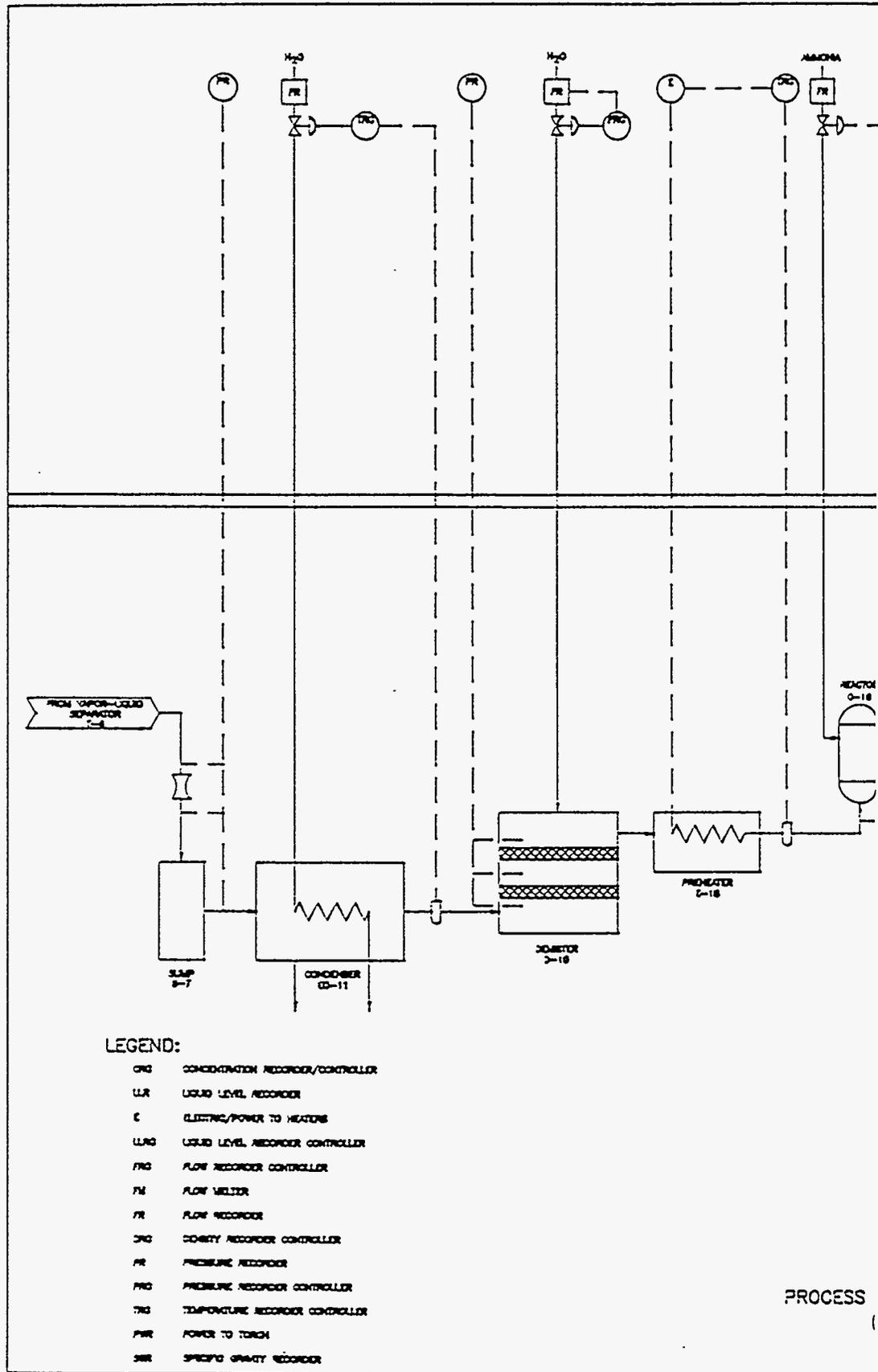
- LLR LIQUID LEVEL RECORDER
- E ELECTRIC ON/OFF SWITCH
- LLRC LIQUID LEVEL RECORDER CONTROLLER
- FRC FLOW RECORDER CONTROLLER
- FM FLOW METER
- FR FLOW RECORDER
- DRC DENSITY RECORDER CONTROLLER
- PRC PRESSURE RECORDER CONTROLLER
- TRC TEMPERATURE RECORDER CONTROLLER
- PWR POWER TO TORCH
- SGR SPECIFIC GRAVITY RECORDER

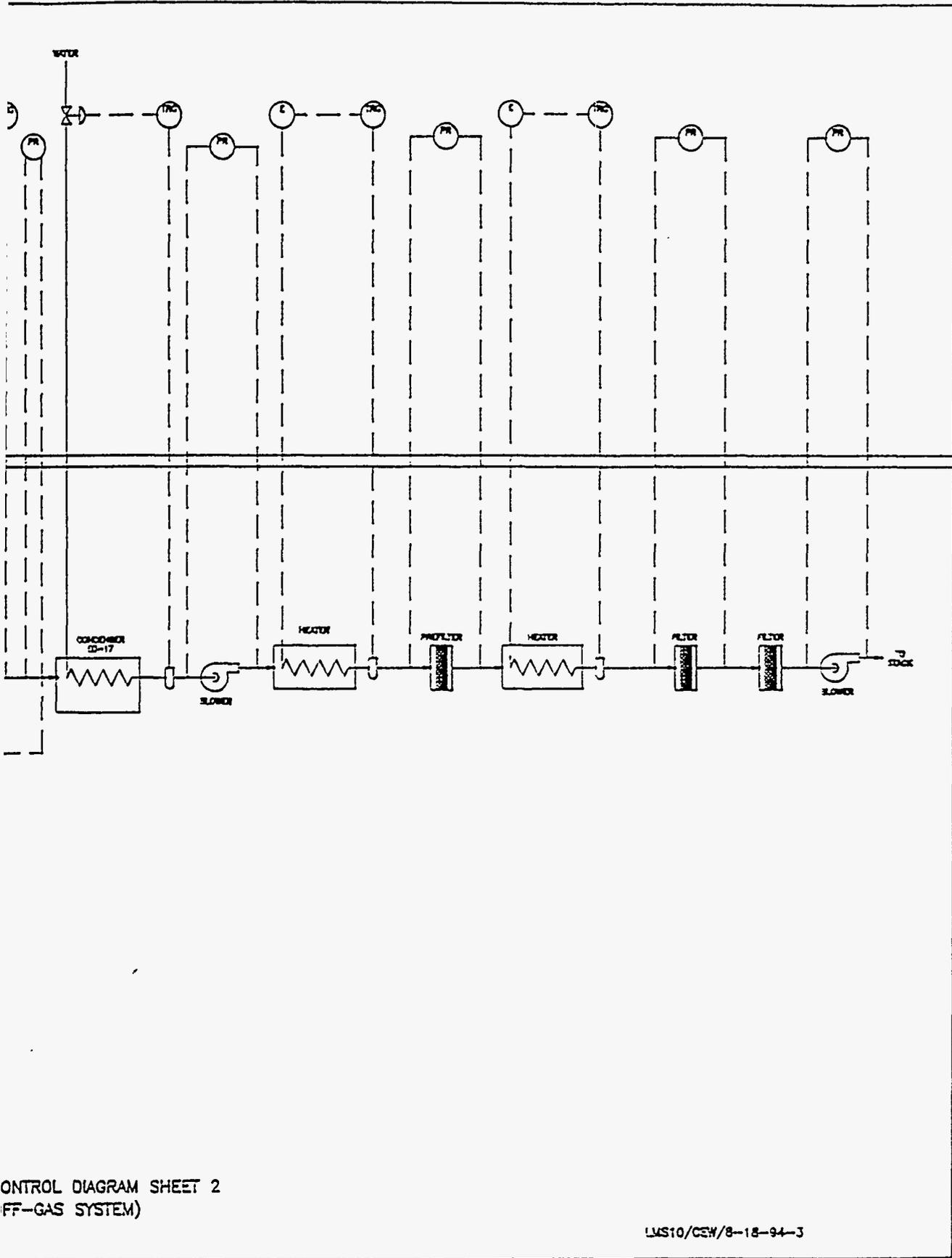
Figure 6-1 Process Control Diagram



CONTROL DIAGRAM SHEET 1

LMS9/CEW/8-19-93-6





CONTROL DIAGRAM SHEET 2
(FF-GAS SYSTEM)

LMS10/CEW/8-18-94-3

7.0 PROCESS EQUIPMENT DESCRIPTION

The equipment list for the plasma arc calcination process is presented in Table 7-1, Plasma Arc Calcination Equipment List. The equipment sizing is based on the material balance in Appendix A and a retrieved waste processing rate of 76 L/minute (20 gal/minute). Equipment development, for any continuing work would be a separate activity by the program. Results and plans for such a development are not yet formalized.

Table 7-1 Plasma Arc Calcination Equipment List

Equipment Name	Equipment ID	Capacity	Physical Size	Material	Process Control ^f
Evaporator Feed Sample Tank	TK-1A, 1B	189.3 m ³	7.3 m dia x 4.6 m h	Carbon Steel	LLR, E
Evaporator Feed Tank	TK-2	56.8 m ³	4.9 m dia x 3 m h	Carbon Steel	LLRC, FM, FRC
Evaporator	EV-3	96.6 m ³	4.3 m dia x 9.15 m h	Stainless Steel	DRC
Calciner Feed Tank	TK-4	22.7 m ³	3.6 m dia x 2.25 m h	Carbon Steel	LLRC, E, FRC, FM
Plasma Arc Calciner and Quench Tank with Burner Assembly	C-5	0.91 m ³ /hr	2 m dia x 8 m h	Carbon Steel	LLRC, TRC, FRC, PSR, SGR
Vapor-Liquid Separator	T-6	1.37 m ³ /sec	1 m dia x 1 m h	Stainless Steel	Not defined
Sump	S-7	3.8 m ³	1 m dia x 4.9 m h	Stainless Steel	PR
Product Receiver Tank	TK-12	56.8 m ³	4.9 m dia x 3 m h	Carbon Steel	LLR, E
Settle/Decant Sample Tank	TK-13	56.8 m ³	4.9 m dia x 3 m h	Carbon Steel	LLR, E
Solids Product Sample and Transfer Tank	TK-14	28.8 m ³	2.1 m x 4.9 m x 3 m h	Carbon Steel	LLRC, E
Liquid Product Transfer Tank	TK-8	56.8 m ³	4.9 m dia x 3 m h	Carbon Steel	LLRC, E, FM, FRC
Liquid Waste Collection Tank	TK-9	56.8 m ³	4.9 m dia x 3 m h	Carbon Steel	LLRC, E, FM, FRC
Demister	D-10	1.2 m ³ /s	vendor spec.	Stainless Steel	FR, FRC
Pre-Heater	E-18	0.13 MW	vendor spec.	Stainless Steel	E, TRC
NO ₂ Reactor	C-16	1.2 m ³ /s at 2000 ppm NO _x	vendor spec.	Stainless steel	FR, CRC, PR
Condenser	EC-11	1.1 MW	vendor spec.	Stainless Steel	FR, TRC
Condenser	EC-15	2.5 MW	vendor spec.	Stainless Steel	PRC, FR
Condenser	EC-17	0.29 MW	vendor spec.	Stainless Steel	TRC
Ammonia Storage Tank	TK-301	1.9 m ³	1 m dia x 2.5 m h	Carbon Steel	FR, LLRC

^fLegend for Process Control abbreviations found on Figure 6-1, Process Control Diagram

NOTE: More extensive instrumentation will be required for process control and monitoring that is NOT provided in this preliminary list.

7.1 MATERIAL OF CONSTRUCTION

The material of construction for the calciner may be a significant development activity. Under the worst of possible conditions, a calciner liner material must be available to withstand the corrosive molten sodium hydroxide at the projected operating conditions of 850°C (1560°F). Laboratory testing performed by WHC Hanford show the results of the corrosivity of the molten sodium hydroxide. PNL is also performing corrosion testing to measure the corrosion rates for carbon steel (1010 steel), 304L (stainless steel), 904L (25%Ni, 21%Cr, 4%Mo, bal Fe), Alloy 625 (nickel-base alloy), and Nickel 200 (commercially pure nickel). An interim corrosion study, ranking the above materials for corrosion performance, is expected to be completed by the end of this fiscal year.

Recent vendor information and planned development activity for 1995 indicates that at least one vendor has a calcination reactor which would not hold a molten calcine, but would react the material "on-the-fly" (Delegard et al. 1994). Under the circumstance that the reaction is conducted in the gas phase in a high velocity parallel flow system, the reactor may be water jacketed and be constructed of carbon steel.

7.2 CONTAINMENT/CONFINEMENT

Most of the major equipment depicted in Figure 5-1 will be contained in a shielded air filtered high-radiation zone under a slight vacuum relative to atmospheric pressure.

7.3 UTILITIES

Utilities include electricity and steam used by the facility for processing. Electrical consumption is not fully defined at this time due to the uncertainty associated with equipment selection. However, preliminary calculations (Appendix B) show a heating and cooling costs (including those of the plasma torch) are on the order of 6.6 MW. Evaporation in EV-3, pumpwork, and fan work were not included in this initial estimate.

8.0 OFF-STANDARD CONDITIONS

Off-standard conditions and deviations in the process variables can be expected to occur. Off-standard conditions typically result from failure of process equipment or instrumentation. The general response to failure of equipment or instrumentation is to interrupt operations and repair or replace the failed item. Since the feed is sampled, analyzed, and adjusted prior to processing, the stream conditions are well established at the start of the process.

8.1 EVAPORATOR

Some off-standard conditions expected in the feed evaporator/concentrator (EV-3) include high temperature, low vacuum, high liquid level, and low liquid level. High temperature in the evaporator occurs due to over-concentration or loss of vacuum. If over-concentration is occurring, the steam flow to the evaporator is reduced and the concentrated product flow rate is effectively increased. If vacuum is lost or reduced, the temperature in the evaporator increases. Vacuum is recovered to reduce the temperature. Vacuum is recovered by increasing the water flow to the condenser or reducing steam to the evaporator.

A high liquid level would result from a loss of product flow from the evaporator. Increasing product flow reduces the liquid level. A plugged product line would also result in a high liquid level. Interruption of processing would be required to unplug the line. A low liquid level would result from loss of feed flow or a high steam flow rate or a high product rate. The low liquid level is corrected by restoring feed flow or reducing steam flow or reducing the product rate.

8.2 CALCINER

Off-standard conditions expected in the calciner (C-5) are similar to those in the evaporator, including high temperature or low temperature and high pressure. In the quench tank, high or low temperature and high or low liquid level are expected off-standard conditions.

In the calciner, high or low temperatures are adjusted by changing the power to the plasma arc. High pressure, without any other off-standard conditions such as high temperature, is corrected by reducing the feed flow rate.

In the quench tank, high and low temperature are corrected by adjusting the addition of make-up water. The liquid level is adjusted by increasing or decreasing the flow rate to the product receiver tank. A high liquid level could be caused by a failed pump. In this instance, processing would be interrupted to repair/replace the pump or a switch could be made to a redundant pump system, if provided. Some of the more crucial operations with potential for high failure rates, such as the pumps to and from the evaporator and calciner may require redundant systems to achieve the desired on-line efficiency.

8.3 OTHER EQUIPMENT

In the offgas system, off-standard conditions include: high or low temperatures, high differential pressures, high or low flow, and high radiation readings. High temperatures in condensers are corrected by increasing the flow of cooling water. Low temperatures in heaters are corrected by decreasing flow rates, increasing power to the heaters, or heater replacement.

High differential pressures in demisters and filters, caused by partial plugging, require reduction in flow rates or flushing/replacement.

High or low flows result from several causes. High flow may result from failures in process equipment causing air in-leakage. Finding and repairing the source of the leak is required to reduce the high flow rates. Low flow rates are caused by plugging of lines or the failure of a blower. Unplugging the line or repairing the blower recovers the offgas flow rate.

High radiation readings from the offgas system result from process upsets in the evaporator/calcliner/other equipment or the failure of the scrubber/demister/filters. A common response is to shutdown the system, followed by a review of process operations to determine the source of the high readings. Replacement of equipment or a change in process conditions is required correct the high readings.

9.0 SAFETY AND REGULATORY CONSIDERATIONS

The following are identified as general areas of safety concern (1) safety aspects of the process, (2) equipment design to minimize leaks, (3) facility layout to minimize worker exposure, and (4) process design to minimize waste. A brief discussion of these concerns are addressed in the following sections.

9.1 SAFETY ASPECTS OF THE CALCINATION PROCESS

In this section, the acute releases as a result of accidents are determined. Accidents are defined as those events that are "not expected to occur during the life of the plant." Assumed worst case accidents for the proposed facility have been postulated and a dose consequence presented.

The consequences of the worst-case accidents can be used in evaluating the safety of the proposed equipment. The consequences of potential accidents can be compared against risk acceptance guidelines. If the consequences are too high, an alternative technology or modification to the proposed flowsheet should be developed.

9.1.1 Risk Acceptance Guidelines

'Risk acceptance' guidelines take two forms. The first is usually called a siting guideline. An example of a siting guideline is Section 100.11 of Title 10 of the *Code of Federal Regulations* (10 CFR 100). The purpose of the siting guideline is to ensure that the facility is located so that even if a major accident occurred, the dose consequences to the maximally exposed individual under the most adverse meteorological conditions would not exceed the 'once-in-a-lifetime' accidental or emergency dose for radiation workers (10 CFR 100, Section 100.11).

The U.S. Department of Energy also specifies a siting guideline. *General Design Criteria*, DOE Order 6430.1A, specifies, in Section 0200-1.2 and -1.3, that the maximum dose to offsite individuals shall not exceed 25 rem to the whole body. These limits are the same as those found in 10 CFR 100. Also, 10 CFR 100 states that the siting guidance is not meant to imply that these doses are acceptable but meant to be values that can be used to evaluate sites with respect to very low probability events.

The second type of 'risk acceptance' guideline is the one used for determining if the consequences of accidents at existing facilities are acceptable.

Potential accidents for the calcination process include: (1) high-pressure failure due to solids plugging, (2) explosion potential due to molten hydroxide/water contact within the calciner, and (3) explosion potential due to generation of combustible gases. These accidents are discussed below.

1. Fluid velocity must be maintained to prevent plugging waste feed lines. Secondary containment areas will be constructed

with leak detection and offgas control. The evaporator can be pressurized by (1) adding too much steam when attempting to bring the concentrator to the boiling or operational temperature and cause the concentrator to heat unevenly or a high steam flow may result in an offgas rate which exceeds the capacity of the vessel vent system, and (2) adding chemicals too quickly while the concentrator is running.

2. The calcining system operates at approximately atmospheric pressure. However, if there were a very rapid oxidation reaction in the calciner (or possibly calciner feed tank), a surge tank or pressure relief system may be necessary. The temperature and pressure of the plasma arc calciner must be monitored closely to prevent the loss of control of the oxidation reaction. If molten salt is added to the water in large quantities, a layer will form, trapping the water, producing steam, and can eventually result in a steam explosion. This can be resolved by using a steam jet to disperse the molten salt into small droplets and by slowly quenching the stream to a total dissolution.
3. The pressure in the offgas must be monitored to prevent operation with a plugged offgas line which could cause over-pressurization of the calciner.
4. Formation of the explosive solid, NH_4NO_3 , by reactions of gas components are possible, but unlikely, at sampling points for the NO_x reactor. The likelihood of formation is dependent on the reaction kinetics associated with the catalytic reactor and the cooler temperatures expected at the sampling point. The gas sample must be maintained at a temperature above the NH_4NO_3 disassociation temperature (nominally 210°C [410°F]) or the sample must be diluted.

9.1.2 Consequence Determination--Maximum Individual Doses

Information provided in Boomer *et al.* (1993) provides the consequences of worst-case accidents. The consequences were determined using the GENII computer code (Napier *et al.* 1988). Offsite whole body doses from the inhalation, ingestion, submersion, and ground shine pathway were determined. The dose presented in the document (Boomer *et al.* 1993) caused by the incineration process is applicable to this flowsheet process. The consequences are 1 E-4 rem .

The thermal processing (calcination at $800\text{--}1000^\circ\text{C}$ [$1470\text{--}1830^\circ\text{F}$]) is conducted in a closed system. The decomposition reactions do not appear to pose any unusual safety concerns. The treatment process will require close monitoring and tight control of the entire process to carry out the reactions safely. The release of oxides of nitrogen, sulfur, volatile cesium and technetium will require offgas treatment with the proper controls. Reduction of offgas stream

temperature in the quench will significantly control volatile component losses. The system design should assure the treatment process can be operated safely.

9.2 EQUIPMENT DESIGN TO MINIMIZE LEAKS

All process equipment will be made of the appropriate material of construction and wall thickness to withstand the conditions. All piping joints will be welded whenever possible. Areas with leak potential will have secondary containment units as well as leak detectors.

9.3 FACILITY LAYOUT TO MINIMIZE WORKER EXPOSURE

All equipment that will contain radioactive material will be within secondary containment to shield workers. This will be equipped with leak detectors, radiation shielding, and measures to prevent contamination of others areas of the facility.

9.4 PROCESS DESIGN TO MINIMIZE WASTE

The water and chemicals used in this process will be carefully monitored for efficiency so the amount of new waste can be kept at a minimum. The water used in the system will also be recycled to reduce overall contaminated quantity. Specific points of recycle are those of streams 12 and 48 (see Figure 5-1, Sheet 1), each of which may accept condensate from the evaporator. In such case, however, condensate storage should be considered in the event that the evaporator does not operate continuously.

9.5 ENVIRONMENTAL CONSIDERATIONS

Radionuclides will be emitted into the atmosphere during normal operations and must be kept within the levels of acceptable radiation exposure according to regulations. The offgas system will be closely monitored to maintain a level that complies with the National Emissions Standards for Hazardous Air Pollutants (Section 112) regulations. The offgas system must maintain a rate of release of radioactive materials at the lowest practical level consistent with current technology. Tritiated water should provide the greatest portion of a committed dose consequence from this process as the process will release approximately 3,300 kg of water daily to the atmosphere (Hendrickson 1992 and WHC 1991). With the exception of tritiated water the release can be managed by careful control and continuous monitoring of the offgas. HEPA filters with automatic closure will be used to control the pressure.

Leakage of hazardous material into the soil is possible because of accidents and other unexpected problems. Close monitoring of all systems will detect leaks which can be attended to promptly to prevent contamination of a large area.

Some of the gases formed in the calciner are hazardous and pose a threat to the environment when there is no downstream scrubbing and NO₂ treatment

systems. The calciner, although expected to operate at slightly subatmospheric pressures, must be monitored closely for gas leakage to prevent contamination of the atmosphere.

9.6 REGULATORY CONSIDERATIONS

Waste treatment programs have not yet definitized final product acceptance standards with regard to radionuclide content. The Nuclear Regulatory Commission standards extant on waste classification (10 CFR 61.55) would prohibit the Department of Energy disposal of materials with a transuranic composition of greater than 3.7×10^{12} Bq/g (100 nCi/g) in near-surface disposal units.

Organic constituents in aqueous solutions may be a potential problem depending on the final criteria selection. Chelating agents such as oxalic acid (and oxalates), citric acid (and citrates), and salts of EDTA have been specifically identified by vendors as having the potential to cause problems with cement solidification of low-level wastes (NRC 1991). If other tanks are selected for organic destruction beyond those previously listed for resolution of safety concerns, the flowsheet throughput would need to be modified to provide organic destruction for additional tank waste.

The requirements for National Environmental Policy Act (NEPA⁴) documentation and hazardous waste status are not detailed in this report. As the State of Washington maintains delegation for federal hazardous waste regulations (WAC 173-303), standards for treatment and disposal must be met. A variety of strategies for providing adequate permitting are expected.

9.7 HEALTH

All applicable Occupational Safety and Health Administration safety laws will be complied with during construction and operation of the facility. Protective clothing and equipment will be provided to all workers as the job requires. Offsite and onsite radioactive dose will remain below the dose limit allowed by health and safety regulations. Accumulated radiation exposure of individual workers will not exceed the yearly limit (400 mrem/year for radiation workers and 40 mrem/year for nonradiation workers). For workers who rarely enter radiation zones (clerical staff, administrative personnel), the limit is assumed to be 7 mrem/year (Boomer *et al.* 1993).

9.8 CHEMICAL CONSIDERATIONS

It is assumed the facility will contain common acids and bases, e.g. nitric acid, sodium hydroxide, and liquid ammonia (used in the NO₂ reactor). Workers will be trained in the handling of hazardous chemicals and the wearing of protective clothing.

⁴ 42 U.S.C. § 4321 *et seq.*

9.8 CHEMICAL CONSIDERATIONS

It is assumed the facility will contain common acids and bases, e.g. nitric acid, sodium hydroxide, and liquid ammonia (used in the NO₂ reactor). Workers will be trained in the handling of hazardous chemicals and the wearing of protective clothing.

9.9 MECHANICAL CONSIDERATIONS

All equipment with mechanical potential danger to the environment or workers will be appropriately guarded or within secondary containment units and will not be directly accessible to workers. Safety devices which detect mechanical failure within the facility will be monitored at all times. The system will be designed so that a rupture of the plasma arc calciner will not exceed the capacity of the cell offgas system.

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10.0 ESSENTIAL CHEMICALS

The process will require ammonia storage to provide ammonia to the NO_x reactor. The feed tank, TK-301, is designed to hold approximately 1900 L (500 gal) of liquid ammonia. Water and caustic addition may be required but specific volumes have not yet been defined. If the ammonia stored is an aqueous solution the water will be knocked out in condenser EC-17 and sent via stream 40 to the liquid waste collection tank, TK-9. Slight additional cooling would be required in the condenser.

Presently undefined, chemical addition streams (8 and 30) (see Figure 5-1, Sheet 1) have been associated with the waste evaporator and product receiver tank, respectively. Chemical addition in stream 8 may be in the form of caustic or nitrate solutions for evaporator operation improvement.

Chemical addition in stream 30, is perceived to have a much greater role in product acceptance than that of stream 8 as it would be expected to add a flocculant. Specifically, recent work (Delegard *et al.* 1993) in material solubilities leads one to believe that the highly oxidative environment of the calciner may yield plutonium in the highly soluble forms of Pu(V) and Pu(VI). Additional concerns of neptunium solubility due to this oxidation also exist. Future solubility work is intended to define appropriate precipitating agents for the plutonium and neptunium while leaving chromium in solution; however, it is currently believed that trace addition of hydroxylamine should suffice to precipitate these materials and improve material separations capability.

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11.0 REFERENCES

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12.0 ACKNOWLEDGEMENTS

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APPENDIX A SUMMARY DATA - Plasma Arc Calcination Process

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STREAM NAME	1	2	3	4	5	6	7	8	9	9a
LIQUID COMPONENTS										
Volume Flow (L/D)	1.09 E+05	5.45 E+04	5.45 E+04	5.45 E+04	5.45 E+04	1.09 E+05	1.09 E+05			
Specific Gravity	1.15 E+00									
Total Flow (Kg/D)	1.25 E+05	6.26 E+04	6.26 E+04	6.26 E+04	6.26 E+04	1.25 E+05	1.25 E+05		8.72 E+04	2.62 E+05
O2										
F2										
I2										
N2										2.07 E+03
NO2										
CO										5.50 E+02
SO2										
Al+3	6.74 E+02	3.37 E+02	3.37 E+02	3.37 E+02	3.37 E+02	6.74 E+02	6.74 E+02			
B+3	8.93 E-01	4.47 E-01	4.47 E-01	4.47 E-01	4.47 E-01	8.93 E-01	8.93 E-01			
Ba+2	6.20 E-01	3.10 E-01	3.10 E-01	3.10 E-01	3.10 E-01	6.20 E-01	6.20 E-01			
Ca+2	8.85 E+00	4.43 E+00	4.43 E+00	4.43 E+00	4.43 E+00	8.85 E+00	8.85 E+00			
Cr+3	3.10 E+01	1.55 E+01	1.55 E+01	1.55 E+01	1.55 E+01	3.10 E+01	3.10 E+01			
Cs+	1.89 E-01	9.44 E-02	9.44 E-02	9.44 E-02	9.44 E-02	1.89 E-01	1.89 E-01			
Fe+3	3.50 E+01	1.75 E+01	1.75 E+01	1.75 E+01	1.75 E+01	3.50 E+01	3.50 E+01			
K+	3.96 E+01	1.98 E+01	1.98 E+01	1.98 E+01	1.98 E+01	3.96 E+01	3.96 E+01			
La+3	5.09 E+00	2.55 E+00	2.55 E+00	2.55 E+00	2.55 E+00	5.09 E+00	5.09 E+00			
Mg+2	3.76 E+00	1.88 E+00	1.88 E+00	1.88 E+00	1.88 E+00	3.76 E+00	3.76 E+00			
Mn+6	6.11 E+00	3.05 E+00	3.05 E+00	3.05 E+00	3.05 E+00	6.11 E+00	6.11 E+00			
Na+	5.69 E+03	2.85 E+03	2.85 E+03	2.85 E+03	2.85 E+03	5.69 E+03	5.69 E+03			
Ni+3	7.15 E+00	3.57 E+00	3.57 E+00	3.57 E+00	3.57 E+00	7.15 E+00	7.15 E+00			
Sr+2	3.29 E-02	1.65 E-02	1.65 E-02	1.65 E-02	1.65 E-02	3.29 E-02	3.29 E-02			
UO2+2	7.76 E-02	3.88 E-02	3.88 E-02	3.88 E-02	3.88 E-02	7.76 E-02	7.76 E-02			
Zn+2	1.20 E+00	6.01 E-01	6.01 E-01	6.01 E-01	6.01 E-01	1.20 E+00	1.20 E+00			
Cl-	1.40 E+02	7.02 E+01	7.02 E+01	7.02 E+01	7.02 E+01	1.40 E+02	1.40 E+02			
CO3-2	9.65 E+02	4.82 E+02	4.82 E+02	4.82 E+02	4.82 E+02	9.65 E+02	9.65 E+02			
F-	4.95 E+01	2.48 E+01	2.48 E+01	2.48 E+01	2.48 E+01	4.95 E+01	4.95 E+01			
I-	5.04 E-04	2.52 E-04	2.52 E-04	2.52 E-04	2.52 E-04	5.04 E-04	5.04 E-04			
NO2-	1.06 E+03	5.28 E+02	5.28 E+02	5.28 E+02	5.28 E+02	1.06 E+03	1.06 E+03			
NO3-	5.28 E+03	2.64 E+03	2.64 E+03	2.64 E+03	2.64 E+03	5.28 E+03	5.28 E+03			
OH-	2.97 E+03	1.49 E+03	1.49 E+03	1.49 E+03	1.49 E+03	2.97 E+03	2.97 E+03			
PO4-3	1.38 E+02	6.89 E+01	6.89 E+01	6.89 E+01	6.89 E+01	1.38 E+02	1.38 E+02			
SO4-2	1.68 E+02	8.42 E+01	8.42 E+01	8.42 E+01	8.42 E+01	1.68 E+02	1.68 E+02			
TcO4-	1.17 E+00	5.88 E-01	5.88 E-01	5.88 E-01	5.88 E-01	1.17 E+00	1.17 E+00			
H2O	1.06 E+05	5.32 E+04	5.32 E+04	5.32 E+04	5.32 E+04	1.06 E+05	1.06 E+05		8.72 E+04	
M+O2	1.42 E+01	7.08 E+00	7.08 E+00	7.08 E+00	7.08 E+00	1.42 E+01	1.42 E+01			
Organic Carbon	1.49 E+03	7.45 E+02	7.45 E+02	7.45 E+02	7.45 E+02	1.49 E+03	1.49 E+03			
ZrO2+2H2O	2.11 E+00	1.05 E+00	1.05 E+00	1.05 E+00	1.05 E+00	2.11 E+00	2.11 E+00			
PA5										
Ammonia										
Cs-Ba 137 (Bq/D)	6.07 E+14	3.03 E+14	3.03 E+14	3.03 E+14	3.03 E+14	6.07 E+14	6.07 E+14			
Sr-Y 90 (Bq/D)	1.69 E+14	8.47 E+13	8.47 E+13	8.47 E+13	8.47 E+13	1.69 E+14	1.69 E+14			
Tc 99 (Bq/D)	4.51 E+11	2.25 E+11	2.25 E+11	2.25 E+11	2.25 E+11	4.51 E+11	4.51 E+11			
Pu (Bq/D)	1.75 E+11	8.73 E+10	8.73 E+10	8.73 E+10	8.73 E+10	1.75 E+11	1.75 E+11			
Am (Bq/D)	5.85 E+11	2.92 E+11	2.92 E+11	2.92 E+11	2.92 E+11	5.85 E+11	5.85 E+11			

STREAM NAME	1	2	3	4	5	6	7	8	9	9a
SOLID COMPONENTS										
Total Flow (Kg/D)	3.87 E+02	1.93 E+02	1.93 E+02	1.93 E+02	1.93 E+02	3.87 E+02	3.87 E+02			
Al+3	3.55 E+01	1.77 E+01	1.77 E+01	1.77 E+01	1.77 E+01	3.55 E+01	3.55 E+01			
B+3	4.71 E-02	2.35 E-02	2.35 E-02	2.35 E-02	2.35 E-02	4.71 E-02	4.71 E-02			
Ba+2	6.89 E-02	3.44 E-02	3.44 E-02	3.44 E-02	3.44 E-02	6.89 E-02	6.89 E-02			
Ca+2	9.84 E-01	4.92 E-01	4.92 E-01	4.92 E-01	4.92 E-01	9.84 E-01	9.84 E-01			
Cr+3	1.63 E+00	8.17 E-01	8.17 E-01	8.17 E-01	8.17 E-01	1.63 E+00	1.63 E+00			
Cs+	2.09 E-02	1.05 E-02	1.05 E-02	1.05 E-02	1.05 E-02	2.09 E-02	2.09 E-02			
Fe+3	1.84 E+00	9.19 E-01	9.19 E-01	9.19 E-01	9.19 E-01	1.84 E+00	1.84 E+00			
K+	3.99 E-01	2.00 E-01	2.00 E-01	2.00 E-01	2.00 E-01	3.99 E-01	3.99 E-01			
La+3	5.65 E-01	2.83 E-01	2.83 E-01	2.83 E-01	2.83 E-01	5.65 E-01	5.65 E-01			
Mg+2	4.19 E-01	2.09 E-01	2.09 E-01	2.09 E-01	2.09 E-01	4.19 E-01	4.19 E-01			
Mo+6	3.22 E-01	1.61 E-01	1.61 E-01	1.61 E-01	1.61 E-01	3.22 E-01	3.22 E-01			
Na+	5.75 E+01	2.88 E+01	2.88 E+01	2.88 E+01	2.88 E+01	5.75 E+01	5.75 E+01			
Ni+3	3.76 E-01	1.88 E-01	1.88 E-01	1.88 E-01	1.88 E-01	3.76 E-01	3.76 E-01			
Si+4	3.94 E+01	1.97 E+01	1.97 E+01	1.97 E+01	1.97 E+01	3.94 E+01	3.94 E+01			
Sr+2	1.74 E-03	8.68 E-04	8.68 E-04	8.68 E-04	8.68 E-04	1.74 E-03	1.74 E-03			
UD+2	4.08 E-03	2.04 E-03	2.04 E-03	2.04 E-03	2.04 E-03	4.08 E-03	4.08 E-03			
Zn+2	1.34 E-01	6.70 E-02	6.70 E-02	6.70 E-02	6.70 E-02	1.34 E-01	1.34 E-01			
Cl-	1.40 E-01	7.02 E-02	7.02 E-02	7.02 E-02	7.02 E-02	1.40 E-01	1.40 E-01			
OS-2	9.66 E-01	4.83 E-01	4.83 E-01	4.83 E-01	4.83 E-01	9.66 E-01	9.66 E-01			
F-	4.96 E-02	2.48 E-02	2.48 E-02	2.48 E-02	2.48 E-02	4.96 E-02	4.96 E-02			
I-	5.04 E-04	2.52 E-04	2.52 E-04	2.52 E-04	2.52 E-04	5.04 E-04	5.04 E-04			
NO2-	1.05 E+00	5.28 E-01	5.28 E-01	5.28 E-01	5.28 E-01	1.05 E+00	1.05 E+00			
NO3-	5.30 E+00	2.65 E+00	2.65 E+00	2.65 E+00	2.65 E+00	5.30 E+00	5.30 E+00			
OH-	2.08 E+02	1.04 E+02	1.04 E+02	1.04 E+02	1.04 E+02	2.08 E+02	2.08 E+02			
PO4-3	1.38 E-01	6.89 E-02	6.89 E-02	6.89 E-02	6.89 E-02	1.38 E-01	1.38 E-01			
SO4-2	1.68 E-01	8.42 E-02	8.42 E-02	8.42 E-02	8.42 E-02	1.68 E-01	1.68 E-01			
ToO4-	6.19 E-02	3.09 E-02	3.09 E-02	3.09 E-02	3.09 E-02	6.19 E-02	6.19 E-02			
MnO2	7.44 E-01	3.72 E-01	3.72 E-01	3.72 E-01	3.72 E-01	7.44 E-01	7.44 E-01			
Organic Carbon	3.04 E+01	1.52 E+01	1.52 E+01	1.52 E+01	1.52 E+01	3.04 E+01	3.04 E+01			
ZrO2-2H2O	2.34 E-01	1.17 E-01	1.17 E-01	1.17 E-01	1.17 E-01	2.34 E-01	2.34 E-01			
Al2O3										
Am2O3										
B2O3										
BaO										
CaO										
Cr2O3										
Cs2O										
Fe2O3										
K2O										
La2O3										
MgO										
MnO3										
Na2O										
Ni2O3										
P2O5										
PuO2										
SiO2										
SO										
Tc2O7										
U3O8										
ZnO										
ZrO2										
Cs-Ba 137 (Bq/D)	6.70 E+13	3.35 E+13	3.35 E+13	3.35 E+13	3.35 E+13	6.70 E+13	6.70 E+13			
Sr-Y 90 (Bq/D)	8.92 E+12	4.48 E+12	4.48 E+12	4.48 E+12	4.48 E+12	8.92 E+12	8.92 E+12			
Tc 99 (Bq/D)	2.37 E+10	1.19 E+10	1.19 E+10	1.19 E+10	1.19 E+10	2.37 E+10	2.37 E+10			
Pu (Bq/D)	9.21 E+09	4.59 E+09	4.59 E+09	4.59 E+09	4.59 E+09	9.21 E+09	9.21 E+09			
Am (Bq/D)	3.08 E+10	1.54 E+10	1.54 E+10	1.54 E+10	1.54 E+10	3.08 E+10	3.08 E+10			

STREAM NAME	10	11	12	12a	13	14	15	16	17	18
LIQUID COMPONENTS										
Volume Flow (L/D)	2.18 E+04	2.18 E+04	6.55 E+04		7.41 E+04	4.03 E+04			1.56 E+04	
Specific Gravity	1.74 E+00	1.74 E+00	1.00 E+00		1.33 E+00	1.33 E+00			1.04 E+00	
Total Flow (Kg/D)	3.80 E+04	3.80 E+04	6.55 E+04	4.46 E+04	1.02 E+05	5.62 E+04	1.01 E+05	9.23 E+04	1.62 E+04	9.09 E+04
CO2							1.11 E+02	1.11 E+02	5.50 E+01	5.55 E-01
F2							4.96 E+01	4.96 E+01	4.91 E+01	4.96 E-01
I2							1.01 E-03	1.01 E-03	9.98 E-04	1.01 E-05
N2				3.42 E+04			3.56 E+04	3.56 E+04		3.56 E+04
NO2							1.55 E+02	1.55 E+02		7.74 E+01
O2				1.04 E+04			1.27 E+04	1.27 E+04		1.26 E+04
SO2							4.50 E+00	4.50 E+00	2.23 E+00	2.23 E-02
Al+3	6.74 E+02	6.74 E+02			1.10 E+03	6.07 E+02				
B+3	8.93 E-01	8.93 E-01								
Ba+2	6.20 E-01	6.20 E-01								
Ca+2	8.85 E+00	8.85 E+00								
Cr+3	3.10 E+01	3.10 E+01			7.18 E+01	3.95 E+01				
Cs+	1.89 E-01	1.89 E-01			4.61 E-01	2.54 E-01				
Fe+3	3.50 E+01	3.50 E+01								
K+	3.96 E+01	3.96 E+01			8.79 E+01	4.83 E+01				
La+3	5.09 E+00	5.09 E+00								
Mg+2	3.76 E+00	3.76 E+00								
Mn+6	6.11 E+00	6.11 E+00								
Na+	5.69 E+03	5.69 E+03			1.27 E+04	6.96 E+03				
Ni+3	7.15 E+00	7.15 E+00								
Sn+2	3.29 E-02	3.29 E-02								
UO2+2	7.76 E-02	7.76 E-02								
Zn+2	1.20 E+00	1.20 E+00								
Cl-	1.40 E+02	1.40 E+02			3.12 E+02	1.72 E+02				
CO3-2	9.65 E+02	9.65 E+02			8.03 E+03	4.44 E+03			7.50 E+01	7.57 E-01
F-	4.95 E+01	4.95 E+01								
I-	5.04 E-04	5.04 E-04								
NO2-	1.06 E+03	1.06 E+03			9.75 E+01	5.36 E+01	9.75 E+01	9.75 E+01	9.66 E+01	9.75 E-01
NO3-	5.28 E+03	5.28 E+03			3.26 E+02	1.79 E+02	3.26 E+02	3.26 E+02	4.26 E+02	4.30 E+00
OH-	2.97 E+03	2.97 E+03			4.69 E+03	2.58 E+03				
PO4-3	1.33 E+02	1.33 E+02								
SO4-2	1.68 E+02	1.68 E+02			3.60 E+02	1.98 E+02			3.34 E+00	3.37 E-02
TcO4-	1.17 E+00	1.17 E+00								
H2O	1.92 E+04	1.92 E+04	6.55 E+04		7.41 E+04	4.03 E+04	5.18 E+04	4.32 E+04	1.54 E+04	4.26 E+04
HClO2	1.42 E+01	1.42 E+01			3.15 E+01	1.73 E+01				
Organic Carbon	1.49 E+03	1.49 E+03			3.31 E+01	1.82 E+01				
ZnO2+2H2O	2.11 E+00	2.11 E+00								
P2O5					1.47 E+02	8.09 E+01	3.68 E+01	3.68 E+01	3.64 E+01	3.68 E-01
Ammonia										
Cs-Ba 137 (Bq/D)	6.07 E+14	6.07 E+14			1.48 E+15	8.14 E+14				
Sr-Y 90 (Bq/D)	1.69 E+14	1.69 E+14								
Tc 99 (Bq/D)	4.51 E+11	4.51 E+11								
Pu (Bq/D)	1.75 E+11	1.75 E+11								
Am (Bq/D)	5.85 E+11	5.85 E+11								

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STREAM NAME	10	11	12	12a	13	14	15	16	17	18
SLID COMPONENTS	3.87 E+02	3.87 E+02	1.49 E+03	8.21 E+02	2.99 E+00	1.50 E+00	1.48 E+00	1.50 E+02		
Total Flow (kg/d)										
Al+3	3.55 E+01	3.55 E+01	4.71 E+02	6.89 E+02	9.84 E+01	1.63 E+00	1.63 E+00	1.63 E+00		
Ca+2	6.89 E+02	6.89 E+02	4.71 E+02	6.89 E+02	9.84 E+01	1.63 E+00	1.63 E+00	1.63 E+00		
Ca+2	9.84 E+01	9.84 E+01	1.63 E+00							
Ca+2	1.63 E+00									
Ca+2	2.09 E+02	2.09 E+02	1.84 E+00							
Fe+3	1.84 E+00									
K+	3.99 E+01	3.99 E+01	5.65 E+01							
La+3	5.65 E+01	5.65 E+01	4.19 E+01							
Mg+2	4.19 E+01	4.19 E+01	3.22 E+01							
NH+4	5.75 E+01	5.75 E+01	3.76 E+01							
NH+3	3.76 E+01	3.76 E+01	3.94 E+01							
Si+4	3.94 E+01	3.94 E+01	1.74 E+03	4.08 E+03	1.34 E+01	1.34 E+01	1.34 E+01	1.34 E+01		
S+2	1.74 E+03	4.08 E+03	1.34 E+01							
Li+2	4.08 E+03	1.34 E+01								
Zn+2	1.34 E+01	1.34 E+01	1.40 E+01	9.66 E+01	4.96 E+02	5.04 E+04	5.04 E+04	5.04 E+04		
Cl-	1.40 E+01	9.66 E+01	4.96 E+02	5.04 E+04						
DB-2	9.66 E+01	4.96 E+02	5.04 E+04							
F-	4.96 E+02	5.04 E+04								
I-	5.04 E+04									
NO2-	1.05 E+00									
NO3-	5.30 E+00	2.08 E+02	1.38 E+01							
OH-	2.08 E+02	1.38 E+01								
SO4-2	1.68 E+01	6.19 E+02	7.44 E+01							
TCO4-	6.19 E+02	7.44 E+01								
M+2	7.44 E+01									
Organic Carbon	3.04 E+01	6.73 E+01	3.70 E+01	1.35 E+03	6.74 E+04	6.74 E+04	6.74 E+04	6.74 E+04		
ZnO+2O2	2.34 E+01	6.73 E+01	3.70 E+01	1.35 E+03	6.74 E+04	6.74 E+04	6.74 E+04	6.74 E+04		
Al2O3	8.89 E+02	4.89 E+02	1.78 E+00	8.91 E+01	8.22 E+01	8.22 E+01	8.22 E+01	8.22 E+01		
Al2O3	1.18 E+02	6.47 E+03	2.36 E+05	1.18 E+02						
Al2O3	6.70 E+00	3.68 E+00	1.34 E+02	6.71 E+03	6.55 E+03	6.55 E+03	6.55 E+03	6.55 E+03		
FeO	1.70 E+00	9.36 E+01	3.41 E+03	1.70 E+03	1.69 E+03	1.69 E+03	1.69 E+03	1.69 E+03		
CaO	3.05 E+01	1.68 E+01	6.10 E+02	3.05 E+02						
O2O2	1.05 E+00	5.81 E+01	2.12 E+03	1.05 E+03						
CSO2	4.92 E+03	2.71 E+03	9.86 E+03	4.93 E+03	4.88 E+03	4.88 E+03	4.88 E+03	4.88 E+03		
Fe2O3	1.16 E+02	6.40 E+01	2.33 E+01	1.16 E+01	1.17 E+01	1.17 E+01	1.17 E+01	1.17 E+01		
K2O	1.07 E+00	5.86 E+01	2.13 E+03	1.07 E+03						
Li2O	1.47 E+01	8.07 E+00	2.94 E+02	1.47 E+02	1.46 E+02	1.46 E+02	1.46 E+02	1.46 E+02		
MgO	1.54 E+01	8.44 E+00	3.08 E+02	1.54 E+02	1.52 E+02	1.52 E+02	1.52 E+02	1.52 E+02		
MnO	2.14 E+01	1.17 E+01	4.28 E+02	2.14 E+02	2.12 E+02	2.12 E+02	2.12 E+02	2.12 E+02		
N2O	1.71 E+02	9.43 E+01	3.43 E+01	1.71 E+01	1.72 E+01	1.72 E+01	1.72 E+01	1.72 E+01		
Ni2O	2.35 E+01	1.29 E+01	4.70 E+02	2.35 E+02	2.33 E+02	2.33 E+02	2.33 E+02	2.33 E+02		
P2O5	2.28 E+01	1.25 E+01	4.57 E+04	2.28 E+04						
SiO2	5.49 E+02	3.02 E+02	1.10 E+04	5.50 E+04	5.45 E+04	5.45 E+04	5.45 E+04	5.45 E+04		
SIO2	1.87 E+02	1.03 E+02	3.74 E+01	1.87 E+01						
SrO	9.07 E+02	4.99 E+02	1.82 E+04	9.09 E+04	9.00 E+04	9.00 E+04	9.00 E+04	9.00 E+04		
TiO2	2.62 E+00	1.44 E+00	5.25 E+03	2.62 E+03						
UO3	1.88 E+01	1.03 E+01	3.76 E+04	1.88 E+04						
ZnO	3.68 E+00	2.02 E+00	7.37 E+03	3.69 E+03						
ZrO2	4.01 E+00	2.20 E+00	8.02 E+03	4.01 E+03						
CS-84 57 (kg/d)	6.70 E+03	6.70 E+03	8.18 E+02	2.98 E+00	1.49 E+00	1.49 E+00	1.49 E+00	1.49 E+00		
Sr+90 (kg/d)	8.22 E+02	8.22 E+02	2.16 E+04	7.88 E+01	3.92 E+01	3.92 E+01	3.92 E+01	3.92 E+01		
Tc 99 (kg/d)	2.37 E+00	2.37 E+00	1.05 E+02	2.11 E+09	1.05 E+09	1.05 E+09	1.05 E+09	1.05 E+09		
Pu (kg/d)	9.21 E+09	9.21 E+09	4.07 E+01	2.24 E+03	8.14 E+03	4.07 E+03	4.07 E+03	4.07 E+03		
Am (kg/d)	3.03 E+00	3.03 E+00	1.35 E+02	2.72 E+09	1.35 E+09	1.35 E+09	1.35 E+09	1.35 E+09		

STREAM NAME	19	20	21	22	23	24	25	26	28	29
LIQUID COMPONENTS										
Volume Flow (L/D)		3.95 E+04			5.14 E+02				3.34 E+04	3.47 E+04
Specific Gravity		1.00 E+00			1.00 E+00				1.38 E+00	1.36 E+00
Total Flow (Kg/D)	2.79 E+03	3.95 E+04	5.14 E+04	5.14 E+04	5.14 E+02	3.82 E+01	5.15 E+04	5.14 E+04	4.60 E+04	4.73 E+04
O2		5.28 E-01	2.78 E-02	1.39 E-03			1.39 E-03	6.94 E-05		
F2		4.71 E-01	2.48 E-02	1.24 E-03			1.24 E-03	6.19 E-05		
I2		9.58 E-05	5.04 E-07	2.52 E-08			2.52 E-08	1.26 E-09		
N2	2.07 E+03		3.56 E+04	3.56 E+04			3.57 E+04	3.57 E+04		
NO2			7.74 E+01	7.74 E+01			7.74 E-01	7.74 E-01		
CO2	5.50 E+02		1.26 E+04	1.26 E+04			1.26 E+04	1.26 E+04		
SO2		2.14 E-02	1.12 E-03	5.62 E-05			5.62 E-05	2.81 E-05		
Al+3									4.96 E+02	4.96 E+02
B+3										
Ba+2										
Ca+2										
Cr+3									3.23 E+01	3.23 E+01
Cs+									2.08 E-01	2.08 E-01
Fe+3										
K+									3.96 E+01	3.96 E+01
La+3										
Mg+2										
Mn+6										
Na+									5.69 E+03	5.69 E+03
Ni+3										
S+2										
UD+2										
Zn+2										
Cl-									1.41 E+02	1.41 E+02
CO3-2		7.19 E-01	3.79 E-02	1.89 E-03			1.89 E-03	9.47 E-05	3.64 E+03	3.64 E+03
F-										
I-										
NO2-		9.26 E-01	4.88 E-02	2.44 E-03			2.44 E-03	1.22 E-04	4.39 E+01	4.39 E+01
NO3-		4.09 E+00	2.15 E-01	1.08 E-02			1.08 E-02	5.38 E-04	1.47 E+02	1.47 E+02
OH-									2.11 E+03	2.11 E+03
PO4-3										
SO4-2		3.20 E-02	1.69 E-03	8.43 E-05			8.43 E-05	4.21 E-06	1.62 E+02	1.62 E+02
TcO4-										
H2O	1.68 E+02	3.95 E+04	3.09 E+03	3.09 E+03	5.14 E+02		3.15 E+03	3.09 E+03	3.34 E+04	3.47 E+04
MnO2									1.42 E+01	1.42 E+01
Organic Carbon									1.49 E+01	1.49 E+01
ZrO2-2H2O										
P2O5		3.49 E-01	1.84 E-02	9.20 E-04			9.20 E-04	4.60 E-05	6.62 E+01	6.62 E+01
Ammonia						3.82 E+01	3.82 E-01	1.91 E-02		
Cs-Ba 137 (Bq/D)									6.66 E+14	6.66 E+14
Str-90 (Bq/D)										
Tc 99 (Bq/D)										
Pu (Bq/D)										
Am (Bq/D)										

STREAM NAME	19	20	21	22	23	24	25	26	28	29
SOLID COMPONENTS										
Total Flow (kg/D)		1.50 E+02							6.72 E+02	6.72 E+02
Al+3										
B+3										
Ba+2										
Ca+2										
Cr+3										
Cs+										
Fe+3										
K+										
La+3										
Mg+2										
Mn+6										
Nb+										
Ni+3										
Si+4										
Sr+2										
UO2+2										
Zn+2										
Cl-										
CO3-2										
F-										
I-										
NO2-										
NO3-										
OH-										
PO4-3										
SO4-2										
TO4-										
M+02		1.65 E-05							7.41 E-01	7.41 E-01
Organic Carbon		6.74 E-05							3.03 E-01	3.03 E-01
ZrO2·2H2O										
Al2O3		8.91 E-03							4.00 E+02	4.00 E+02
Am2O3		1.18 E-07							5.29 E-03	5.29 E-03
B2O3		6.71 E-05							3.01 E+00	3.01 E+00
BaO		1.71 E-05							7.66 E-01	7.66 E-01
CaO		3.05 E-04							1.37 E+01	1.37 E+01
Cr2O3		1.05 E-05							4.75 E-01	4.75 E-01
Cs2O		4.93 E-03							2.21 E-03	2.21 E-03
Fe2O3		1.17 E-03							5.24 E+01	5.24 E+01
K2O		1.07 E-05							4.79 E-01	4.79 E-01
La2O3		1.47 E-04							6.60 E+00	6.60 E+00
MgO		1.54 E-04							6.91 E+00	6.91 E+00
MnO3		2.14 E-04							9.61 E+00	9.61 E+00
Nb2O		1.72 E-03							7.71 E+01	7.71 E+01
Ni2O3		2.35 E-04							1.05 E+01	1.05 E+01
P2O5		2.28 E-05							1.02 E-01	1.02 E-01
PuO2		5.50 E-07							2.47 E-02	2.47 E-02
SiO2		1.87 E-03							8.40 E+01	8.40 E+01
SrO		9.08 E-07							4.03 E-02	4.03 E-02
Tc2O7		2.62 E-05							1.18 E+00	1.18 E+00
UO3		1.88 E-05							8.45 E-02	8.45 E-02
ZnO		3.69 E-05							1.65 E+00	1.65 E+00
ZrO2		4.01 E-05							1.80 E+00	1.80 E+00
Cs-Ba 137 (Bq/D)		1.49 E+03							6.70 E+12	6.70 E+12
Sr-Y 90 (Bq/D)		3.92 E+09							1.77 E+14	1.77 E+14
Tc 99 (Bq/D)		1.05 E+07							4.74 E+11	4.74 E+11
Pu (Bq/D)		4.07 E+05							1.83 E+11	1.83 E+11
Am (Bq/D)		1.35 E+07							6.11 E+11	6.11 E+11

STREAM NAME	30	31	32	33	34	35	36	37	38	39
LIQUID COMPONENTS										
Volume Flow (L/D)	1.38 E+03			8.64 E+03	3.54 E+04	4.41 E+04	2.00 E+04	7.97 E+04	5.15 E+02	2.00 E+04
Specific Gravity	1.00 E+00			1.00 E+00	1.33 E+00	1.27 E+00	1.00 E+00	1.15 E+00	1.00 E+00	1.00 E+00
Total Flow (Kg/D)	1.38 E+03	1.50 E+02	1.50 E+02	8.64 E+03	4.72 E+04	5.58 E+04	2.00 E+04	9.20 E+04	5.15 E+02	2.00 E+04
O2							2.78 E-01	5.53 E+01	2.64 E-02	2.78 E-01
F2							2.48 E-01	4.93 E+01	2.35 E-02	2.48 E-01
I2							5.04 E-06	1.00 E-03	4.79 E-07	5.04 E-06
NO2										
SO2							1.12 E-02	2.24 E+00	1.07 E-03	1.12 E-02
Al+3		1.49 E+02	1.49 E+02		3.48 E+02	3.48 E+02		3.48 E+02		
B+3										
Ba+2										
Ca+2										
Cr+3		6.46 E-04	6.46 E-04		3.23 E+01	3.23 E+01		3.23 E+01		
Cs+		4.15 E-06	4.15 E-06	4.60 E-06	2.08 E-01	2.08 E-01		2.08 E-01		
Fe+3										
K+				8.77 E-04	3.96 E+01	3.96 E+01		3.96 E+01		
La+3										
Mg+2										
Mn+6										
Na+		1.14 E-01	1.14 E-01	1.26 E-01	5.69 E+03	5.69 E+03		5.69 E+03		
Ni+3										
S+2										
UO2+2										
Zn+2										
Cl-		2.81 E-03	2.81 E-03		1.41 E+02	1.41 E+02		1.41 E+02		
CO3-2		7.27 E-02	7.27 E-02		3.63 E+03	3.63 E+03	3.79 E-01	3.71 E+03	3.60 E-02	3.79 E-01
F-										
I-										
NO2-		8.78 E-04	8.78 E-04	1.95 E-03	4.39 E+01	4.39 E+01	4.88 E-01	1.41 E+02	4.63 E-02	4.88 E-01
NO3-		2.93 E-03	2.93 E-03	6.51 E-03	1.47 E+02	1.47 E+02	2.15 E+00	5.74 E+02	2.04 E-01	2.15 E+00
OH-		4.22 E-02	4.22 E-02	9.37 E-02	2.11 E+03	2.11 E+03		2.11 E+03		
PO4-3										
SO4-2		3.24 E-03	3.24 E-03		1.62 E+02	1.62 E+02	1.69 E-02	1.65 E+02	1.60 E-03	1.69 E-02
To4-										
H2O	1.38 E+03	6.95 E-01	6.95 E-01	8.64 E+03	3.47 E+04	4.34 E+04	2.00 E+04	7.88 E+04	5.14 E+02	2.00 E+04
H2O2					1.42 E+01	1.42 E+01		1.42 E+01		
Organic Carbon		2.98 E-04	2.98 E-04		1.49 E+01	1.49 E+01		1.49 E+01		
ZrO2+2H2O										
P2O5		1.32 E-03	1.32 E-03	7.36 E-04	6.62 E+01	6.62 E+01	1.84 E-01	1.03 E+02	1.75 E-02	1.84 E-01
Ammonia							1.82 E-01	1.82 E-01		1.82 E-01
Cs-Ba 137 (Bq/D)		1.33 E+10	1.33 E+10	1.48 E+10	6.66 E+14	6.66 E+14		6.66 E+14		
Sr-Y 90 (Bq/D)										
Tc 99 (Bq/D)										
Pu (Bq/D)										
Am (Bq/D)										

STREAM NAME	30	31	32	33	34	35	36	37	38	39
SOLID COMPONENTS										
Total Flow (Kg/D)		3.89 E+02	3.89 E+02	1.33 E+03	2.83 E+02	2.84 E+02	7.48 E-03	2.86 E+02		7.48 E-03
Al+3										
B+3										
Ba+2										
Ca+2										
Cr+3										
Cs+										
Fe+3										
K+										
La+3										
Mg+2										
Mn+6										
Na+										
Ni+3										
Si+4										
Sr+2										
UO2+2										
Zn+2										
Cl-										
CO3-2										
F-										
I-										
NO2-										
NO3-										
OH-										
PO4-3										
SO4-2										
TO4-										
MnO2		7.33 E-01	7.33 E-01	1.65 E-03	7.41 E-03	9.05 E-03	8.24 E-06	1.07 E-02		8.24 E-06
Organic Carbon		3.00 E-01	3.00 E-01	6.74 E-04	3.03 E-03	3.70 E-03	3.37 E-06	4.37 E-03		3.37 E-06
ZnO:ZnO										
Al2O3		1.20 E+02	1.20 E+02	8.91 E+01	2.80 E+02	2.81 E+02	4.46 E-03	2.82 E+02		4.46 E-03
Am2O3		5.24 E-03	5.24 E-03	1.18 E-05	5.29 E-05	6.47 E-05	5.89 E-03	7.64 E-05		5.89 E-03
B2O3		2.98 E+00	2.98 E+00	6.71 E-03	3.01 E-02	3.69 E-02	3.36 E-05	4.35 E-02		3.36 E-05
BaO		7.58 E+01	7.58 E+01	1.70 E-03	7.66 E-03	9.36 E-03	8.53 E-06	1.11 E-02		8.53 E-06
CaO		1.36 E+01	1.36 E+01	3.05 E-02	1.37 E-01	1.68 E-01	1.53 E-04	1.98 E-01		1.53 E-04
Cr2O3		4.70 E-01	4.70 E-01	1.05 E-03	4.75 E-03	5.81 E-03	5.29 E-06	6.86 E-03		5.29 E-06
Cs2O		2.19 E-03	2.19 E-03	4.93 E-03	2.21 E-05	2.22 E-05	2.46 E-03	2.71 E-05		2.46 E-03
Fe2O3		5.19 E+01	5.19 E+01	1.17 E-01	5.24 E-01	6.40 E-01	5.83 E-04	7.57 E-01		5.83 E-04
K2O		4.74 E-01	4.74 E-01	1.07 E-05	4.79 E-03	4.80 E-03	5.33 E-06	5.86 E-03		5.33 E-06
La2O3		6.54 E+00	6.54 E+00	1.47 E-02	6.60 E-02	8.03 E-02	7.35 E-05	9.54 E-02		7.35 E-05
MgO		6.84 E+00	6.84 E+00	1.54 E-02	6.90 E-02	8.44 E-02	7.69 E-05	9.97 E-02		7.69 E-05
MnO3		9.51 E+00	9.51 E+00	2.14 E-02	9.61 E-02	1.17 E-01	1.07 E-04	1.39 E-01		1.07 E-04
Na2O		7.64 E+01	7.64 E+01	1.72 E-03	7.71 E-01	7.73 E-01	8.59 E-04	9.44 E-01		8.59 E-04
Ni2O3		1.04 E+01	1.04 E+01	2.35 E-02	1.05 E-01	1.29 E-01	1.17 E-04	1.52 E-01		1.17 E-04
P2O5		1.01 E-01	1.01 E-01	2.28 E-04	1.03 E-03	1.23 E-03	1.14 E-06	1.48 E-03		1.14 E-06
PbO2		2.45 E-02	2.45 E-02	5.50 E-05	2.47 E-04	3.02 E-04	2.75 E-07	3.57 E-04		2.75 E-07
SiO2		8.31 E+01	8.31 E+01	1.87 E-01	8.40 E-01	1.03 E+00	9.35 E-04	1.21 E+00		9.35 E-04
SrO		4.04 E-02	4.04 E-02	9.09 E-05	4.03 E-04	4.99 E-04	4.54 E-07	5.89 E-04		4.54 E-07
Tc2O7		1.17 E+00	1.17 E+00	2.62 E-03	1.18 E-02	1.44 E-02	1.31 E-05	1.70 E-02		1.31 E-05
UO3		8.37 E-02	8.37 E-02	1.88 E-04	8.45 E-04	1.03 E-03	9.41 E-07	1.22 E-03		9.41 E-07
ZnO		1.64 E+00	1.64 E+00	3.69 E-03	1.66 E-02	2.02 E-02	1.84 E-05	2.39 E-02		1.84 E-05
ZrO2		1.78 E+00	1.78 E+00	4.01 E-03	1.80 E-02	2.20 E-02	2.01 E-05	2.60 E-02		2.01 E-05
Cs-Ba 137 (Bq/D)		6.62 E+12	6.62 E+12	1.49 E+03	6.70 E+10	6.70 E+10	7.44 E+07	8.18 E+10		7.44 E+07
Sr-Y 90 (Bq/D)		1.75 E+14	1.75 E+14	3.92 E+11	1.77 E+12	2.16 E+12	1.97 E+09	2.56 E+12		1.97 E+09
Tc 99 (Bq/D)		4.66 E+11	4.66 E+11	1.05 E+09	4.74 E+09	5.77 E+09	5.25 E+06	6.81 E+09		5.25 E+06
Pu (Bq/D)		1.81 E+11	1.81 E+11	4.07 E+03	1.83 E+09	2.24 E+09	2.04 E+06	2.65 E+09		2.04 E+06
Am (Bq/D)		6.07 E+11	6.07 E+11	1.35 E+09	6.11 E+09	7.47 E+09	6.81 E+06	8.81 E+09		6.81 E+06

STREAM NAME	40	41	42	43	44	45	47	48	49	50
LIQUID COMPONENTS										
Volume Flow (L/D)	6.18 E+01	3.95 E+04	8.71 E+04				2.00 E+04	1.48 E+04	1.48 E+04	7.23 E+04
Specific Gravity	1.00 E+00	1.00 E+00	1.00 E+00				1.00 E+00	1.00 E+00	1.00 E+00	1.00 E+00
Total Flow (Kg/D)	6.18 E+01	3.95 E+04	8.71 E+04	5.42 E+04		5.42 E+04	2.00 E+04	1.48 E+04	1.48 E+04	7.23 E+04
O2	1.32 E-03	5.29 E-01		6.94 E-05		6.94 E-05	2.78 E-01			
F2	1.18 E-03	4.72 E-01		6.19 E-05		6.19 E-05	2.48 E-01			
I2	2.39 E-03	9.60 E-06		1.26 E-09		1.26 E-09	5.04 E-06			
N2				3.78 E+04		3.78 E+04				
NO2				7.74 E-01		7.74 E-01				
CO				1.32 E+04		1.32 E+04				
SO2	5.34 E-05	2.14 E-02		2.81 E-05		2.81 E-05	1.12 E-02			
Al+3										
B+3										
Ba+2										
Ca+2										
Cr+3										
Cs+										
Fe+3										
K+										
La+3										
Mg+2										
Mn+6										
Nb+										
Ni+3										
Sr+2										
UO2+2										
Zn+2										
Cl-										
CO3-2	1.80 E-03	7.21 E-01		9.47 E-05		9.47 E-05	3.79 E-01			
F-										
I-										
NO2-	2.32 E-03	9.29 E-01		1.22 E-04		1.22 E-04	4.88 E-01			
NO3-	1.02 E-02	4.09 E+00		5.38 E-04		5.38 E-04	2.15 E+00			
OH-										
PO4-3										
SO4-2	8.01 E-05	3.21 E-02		4.21 E-05		4.21 E-05	1.69 E-02			
TaO4-										
H2O	6.14 E+01	3.95 E+04	8.71 E+04	3.26 E+03		3.26 E+03	2.00 E+04	1.48 E+04	1.48 E+04	7.23 E+04
HClO2										
Organic Carbon										
ZnO2+2H2O										
P2O5	8.74 E-04	3.50 E-01		4.60 E-05		4.60 E-05	1.84 E-01			
Ammonia	3.63 E-01	3.63 E-01		1.91 E-02		1.91 E-02	1.82 E-01			
Cs-Ba 137 (Bq/D)										
Sr-Y 90 (Bq/D)										
Tc 99 (Bq/D)										
Pu (Bq/D)										
Am (Bq/D)										

STREAM NAME	40	41	42	43	44	45	47	48	49	50
SOLID COMPONENTS										
Total Flow (Kg/D)		1.50 E-02					7.48 E-03			
Al+3										
B+3										
Ba+2										
Ca+2										
Cr+3										
Cs+										
Fe+3										
K+										
La+3										
Mg+2										
Mn+6										
Na+										
Ni+3										
Si+4										
Sr+2										
UO2+2										
Zn+2										
Cl-										
CO3-2										
F-										
I-										
NO2-										
NO3-										
OH-										
PO4-3										
SO4-2										
TiO4-										
MnO2		1.65 E-05					8.24 E-05			
Organic Carbon		6.74 E-05					3.37 E-05			
ZrO2·2H2O										
Al2O3		8.91 E-03					4.46 E-03			
Am2O3		1.18 E-07					5.89 E-08			
B2O3		6.71 E-05					3.36 E-05			
BaO		1.71 E-05					8.53 E-05			
CaO		3.05 E-04					1.53 E-04			
Cr2O3		1.05 E-05					5.29 E-05			
CS2O		4.93 E-03					2.46 E-03			
Fe2O3		1.17 E-03					5.83 E-04			
K2O		1.07 E-05					5.33 E-05			
La2O3		1.47 E-04					7.35 E-05			
MgO		1.54 E-04					7.69 E-05			
MnO		2.14 E-04					1.07 E-04			
Na2O		1.72 E-03					8.59 E-04			
Ni2O3		2.35 E-04					1.17 E-04			
P2O5		2.28 E-05					1.14 E-05			
PuO2		5.50 E-07					2.75 E-07			
SiO2		1.87 E-03					9.35 E-04			
SrO		9.03 E-07					4.54 E-07			
Ta2O5		2.62 E-05					1.31 E-05			
UO3		1.88 E-05					9.41 E-07			
ZnO		3.69 E-05					1.84 E-05			
ZrO2		4.01 E-05					2.01 E-05			
Cs-Ba 137 (Bq/D)		1.49 E+03					7.44 E+07			
Sr-Y 90 (Bq/D)		3.92 E+09					1.97 E+09			
Tc 99 (Bq/D)		1.05 E+07					5.25 E+05			
Pu (Bq/D)		4.07 E+05					2.04 E+05			
Am (Bq/D)		1.35 E+07					6.81 E+05			

STREAM NAME	51
LIQUID COMPONENTS	
Volume Flow (L/D)	7.97 E+04
Specific Gravity	1.15 E+00
Total Flow (Kg/D)	9.20 E+04
CO2	5.53 E+01
F2	4.93 E+01
I2	1.00 E-03
N2	
NO2	
O2	
SO2	2.24 E+00
Al+3	3.48 E+02
B+3	
Ba+2	
Ca+2	
Cr+3	3.23 E+01
Cs+	2.08 E-01
Fe+3	
K+	3.96 E+01
La+3	
Mg+2	
Mn+6	
Na+	5.69 E+03
Ni+3	
Sr+2	
UO2+2	
Zn+2	
Cl-	1.41 E+02
CO3-2	3.71 E+03
F-	
I-	
NO2-	1.41 E+02
NO3-	5.74 E+02
OH-	2.11 E+03
PO4-3	
SO4-2	1.65 E+02
TcO4-	
H2O	7.88 E+04
H+O2	1.42 E+01
Organic Carbon	1.49 E+01
ZrO2·2H2O	
P2O5	1.03 E+02
Ammonia	1.82 E-01
Cs-Ba 137 (Bq/D)	6.66 E+14
Sr-Y 90 (Bq/D)	
Tc 99 (Bq/D)	
Pu (Bq/D)	
Am (Bq/D)	

STREAM NAME	51
SOLID COMPONENTS	
Total Flow (Kg/D)	2.86 E+02
Al+3	
B+3	
Ba+2	
Ca+2	
Cr+3	
Cr+6	
Fe+3	
K+	
La+3	
Mg+2	
Mn+2	
Nb+5	
Ni+2	
Si+4	
Sr+2	
UO2+2	
Zn+2	
Cl-	
CO3-2	
F-	
I-	
NO2-	
NO3-	
OH-	
PO4-3	
SO4-2	
TOC4-	
MnO2	1.07 E-02
Organic Carbon	4.37 E-03
ZrO2·2H2O	
Al2O3	2.82 E+02
Am2O3	7.64 E-05
B2O3	4.35 E-02
BaO	1.11 E-02
CaO	1.98 E-01
Cr2O3	6.86 E-03
Cr2O	2.71 E-05
Fe2O3	7.57 E-01
K2O	5.86 E-03
La2O3	9.54 E-02
MgO	9.97 E-02
MnO3	1.39 E-01
Nb2O	9.44 E-01
Ni2O3	1.52 E-01
P2O5	1.48 E-03
PbO2	3.57 E-04
SiO2	1.21 E+00
SO	5.89 E-04
Ta2O7	1.70 E-02
U3O8	1.22 E-03
ZrO	2.39 E-02
ZrO2	2.40 E-02
Cs-Ba 137 (Bq/D)	8.18 E+10
Sr-Y 90 (Bq/D)	2.56 E+12
Tc 99 (Bq/D)	6.81 E+09
Pu (Bq/D)	2.65 E+09
Am (Bq/D)	8.81 E+09

APPENDIX B ASSUMPTIONS AND CALCULATIONS FOR CALCINATION FLOWSHEET

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ASSUMPTIONS AND CALCULATIONS FOR CALCINATION FLOWSHEET

The assumptions used for the mass balance inputs to ASPEN and limited energy balances for the selected equipment are described in the following sections. Particular units are tabulated below for ease of reference.

<u>UNIT OPERATION</u>	<u>Page</u>
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CALCINER, C-5	B-2
VAPOR/LIQUID SEPARATOR, T-6	B-5
VENTURI SCRUBBER AND SUMP, S-7	B-5
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CONDENSER, EC-11	B-7
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PRE-HEATER TO NO _x REACTOR, E-18	B-8
NO _x REACTOR, C-16	B-9
CONDENSER, EC-17	B-9
HEATERS FOR FILTER PROTECTION	B-10

EVAPORATOR, EV-3

Feed: 20 gal/minute (based on IPM design specifications, WHC 1993). Determine mass flowrate, \dot{m} , to evaporator. For 20 gal/minute and a feed density 1.15 g/mL:

$$\dot{m} = \left(\frac{20 \text{ gal}}{\text{min}} \right) \left(\frac{3.785 \text{ L}}{\text{gal}} \right) \left(\frac{1.15 \text{ kg}}{\text{L}} \right) \left(\frac{1440 \text{ min}}{\text{D}} \right) = 1.25 \times 10^5 \text{ kg/D}$$

Concentrate to 50 wt% H₂O bottoms with balance of water going to offgas.

Temperature: Bottoms are 102°C (216°F), assuming slight boiling point elevation due to sodium.

Gaseous effluent = 100°C (212°F)

Pressure: Slightly below atmospheric, $\leq 101.3 \text{ kPa}$ (14.7 lb/in²) (absolute)

Offgas Mass:	H ₂ O in evaporator feed	= 1.064 x 10 ⁵ kg/D
	Non-H ₂ O in feed	= 1.920 x 10 ⁴ kg/D
	Bottoms H ₂ O at 50 wt%	= 1.920 x 10 ⁴ kg/D
	Offgas H ₂ O (stream 9)	= 8.720 x 10 ⁴ kg/D

CALCINER, C-5

Flowrate: = 4 gal/minute concentrated complexant concentrate
 = 3.80×10^4 kg/D, (Stream 11) (D = 24 hrs)

Temperature: Effective operating temperature = 85°C (185°F)
 $T_{in} = 80^\circ\text{C}$ (176°F)
 $T_{out} = 85^\circ\text{C}$ (185°F), for offgas and liquid slurry

Pressure: Slightly above atmospheric pressure

Compositions:

a) Process air (Stream 12A) to calciner:

The amount of process air used is based on data from the WSTC test. The test used 160 std ft³/minute process gas and 250 std ft³/minute shroud gas to the torch. The feed flowrate was 1.8 gal/minute.

Scale up to 4 gal/minute:

$$\frac{410 \text{ std ft}^3/\text{min}}{1.8 \text{ gal/min}} (4 \text{ gal/min}) = \frac{911 \text{ ft}^3 \text{ air}}{\text{min}} = \frac{25,800 \text{ L air}}{\text{min}}$$

Assume dry air, ideal gas, STP conditions (20°C, 1 atm), and 79 mole percent N₂ and 21 mole percent O₂. Calculate the component mass flowrates of the process air to the process.

$$\dot{n} = \left(\frac{25,800 \text{ L}}{\text{min}} \right) \left(\frac{\text{gmol air}}{24.053 \text{ L}} \right) = \frac{1,073 \text{ gmol air}}{\text{min}}$$

Mass flowrate for N₂:

$$\dot{m}(N_2) = \left(\frac{1073 \text{ gmol air}}{\text{min}} \right) \left(\frac{0.79 \text{ gmol } N_2}{\text{gmol air}} \right) \left(\frac{0.028 \text{ kg } N_2}{\text{gmol } N_2} \right) \left(\frac{1440 \text{ min}}{\text{day}} \right) = 3.418 \times 10^4 \frac{\text{kg } N_2}{\text{day}}$$

Mass flowrate for O₂:

$$\dot{m}(O_2) = \left(\frac{1073 \text{ gmol air}}{\text{min}} \right) \left(\frac{0.21 \text{ gmol } O_2}{\text{gmol air}} \right) \left(\frac{0.032 \text{ kg } O_2}{\text{gmol } O_2} \right) \left(\frac{1440 \text{ min}}{\text{day}} \right) = 1.038 \times 10^4 \frac{\text{kg } O_2}{\text{day}}$$

b) Offgas from calciner quench bath (Stream 15)

Temperature: 85°C (185°F)

Pressure: 101 kPa [14.7 lb/in²] (abs)

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Flowrate: (Process air) + (N₂, NO₂, and O₂ generated by reactions) - (N₂ and O₂ reacted) + (water vapor and aerosols)
= 1.01 x 10⁵ kg/D (calculated by ASPEN)

Energy: WSTC Test System used 9,086 kJ/L of thermal power with an electrical-to-thermal efficiency of 88%. For feed rate of 15.1 L/minute, scale-up power for torch:

$$\text{Torch Power} = \left(\frac{9,086 \text{ kJ}}{L} \right) \left(\frac{15.1 L}{\text{min}} \right) \left(\frac{\text{min}}{60 S} \right) \left(\frac{MW \cdot S}{1000 \text{ kJ}} \right) = 2.3 \text{ MW}$$

Composition: The following compositions are assumed due to lack of material balance data for the integral quench calciner.

- The quench liquor makeup water is controlled to maintain the liquor five percent off of the solubility limit line of Na₂CO₃ in NaOH (see §4.0 and below).
- 5 percent of the Cs and Tc to the calciner remain entrained in the calciner offgas
- 0.2 percent of the solid oxides formed during calcination are entrained in the offgas. Makeup water (stream 12) is used to provide additional scrubbing capacity prior to entry to primary quench volume.
- 86% of the NO₂ is reacted while 91% of the NO₃ is reacted. Half of the unreacted NO₂/NO₃ exits in the offgas and the other half to the solids slurry product.

Quench Mass Requirement:

For purposes of maintaining product solubility in the quench tank, additional water, beyond what travels with the offgas, is required to be admitted in stream 12. From Figure 4-1, the sodium carbonate saturation line may be linearly approximated over the range of zero to twenty weight percent NaOH by the endpoint pairs of (0, 0.287) and (0.20, 0.065) [(wt% NaOH, wt% Na₂CO₃)].

Let Z = Stream 13 equivalent caustic mass, allowing Al⁺³ to act in molar fashion in the common ion solubility limitation of sodium carbonate.

$$Z = \left[\frac{\dot{m}_{OH^-} \frac{kg}{D}}{17.0073 \frac{kg \text{ OH}^-}{kgmol \text{ OH}^-}} + \frac{\dot{m}_{Al^{+3}} \frac{kg}{D}}{26.98154 \frac{kg \text{ Al}^{+3}}{kgmol \text{ Al}^{+3}}} \right] \cdot \frac{39.9971 \frac{kg \text{ NaOH}}{kgmol \text{ NaOH}}}{1} [=] \frac{kg \text{ NaOH}}{D}$$

Let K = Stream 13 Na₂CO₃ mass:

$$K = \left[\frac{\frac{\dot{m}_{CO_3} \text{ kg}}{D}}{\frac{60.0092 \text{ kg } CO_3}{\text{kgmol } CO_3}} \right] \cdot \frac{105.98874 \text{ kg } Na_2CO_3}{\text{kgmol } Na_2CO_3} [=] \frac{\text{kg } Na_2CO_3}{D}$$

Let T = total mass of stream 13 required to maintain a 5% buffer from the saturation line.

Solving a linear solution from the data points and definitions above:

$$T = \frac{K + 1.11 Z}{0.287} \cdot (1.05)$$

$$\begin{aligned} \text{For: } \dot{m}_{CO_3} &= 8080 \text{ kg/D} \\ \dot{m}_{OH^-} &= 4690 \text{ kg/D} \\ \dot{m}_{Al+3} &= 1050 \text{ kg/D} \\ T &= 103,323 \text{ kg/D} \end{aligned}$$

Checking the result, Z/T = 12.2 wt% NaOH while K/T = 13.8 wt% sodium carbonate. This solution should clearly maintain product solubility at expected temperatures. The ASPEN code algorithm for the quench thus adds water in stream 12 until the total mass converges in stream 13.

Composition H₂O: Calculate the water in the calciner offgas. For 85°C (185°F), the partial pressure of saturated steam (Perry 1984, pg 3-237):

$$P_s = 58.6 \text{ kPa (8.5 lb/in}^2\text{) (abs)}$$

Partial pressure due to air, P_a, is P_{Total} - P_s :

$$P_a = 101.3 - 58.6 = 42.7 \text{ kPa (6.2 lb/in}^2\text{) (abs)}$$

Use ratio of partial pressures to find amount of water in the calciner offgas. For calculation purposes, assume N₂ is the majority (79 mole percent) of non-condensables (NC).

$$\frac{P_s}{P_a} = \frac{\text{moles } H_2O}{\text{moles } N_2} = \frac{58.6}{42.7}$$

$$\frac{\text{kg H}_2\text{O}}{\text{kg NC}} = \frac{58.6 \cdot \frac{18 \text{ kg H}_2\text{O}}{\text{kgmol}}}{42.7 \cdot \frac{28 \text{ kg NC}}{\text{kgmol}}} = \frac{0.88 \text{ kg H}_2\text{O}}{\text{kg NC}}$$

VAPOR/LIQUID SEPARATOR, T-6

A cyclone separator can be used to separate atomized solution and particles from the offgas stream from the calciner. General application of liquid particle separators indicate that for a boiling or bubbling operation, with fine to coarse particles, impingement or cyclone collection is recommended (Ludwig 1980, Volume 1, page 152). The cyclone is very efficient at removing relatively high loadings of large particles (40-50 microns). The efficiency for removal of entrained water is assumed to be 95 percent for the flowsheet material balance.

Flowrate: (Stream 15) Offgas flowrate from calciner = 1.01×10^5 kg/D

Temperature: Assume temperature remains constant, T = 85°C (185°F)

Composition: The amount of water in the calciner offgas at 85°C (185°F) was previously calculated to be:

$$\frac{0.88 \text{ kg H}_2\text{O}}{\text{kg NC}}$$

VENTURI SCRUBBER AND SUMP, S-7

The venturi scrubber uses a concurrent flow of water to scrub the incoming gas stream. The incoming particles are essentially wetted by the water and are made larger and/or heavier for separation. The separating ability of most units is limited to 5-micron particles. However, some will take out 1 to 5-micron particles (Ludwig 1980, page 172). For this flowsheet application, the venturi is expected to remove particles in the 1.0 micron range.

Flowrate: (stream 16), 5.705×10^5 kg/D (gas/liquid phase)
1.66 kg/D (entrained particles)

Temperature: Assume no heat transfer and no temperature change.
 $T_{in} = T_{out} = 85^\circ\text{C} (185^\circ\text{F})$

Efficiency: The collection efficiency is assumed to be 90 percent for 1.0 micron particles (Ludwig 1980, page 152)

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Composition: Assume 90 percent of the entrained 'solids' are scrubbed and 10 percent remains entrained in the vapor.

100 percent of the gases (O_2 , N_2 , H_2O vapor, NO , CO_2 , CO) are carried through the venturi.

Water to the venturi is based on 0.67 L H_2O per m^3 gas (5 gal H_2O per 1,000 ft^3 gas) (Perry 1973, page 18-91). For $\Delta T=0$, the water contained in the saturated vapor is the same as previously calculated for the calciner offgas: 0.88 kg H_2O /kg NC.

CONDENSER, EC-15

Condensers cool the offgas, remove particles, condense water vapor, and remove other condensables. The moisture-laden offgas enters the top of the condenser and is cooled as it flows downward through a tube bundle. Cooling water flows countercurrently on the shell side. Condensate drains out the bottom and is collected in the liquid collection tank. Cooling water for the condenser is provided by a closed loop cooling water system with an evaporative cooling tower.

A standard tube-and-shell, single-pass condenser design with baffles and a floating head may be used for offgas treatment. Most of the entrained water droplets exiting the condenser should be in the size range of 1 to 20 microns, which is typical for condensing steam (Perry 1984).

Flowrate: Total flow to condenser: 8.72×10^4 kg/OD (Stream 9)

Temperature: $T_{out} = 45^\circ C$ (113°F)
 $T_{in} = 100^\circ C$ (212°F)

Composition: Assume majority of water is condensed and removed. Calculate enthalpy change for saturated steam (vapor) at $100^\circ C$ (212°F) being cooled and condensed to $45^\circ C$ (113°F).

Energy Requirement: From steam tables,

$$\hat{H}_{v,100^\circ C} = 2675 \text{ kJ/kg (enthalpy of saturated vapor)}$$

$$\hat{H}_{v,45^\circ C} = 2581 \text{ kJ/kg (enthalpy of saturated vapor)}$$

$$\hat{H}_{l,45^\circ C} = 188 \text{ kJ/kg (enthalpy of liquid)}$$

$$Q = (\hat{H}_{v,100^\circ C} - \hat{H}_{l,45^\circ C})\dot{m}_{\text{condensate}} + (\hat{H}_{v,100^\circ C} - \hat{H}_{v,45^\circ C})\dot{m}_{\text{vapor}}$$
$$Q = (2675 - 188)(8.71 \times 10^4) + (2675 - 2581)(1.68 \times 10^2) \text{ kJ/day}$$

$$Q = 2.51 \text{ MW}$$

Flowrate of Water In Saturated Gas Stream Leaving Condenser (EC-15)

From a psychometric chart (Perry 1984, pg 12-5), the amount of water remaining in 45°C (113°F) humid air at 100 percent relative humidity:

$$h_a = 0.064 \text{ kg H}_2\text{O/kg dry air} \quad (\text{absolute humidity})$$

$$h_v = 0.99 \text{ m}^3/\text{kg dry air} \quad (15.9 \text{ ft}^3/\text{lb dry air}) \quad (\text{humid volume})$$

Assume an air in-leakage to condenser of 1.42 m³/min (50 ft³/minute). The total saturated air at 45°C is equal to the evaporator offgas plus the air in-leakage. The amount of water in the Stream 19 is calculated by ASPEN using the absolute humidity value given above.

$$\text{Stream 19 H}_2\text{O flow} = 1.68 \times 10^2 \text{ kg/D}$$

CONDENSER, EC-11

$$\text{Flowrate: (Stream 18), } 9.08 \times 10^4 \text{ kg/OD}$$

Assume the gas stream exiting the condenser (Stream 21) consists primarily of noncondensables O₂, N₂, and NO₂ (100 percent). Assume 95 percent of all other components are removed in the condenser condensate (stream 20) with 5 percent carried in stream 21. Assume 100 percent of the entrained solids are removed in stream 20.

Assume dry gas at STP conditions:

$$\frac{24.053 \text{ m}^3}{\text{kgmol air}}, \text{ Avg. Mwt (air)} = 29.0$$

$$\text{Flowrate}_{\text{Air}} = \left(\frac{9.08 \times 10^4 \text{ kg}}{\text{OD}} \right) \left(\frac{\text{kgmol air}}{29 \text{ kg}} \right) \left(\frac{24.053 \text{ m}^3}{\text{kgmol}} \right) = 7.53 \times 10^4 \frac{\text{m}^3}{\text{D}} = 872 \frac{\text{L}}{\text{s}}$$

Temperature: $T_{\text{in}} = 180^\circ\text{C} \text{ (356}^\circ\text{F)}$
 $T_{\text{out}} = 45^\circ\text{C} \text{ (113}^\circ\text{F)}$
 Cooling H₂O at 40°C (104°F)

Composition: Calculated by ASPEN using 0.064 kg H₂O/kg dry air for saturated air at 45°C, the amount of water in the exit gas = 3.09 x 10³ kg/D

Energy Requirements, from steam tables,
 $\hat{H}_{v,85^\circ\text{C}} = 2650.3 \text{ kJ/kg}$

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$$\begin{aligned} \hat{H}_{l,45^\circ\text{C}} &= 188.2 \text{ kJ/kg} \\ \hat{H}_{v,45^\circ\text{C}} &= 2581.5 \text{ kJ/kg} \\ Q &= (\hat{H}_{v,85^\circ\text{C}} - \hat{H}_{l,45^\circ\text{C}})\dot{m}_{\text{condensate}} + (\hat{H}_{v,85^\circ\text{C}} - \hat{H}_{v,45^\circ\text{C}})\dot{m}_{\text{vapor}} \\ Q &= (2650 - 188)(3.94 \times 10^4) + (2650 - 2581)(3.09 \times 10^3) \text{ kJ/day} \\ Q &= 1.13 \text{ MW} \end{aligned}$$

DEMISTER, D-10

The demister removes droplets from the offgas stream prior to entering the NO_x reactor. Water particles are collected in a fine-meshed pad and drain to the liquid collection tank. Demister designs have collection efficiencies up to 99.98 wt% for submicron particles. The mechanisms of mist separation for this type of element are diffusion, impaction, and inertial effects, with diffusion controlling for submicron particles.

Assume a demister with a de-entrainment of 0.5 mg H₂O/m³ gas. The stream exiting the demister (stream 22) is assumed to be a saturated water vapor stream with 100 percent of the incoming N₂, O₂, and NO₂ and contains zero entrained particles, with the captured water droplets containing 95% of ionic salt components of the inlet stream.

PRE-HEATER TO NO_x REACTOR, E-18

A heater is required to preheat the offgas to 256°C (493°F) before entering the NO_x reactor. Additional heaters are used to maintain the offgas to the HEPA filters at 80°C (40° above the dew point).

$$\begin{aligned} Q &= [(\dot{m} C_p)_{\text{air}} + (\dot{m} C_p)_{\text{H}_2\text{O}}] \Delta T \\ \dot{m}_{\text{air}} &= \text{Process gas (O}_2, \text{N}_2, \text{and NO}_2) \text{ flow} = 4.82 \times 10^4 \text{ kg/day} \\ \dot{m}_{\text{H}_2\text{O}} &= \text{Process water vapor flow} = 3.09 \times 10^3 \text{ kg/day} \end{aligned}$$

Heat Capacity Calculations (Himmelblau, 1974) C _p			
	T(°C)	C _p (J/gmol °C)	C _p (kWs/kg °C)
Air	45.	29.18	
	256.	32.22	
	mean	29.70	1.024
Water	T(°C)	C _p (J/gmol °C)	C _p (kWs/kg °C)
	45.	33.02	
	256.	32.92	
	mean	32.97	1.830

$$\Delta T = 45^{\circ}\text{C} \rightarrow 256^{\circ}\text{C} = 211^{\circ}\text{C}$$

$$Q = [(\dot{m}_{\text{air}} \cdot C_{p_{\text{air}}}) + (\dot{m}_{\text{H}_2\text{O}} \cdot C_{p_{\text{H}_2\text{O}}})] \cdot \Delta T \cdot \frac{\text{day}}{1440 \text{ min}} \cdot \frac{\text{min}}{60 \text{ s}} = 134 \text{ kW}$$

NO_x REACTOR, C-16

A catalyst bed vessel is provided for reacting the NO_x/NH₃ gas streams. A high temperature blower system is shown to draw the NO_x offgas and NH₃ mixture through the catalyst system and discharge the resulting gas to the stack.

Flowrate: Process gas (stream 22) = 5.14×10^4 kg/D

Temperature: $T_{\text{in}} = 250^{\circ}\text{C}$ (482°F)
 $T_{\text{out}} = 450^{\circ}\text{C}$ (842°F)

Assume stoichiometric ratio for amount of ammonia required. Reactions are:



The size of the reactor is left as "to be determined."

CONDENSER, EC-17

Flowrate: (Stream 25), 5.14×10^4 kg/OD

Assume the gas stream exiting the condenser (Stream 26) consists primarily of noncondensables O₂, and N₂ (100 percent).

Assume dry gas at STP conditions:

$$\frac{24.053 \text{ m}^3}{\text{kgmol air}}, \text{ Avg. Mwt (air)} = 29.0$$

$$\text{Flowrate}_{\text{Air}} = \left(\frac{4.83 \times 10^4 \text{ kg}}{\text{OD}} \right) \left(\frac{\text{kgmol air}}{29 \text{ kg}} \right) \left(\frac{24.053 \text{ m}^3}{\text{kgmol}} \right) = 4.01 \times 10^4 \frac{\text{m}^3}{\text{D}} = 464 \frac{\text{L}}{\text{s}}$$

Temperature: $T_{\text{in}} = 450^{\circ}\text{C}$ (842°F)
 $T_{\text{out}} = 45^{\circ}\text{C}$ (113°F)
 Cooling H₂O at 40°C (104°F)

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Composition: Calculated by ASPEN using 0.064 kg H₂O/kg dry air for saturated air at 45°C, the amount of water in the exit gas = 3.09 x 10³ kg/D

Energy Requirements for the water, from steam tables,

$$\hat{H}_{v,450^{\circ}\text{C}} = 3373.9 \text{ kJ/kg}$$

$$\hat{H}_{l,45^{\circ}\text{C}} = 188.2 \text{ kJ/kg}$$

$$\hat{H}_{v,45^{\circ}\text{C}} = 2581.5 \text{ kJ/kg}$$

$$Q = (\hat{H}_{v,450^{\circ}\text{C}} - \hat{H}_{l,45^{\circ}\text{C}})\dot{m}_{\text{condensate}} + (\hat{H}_{v,450^{\circ}\text{C}} - \hat{H}_{v,45^{\circ}\text{C}})\dot{m}_{\text{vapor}}$$

$$Q = (3374 - 188)(61.4) + (3374 - 2581)(3.09 \times 10^3) \text{ kJ/day}$$

$$Q = 286 \text{ kW}$$

Energy Requirements for cooling the air ($C_{p,\text{mean}} = 30.25 \text{ J/gmol } ^{\circ}\text{C}$) with a mass of 4.83 x 10⁴ kg/D are 236 kW for a total unit cooling requirement of 522 kW.

HEATERS FOR FILTER PROTECTION

As described above, the process gas bound for the stack will be reheated to 80°C to prevent condensation on the filtration units (dehumidification). Although the metal mesh filters placed into the design, along with their aqueous washdown, would obviate the need to preheat the stream prior to release, the heating requirements of such a stream are conducted here. In the manner of the preheater to the NO_x Reactor, for 35°C temperature rise ($C_{p,m}$ of air = 29.26 J/gmol °C, $C_{p,m}$ of water vapor = 33.02 J/gmol °C), the heating requirement is determined to be 23.3 kW.

APPENDIX C PREVIOUS CALCINATION STUDIES

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PREVIOUS CALCINATION STUDIES

Notes from PNL-3495 (Larson 1980)

An extensive body of information related to radioactive waste calcination exists. This information was developed through hot and cold testing at Hanford (Larson 1980, Bonner *et al.* 1976, Allemann and Johnson 1960), other DOE sites, other U.S. sites, and in full-scale operations in other countries. Most of the tests and operations, particularly commercial sites, use an acidic feed stream. In European operations, calcination is used to prepare waste for final disposal vitrification. This calcination-vitrification approach is similar to the work done at the Hanford Site (Larson 1980).

The primary goal of calcination is organic destruction. In addition, decomposition of nitrate and nitrite compounds is also expected. The destruction of organic compounds in an oxidizing atmosphere in the plasma arc will produce H_2 , CO_2 , and water. These and other gaseous products from calcination are scrubbed in the quench and the offgas treatment system.

Spray Calcination Testing

The spray calciner used in Hanford Site tests is similar to calcination processes suggested for organic destruction of Hanford Site tank wastes. However, the product sought in the spray calcination tests was a dry oxide. In the organic destruction process, production of insoluble compounds, such as oxides of aluminum are not desirable. In the proposed organic destruction process, an alkaline quench is an integral part of the calcination equipment to provide a dissolution of the resultant salts.

A major process concern with the calcination of tank waste is the properties of the high sodium waste generated by a calciner operation at $800^\circ C$ to $1000^\circ C$ ($1470^\circ F$ to $1830^\circ F$). Calcination of acid waste proceeds to a flowable calcine, oxide powder. Alkaline wastes produce molten sodium compounds that adhere to walls and form large sticky clumps and lumps.

A high sodium feed produced a calcine that agglomerates at temperatures as low as $310^\circ C$ ($590^\circ F$). Low sodium and acidic feeds produced a calcine product that was free-flowing up to $900^\circ C$ ($1650^\circ F$). The calcine produced by the spray calciner is hygroscopic and has high surface activity. The calcine is good feed for melting or pelletizing processes.

The spray calciner typically operated in the range of $400^\circ C$ and $800^\circ C$ ($750^\circ F$ and $1470^\circ F$). For the spray calciner, heat was supplied externally. The highest temperature is at the wall and the lowest temperature near the centerline of the calciner. At the temperatures above, the soluble metal salts and the other compounds will begin to decompose. In the oxidizing atmosphere in the calciner, metal oxides are produced. Other salts that do not decompose at the calciner temperature remain unchanged. The spray calciner produces a 'dry' calcine that drops to the bottom of the calciner vessel.

The spray calciner experienced 'spraying' of droplets. Some droplets hit the wall and caused caking. Drying of the waste is expected at the wall temperatures. The amount of wall impingement and caking is dependent on a number of factors, including feed flow rate, air flow rate, temperature, and percentage of solids in the feed. The calcine will stick to the wall at temperatures that cause sintering and melting. A vibrator was used to periodically remove buildup from the calciner walls. The vibrator was typically used several times per hour.

In Hanford tests with alkaline waste, carbonaceous compounds such as formic acid and sugar were added to aid in the decomposition of sodium nitrate. With acidic feed, formic acid was added to decrease the oxidizing potential. The additives helped to improve the calcination process.

The calcination process for tank waste may benefit from the organic compounds in the feed to aid in denitration of the waste. Whether or not chemical additions are also needed can be determined by continued testing.

Feed

In the PNL work, neutralized defense waste was expected to have 7 percent to 17 percent solids. A pressurized feed system is needed to handle this level of solids. Typical problems expected in the feed system include: (1) flowmeter pluggage, (2) erosion of the pump, piping elbows, and valves, and (3) solids mixing difficulties in the feed tank. Erosion during testing required equipment replacement after 2,500 hours of operation. In addition to the feed tank, the other tanks must be designed to handle a high percentage of solids.

Feed rates greater than 10 to 20 L/hour are expected to be easier to control. Actual plant feed rates to a plasma arc calciner 15.1 L/min (4 gal/minute) should be relatively easy to control.

For spray calciner testing, the neutralized waste feed was a slurry rather than a solution. The calcined particles from the neutralized feed were larger than the particles from the acid waste solution feed. The composition of the neutralized waste particles are also different. In the plasma arc operation, solids in the feed may reduce the effectiveness of decomposition reactions for some compounds. However, the oxidation of organic compounds is expected to be complete at the plasma arc operating conditions.

Comment: The chamber for 'calcination' should be much larger than the spray pattern resulting from the feed addition to the plasma arc flame to reduce spraying of droplets onto the wall.

Offgas Treatment

In the spray calciner system, offgas treatment was designed to remove condensable compounds and to adsorb/absorb selected noncondensables. The offgas system must also be able to handle entrained particles. The particles

would be expected to remain as solids/insolubles in the offgas treatment system.

The spray calciner offgas system included a quench tower, NO_x scrubber, fission product absorbers, a demister, a cyclone separator, and filters. A venturi scrubber was used to provide particulate matter removal, cooling, and some NO_x removal. Other unit operations included condensers and a NO_x destructor.

The gases leaving the spray calciner are about 250°C to 300°C (482°F to 572°F), which is roughly the temperature of the calcine at the bottom of the calciner. The offgas includes water, CO₂, nitrogen, oxygen, and Cs oxide. Nitrogen and oxygen come from air inputs. Fluorides and other halides should also volatilize to some extent. Volatile non-fission products such as F, Cl, S, and Hg cause corrosion problems for the offgas system.

Large amounts of air in the spray calciner offgas increased the complications of radionuclide removal. Volatile fission products of concern in the spray calciner system included tritium, iodine, and technetium. Ru-Rh was also a concern with the shorter cooled wastes, but will not be present in Hanford tank waste.

Operating Concerns

Operating concerns with the spray calciner included waste foaming and rework. The high sodium neutralized waste, envisioned as feed to the spray calciner, included about 39 g/L solubles and 48.3 g/L insolubles. Sodium was primarily present as 38.3 g/l sodium carbonate. The largest insoluble component was Fe(OH)₃ at 23.5 g/L. Aluminum, as Al₂O₃, was an insignificant component. The specific gravity was 1.09.

In the process envisioned by PNL for treating tank waste, only the separated cesium and plutonium combined with insoluble sludge was used as feed to the calciner/melter system. In this scheme, the bulk of the salts were sent to onsite bulk storage that approximates grout disposal. The solids content of the feed to the calciner is about 9 percent.

Other Topics

Other topics pertaining to the spray calciner testing in the document (Larson 1980) include the following:

1. Accident and safety analyses
2. Essential materials, utilities, waste, and emissions
3. Process control, temperature control
4. Use of two opposing vibrators to clean walls
5. Sketches and operating conditions for major equipment pieces.

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APPENDIX D UNIT OPERATIONS MATERIAL BALANCES

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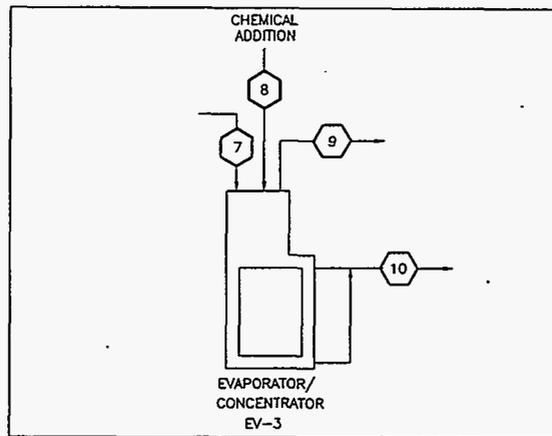


Figure D-1 Waste Feed Evaporator

Table D-1 Waste Feed Evaporator Material Balance

LIQUID COMPONENTS			SOLID COMPONENTS			
STREAM NAME	7	9	10	STREAM NAME	7	10
Volume Flow (L/CD)	1.09 E+05		2.18 E+04	Total Flow (Kg/CD)	3.87 E+02	3.87 E+02
Specific Gravity	1.15 E+00		1.74 E+00	Al+3	3.55 E+01	3.55 E+01
Total Flow (Kg/CD)	1.25 E+05	8.72 E+04	3.80 E+04	Ba+3	4.71 E-02	4.71 E-02
Al+3	6.74 E+02		6.74 E+02	Ba+2	6.89 E-02	6.89 E-02
Ba+3	8.93 E-01		8.93 E-01	Ca+2	9.84 E-01	9.84 E-01
Ba+2	6.20 E-01		6.20 E-01	Cr+3	1.63 E+00	1.63 E+00
Ca+2	8.85 E+00		8.85 E+00	Cs+	2.09 E-02	2.09 E-02
Cr+3	3.10 E+01		3.10 E+01	Fe+3	1.84 E+00	1.84 E+00
Cs+	1.89 E-01		1.89 E-01	K+	3.99 E-01	3.99 E-01
Fe+3	3.50 E+01		3.50 E+01	La+3	5.65 E-01	5.65 E-01
K+	3.96 E+01		3.96 E+01	Mg+2	4.19 E-01	4.19 E-01
La+3	5.09 E+00		5.09 E+00	Mo+6	3.22 E-01	3.22 E-01
Mg+2	3.76 E+00		3.76 E+00	Na+	5.75 E+01	5.75 E+01
Mo+6	6.11 E+00		6.11 E+00	Ni+3	3.76 E-01	3.76 E-01
Na+	5.69 E+03		5.69 E+03	Si+4	3.94 E+01	3.94 E+01
Ni+3	7.15 E+00		7.15 E+00	Sr+2	1.74 E-03	1.74 E-03
Sr+2	3.29 E-02		3.29 E-02	UO2+2	4.08 E-03	4.08 E-03
UO2+2	7.76 E-02		7.76 E-02	Zn+2	1.34 E-01	1.34 E-01
Zn+2	1.20 E+00		1.20 E+00	Cl-	1.40 E-01	1.40 E-01
Cl-	1.40 E+02		1.40 E+02	CO3-2	9.66 E-01	9.66 E-01
CO3-2	9.66 E+02		9.66 E+02	F-	4.96 E-02	4.96 E-02
F-	4.95 E+01		4.95 E+01	I-	5.04 E-04	5.04 E-04
I-	5.04 E-04		5.04 E-04	NO2-	1.05 E+00	1.05 E+00
NO2-	1.06 E+03		1.06 E+03	NO3-	5.30 E+00	5.30 E+00
NO3-	5.28 E+03		5.28 E+03	OH-	2.08 E+02	2.08 E+02
OH-	2.97 E+03		2.97 E+03	PO4-3	1.38 E-01	1.38 E-01
PO4-3	1.38 E+02		1.38 E+02	SO4-2	1.68 E-01	1.68 E-01
SO4-2	1.68 E+02		1.68 E+02	ToO4-	6.19 E-02	6.19 E-02
ToO4-	1.17 E+00		1.17 E+00	MnO2	7.44 E-01	7.44 E-01
H2O	1.06 E+05	8.72 E+04	1.92 E+04	Organic Carbon	3.04 E+01	3.04 E+01
MnO2	1.42 E+01		1.42 E+01	ZrO2:2H2O	2.34 E-01	2.34 E-01
Organic Carbon	1.49 E+03		1.49 E+03	Cs-Ba 137 (Bq/CD)	6.70 E+13	6.70 E+13
ZrO2:2H2O	2.11 E+00		2.11 E+00	Sr-Y 90 (Bq/CD)	8.92 E+12	8.92 E+12
				Tc 99 (Bq/CD)	2.37 E+10	2.37 E+10
				Pu (Bq/CD)	9.21 E+09	9.21 E+09
				Am (Bq/CD)	3.08 E+10	3.08 E+10

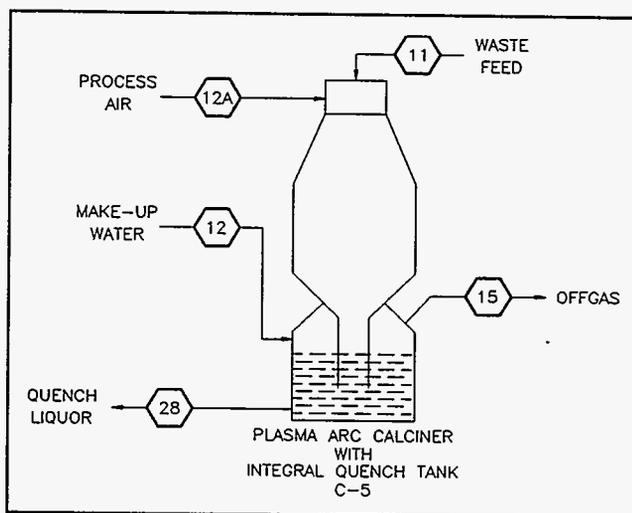


Figure D-2 Plasma Arc Calciner with Integral Quench

Table D-2 Plasma Arc Calciner and Integral Quench Material Balance

LIQUID COMPONENTS					SOLID COMPONENTS				
STREAM NAME	11	12a	12	15	28	STREAM NAME	11	15	28
Volume Flow (L/CD)	2.18 E+04		6.55 E+04		3.34 E+04	Total Flow (Kg/CD)	3.87 E+02	2.99 E+00	6.72 E+02
Specific Gravity	1.74 E+00		1.00 E+00		1.38 E+00	Al+3	3.55 E+01		
Total Flow (Kg/CD)	3.80 E+04	4.46 E+04	6.55 E+04	1.01 E+05	4.60 E+04	B+3	4.71 E-02		
CO2				1.11 E+02		Ba+2	6.89 E-02		
F2				4.96 E+01		Ca+2	9.84 E-01		
I2				1.01 E-03		Cr+3	1.63 E+00		
N2		3.42 E+04		3.56 E+04		Cs+	2.09 E-02		
NO2				1.55 E+02		Fe+3	1.84 E+00		
O2		1.04 E+04		1.27 E+04		K+	3.99 E-01		
SO2				4.50 E+00		La+3	5.65 E-01		
Al+3	6.74 E+02				4.96 E+02	Mg+2	4.19 E-01		
B+3	8.93 E-01					Mo+6	3.22 E-01		
Ba+2	6.20 E-01					Na+	5.75 E+01		
Ca+2	8.85 E+00					Ni+3	3.76 E-01		
Cr+3	3.10 E+01				3.23 E+01	Si+4	3.94 E+01		
Cs+	1.89 E-01				2.08 E-01	Sr+2	1.74 E-03		
Fe+3	3.50 E+01					UO2+2	4.08 E-03		
K+	3.96 E+01				3.96 E+01	Zn+2	1.34 E-01		
La+3	5.09 E+00					Cl-	1.40 E-01		
Mg+2	3.76 E+00					CO3-2	9.66 E-01		
Mo+6	6.11 E+00					F-	4.96 E-02		
Na+	5.69 E+03				5.69 E+03	I-	5.04 E-04		
Ni+3	7.15 E+00					NO2-	1.05 E+00		
Sr+2	3.29 E-02					NO3-	5.30 E+00		
UO2+2	7.76 E-02					OH-	2.08 E+02		
Zn+2	1.20 E+00					PO4-3	1.38 E-01		
Cl-	1.40 E+02				1.41 E+02	SO4-2	1.68 E-01		
CO3-2	9.65 E+02				3.64 E+03	To4-	6.19 E-02		
F-	4.95 E+01					MnO2	7.44 E-01	3.30 E-03	7.41 E-01
I-	5.04 E-04					Organic Carbon	3.04 E+01	1.35 E-03	3.03 E-01
NO2-	1.05 E+03			9.75 E+01	4.39 E+01	ZrO2·2H2O	2.34 E-01		
NO3-	5.28 E+03			3.26 E+02	1.47 E+02	Al2O3		1.78 E+00	4.00 E+02
OH-	2.97 E+03				2.11 E+03	Am2O3		2.36 E-05	5.29 E-03
PO4-3	1.38 E+02					B2O3		1.34 E-02	3.01 E+00
SO4-2	1.68 E+02				1.62 E+02	BaO		3.41 E-03	7.66 E-01

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LIQUID COMPONENTS					SOLID COMPONENTS				
STREAM NAME	11	12a	12	15	28	STREAM NAME	11	15	28
ToC ₄ -	1.17 E+00					CaO		6.10 E-02	1.37 E+01
H ₂ O	1.92 E+04		6.55 E+04	5.18 E+04	3.34 E+04	Cr ₂ O ₃		2.12 E-03	4.75 E-01
MnO ₂	1.42 E+01				1.42 E+01	Cs ₂ O		9.86 E-06	2.21 E-03
Organic Carbon	1.49 E+03				1.49 E+01	Fe ₂ O ₃		2.33 E-01	5.24 E+01
ZrO ₂ :2H ₂ O	2.11 E+00					K ₂ O		2.13 E-03	4.79 E-01
P ₂ O ₅				3.68 E+01	6.62 E+01	La ₂ O ₃		2.94 E-02	6.60 E+00
Ammonia						HgO		3.08 E-02	6.91 E+00
Cs-Ba 137 (Bq/CD)	6.07 E+14				6.66 E+14	MoO ₃		4.28 E-02	9.61 E+00
Sr-Y 90 (Bq/CD)	1.69 E+14					Na ₂ O		3.43 E-01	7.71 E+01
Tc 99 (Bq/CD)	4.51 E+11					Ni ₂ O ₃		4.70 E-02	1.06 E+01
Pu (Bq/CD)	1.75 E+11					P ₂ O ₅		4.57 E-04	1.02 E-01
Am (Bq/CD)	5.85 E+11					PuO ₂		1.10 E-04	2.47 E-02
						SiO ₂		3.74 E-01	8.40 E+01
						SrO		1.82 E-04	4.08 E-02
						Tc ₂ O ₇		5.25 E-03	1.18 E+00
						U ₃ O ₈		3.76 E-04	8.45 E-02
						ZnO		7.37 E-03	1.65 E+00
						ZrO ₂		8.02 E-03	1.80 E+00
						Cs-Ba 137 (Bq/CD)	6.70 E+13	2.98 E+10	6.70 E+12
						Sr-Y 90 (Bq/CD)	8.92 E+12	7.88 E+11	1.77 E+14
						Tc 99 (Bq/CD)	2.37 E+10	2.11 E+09	4.74 E+11
						Pu (Bq/CD)	9.21 E+09	8.14 E+08	1.83 E+11
						Am (Bq/CD)	3.08 E+10	2.72 E+09	6.11 E+11

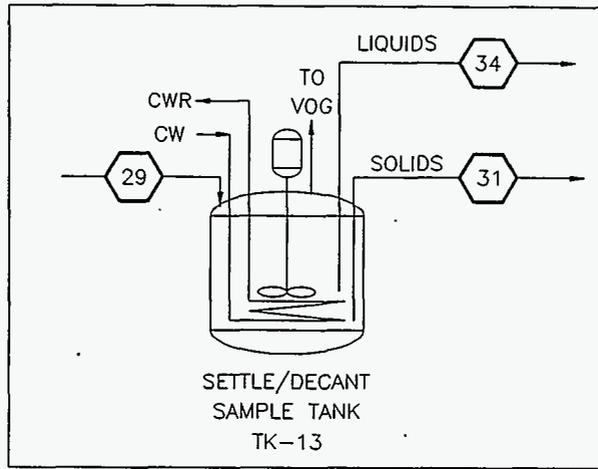


Figure D-3 Settle/Decant Sample Tank

Table D-3 Settle/Decant Sample Tank Material Balance

LIQUID COMPONENTS				SOLID COMPONENTS			
STREAM NAME	29	31	34	STREAM NAME	29	31	34
Volume Flow (L/D)	3.47 E+04		3.54 E+04	Total Flow (Kg/D)	6.72 E+02	3.89 E+02	2.83 E+02
Specific Gravity	1.36 E+00		1.33 E+00	MnO2	7.41 E-01	7.33 E-01	7.41 E-03
Total Flow (Kg/D)	4.73 E+04	1.50 E+02	4.72 E+04	Organic Carbon	3.03 E-01	3.00 E-01	3.03 E-03
Al+3	4.96 E+02	1.49 E+02	3.48 E+02	Al2O3	4.00 E+02	1.20 E+02	2.80 E+02
Cr+3	3.23 E+01	6.46 E-04	3.23 E+01	Am2O3	5.29 E-03	5.24 E-03	5.29 E-05
Cs+	2.08 E-01	4.15 E-06	2.08 E-01	B2O3	3.01 E+00	2.98 E+00	3.01 E-02
K+	3.96 E+01		3.96 E+01	BaO	7.66 E-01	7.58 E-01	7.66 E-03
Na+	5.69 E+03	1.14 E-01	5.69 E+03	CaO	1.37 E+01	1.36 E+01	1.37 E-01
Cl-	1.41 E+02	2.81 E-03	1.41 E+02	Cr2O3	4.75 E-01	4.70 E-01	4.75 E-03
CO3-2	3.64 E+03	7.27 E-02	3.63 E+03	Cs2O	2.21 E-03	2.19 E-03	2.21 E-05
NO2-	4.39 E+01	8.78 E-04	4.39 E+01	Fe2O3	5.24 E+01	5.19 E+01	5.24 E-01
NO3-	1.47 E+02	2.93 E-03	1.47 E+02	K2O	4.79 E-01	4.74 E-01	4.79 E-03
OH-	2.11 E+03	4.22 E-02	2.11 E+03	La2O3	6.60 E+00	6.54 E+00	6.60 E-02
SO4-2	1.62 E+02	3.24 E-03	1.62 E+02	MgO	6.91 E+00	6.84 E+00	6.90 E-02
H2O	3.47 E+04	6.95 E-01	3.47 E+04	MnO3	9.61 E+00	9.51 E+00	9.61 E-02
MnO2	1.42 E+01		1.42 E+01	Na2O	7.71 E+01	7.64 E+01	7.71 E-01
Organic Carbon	1.49 E+01	2.98 E-04	1.49 E+01	Ni2O3	1.05 E+01	1.04 E+01	1.05 E-01
PaO5	6.62 E+01	1.32 E-03	6.62 E+01	P2O5	1.02 E-01	1.01 E-01	1.03 E-03
Cs-Ba 137 (Bq/D)	6.66 E+14	1.33 E+10	6.66 E+14	PuO2	2.47 E-02	2.45 E-02	2.47 E-04
				SiO2	8.40 E+01	8.31 E+01	8.40 E-01
				SrO	4.08 E-02	4.04 E-02	4.08 E-04
				Tc207	1.18 E+00	1.17 E+00	1.18 E-02
				U3O8	8.45 E-02	8.37 E-02	8.45 E-04
				ZrO	1.65 E+00	1.64 E+00	1.66 E-02
				ZrO2	1.80 E+00	1.78 E+00	1.80 E-02
				Cs-Ba 137 (Bq/D)	6.70 E+12	6.62 E+12	6.70 E+10
				Sr-Y 90 (Bq/D)	1.77 E+14	1.75 E+14	1.77 E+12
				Tc 99 (Bq/D)	4.74 E+11	4.66 E+11	4.74 E+09
				Pu (Bq/D)	1.83 E+11	1.81 E+11	1.83 E+09
				Am (Bq/D)	6.11 E+11	6.07 E+11	6.11 E+09

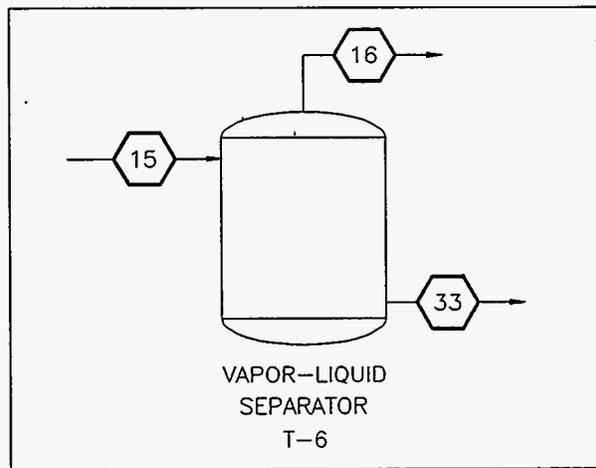


Figure D-4 Vapor-Liquid Separator

Table D-4 Vapor-Liquid Separator Material Balance

LIQUID COMPONENTS			SOLID COMPONENTS				
STREAM NAME	15	16	33	STREAM NAME	15	16	33
Volume Flow (L/CD)			8.64 E+03	Total Flow (Kg/CD)	2.99 E+00	1.50 E+00	1.33 E+00
Specific Gravity			1.00 E+00	MnO2	3.30 E-03	1.65 E-03	1.65 E-03
Total Flow (Kg/CD)	1.01 E+05	9.23 E+04	8.64 E+03	Organic Carbon	1.35 E-03	6.74 E-04	6.74 E-04
CO2	1.11 E+02	1.11 E+02		Al2O3	1.78 E+00	8.91 E-01	8.91 E-01
F2	4.96 E+01	4.96 E+01		Am2O3	2.36 E-05	1.18 E-05	1.18 E-05
I2	1.01 E-03	1.01 E-03		B2O3	1.34 E-02	6.71 E-03	6.71 E-03
N2	3.56 E+04	3.56 E+04		BeO	3.41 E-03	1.70 E-03	1.70 E-03
NO2	1.55 E+02	1.55 E+02		CaO	6.10 E-02	3.05 E-02	3.05 E-02
O2	1.27 E+04	1.27 E+04		Cr2O3	2.12 E-03	1.06 E-03	1.06 E-03
SO2	4.50 E+00	4.50 E+00		Cs2O	9.86 E-06	4.93 E-06	4.93 E-06
Cs+			4.60 E-06	Fe2O3	2.33 E-01	1.17 E-01	1.17 E-01
K+			8.77 E-04	K2O	2.13 E-03	1.07 E-03	1.07 E-03
Na+			1.26 E-01	La2O3	2.94 E-02	1.47 E-02	1.47 E-02
NO2-	9.75 E+01	9.75 E+01	1.95 E-03	MgO	3.08 E-02	1.54 E-02	1.54 E-02
NO3-	3.26 E+02	3.26 E+02	6.51 E-03	MnO3	4.28 E-02	2.14 E-02	2.14 E-02
OH-			9.37 E-02	Na2O	3.43 E-01	1.72 E-01	1.72 E-03
H2O	5.18 E+04	4.32 E+04	8.64 E+03	Ni2O3	4.70 E-02	2.35 E-02	2.35 E-02
P2O5	3.68 E+01	3.68 E+01	7.36 E-04	P2O5	4.57 E-04	2.28 E-04	2.28 E-04
Cs-Ba 137 (Ci/CD)			1.48 E+10	PuO2	1.10 E-04	5.50 E-05	5.50 E-05
				SiO2	3.74 E-01	1.87 E-01	1.87 E-01
				SrO	1.82 E-04	9.09 E-05	9.09 E-05
				Tc2O7	5.25 E-03	2.62 E-03	2.62 E-03
				U3O8	3.76 E-04	1.88 E-04	1.88 E-04
				ZrO	7.37 E-03	3.69 E-03	3.69 E-03
				ZrO2	8.02 E-03	4.01 E-03	4.01 E-03
				Cs-Ba 137 (Bq/CD)	2.98 E+10	1.49 E+10	1.49 E+08
				Sr-Y 90 (Bq/CD)	7.88 E+11	3.92 E+11	3.92 E+11
				Tc 99 (Bq/CD)	2.11 E+09	1.05 E+09	1.05 E+09
				Pu (Bq/CD)	8.14 E+08	4.07 E+08	4.07 E+08
				Am (Bq/CD)	2.72 E+09	1.36 E+09	1.36 E+09

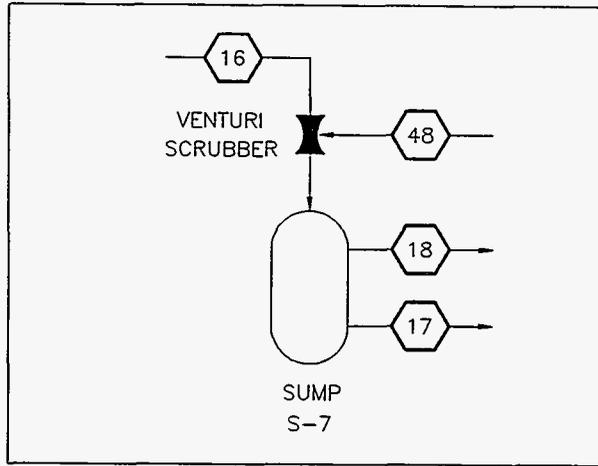


Figure D-5. Venturi Scrubber and Sump

Table D-5 Venturi Scrubber and Sump Material Balance

LIQUID COMPONENTS					SOLID COMPONENTS			
STREAM NAME	16	17	18	48	STREAM NAME	16	17	18
Volume Flow (L/CD)		1.56 E+04		1.48 E+04	Total Flow (Kg/CD)	1.50 E+00	1.48 E+00	1.50 E-02
Specific Gravity		1.04 E+00		1.00 E+00	MnO2	1.65 E-03	1.63 E-03	1.65 E-05
Total Flow (Kg/CD)	9.23 E+04	1.62 E+04	9.09 E+04	1.48 E+04	Organic Carbon	6.74 E-04	6.67 E-04	6.74 E-06
O2	1.11 E+02	5.50 E+01	5.55 E-01		Al2O3	8.91 E-01	8.82 E-01	8.91 E-03
F2	4.96 E+01	4.91 E+01	4.96 E-01		Am2O3	1.18 E-05	1.17 E-05	1.18 E-07
I2	1.01 E-03	9.98 E-04	1.01 E-05		B2O3	6.71 E-03	6.65 E-03	6.71 E-05
N2	3.56 E+04		3.56 E+04		BaO	1.70 E-03	1.69 E-03	1.71 E-05
NO2	1.55 E+02		7.74 E+01		CaO	3.05 E-02	3.02 E-02	3.05 E-04
O2	1.27 E+04		1.26 E+04		Cr2O3	1.06 E-03	1.05 E-03	1.06 E-05
SO2	4.50 E+00	2.23 E+00	2.25 E-02		Cs2O	4.93 E-06	4.88 E-06	4.93 E-08
O3-2		7.50 E+01	7.57 E-01		Fe2O3	1.17 E-01	1.16 E-01	1.17 E-03
NO2-	9.75 E+01	9.65 E+01	9.75 E-01		K2O	1.07 E-03	1.06 E-03	1.07 E-05
NO3-	3.26 E+02	4.26 E+02	4.30 E+00		La2O3	1.47 E-02	1.46 E-02	1.47 E-04
SO4-2		3.34 E+00	3.37 E-02		MgO	1.54 E-02	1.52 E-02	1.54 E-04
H2O	4.32 E+04	1.54 E+04	4.26 E+04	1.48 E+04	MnO3	2.14 E-02	2.12 E-02	2.14 E-04
P2O5	3.68 E+01	3.64 E+01	3.68 E-01		Na2O	1.72 E-01	1.70 E-01	1.72 E-03
					Ni2O3	2.35 E-02	2.33 E-02	2.35 E-04
					P2O5	2.28 E-04	2.26 E-04	2.28 E-06
					PuO2	5.50 E-05	5.45 E-05	5.50 E-07
					SiO2	1.87 E-01	1.85 E-01	1.87 E-03
					SrO	9.09 E-05	9.00 E-05	9.08 E-07
					Tc2O7	2.62 E-03	2.60 E-03	2.62 E-05
					UO3	1.88 E-04	1.86 E-04	1.88 E-06
					ZnO	3.69 E-03	3.65 E-03	3.69 E-05
					ZrO2	4.01 E-03	3.97 E-03	4.01 E-05
					Cs-Ba 137 (Bq/CD)	1.49 E+10	1.48 E+10	1.49 E+08
					Sr-Y 90 (Bq/CD)	3.92 E+11	3.89 E+11	3.92 E+09
					Tc 99 (Bq/CD)	1.05 E+09	1.04 E+09	1.05 E+07
					Pu (Bq/CD)	4.07 E+08	4.03 E+08	4.07 E+06
					Am (Bq/CD)	1.36 E+09	1.35 E+09	1.36 E+07

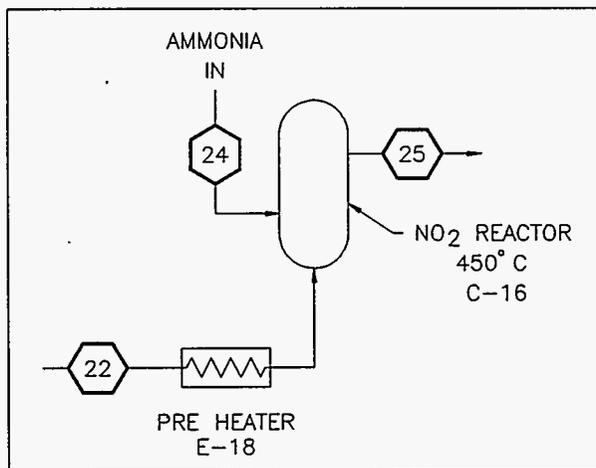


Figure D-6 NO₂ Reactor

Table D-6 NO₂ Reactor Material Balance

LIQUID COMPONENTS			
STREAM NAME	22	24	25
Volume Flow (L/DD)			
Specific Gravity			
Total Flow (Kg/DD)	5.14 E+04	3.82 E+01	5.15 E+04
CO2	1.39 E-03		1.39 E-03
F2	1.24 E-03		1.24 E-03
I2	2.52 E-03		2.52 E-03
N2	3.56 E+04		3.57 E+04
NO2	7.74 E+01		7.74 E-01
O2	1.26 E+04		1.26 E+04
SO2	5.62 E-05		5.62 E-05
CO3-2	1.89 E-03		1.89 E-03
NO2-	2.44 E-03		2.44 E-03
NO3-	1.08 E-02		1.08 E-02
SO4-2	8.43 E-05		8.43 E-05
H2O	3.09 E+03		3.15 E+03
F2O5	9.20 E-04		9.20 E-04
Ammonia		3.82 E+01	3.82 E-01

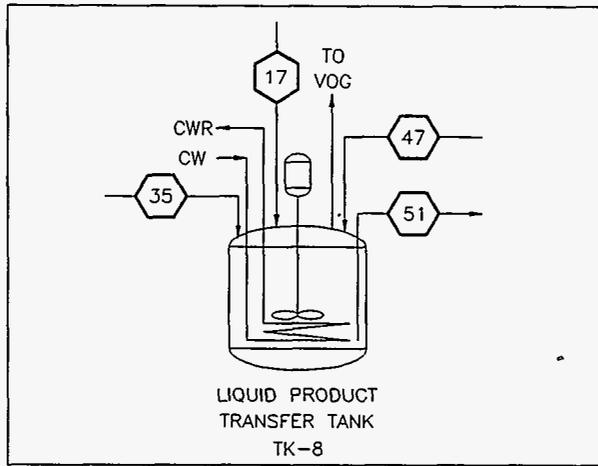


Figure D-7 Liquid Product Transfer Tank

Table D-7 Liquid Product Transfer Tank Material Balance

LIQUID COMPONENTS					SOLID COMPONENTS				
STREAM NAME	17	35	47	51	STREAM NAME	17	35	47	51
Volume Flow (L/D)	1.56 E+04	4.41 E+04	2.00 E+04	7.97 E+04	Total Flow (Kg/D)	1.48 E+00	2.84 E+02	7.48 E-03	2.86 E+02
Specific Gravity	1.04 E+00	1.27 E+00	1.00 E+00	1.15 E+00	MnO2	1.63 E-03	9.05 E-03	8.24 E-06	1.07 E-02
Total Flow (Kg/D)	1.62 E+04	5.58 E+04	2.00 E+04	9.20 E+04	Organic Carbon	6.67 E-04	3.70 E-03	3.37 E-06	4.37 E-03
CO2	5.50 E+01		2.78 E-01	5.53 E+01	Al2O3	8.82 E-01	2.81 E+02	4.46 E-03	2.82 E+02
F2	4.91 E+01		2.48 E-01	4.93 E+01	Am2O3	1.17 E-05	6.47 E-05	5.89 E-08	7.64 E-05
I2	9.98 E-04		5.04 E-06	1.00 E-03	B2O3	6.65 E-03	3.69 E-02	3.36 E-05	4.35 E-02
SO2	2.23 E+00		1.12 E-02	2.24 E+00	BaO	1.69 E-03	9.36 E-03	8.53 E-06	1.11 E-02
Al+3		3.48 E+02		3.48 E+02	CaO	3.02 E-02	1.68 E-01	1.53 E-04	1.98 E-01
Cr+3		3.23 E+01		3.23 E+01	Cr2O3	1.05 E-03	5.81 E-03	5.29 E-06	6.86 E-03
Cs+		2.08 E-01		2.08 E-01	Cs2O	4.88 E-06	2.22 E-05	2.46 E-08	2.71 E-05
K+		3.96 E+01		3.96 E+01	Fe2O3	1.16 E-01	6.40 E-01	5.83 E-04	7.57 E-01
Na+		5.69 E+03		5.69 E+03	K2O	1.06 E-03	4.80 E-03	5.33 E-06	5.86 E-03
Cl-		1.41 E+02		1.41 E+02	La2O3	1.46 E-02	8.08 E-02	7.35 E-05	9.54 E-02
CO3-2	7.50 E+01	3.63 E+03	3.79 E-01	3.71 E+03	MgO	1.52 E-02	8.44 E-02	7.69 E-05	9.97 E-02
NO2-	9.65 E+01	4.39 E+01	4.88 E-01	1.41 E+02	MnO3	2.12 E-02	1.17 E-01	1.07 E-04	1.39 E-01
NO3-	4.26 E+02	1.47 E+02	2.15 E+00	5.74 E+02	Na2O	1.70 E-01	7.73 E-01	8.59 E-04	9.44 E-01
OH-		2.11 E+03		2.11 E+03	Ni2O3	2.33 E-02	1.29 E-01	1.17 E-04	1.52 E-01
SO4-2	3.34 E+00	1.62 E+02	1.69 E-02	1.65 E+02	P2O5	2.26 E-04	1.25 E-03	1.14 E-06	1.48 E-03
H2O	1.54 E+04	4.34 E+04	2.00 E+04	7.88 E+04	PL02	5.45 E-05	3.02 E-04	2.75 E-07	3.57 E-04
MnO2		1.42 E+01		1.42 E+01	SiO2	1.85 E-01	1.03 E+00	9.35 E-04	1.21 E+00
Organic Carbon		1.49 E+01		1.49 E+01	SrO	9.00 E-05	4.99 E-04	4.54 E-07	5.89 E-04
P2O5	3.64 E+01	6.62 E+01	1.84 E-01	1.03 E+02	Tc2O7	2.60 E-03	1.44 E-02	1.31 E-05	1.70 E-02
Ammonia			1.82 E-01	1.82 E-01	U3O8	1.86 E-04	1.03 E-03	9.41 E-07	1.22 E-03
Cs-Ba 137 (Bq/D)		6.66 E+14		6.66 E+14	ZrO	3.65 E-03	2.02 E-02	1.84 E-05	2.39 E-02
					ZrO2	3.97 E-03	2.20 E-02	2.01 E-05	2.60 E-02
					Cs-Ba 137 (Bq/D)	1.48 E+10	6.70 E+10	7.44 E+07	8.18 E+10
					Sr-Y 90 (Bq/D)	3.89 E+11	2.16 E+12	1.97 E+09	2.56 E+12
					Tc 99 (Bq/D)	1.04 E+09	5.77 E+09	5.25 E+06	6.81 E+09
					Pu (Bq/D)	4.03 E+08	2.24 E+09	2.04 E+06	2.65 E+09
					Am (Bq/D)	1.35 E+09	7.47 E+09	6.81 E+06	8.81 E+09

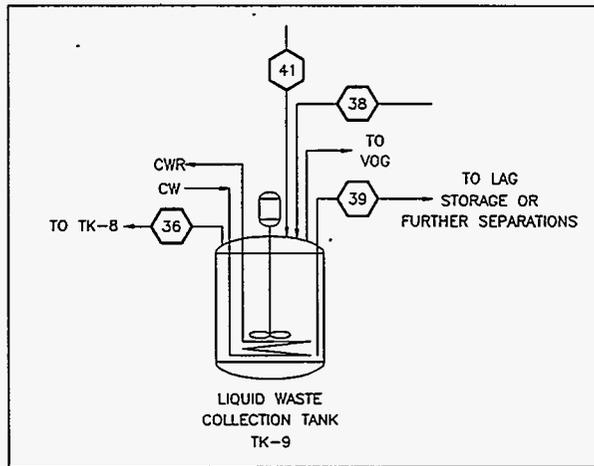


Figure D-8 Liquid Waste Collection Tank

Table D-8 Liquid Waste Collection Material Balance

LIQUID COMPONENTS				SOLID COMPONENTS				
STREAM NAME	36	38	39	41	STREAM NAME	36	39	41
Volume Flow (L/D)	2.00 E+04	5.15 E+02	2.00 E+04	3.95 E+04	Total Flow (Kg/D)	7.48 E-03	7.48 E-03	1.50 E-02
Specific Gravity	1.00 E+00	1.00 E+00	1.00 E+00	1.00 E+00	MnO2	8.24 E-06	8.24 E-06	1.65 E-05
Total Flow (Kg/D)	2.00 E+04	5.15 E+02	2.00 E+04	3.95 E+04	Organic Carbon	3.37 E-06	3.37 E-06	6.74 E-06
CO2	2.78 E-01	2.64 E-02	2.78 E-01	5.29 E-01	Al2O3	4.46 E-03	4.46 E-03	8.91 E-03
F2	2.48 E-01	2.35 E-02	2.48 E-01	4.72 E-01	Am2O3	5.89 E-03	5.89 E-03	1.18 E-07
I2	5.04 E-06	4.79 E-07	5.04 E-06	9.60 E-06	B2O3	3.36 E-05	3.36 E-05	6.71 E-05
SO2	1.12 E-02	1.07 E-03	1.12 E-02	2.14 E-02	BeO	8.53 E-06	8.53 E-06	1.71 E-05
CO3-2	3.79 E-01	3.60 E-02	3.79 E-01	7.21 E-01	CaO	1.53 E-04	1.53 E-04	3.05 E-04
NO2-	4.88 E-01	4.63 E-02	4.88 E-01	9.29 E-01	Cr2O3	5.29 E-06	5.29 E-06	1.06 E-05
NO3-	2.15 E+00	2.04 E-01	2.15 E+00	4.09 E+00	Cs2O	2.46 E-08	2.46 E-08	4.93 E-08
SO4-2	1.69 E-02	1.60 E-03	1.69 E-02	3.21 E-02	Fe2O3	5.83 E-04	5.83 E-04	1.17 E-03
H2O	2.00 E+04	5.14 E+02	2.00 E+04	3.95 E+04	K2O	5.33 E-06	5.33 E-06	1.07 E-05
P2O5	1.84 E-01	1.75 E-02	1.84 E-01	3.50 E-01	La2O3	7.35 E-05	7.35 E-05	1.47 E-04
Ammonia	1.82 E-01		1.82 E-01	3.63 E-01	MgO	7.69 E-05	7.69 E-05	1.54 E-04
					MnO	1.07 E-04	1.07 E-04	2.14 E-04
					Na2O	8.59 E-04	8.59 E-04	1.72 E-03
					Ni2O3	1.17 E-04	1.17 E-04	2.35 E-04
					P2O5	1.14 E-06	1.14 E-06	2.28 E-06
					PO2	2.75 E-07	2.75 E-07	5.50 E-07
					SiO2	9.35 E-04	9.35 E-04	1.87 E-03
					SnO	4.54 E-07	4.54 E-07	9.08 E-07
					Tc2O7	1.31 E-05	1.31 E-05	2.62 E-05
					UBO3	9.41 E-07	9.41 E-07	1.88 E-06
					ZnO	1.84 E-05	1.84 E-05	3.69 E-05
					ZrO2	2.01 E-05	2.01 E-05	4.01 E-05
					Cs-Ba 137 (Bq/D)	7.44 E+07	7.44 E+07	1.49 E+08
					Str-Y 90 (Bq/D)	1.97 E+09	1.97 E+09	3.92 E+09
					Tc 99 (Bq/D)	5.25 E+06	5.25 E+06	1.05 E+07
					Pu (Bq/D)	2.04 E+06	2.04 E+06	4.07 E+06
					Am (Bq/D)	6.81 E+06	6.81 E+06	1.36 E+07