Americium-Curium Stabilization - 5" Cylindrical Induction Melter System Design Basis

by

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DISCLAIMER

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Americium-Curium Stabilization - 5" Cylindrical Induction Melter System Design Basis (U)

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DISCLAIMER

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I. INTRODUCTION

Approximately 11,000 liters (3,600 gallons) of solution containing isotopes of Am and Cm are currently stored in F-Canyon Tank 17.1. These isotopes were recovered during plutonium–242 production campaigns in the mid- and late-1970's. The continued storage of these isotopes was identified as an item of primary concern in the Defense Nuclear Facility Safety Board's (DNFSB) Recommendation 94-1 [Ref. 1]. Currently, there are no existing SRS facilities that can be used to stabilize this material for safe interim storage and transportation to the heavy isotopes program at the Oak Ridge National Laboratory (ORNL). An analysis of several alternatives resulted in the recommendation to stabilize the Am-Cm solution in a high-lanthanide glass [Ref. 2,3]. The Multi-Purpose Processing Facility (MPPF) in the F-Canyon will be used for the vitrification process. Pretreatment operations will be performed in existing canyon vessels to separate actinides and lanthanides from other impurities (primarily iron, aluminum, and sodium) prior to the vitrification operation.

Experimental work for the project began in 1995 by the Savannah River Technology Center (SRTC). Surrogate (non-radioactive) feed solutions were used. Initially, platinum-bushing melters were investigated. After several years of development work with various bushing melter designs, it was determined that the technical risks associated with a bushing melter were unacceptable, and therefore, work began on development of a platinum cylindrical induction melter (CIM). The CIM allowed for more precise temperature control throughout the melter, is more structurally sound at the high temperatures required for vitrification of this particular feed, and is better suited to the MPPF environment. The other major process modification was the move to a batch process. The proposed baseline flowsheet involves precipitating the actinide materials with oxalic acid and washing the precipitate to lower the nitric acid concentration. The subsequent oxalate precipitate is then mixed with glass formers. The resultant mixture is then dried and heated to approximately 1450°C to produce a molten glass product. The glass is then poured through a drain tube into a stainless steel cylinder. A more detailed summary of this process development can be found in the Am-Cm Stabilization Development Program Plan [Ref. 4]. Details of the process are given in the various sections of this document, and Attachment 1 gives an overall flowsheet of the process.

Following testing on the 3-inch Cylindrical Induction Melter in September 1998, a document was prepared to provide preliminary design basis information for the CIM system to the Design Team [Ref. 5]. The original document included information for the 3-inch CIM system, as well as information for the 5-inch system that was being installed. Following installation of the 5-inch CIM system, a series of runs were completed to characterize the system and demonstrate the batch vitrification flowsheet. These tests culminated with the completion of four Integrated Demonstration Runs in the 5-inch CIM in December 1998 [Ref. 6]. This document provides the design bases information for the batch vitrification process in the 5-inch CIM system.

There are several limitations with regards to the design bases that should be noted:

- Several operational bases are preliminary in that development activities are still in progress and will continue throughout FY1999. Preliminary information provided is that necessary to initiate the design process. Potential changes to these operational bases resulting from additional Pilot Facility testing will not impact fundamental design bases without formal design change control.
- It is assumed that the vitrification cycle is accomplished by controlling power to the induction coils (i.e. no temperature sensors monitoring the contents of the melter, the melter vessel or the drain tube).
- Power system specifications, heating stations, induction coil configurations, etc. are as specified by Ameritherm (the vendor of the Pilot Scale Systems) for the Am-Cm Pilot Facility.
- The MPPF Design Authority will specify the final configuration for transfers between Tank 17.3E and the Feed Tank, between the Feed Tank and the Batch Tank and between the Spent Wash Tank and the Precipitator.
- Criteria for determining the capacity of process vessels lies with the Design Authority and Design.
- The Preliminary Design Basis Document does not address canister welding.
- The Preliminary Design Basis Document does not address glass sampling.
- The Preliminary Design Basis Document does not address techniques or criteria for analytically determining the composition of the Am/Cm contents of a canister.
- The final frit requirement will be based on Tank 17.3E analyses, specific gravity of Feed Tank contents, and precipitator batch volume. Sampling of feed beyond Tank 17.3E is not required as part of the baseline process.

II. MATERIAL BALANCE

The Preliminary Design Basis Document [Ref. 5] provided material balance calculations for the Americium-Curium pretreatment and vitrification processes. During the 5-inch CIM Integrated Demonstration Runs, a total lanthanide loading of ~60% was used. This translates to a Tank 17.3E loading of ~47% as opposed to the material balance bases of 28%. Additional work is underway to determine the optimal and bounding lanthanide loading for the batch flowsheet. Upon completion of this work, the material balance will be updated. As a result, the material balance is not presented in this document. Additionally, as discussed above, any changes resulting from a change in the material balance will be accommodated such that the design effort is not impacted.

III. FEED DESCRIPTION

General

Tables III-1 and III-2 give the composition of Tanks 17.1 and 17.3 (post pre-treatment). The tables include the following information and are based on the material balance that was updated in September 1998 to reflect the February 1998 analysis of Tank 17.1 [Ref. 5].

- Nominal Cation Content in mg/L
- Nominal Anion Content in mg/L
- Nominal HNO3 Concentration, M
- Specific Gravity
- Nominal Total Solids Concentration on an Oxide basis
- Radionuclide Concentration Including Watts/Liter per Radionuclide and Total Heat Content

Note: Tank 17.1 values based on 15,000 liter feed volume, Tank 17.3 based on 1166 liter feed volume.

Control of Composition of Feed Batched to Precipitator Batch Tank

Once the Am/Cm feed has been pre-treated in the canyon and accumulated in the 17.3E Evaporator, it will be the responsibility of Operations to sample and compositionally characterize the feed. Of paramount importance is that Operations maintain a set composition, since it is not practical to compositionally characterize each batch of feed batched to the Precipitator. This can be best accomplished by establishing a relationship between the specific gravity of the contents of 17.3E and the total solids contents on an oxide basis. By assuring that the specific gravity of the contents of 17.3E remain within an established tolerance of specific gravity, down stream process-operating parameters can be established and held to as constants.

TABLE III-1. Tank 17.1 Composition

Cation	Cations (mg/l)	Oxide	Oxides (mg/l)	Anion	Anions (mg/l)
Lanthanides					
La	984.56	La_2O_3	1154.69	NO_3	16662.22
Ce	773.78	Ce_2O_3	906.33	NO_2	676.79
Pr	661.17	Pr_2O_3	773.77	C_2O_4	1147.59
Nd	1898.99	Nd_2O_3	2214.22	SO_4	9566.49
Sm	450.12	Sm_2O_3	521.91	F	208.02
Eu	91.45	Eu_2O_3	105.88	PO_4	1197.08
Gd	232.12	Gd_2O_3	267.54	Cl	970.44
Tb	30.27	Tb_2O_3	34.84		
Dy	30.26	Dy_2O_3	34.74		
Ho	30.27	Ho_2O_3	34.67		
Er	30.27	Er_2O_3	34.61		
Tm	40.40	Tm_2O_3	46.46		
Yb	30.27	Yb_2O_3	34.46		
Lu	30.26	Lu_2O_3	34.41		
Actinides					
Am	594.64	Am_2O_3	653.39		
Cm	146.99	Cm_2O_3	161.27		
Np	1.73	Np_2O_5	1.90		
Pu	158.73	PuO_2	174.35		
U	610.08	UO_3	733.07		
Cs	3.56	Cs_2O	3.77		
Metals					
Al	1094.16	Al_2O_3	2067.41		
Ca	66.61	CaO	93.20		
Cr	393.88	Cr_2O_3	575.70		
Fe	4853.59	Fe_2O_3	6939.17		
K	217.00	K_2O	261.40		
Mn	242.72	MnO	313.40		
Na	549.37	Na_2O	740.55		
Ni	288.41	NiO	367.03		
Zn	21.20	ZnO	26.39		
Zr	4.07	ZrO_2	5.49		
Radionuclide	Watts per gm Radionuclide	Total Watts per Liter per Radionuclide	Total Solids Oxide Basis (g/l)	Nominal HNO3 Conc. (M)	Specific Gravity (g/cm^3)
U	3.73E-07	2.2756E-07	19.32	5.7	1.20
Pu	0.0396	0.0063			
Am	0.0105	0.0062			
Cm	2.7200	0.3998			
	Total W/liter	0.412			

TABLE III-2. Tank 17.3 Post Pretreatment Composition

Cation	Cations (mg/l)	Oxide	Oxides (mg/l)	Anion	Anions (mg/l)
Lanthanides					
La	12577.34	La_2O_3	14750.71	NO_3	111100
Ce	9911.79	Ce_2O_3	11609.69	NO_2	157.36
Pr	8490.90	Pr_2O_3	9936.90	C_2O_4	267.05
Nd	24409.96	Nd_2O_3	28462.01	SO_4	2219.80
Sm	5770.64	Sm_2O_3	6691.06	F	48.32
Eu	1173.51	Eu_2O_3	1358.69	PO_4	278.33
Gd	2982.23	Gd_2O_3	3437.32	Cl	225.56
Tb	377.80	Tb_2O_3	434.85		
Dy	377.67	Dy_2O_3	433.45		
Ho	377.85	Ho_2O_3	432.82		
Er	377.82	Er_2O_3	432.00		
Tm	507.83	Tm_2O_3	579.99		
Yb	377.35	Yb_2O_3	429.69		
Lu	377.10	Lu_2O_3	428.80		
Actinides					
Am	7605.68	Am_2O_3	8357.12		
Cm	1872.82	Cm_2O_3	2054.85		
Np	0.40	Np_2O_5	0.44		
Pu	89.84	PuO_2	98.68		
U	141.83	UO_3	170.42		
Cs	0.82	Cs_2O	0.87		
Metals					
Al	254.19	Al_2O_3	480.29		
Ca	15.49	CaO	21.67		
Cr	91.53	Cr_2O_3	133.79		
Fe	1127.00	Fe_2O_3	1611.27		
K	50.28	K_2O	60.56		
Mn	6152.48	MnO	7944.08		
Na	127.65	Na_2O	172.08		
Ni	67.15	NiO	85.46		
Zn	4.94	ZnO	6.14		
Zr	0.94	ZrO_2	1.27		

Radionuclide	Watts per gm Radionuclide	Total Watts per Liter per Radionuclide	Total Solids Oxide Basis (g/l)	Nominal HNO3 Conc. (M)	Specific Gravity (g/cm^3)
U	3.73E-07	5.2902E-08	100.62	1.0	1.20
Pu	0.0396	0.0036			
Am	0.0105	0.0799			
Cm	2.7200	5.0941			
	Total W/liter	5.18			

IV. GLASS FORMER

Composition

The nominal 25SrABS frit composition (see Table IV-1) was selected based on a balance between the feed loading, melting characteristics of the frit, and interactions between the frit and the oxalate precipitate. Although the specifications for size and size distribution are not defined at this time, the 25SrABS frit was obtained from a vendor to support testing in the Drain Tube Test Stand (DTTS) and the Cylindrical Induction-Heated Melter (CIM) and will be manufactured to the compositional specifications for operations (FY99) testing. The compositional specifications submitted to the vendor are shown in Table IV-1.

Table IV-1. Compositional Tolerance for the 25SrABS Frit

Component	Concentration (wt%)
La_2O_3	25.0 +/- 1.00
Al_2O_3	24.9 +/- 1.00
B_2O_3	13.5 +/- 0.50
SiO_2	33.7 +/- 1.00
SrO	2.9 +/- 0.25
Total	100.0

Particle Size

The particle size and/or shape of the 25SrABS glass former have not been finalized but should not impact initial design activities. This is being addressed in the DTTS and the CIM pilot facility. However, particle size and/or shape has been shown to effect volume expansion and/or high-temperature bubble formation. The volume expansion is most prevalent when the particle size of the 25SrABS frit is relatively small (e.g., < 100 mesh). When coarse 25SrABS cullet is used, the effects of the volume expansion are minimized, if not eliminated. The exact form/size of the glass former will be specified at the completion of current glass former testing. However, all forms/sizes under consideration will conform to a specification for a solid pellet/granular form added manually to the melter vessel.

V. PRODUCT DESCRIPTION

Nominal Composition

Table V-1 shows the nominal compositions (in wt%) of the 25SrABS glass former, the nominal baseline glass composition (AmCm-1a) based on a 47 wt% Tank 17.3E loading and the most recent material balance calculations [see Material

Balance section of SRT-AMC-98-0225, Ref. 5], and the AmCm-1a surrogate composition.

The compositional specifications (or tolerances) that will be allowed in the MPPF have not yet been determined. This is being addressed in a 20% composition variability study, which is in progress and is scheduled to be completed later this fiscal year. When the compositional variability study and additional CIM tests are completed, the material balance for the batch vitrification process will be updated.

The AmCm-1a surrogate glass is very similar in composition to that estimated as the baseline. There are some minor differences in the relative percentage of the lanthanide oxides. This stems from the fact that the oxides of Tb, Dy, Ho, Er, Tm, Yb, and Lu appear to be at or below detection limits of the analytical equipment. Assuming that these oxide components are not present in the incoming actinide-bearing stream, one can distribute their contribution (2.66 wt%) over the remaining lanthanide oxides (i.e., increase the other seven Ln_2O_3 concentrations by 0.38 wt%). Previous work has suggested that the total Ln_2O_3 concentration is critical, not the distribution although this will also be addressed in the compositional variability study. This "redistribution" technique keeps the total Ln_2O_3 content equivalent to that of the nominal baseline glass (AmCm-1a).

<u>Product Density</u>

The glass density as a function of temperature has not been determined. For material balance purposes, a density of ~3.7 g/cc was used to calculate the volume occupied by 1.1 - 2.0 kg of glass. For purposes of specifying the canister height, it is recommended that a glass density of 3.5 g/cc be assumed. Work is in progress to determine the high-temperature density of the various lanthanide-based glasses.

<u>Product Viscosity</u>

Table V-2 gives the viscosity of AmCm-1a glass surrogate as a function of temperature. These design and operating bases are specified in a subsequent section of this document. It should be noted that the viscosity data for AmCm-1a is limited to a relatively narrow temperature range (approximately 1285° - 1385°C). This is a result of the steep dependence of viscosity with temperature for the lanthanide borosilicate glasses. Above 1385°C, the AmCm-1a viscosity approaches the lower detection limit of the viscometer. Below 1300°C, crystallization may effect the viscosity measurement due to the liquidus temperature of the glass.

Table V-1. Actinide-Bearing Feed Material, 25SrABS Frit Composition, and Target Glass Composition ("actual" and surrogate) on an Oxide (wt%) Basis

Oxide	Actinide-Bearing Feed Material (Tank 17.3E)	25SrABS Frit	AmCm-1a Glass (47% loaded)	AmCm-1a Glass (surrogate)
Lanthanide Oxides				
La_2O_3	15.05	25.00	20.323	20.502
Ce_2O_3	12.94	-	6.082	6.260
Pr_2O_3	11.26	-	5.292	5.471
Nd_2O_3	32.80	-	15.416	15.595
Sm_2O_3	7.49	-	3.520	3.669
Eu_2O_3	1.56	-	0.733	0.912
Gd_2O_3	3.98	-	1.871	2.049
Tb_2O_3	0.36	-	0.169	0.00
Dy_2O_3	0.36	-	0.169	0.00
Ho_2O_3	0.36	-	0.169	0.00
Er_2O_3	0.35	-	0.165	0.00
Tm_2O_3	0.53	-	0.249	0.00
Yb_2O_3	0.35	-	0.165	0.00
Lu_2O_3	0.35	-	0.165	0.00
Actinide Oxides				
Am_2O_3	9.70	-	4.559	4.559 (Er_2O_3)
Cm_2O_3	2.38	-	1.119	1.119 (Er_2O_3)
Np_2O_3	0.00	-	0.00	0.00
PuO_2	0.00	-	0.00	0.00
UO3	0.00	-	0.00	0.00
Cs_2O	0.00	-	0.00	0.00
Metallic oxides				
Al_2O_3	0.01	24.87	13.186	13.186
B_2O_3	0.00	13.54	7.176	7.176
CaO	0.00	-	0.00	0.00
Cr_2O_3	0.00	-	0.00	0.00
Fe_2O_3	0.03	-	0.014	0.014
K_2O	0.00	-	0.00	0.00
MnO	0.14	-	0.066	0.066
Na_2O	0.00	-	0.00	0.00
NiO	0.00	-	0.00	0.00
SiO_2	0.00	33.68	17.850	17.850
SrO	0.00	2.91	1.542	1.542
ZnO	0.00	-	0.00	0.00
ZrO_2	0.00	-	0.00	0.00
Total	100.00	100.00	100.00	100.00

Table V-2. Viscosity of AmCm-1a Glass Surrogate as a Function of Temperature

Temperature (°C)	Viscosity (Poise)
1285	22.12
1334	12.38
1384	7.34

Acceptance Criteria

To ensure that the glass is both processable and meets product performance specifications a set of 'acceptance' criteria have been established for the variability study in order to establish the optimal operating range for the batch vitrification process. These criteria focus on the processing criteria (liquidus temperature and viscosity) and product performance criteria (recoverability and durability).

Processing Criteria

Viscosity

Glass viscosity data is critical in establishing the length and internal diameter of the drain tube and the temperature operating parameters to ensure a target glass pour rate of greater than 8.0 kg/hr is attained. Expected acceptable viscosities can range from ~3 to ~30 poise at 1350°C. Viscosities outside this range at a fixed temperature will be considered less than optimal due to the potential to result in a non-continuous pour stream (considered to be <8 kg/hr).

Liquidus Temperature (T_L)

The nominal CIM operating temperatures are in the range of 1350° - 1450°C. To avoid the potential negative effects of crystallization within the melter, a liquidus temperature criteria has been set at 1250°C - 1350°C. Lanthanide-based glasses with $T_L \leq$ 1250°C - 1350°C lower the risk of crystallization in the melter.

Product Performance Criteria

Durability

An acceptable durability (as defined by the Product Consistency Test -PCT) is equal to or better than the EA glass limit based on B release (with the appropriate confidence limits applied). Typically, Na and Li are also tracked, but the SrABS frit does not contain either Na or Li and only Na exists in the waste stream at an extremely low concentration.

Recoverability

The recoverability criteria is that 98% of the total lanthanides can be recovered from the glass with concentrated (15.7 M) nitric acid within 2 hours with heating (110°C) and the glass ground to approximately 60 mesh [Ref. 7].

VI. FLAMMABILITY CONTROL

Controlled air purges to the various process vessels are required to prevent a flammable hydrogen-air mixture occurring in the vapor space of each vessel. Tanks to be addressed are 17.1, 16.1E, 16.3, 17.3E, Feed Tank, Batch Tank, Precipitator, and Spent Wash Tank. The following equation is used to calculate the scfm of air purge required to limit the hydrogen concentration to 25% of its Lower Flammability Limit (LFL):

scfm (@0°C, 1.0 atm) = (Total watts)(6.242E+18 ev/sec-watt)(G Value)(3600 sec/hr)(6.023E+23 molecules/g-mol)({100/((.25)(LFL))-1}(22.4 L/g-mol)(60 min/hr)

where,

- o Total watts = see material balance
- o G Value, molecules of H2/100 eV = 1.1217/(1.0+1.702 [NO3]) where [NO3] = the nitrate concentration, M [Ref. 8]
- o LFL for hydrogen in air = 4.1 vol%

The required air purges for each of the above process vessels have been calculated and recorded in the material balance [Ref. 5]. However, if the maximum inventory of a process vessel is different than that listed for that vessel in the material balance calculation bases, the air purge must be scaled to the new process vessel inventory.

VII. CANISTER

General

The batch flowsheet process operating parameters (assuming a 5-inch diameter CIM) are designed to produce a batch of washed oxalate precipitate which when combined with the proper quantity of glass formers will produce 1.1 - 2.0 kg of glass.

Design Bases

- Nominal Internal Diameter – 2.0"
- Minimum wall thickness – to be specified by Design
- Height - to be specified by Design considering required melter freeboard
- Reference Materials of Construction – to be specified by Design
- Nominal glass fill – 1.1 - 2.0 kg
- Nominal Steady State Centerline Glass Temperature of Canister Filled with 1.1 - 2.0 kg Glass - ~275°C
- Design Basis Glass Density in Canister at Steady State Temperature – 3.5 to 3.7 g/cc (exact density has not been determined and will depend on waste loading)
- External Canister Surface Vertical Temperature During Canister Fill
  This was determined during glass pours from the 5-inch CIM during Integrated Demonstration Runs and varied from 235°C near the top of the canister to ~615°C in the area containing glass.

NOTE: Many of these requirements were previously documented [Ref. 9].

VIII. CANISTER SCALE

General

A canister scale is desired to determine the total weight of glass poured into each canister.

Design Bases

- Sensitivity – 0.1g

IX. MELTER FEED PREP

General

The pre-treatment process will produce a feed that is nominally 1.0 M in nitric acid and contains nominally 100 grams/L of total solids on an oxide basis. This product stream will undergo additional treatment in the Multi-Purpose Processing Facility (MPPF) to further reduce the nitric acid concentration and transition metal content. The lanthanide and actinide content of the 17.3E feed will be precipitated on a batch basis as oxalates. After allowing the oxalate solids to settle, the supernate will be decanted. Following the addition of a dilute oxalic acid wash solution, the oxalate solids will be agitated, allowed to settle once again and the spent wash decanted. The washed oxalate solids will then be resuspended and transferred by gravity into a Cylindrical Induction Heated Melter (CIM).

Note: The current process requires that the proper quantity of glass formers has already been charged to the CIM prior to transfer of a batch of washed oxalate solids into the melter from the precipitator.

Feed Tank

General

This process vessel will receive transfers from 17.3E for subsequent transfer to the Precipitator Batch Tank. The capacity of this process vessel will depend on how many Precipitator batches the tank is to accommodate. The Design Authority will specify the working volume of this process vessel.

Compositional Control

It is imperative that the specific gravity of the contents of the Feed Tank remain within the specific gravity tolerance established for 17.3E and for which all process operating parameters have been established in the down stream processes. Because of the high watt density of the feed and the continuous air purge through the vapor space to prevent a flammable atmosphere of air-hydrogen, the contents of the Feed Tank will have a tendency to concentrate even with the capability specified to control the temperature of the contents of the Feed Tank. Therefore, continuous monitoring of the specific gravity of the contents is required and the ability to bring the specific gravity to within specifications by periodic water addition is required.

Design Bases

- Nominal Working Volume - specified by the Design Authority
- Material of Construction - specified by the Design Authority
- Free Board – specified by the Design Authority
- Cooling Coil or Jacket - Design Authority to specify maximum allowable temperature of vessel contents and the design temperature of cooling water supply
- Transfer line from 17.3E
- Overflow Line from Precipitator Batch Tank terminating in Feed Tank vapor space
- Vapor Space Pressure – negative with respect to cell pressure, with pressure requirement to be specified by the Design Authority
- Air Purge - to limit hydrogen concentration in vapor space to 25% of its LFL
- Agitator - agitator blade configuration and agitator speed to be determined by Design

Minimum Services

- Process Air (to prevent a flammable mixture of hydrogen and air occurring in vessel vapor space)
- Instrument Air – to service pneumatic bubblers
- Process Water (to maintain the SpG within specifications)
- 50 wt% Nitric Acid (for vessel decontamination)
- Cooling Water to Cooling Coils
- Power (or process air) to agitator
- Vessel Vent (see Stream #87 in Material Balance for estimated Composition/Flowrate)

Minimum Real Time Monitoring Parameters

- Temperature of Contents
- Specific Gravity of Contents
- Liquid Level of Contents
- Cooling Water Flow
- Vapor Space Pressure
- Air Purge Rate
- Agitator Speed (or alternative parameter to infer agitator speed)

Recommended Alarms/Interlocks

- Alarm - HIGH Liquid Level
- Interlock at HIGH-HIGH Liquid Level – stops transfer from 17.3E
- Alarm - HIGH Temperature of Tank Contents
- Alarm - LOW cooling water flow
- Alarm - LOW air purge rate

Precipitator Batch Tank

General

The function of this tank is to receive feed from the Feed Tank and deliver a controlled feed batch volume to the Precipitator. This tank will have an overflow to the Feed Tank, which will control the size of the batch transfer volume into the Precipitator Tank. The elevation of the Precipitator Batch Tank must enable gravity draining into the Precipitator.

Design Bases

- Capacity – specified by the Design Authority
- Nominal Working Volume

For 5-inch Diameter Melter – 6.91 Liters

- Overflow Pipe Elevation – to provide nominal working volumes specified above
- Material of Construction - specified by the Design Authority
- Free Board - specified by the Design Authority
- Nominal Operating Temperature of Contents - specified by the Design Authority
- Maximum Temperature of Contents specified by the Design Authority
- Drain Line (with automated valve) to Precipitator
- Cooling Coil or Jacket - Design Authority to specify maximum allowable temperature of vessel contents and the design temperature of cooling water supply
- Vapor Space Pressure – negative with respect to cell pressure. Pressure requirement to be specified by the Design Authority
- Precipitator Batch Tank Elevation - such that the contents will drain by gravity into the Precipitator
- Air Purge - to limit hydrogen concentration in vapor space to 25% of its LFL

Minimum Services

- Process Air (to prevent a flammable mixture of hydrogen and air occurring)
- Instrument Air – to service pneumatic bubblers
- Process Water
- Nitric Acid (50 wt%) – for vessel decontamination
- Cooling Water
- Vessel Vent (see Stream # 88 in Material Balance for estimated Composition/Flowrate)
- Power (or process air) to agitator (Note: the current system does not use an agitator)

Minimum Real Time Monitoring Parameters

- Temperature of Contents
- Liquid Level of Contents
- Cooling Water Flow
- Vapor Space Pressure
- Air Purge Rate

Recommended Alarms/Interlocks

- Alarm - HIGH level
- Interlock at HIGH-HIGH Liquid Level – stops transfer from Feed Tank
- Alarm - HIGH Temperature

- Alarm - LOW cooling water flow
- Alarm - LOW air purge rate

Precipitator

General

The function of the precipitator is to provide washed rare-earth/actinide oxalate slurry to the melter while minimizing losses of radioactive species. The oxalate slurry is created in the precipitator by the reaction of the dissolved rare-earth/actinide nitrates with oxalic acid to form insoluble oxalates. The precipitation process must be tightly controlled to create a consistent settled solids volume in order to maintain the free solution requirements for transferring the oxalate slurry into the melter without splashing out of the melter. The geometry of the precipitator, the agitation system and the vessel washing system must allow complete gravity draining of the vessel without splashing or solids holdup. All work to date has been performed with a vertical drop line to the melter.

Drawing EES-22674-MO-001 is the recommended design of the precipitator for batching a 5-inch CIM. See Figure IX-1 for a conceptual design of the precipitator.

Cycle

- Batch Precipitator from Precipitator Batch Tank
- Initiate Agitation
- Bring temperature of batch to 30°C
- Meter in 8.0 wt% oxalic acid
- Digest with agitation
- Turn off agitator
- Allow solids to settle
- Decant supernate to Spent Wash Tank
- Add 0.10 M oxalic acid wash
- Initiate agitation
- Digest with agitation
- Turn off agitator
- Allow solids to settle
- Decant spent wash to Spent Wash Tank
- Initiate agitation
- Open drain valve
- Initiate rinse using de-ionized water
- Stop vessel wall rinse and close drain valve (in that order)

Process Operating Parameters

	5-inch CIM
o Feed Batch Volume, L	6.91
o Precipitant (oxalic acid) Conc., wt%	8.0
o Precipitant Volume, L	12.2
o Precipitant Temp. , °C	30[(a)]
o Precipitant Addition Rate, ml/min	350
o Precipitation Agitator Speed, rpm	450
o Digestion Period, min	10
o Settling Period, min	30
o Decant Rate, gpm	TBD
o Wash (oxalic acid) Conc., M	0.10[(b)]
o Wash Volume, L	7.0
o Wash Period, min	10
o Washing Agitator Speed, rpm	450

(a) Settling, decant and wash may be performed at lower temperature. Control of temperature from 25-60°C is desired.
(b) Minimum Concentration – 0.08 M
Maximum Concentration – 0.12M

o Settling Period, min	20
o Mixing Period Prior to Draining, min	1.0
o Vessel Rinse (water)	DI water
o Vessel Rinse Vol., L	0.267
o Vessel Rinse Addition Rate, ml/min	800

NOTE: See Figure IX-2 for typical particle size distribution of washed oxalate solids

Design Bases

Specific

	5-inch CIM
o Material of Construction	specified by DA
o Capacity	specified by DA
o Nominal Maximum Working Inventory, L	19.2
o Freeboard	specified by DA
o Precipitator ID, in	10.0
o Prec. Min Bottom Slope, °	30
o Oxalic acid feed tube elevation	6.5L level
o Agitator Impeller Type	radial turbine
o Number of Impellers	2.0

o Impeller Dia., in	3.0
o Impeller Elevation	Solid/Liquid Interface 7.0" above lower impeller
o Settled Solids Vol., L	1.9
o Total Vol. After Decant, L	2.5
o Decant Tube Elev.	to leave volume noted in prior basis
o Drain Tube ID, in	1.0
o Drain Tube Orientation	vertical
o Drain Valve Type	Ball
o Nominal Height Drain Tube End Above Melter, in	2.0
o Vol. of Settled Solids, L/L Feed	0.270

Note: The volume occupied by the settled oxalate solids is a function of the particle size of the solids. The particle size of the oxalate solids is a function of the rate at which the precipitant (8.0 wt% oxalic acid) is added to the feed, the mixing characteristics afforded by the Precipitator's system of agitation, the digestion period and the temperature at which the precipitation and digestion takes place.

General

- Cold Feed Requirements – see Operating Parameters

  The quantities of cold feeds listed in this section are based on 6.91 L of feed for a 5-inch CIM. If the actual composition of feed in 17.3E differs significantly from that shown in the material balance, the feed volumes will change and these quantities of cold feeds would change accordingly. Cold feeds should be made up with deionized water.

- Precipitator Elevation – must allow gravity draining of the washed precipitate slurry into the Melter. In addition, the precipitator must be able to be moved to clear the outlet from above the melter.
- Cooling Jacket - capable of controlling temperature of Precipitator contents at 25-60°C. Design Authority to specify design temperature of cooling water supply.
- Vapor Space Pressure - negative with respect to cell pressure. Pressure requirement to be specified by the Design Authority
- Air Purge - to limit hydrogen concentration in vapor space to 25% of its LFL
- Spray Ring or Slinger – design to be developed by Design

  Design Criteria - capable of delivering deionized water that completely wets the internal surfaces of the walls of the vertical section of the Precipitator. Provisions to also flush the Precipitator with nitric acid are to be provided. This design should be tested in the Pilot Facility.

- o Conductivity probe (for HIGH level detection) or other suitable level detection device

Minimum Services

- Deionized Water
- Process Air (to prevent a flammable atmosphere from occurring)
- Nitric Acid (50 wt%) - for vessel decontamination
- Cooling water to Cooling Jacket
- Vessel vent (see Stream # 89 in Material Balance for Composition)
- 8 wt% Oxalic Acid
- 0.10 M Oxalic
- 25SrABS glass cullet (see note below)

Note: This is currently not a requirement. The current flowsheet calls for batching the melter directly with the cullet and batching the washed oxalate slurry on top of the cullet. However, future testing may demonstrate an advantage to blending the cullet with the washed oxalate solids in the precipitator.

- Power (or process air) to agitator
- Power to Conductivity Probe or instrument air if pneumatic bubbler is used for high level detection

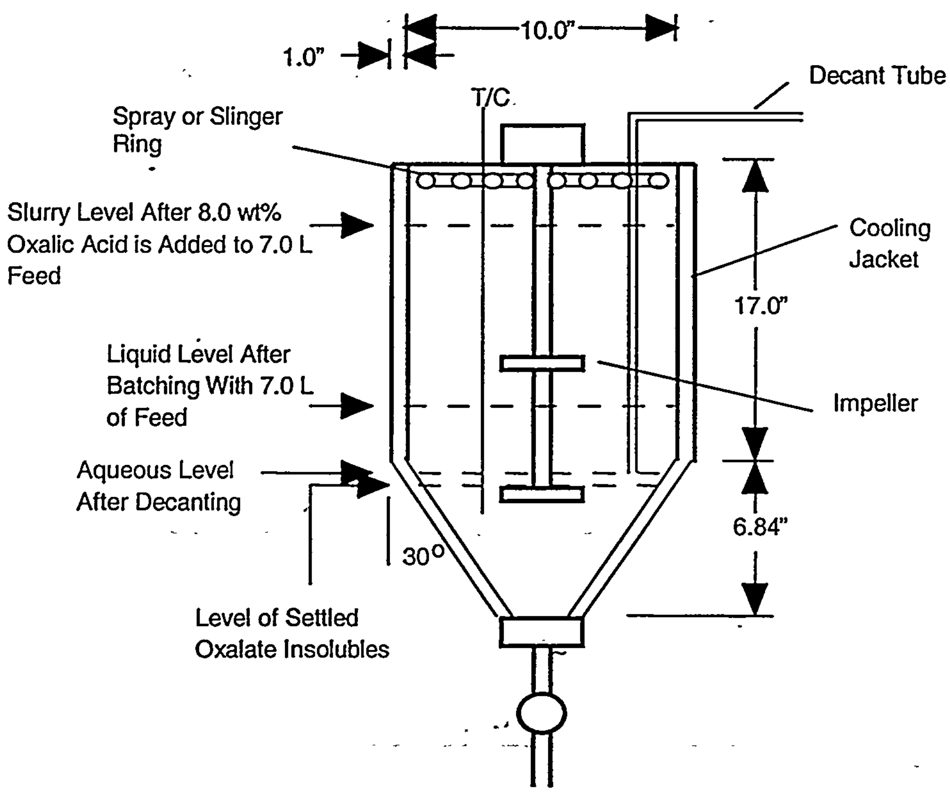
Minimum Real Time Monitoring Parameters

- Temperature of Contents
- Agitator Speed (or alternative parameter to infer agitator speed)
- Agitator Power
- Agitator Torque
- Vapor Space Pressure
- Air Purge Rate

Recommended Alarms/Interlocks

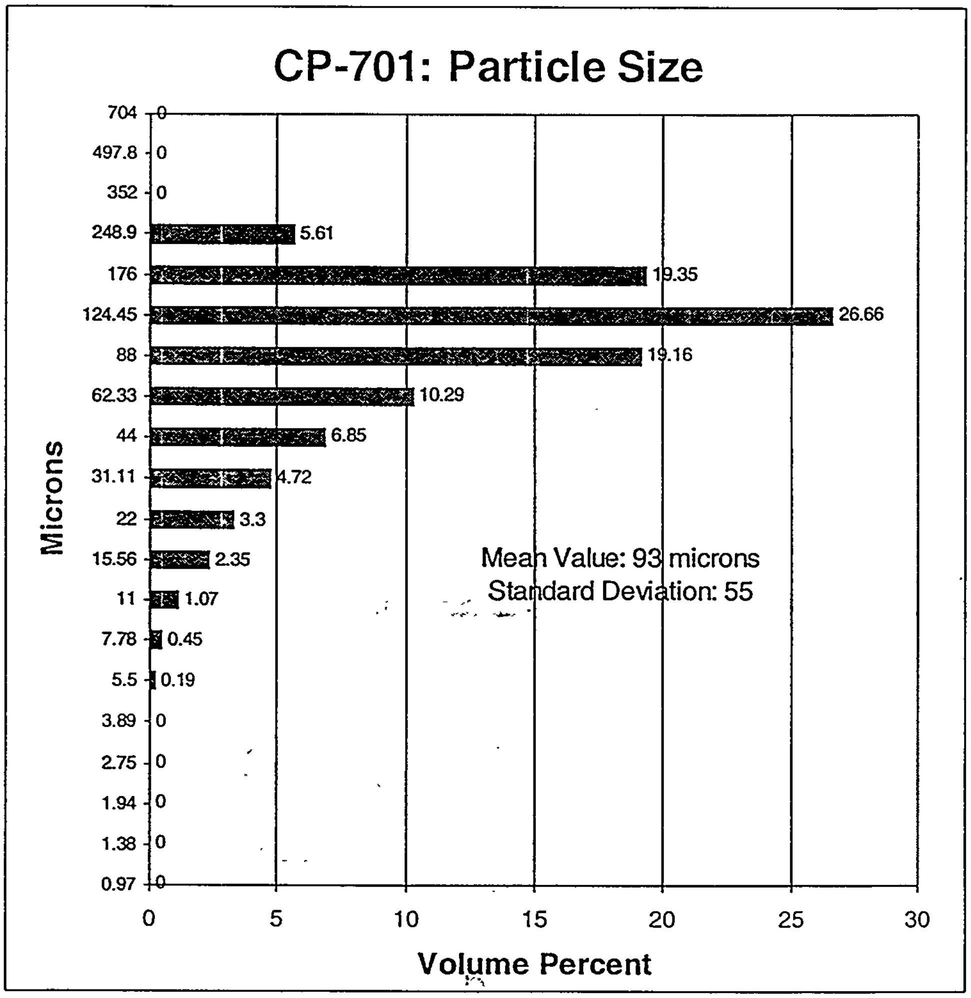
- Alarm at HIGH level
- Alarm - loss of Agitation
- Alarm - HIGH Temperature
- Alarm - LOW cooling water flow
- Alarm - LOW Air Purge Rate

FIGURE IX-1. – Precipitator Tank for 5-Inch CIM



For design bases and operating parameters, see Section IX

FIGURE IX-2. Particle Size Distribution for Washed Oxalate Solids



Spent Wash Tank

General

The function of this process vessel is to accumulate the supernate and spent wash decanted from the Precipitator. If within radionuclide concentration limits, the contents of the Spent Wash Tank will be transferred into the waste handling system.

The Design Authority will specify the working volume of this process vessel. The total volume of supernate plus spent wash from single Precipitator Batch for a 5-inch CIM is approximately 24 Liters. If this process vessel is designed to accommodate the supernate and spent wash from several Precipitator batches, it must be recognized that a single out-of-spec supernate or spent wash batch could contaminate the entire inventory of the Spent Wash Tank.

Design Bases

- Material of Construction - specified by the Design Authority
- Nominal Working Volume - specified by the Design Authority
- Free Board - specified by the Design Authority
- Process Air (to prevent flammable atmosphere from occurring)
- Sampler
- Transfer line - destination to be specified by Design Authority for contents whose radionuclide content is within limits for disposal as waste.
- Transfer line - destination to be specified by Design Authority for contents whose radionuclide content is outside the limits for disposal as waste
- Transfer line from Precipitator decant tube terminating in vapor space of Spent Wash Tank
- Vapor Space Pressure - negative with respect to cell pressure, pressure requirement to be specified by the Design Authority
- Agitator (blade configuration and speed to be determined by Design)

Minimum Services

- Process Water
- 50 wt% Nitric Acid (for vessel decontamination)
- Vessel Vent (Composition/flow rate not part of Materials Balance)
- Power (or air) to agitator
- Instrument air for pneumatic bubblers

Minimum Real Time Monitoring Parameters

- Temperature of Contents
- Specific Gravity of Contents
- Liquid Level of Contents
- Vapor Space Pressure

Recommended Alarms/Interlocks

- Alarm - HIGH level
- Interlock at HIGH-HIGH Level – stops transfer from Precipitator
- Alarm - HIGH Temperature

X. VITRIFICATION

General

The Cylindrical Induction Melter system installed at TNX is a pilot demonstration version of a more robust and remotely operable system to be installed in the Multi-purpose Processing Facility (MPPF). The CIM system is located in 672-T, between the TNX main control room and the IDMS section of the building. It consists of an inductively heated Pt/Rh containment vessel, three Ameritherm, Inc.® induction heating systems and power supplies, a Modicon® control system, a cooling water heat exchanger, and a simple off-gas filtering system. The difference between the CIM and previously tested Am/Cm systems is this Pt/Rh melter vessel is cylindrical in shape and is induction heated, whereas the previous bushing melters were rectangular shaped and direct fired.

An oxalate precipitate produced from the Am/Cm surrogate solution (see Section IX, Melter Feed Preparation), along with 25SrABS glass former, is batched to the melter in a carefully measured mass ratio. Volatilization products and other off-gasses are swept into a semi-circular hood positioned above the top of the CIM vessel, then drawn through a moisture separator and high efficiency particulate air (HEPA) filter before being exhausted to the Large Scale SRAT stack. The glass flows from the bottom of the Pt/Rh vessel by gravity through an inductively heated Pt/Rh drain tube into a stainless steel canister. A separate heat exchanger provides cooling water to the induction coils, heat stations and power supplies to prevent overheating. The individual components are described in more detail in subsequent sections.

The induction heating hardware described is based on what Ameritherm Inc. has designed and installed for the 3-inch CIM system and modified for the 5-inch CIM. Similarly, operating parameters offered have resulted from testing with the 3-inch and 5-inch CIM systems. Operating data/parameters and facility configuration for the 5-inch CIM only will be discussed in this document.

Note: Design bases and operating parameters are predicated on the assumption that MPPF will not have temperature sensors monitoring the melter contents, melter vessel or drain tube. If pyrometers are proven satisfactory for MPPF service, their output is considered a monitoring parameter only.

Note: Previous testing with the 3-inch CIM, coupled with the results from heat transfer models, suggested that a third power supply and induction coil could offer a greater advantage in mitigating bed expansion and assuring a more homogenous glass product. Consequently, the 5-inch CIM was configured with three separate induction coils (and associated heating and coil cooling systems); one for the cylindrical section of the melter, one for the bottom coned portion of the melter and one for the drain tube.

CIM5 Batch Vitrification Cycle

The following describes the nominal process steps executed for the 5-inch CIM Integrated Demonstration Runs [Ref. 6]. *(Values in parentheses represent typical power and temperature readings.)*

1. Add approximately 676 grams of 25SrABS CULLET to the CIM5 vessel. Cullet bed height will be approximately 3.25".

2. Drop the wet oxalate precipitate slurry from the coupled precipitator into the CIM5 vessel. Allow surrogate solids to settle for 10 minutes, then use the decant pump to decant the free liquid until approximately ¼" of free liquid exists above the batch solids bed level. The combined solids bed height will be approximately 8.5".

3. Insert a thermowell into the CIM5 vessel, and adjust the placement of the tip of the thermowell to approximately 2.5 - 3 inches from the bottom of the vessel. The tip of the thermowell should be located approximately at the cullet/precipitate interface.

4. Ensure the top insulation cover is removed to provide adequate vapor venting.

5. Energize the drain tube and vessel bottom 5kW power supplies, followed by the 20 kW vessel power supply, at 0% output. Ensure the READY status is displayed on all three power supply cabinets.

6. Apply power to the vessel (XP-20) induction coil by depressing the HEAT ON button on the XP-20 Heat Station control pendant. Adjust vessel power output to 300/4095 *(0.90 kW)* to the vessel induction coil to begin bed drying.

7. After 1 hour (+/-10 minutes), reduce the vessel power output to 200/4095 *(0.74 kW)* when the batch solids become visible as the free liquid boils away.

8. After about 10 minutes (when the free liquid has boiled away and batch solids are exposed), apply power to the vessel bottom induction coil by depressing the HEAT ON button on the control pendant. Adjust vessel bottom power output to 200/4095 *(0.31 kW)* to achieve subsurface bed drying. Also return the vessel power output to 300/4095 *(0.90 kW).*

9. After 50 minutes, when bed drying has been completed, apply power to the drain tube induction coil by depressing the HEAT ON button on the XP-5 Heat Station 3 control pendant. Maintain the drain tube coil power output at 0% *(0.14 kW)* to ensure any water in the drain tube has been dried.

10. Immediately increase the vessel power output to 350/4095 *(1.02 kW)*, and increase the vessel bottom power output to 250/4095 *(0.32 kW).*

11. Immediately place the insulating cover over the CIM, leaving a ½" gap to allow for venting CO that is generated within the batch bed.

After 5 minutes, set the vessel Delta Output to 20/4095 to achieve a nominal temperature ramp of 8°C per minute to a target SET TEMP of 900°C. Adjust vessel power ramp as needed to attain an 8°C per minute increase at T1D.

13. After 20 minutes, decrease the vessel Delta Output to 16/4095 to maintain a nominal temperature ramp of 8°C per minute as indicated by the vessel wall thermocouple T1D. *(T1D ~ 322°C)*

14. After 6 minutes, decrease the vessel Delta Output to 14/4095 to maintain a nominal temperature ramp of 8°C per minute as indicated by the vessel wall thermocouple T1D. *(T1D ~ 482°C)*

15. After 6 minutes, decrease the vessel Delta Output to 12/4095 to maintain a nominal temperature ramp of 8°C per minute as indicated by the vessel wall thermocouple T1D. *(T1D ~ 534°C)*

16. After 20 minutes, decrease the vessel Delta Output to 10/4095 to maintain a nominal temperature ramp of 8°C per minute as indicated by the vessel wall thermocouple T1D. *(T1D ~ 714°C)*

17. After 20 minutes, turn RAMP OFF to the vessel coil *(at ~ 1370/4095 vessel power, and T1D ~ 900°C).*

18. Immediately SET the vessel bottom power output to 450/4095.

19. After 5 minutes, reposition the top insulation cover over the CIM so as to reduce thermal losses. *(When T3C has reached 500°C)*

20. After 20 minutes, SET the vessel bottom power to RAMP ON at 20/4095 Delta Output to a target SET TEMP of 1000°C. *(T2A ~880°C / T2B ~820°C)*

21. When the vessel bottom power reaches 700/4095 (after ~12 minutes), turn vessel bottom RAMP OFF, and set vessel RAMP ON at 2/4095 Delta Output to attain 4-6°C per minute increases to a SET TEMP of 1400°C at T1D.

22. After 10 minutes, increase the vessel Delta Output to 4/4095.

23. After 45 minutes, increase the vessel Delta Output to 9/4095.

24. After 20 minutes, turn the vessel RAMP OFF.

25. After 5 minutes, RAMP the vessel bottom at 20/4095 Delta Output to attain 4-6°C per minute increases to a SET TEMP of 1400°C.

26. After 6 minutes, increase the vessel bottom power input to 880/4095 and continue RAMP ON at 20/4095 Delta Output. *(T2A ~ 1234°C / T2B ~ 1198°C)*

27. Set vessel RAMP ON to maintain T1D ~ 1400°C SET TEMP while the vessel bottom and drain tube are being brought up to temperature.

28. After 5 minutes, adjust the drain tube power output to 300/4095, then SET the drain tube Delta Output to 50/4095. RAMP ON drain tube to increase the drain tube coil power output to attain approximately 15°C per minute temperature increase to 1300°C SET TEMP as indicated by the drain tube optical pyrometer, T3A.

29. After 5 minutes, decrease the vessel power output to 1650/4095 while in RAMP ON mode to maintain T1D ~ 1400°C.

30. After 8 minutes, ensure the vessel bottom power input is at least 1200/4095, then increase the Delta Output to 30/4095 to attain 4-6°C per minute increases to a SET TEMP of 1400°C.

31. After 15 minutes, SET the drain tube power input to 1650/4095 *(0.79 kW)* and maintain the drain tube in RAMP ON.

32. After 3 - 6 minutes, adjust the vessel power input to1600/4095 and maintain the vessel in RAMP ON.

33. Immediately SET the vessel bottom power input to1950/4095 and maintain the vessel bottom in RAMP ON.

34. Ensure the following power inputs are SET as indicated:
    Vessel in RAMP OFF at 1600/4095 *(4.40 kW)*
    Vessel bottom in RAMP OFF at 1950/4095 *(2.11 kW)*
    Drain tube in RAMP OFF at 1650/4095 *(0.80 kW)*

35. When the vessel (T1D) and vessel bottom (T2B) reach 1400°C, and the drain tube (T3A) reaches 1300°C, begin a 30-minute soak.

36. Maintain the melter vessel at 1400°C (T1D), the vessel bottom at 1380°C to 1400°C (T2A/T2B), and the drain tube at 1300°C (T3A) for 1/2 hour to allow bubbles to dissipate from the glass pool.

37. Following the 30-minute soak, initiate the glass pouring sequence to drain the melter vessel contents into a stainless steel canister.

38. When the pour stream begins to drip or inspection of the vessel indicates the glass level to be no more than ¼", apply the upper drain tube cooling air to terminate pouring.

39. Set the drain tube power input to 0/4095, and then depress the HEAT OFF button on the drain tube XP-5 control pendant.

40. Set the vessel and vessel bottom SET TEMP values to 50°C, then place both to RAMP ON at 50/4095 to decrease power to cool the CIM vessel.

41. When the vessel and vessel bottom power inputs reach 0/4095, depress the HEAT OFF button on the vessel XP-20 and vessel bottom XP-5 control pendants to de-energize the induction coils and shutdown the system.

<u>Melter Vessel</u>

<u>Design Bases</u>

- Dimensional Requirements

  - See Figure X-1
  The CIM5 is a 14" tall cylinder with outside diameter of 5" and a 0.080" thick Pt/20Rh wall. The lower 2" of the cylinder is a 45 degree sloped cone. The flat base of the sloped cone is a 1" diameter circle of Pt/20Rh with a 0.20" I.D. drain tube attached at its center. There exists a ½" wide flange at the extreme top of the 5" OD cylinder, which supports the cold weight of the vessel when assembled in its support stand.

- Materials of Construction

  Pt/20Rh alloy, 0.080" thickness vessel components
  Pt-Pt/13Rh (R-type) thermocouples (for pilot facility only)
  Zircar® insulating sleeve, 3/8" thickness, surrounds vessel cylinder and sloped bottom

- Outside Surface Temperature

  See Figure X-2 [Ref. 10]
  No measured temperature greater than 125°C

  Note: A similar temperature profile will be obtained for the 5-inch CIM but is not expected to differ substantially from that developed from the 3-inch CIM.

- Insulating Cover

  An insulating cover is placed over the top of the melter after the bed has been dried to reduce thermal losses. In the Pilot System, this cover was a 1" thick block of Kaowool® 15C.

Minimum Real Time Monitoring Parameters

- Wall Temperature - See Figure X-3 (for pilot facility only)

  Seven (7) Pt-Pt/13Rh R-type thermocouples welded to vessel wall
  One (1) Mikron® Fiber Optic Infrared temperature transmitter (600 - 1700°C range)

- Bed/Pool Temperature - See Figure X-3 (recommended for pilot facility only)

  Two (2) Pt-Pt/13Rh R-type thermocouples each encased in an 18" long Pt/20Rh alloy sheath thermowells (#4A, #4B)

Recommended Alarms/Interlocks

- Alarm HIGH Temperature (as measured by pyrometer and thermocouples) is 1540°C (for pilot facility only)
- Interlock Power Off at HIGH-HIGH Temperature (as measured by pyrometer and thermocouples) is 1560°C (for pilot facility only)

Heating System

Melter Vessel

The melter containment vessel is 80% platinum/20% rhodium alloy, cylindrically shaped, and heats as a result of exposure to electromagnetic fields generated by the heat station. The vessel is 14" tall overall, consisting of a 12" tall by 5" diameter cylinder, with the bottom 2" tapered to produce a conical transition to the 6" long by 0.20" I.D. drain tube welded to the bottom. The vessel wall thickness is 0.080". The vessel is surrounded by a Zircar® insulating sleeve and water-cooled copper coils through which the electric current is passed which produces the electromagnetic field.

Note: In the pilot facility, seven R-type thermocouples are welded to the vessel wall. Temperature monitoring is also provided by a fiber optic infrared temperature transmitter sensing the infrared energy emitted by the outer Pt/Rh vessel wall.

Melter Vessel and Vessel Bottom (Cone) Power Supplies

The CIM is heated by two independent induction systems: a 20 kW heating system for the Vessel Cylinder and a 5 kW heating system for the Vessel Bottom (Conical) section. The Vessel Cylinder power supply provides up to 20 kW through the heating station to the vessel heating coils at 350 Volts and 75 Amps dc. The frequency range supplied to the melter vessel is 50 - 450 kHz. The Vessel Bottom (Cone) power supply provides up to 5 kW through its heating station to the vessel bottom heating coils at 220 Volts and 30 Amps dc. The frequency range supplied to the vessel bottom is 50 - 450 kHz. High temperature alarms and power interlocks are provided which receive input from the four vessel surface-welded thermocouples and single fiber optic infrared temperature transmitter for the 5-inch cylinder, and two wall welded thermocouples at the bottom cone section of the vessel. The power supplies and heating stations are water cooled from a closed-loop chilled water source. Approximately 6 gal/min water flow for the 20 kW system and 1 gal/min for the 5 kW system at 40 - 60 psi and 68 - 95°F are required to maintain the power supplies and heat stations at their proper operating temperatures. Alarms and interlocks are present to detect low water flow and high water temperature.

Design Bases

Melter Induction Coil Configuration – Dimensional Requirements CIM5 Coil Dimensions (See Figure X-4)

- Material of Construction of Induction Coil
  ¼" Copper tubing, either flat or round (See Figure X-4)
  The copper tubing supplied by Ameritherm, Inc.® is coated with Gyptol® for electrical isolation and corrosion resistance. The coating for the copper coils in the MPPF will be specified by Design.

- Melter Power Supply Description/Power Capacity
  XP-20 power supply provides up to 20 kW at 350 Volts and 75 Amps dc
  XP-5 power supply provides up to 5 kW at 220 Volts and 30 Amps dc
  The frequency range supplied is 50 - 450 kHz (auto load tuning)

Services

- Chilled Water (Total Required) 6.2 GPM @ 40 – 60 PSI

  Chilled Water to XP-20 Power Supply
  5 GPM @ 40 – 60 PSI
  Chilled Water to XP-20 Heat Station/Induction Coil
  1.2 GPM @ 40 – 60 PSI

- Cooling Water Specifications:

pH range	5.0 – 9.0
Conductance	<500 uS/cm @25°C
Resistance	>2000 OHM/cm @25°C
Supply Temp	68°F - 95°F (20°C - 35°C)

- Power Supply

  440 Volts – 3 Phase required

__Minimum Real Time Monitoring Parameters__

- Cooling Water Supply Temperature (50 – 120°F)
- Cooling Water Supply Pump Discharge Pressure (0 – 100 psig)
- Cooling Water Flow to Power Supply (0 – 6 GPM)
- Cooling Water Flow to Heat Station/Induction Coil (0 – 5 GPM)
- Temperature of Chilled Water Exiting Induction Coil (50 – 120°F)
- Power Range: 0 – 20 kW
- Voltage Range: 0 – 200 volts
- Amperage Range: 0 – 50 amps
- Power Ramp Rate Range: 0 – 0.5% per minute
- Frequency Range: 0 – 450 kHz

__Recommended Alarms/Interlocks__

- Interlock Power Off at LOW-LOW Cooling Water Flow to Power Supply
- Interlock Power Off at LOW-LOW Cooling Water Flow to Heat Station / Induction Coil
- Alarm HIGH Power
- Interlock Power Off at HIGH-HIGH Power
- Alarm HIGH Vessel Wall Temperature at 1540°C (pilot facility)
- Alarm at HIGH power ramp rate
- Interlock Power off at HIGH-HIGH Vessel Temperature at 1560°C (pilot facility)

__Power Ramp Limitation__

- Establish Maximum at 0.5% Full Power/min

__Cooling Water Heat Exchanger Unit__

__General__

For the Pilot System, cooling water for the vessel and drain tube induction power supplies, heat stations and coils is provided by a closed loop cooling system. A Koolant Kooler® unit provides cooling water at the necessary temperature and pressure to meet the requirements of the CIM induction heating system. Copper piping and plastic tubing are used to transfer the cooling water between the chiller and induction equipment. A sight glass is used to ensure adequate water level is maintained within the chiller reservoir. Internal controls cycle the cooling fans as needed to maintain the cooling water to within 2°F of the desired temperature. The pump operates constantly to deliver the required water flow and pressure. The setpoint of the chiller is adjusted to maintain the coil heat station and power supply temperatures above the ambient dew point temperature to prevent condensation and the associated electrical problems.

Design Bases

• Capacity	59,000 BTU/Hr
• Discharge Pressure	40 – 60 psig
• Internal Low Press Switch	in at 50 psig, out at 25 psig
• Water Quality	5.0 – 9.0 pH, <500 uS/cm
• Filtration Requirement	Standard process water filter

Services

• Distilled Water	33 Gallon Reservoir Capacity
• Power	460 Volts/3 phase/60Hz
• Cabinet ventilation	maintain 50°F – 80°F ambient temp in cabinet

- Distilled Water Leak Detection Capability in Cabinet

Recommended Alarms/Interlocks

- Alarm at LOW chilled water flow as indicated by internal flow switch
- Interlock Power Off at LOW-LOW chilled water flow as indicated by internal flow switch

Figure X-1. 5-Inch CIM Vessel

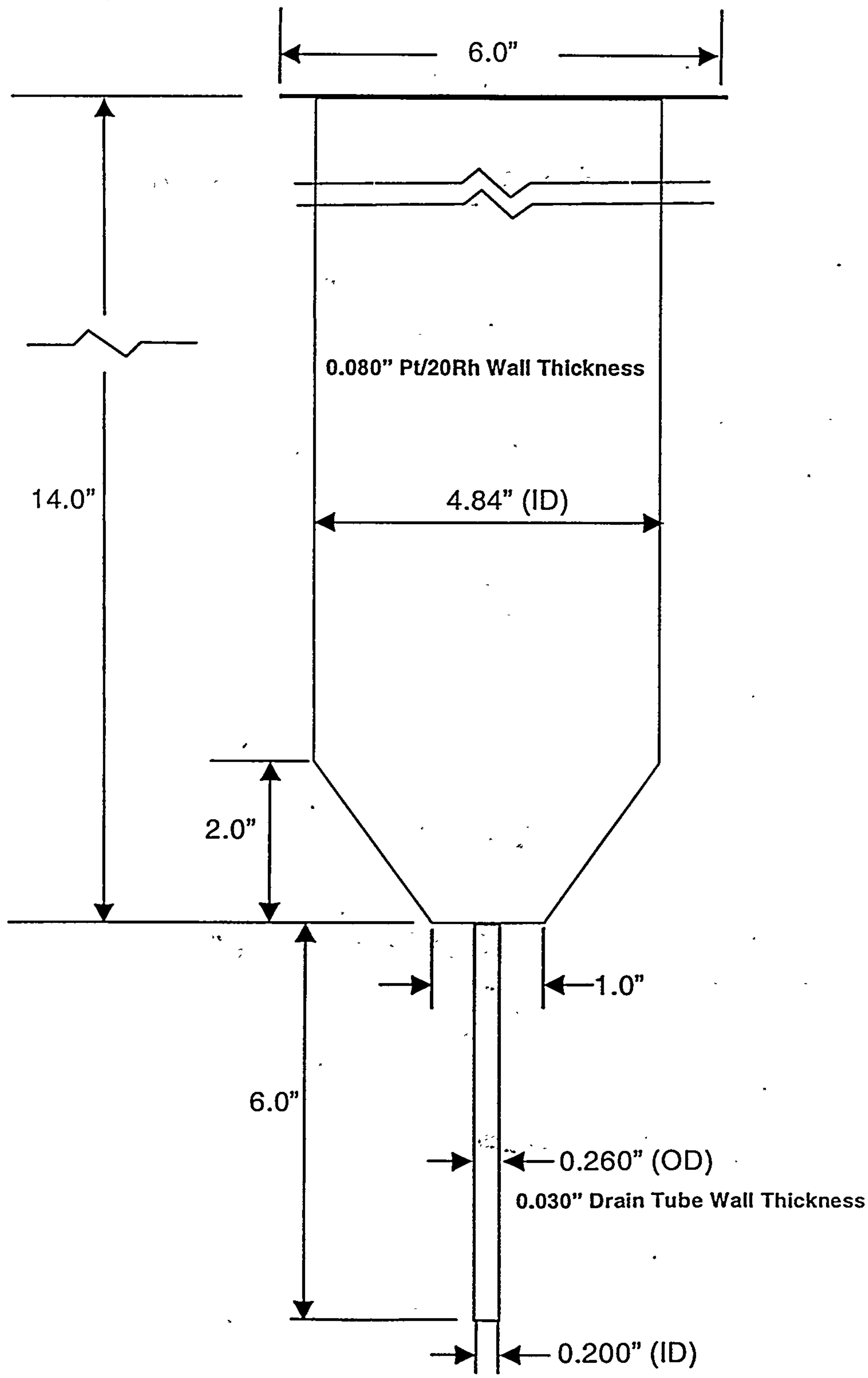


Figure X-2. 3-Inch CIM Outside Surface Temperatures

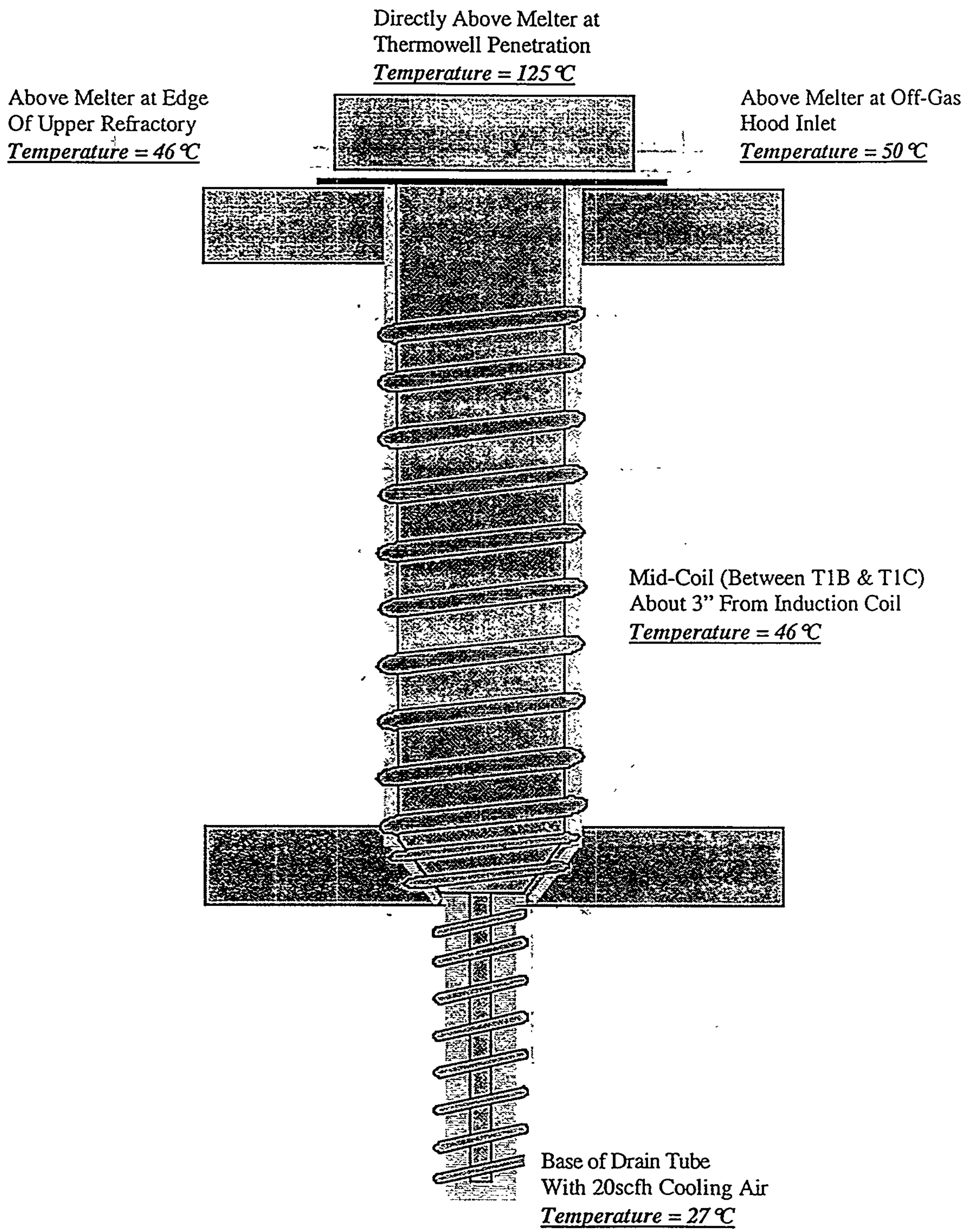


Figure X-3. 5-Inch CIM Temperature Measurement Locations

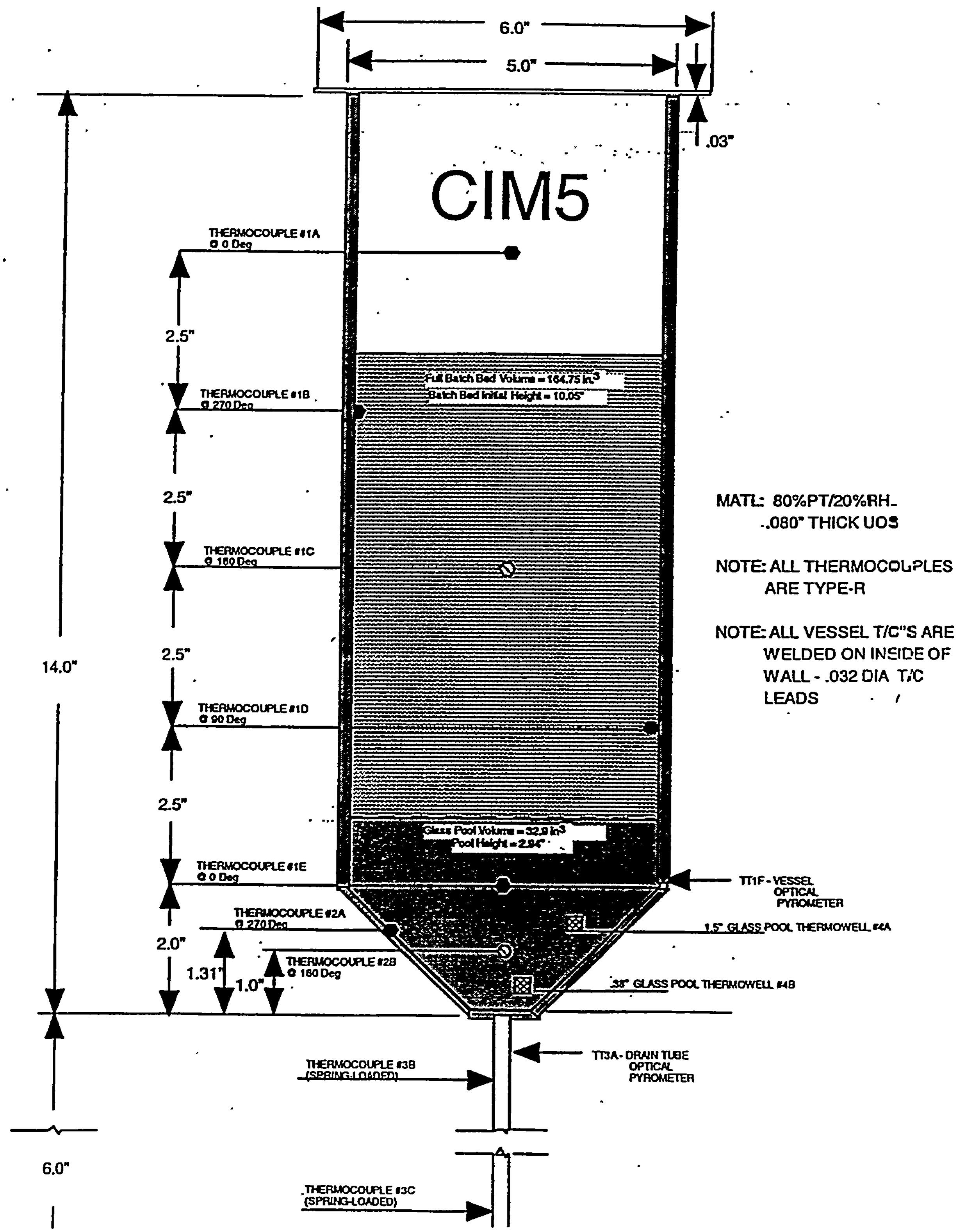
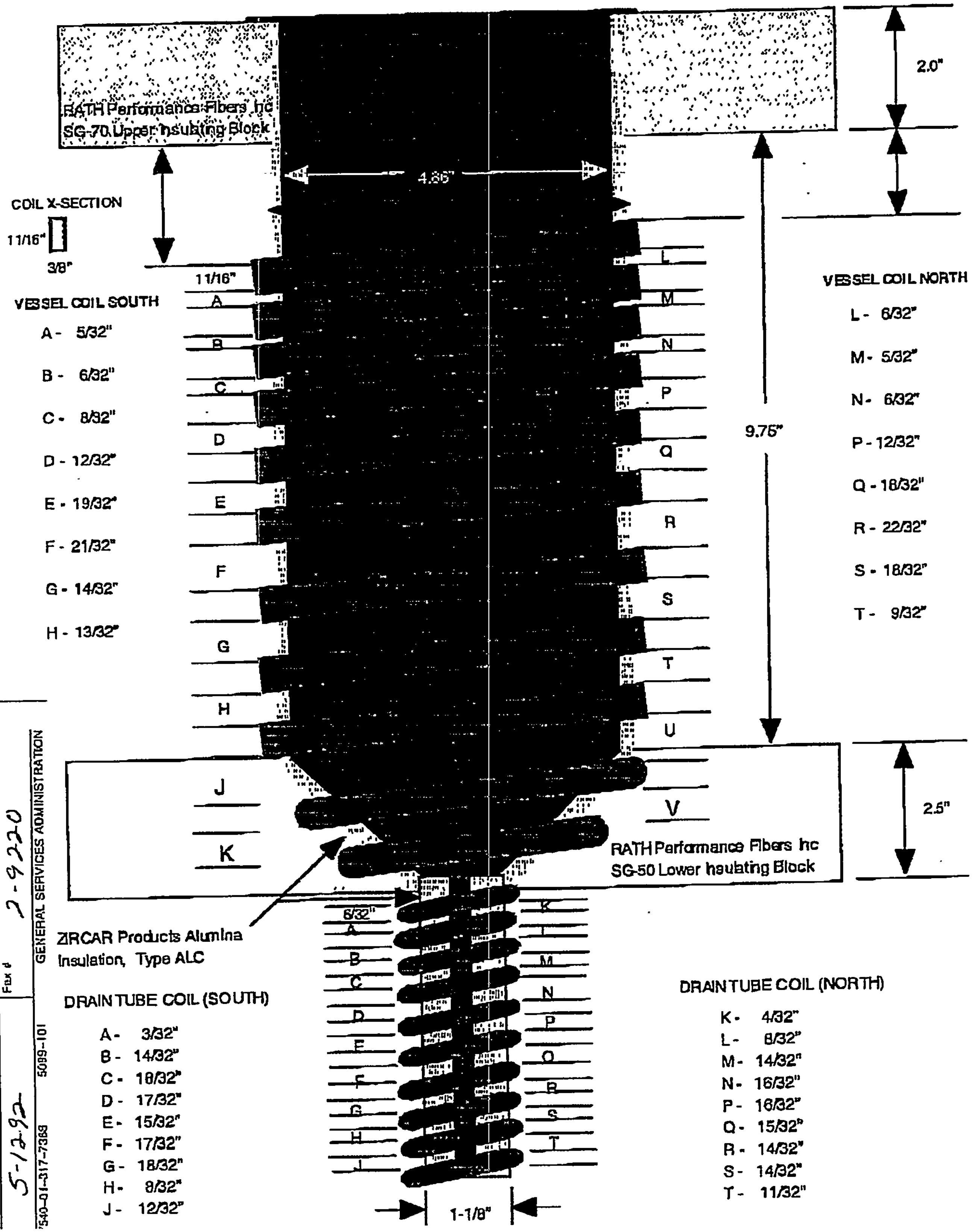


Figure X-4. 5-Inch CIM Coil Configuration



XI. GLASS POURING

General

The 5" Cylindrical Induction Melter (CIM) employs a drain tube located on the bottom of the melter vessel to pour glass into the canister. The nominal 0.20" I.D. 80% platinum-20% rhodium drain tube is 6" long and has a wall thickness of 0.030". The drain tube is inductively heated by the drain tube power supply, which provides up to 5 kW through the heating station to the drain tube heating coils, at 300 volts and 20 amps dc. High temperature alarms and interlocks are provided through spring loaded thermocouples at two elevations on the tube and a pyrometer (in the pilot facility). User programmable power clamps are also are provided through the FactoryLink® control system interface. Both the drain tube power supply and drain tube heating station are water cooled from a closed-loop chilled water system. Approximately 1 gal/min water flow at 40-60 psi and 68-95°F is required to maintain the power supply and heat station at their proper operating temperatures. Alarms and interlocks are present to detect low water flow and high water temperature conditions. Cooling air for stopping glass flow through the drain tube is supplied through two pair of tubes, at flow rates up to 180 SCFH per pair.

The field workstation is also used to control the drain tube heat station power output, either by manual setpoint (% power), or incrementally ramped power increases to a target temperature. Based on Pilot System testing, percent power is the recommended control parameter for the drain tube.

The sequencing of the cooling air applied to the drain tube is controlled by the FactoryLink® workstation in the pilot facility. Timer values for the length of time the Upper Cooling Air is applied and the delay prior to Lower Cooling Air application upon initiating a glass pour stop sequence may be selected by the operator, allowing pour stopping to be controlled consistently. Pushbuttons are also available for documenting the time various pouring events occur, such as glass plug movement, glass plug drop, glass stream initiation, stream dripping upon glass stopping, and glass stopped.

The induction heating hardware described in the following subsections is based on what Ameritherm Inc. has designed and installed for the single drain tube only heating coil. Similarly, the operating parameters discussed reflect the 5-inch CIM with the three independent zones (vessel sidewall, vessel cone and drain tube heating only).

Design bases and operating parameters shown below include reference to temperature sensor monitoring of the drain tube walls. Temperature monitoring using standard Type-R thermocouples spring loaded at the drain tube wall and an optical pyrometer has not proven to be reliable, and is not recommended for use as bases for design or operation. Instead, power is used as the control parameter and is considered extremely reliable and is proven repeatable.

Note: If infrared pyrometers are proven satisfactory for service in MPPF, they should be considered an informational reference parameter only.

Cycle

The methodology employed to drain a vitrified batch from the CIM requires that heat be applied uniformly over the entire length of the drain tube, and requires methods of holding the glass in the drain tube until the pour sequence is initiated and for stopping the molten glass stream at the end of a pour. The drain tube is heated using the induction heating equipment at rates ranging from 12°C per minute to 25°C per minute to a drain tube wall temperature of approximately 1350°C. Data shows that pour initiations (starts) are easily achievable within 90 seconds of the removal of the lower holding air at a drain tube power of approximately 0.84 kW. Optical pyrometer temperature measurements approximately one and one-half to two inches below the flat bottom of the melter vessel cone section are in the 1350 to 1370°C range once holding air is removed (at pour initiation). Pour rates for a melter vessel temperature in the 1400 to 1480°C range are between 12 to 18 kilograms per hour (assuming a homogenous vitrification product). A pour is considered complete at the onset of a discontinuous (dripping) pour stream. Stopping the pour is accomplished by applying cooling air for 30 seconds to the upper portion of the drain tube and applying holding air after 15 seconds to the tip of the drain tube. During the pouring operation, the drain tube power supply is typically held at 100% of the power required to pour (in this case 0.84 kW). Power is immediately dropped by approximately 0.25 kW (200/4095) and then ramped down at up to 30°C per minute following the stopping of a pour.

Pouring Sequence

- Position canister beneath drain tube
- Tare canister
- Assure drain tube tip holding air is on and upper tube cooling air is off
- Set maximum power at 1.0 kW (Note: Full power for the system installed is 5 kW)
- Begin drain tube power ramp sequence (as outlined below)
  Once the drain tube power ramp sequence is complete, turn off drain tube tip holding air to initiate plug drop
- At the end of the pour (as indicated by discontinuous pour rate), turn on cooling air to the upper portion of drain tube for 30 seconds followed by the lower holding after 15 seconds. [Pour stopping is provided by the CIM workstation as an automatic time based sequence of Upper Cooling Air followed by Lower Holding Air.]

Drain Tube Power Ramp Sequence

The following is the typical drain tube power ramp sequence used during the 5-inch CIM Integrated Demonstration Runs [Ref. 6].

1. Ensure the drain tube power supply is in idle, 0/4095, HEAT ON

2. After 5 minutes, manually input 300/4095, and set the following parameters:
   - Delta Output = 50/4095
   - Output Setpoint = 1650/4095
   - Ramp Function = ON

3. After approximately 49 minutes (54 minutes elapsed, includes: 5 minute HEAT ON idle, 27 minutes to ramp to setpoint and 22 minutes for melter cone and vessel wall power to stabilize), set the ramp function to OFF, and begin 30 minute pre-pour soak

4. Initiate draining by maintaining the drain tube coil power at 0.84 kW and remove the Upper Cooling Air

Note: Figure XI-1 illustrates the drain tube power based ramp sequence as demonstrated during the CIM5 Integrated Runs.

Drain Tube

Design Bases

- The general drain tube configuration is shown in Figure XI-2. The drain tube/insulation tube/heating coil space requirements installed in the pilot facility have proven important in avoiding glass accumulation on the insulation tube while maintaining adequate heat applied to the tip. In is considered generally desirable to allow the tip of the Pt/Rh drain tube to extend slightly below the insulation tube when cold (~1/8"). However, the tip of the tube should still be recessed above the lower edge of the lowest coil by approximately 1/8" when hot. Figure XI-3 graphically depicts the vertical spacing relationship between the drain tube, insulation tube and the coil.

Note: The length and internal diameter of the drain tube has been developed from drain tests with oils, field testing, and computer modeling.

- Materials of Construction: 80% Platinum / 20% Rhodium Alloy
  0.20" I.D.
  0.030" wall thickness
  6.0" length

- Insulation Requirements: A Zircar® insulation sleeve with a wall thickness of ~0.25" surrounds drain tube (See Figure XI-2)
- Two Upper Cooling Air Ports @ 180° Apart Directed at Top of Drain Tube
  - Nominal Air Flow per Port - 50 cfh @ 35 psig @ 25°C
- Two Lower Holding Air Ports @ 180° Apart Directed at Tip of Drain Tube
  - Nominal Air Flow per Port - 10 cfh @ 35 psig @ 25°C
- Canister to be centered under the drain tube with top of canister no further than 3 inches and no closer than 2 inches from the lowest edge of the induction coil (approximately two coil diameters from the induction coil)

FIGURE XI-1 – Drain Tube Power Ramp Plot

Drain Tube Power Supply Output (x/4095) during CIM5 Integrated Runs

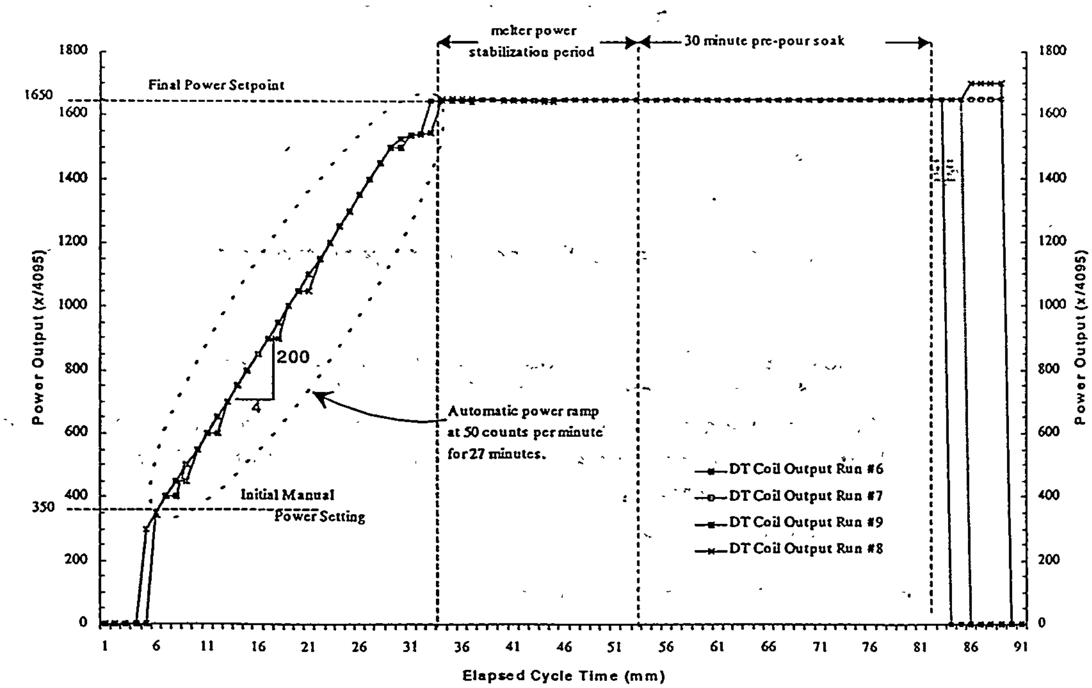
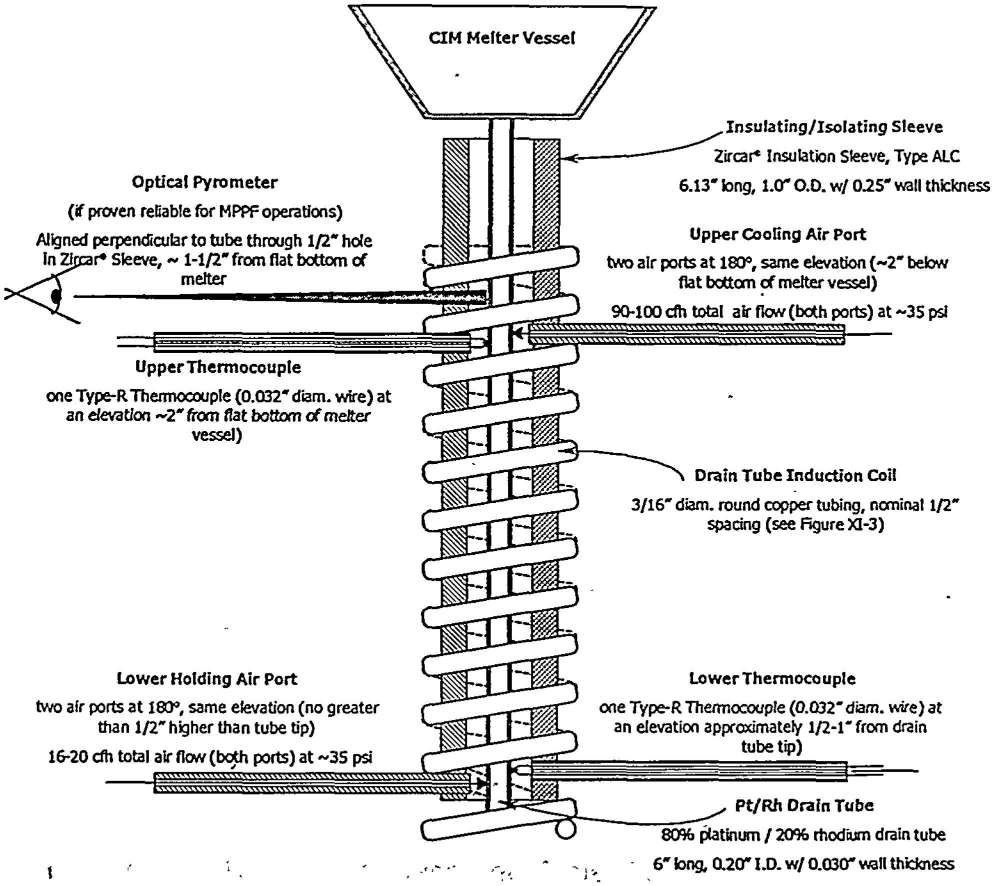


FIGURE XI-2 – Drain Tube Configuration



Minimum Real Time Monitoring Parameters

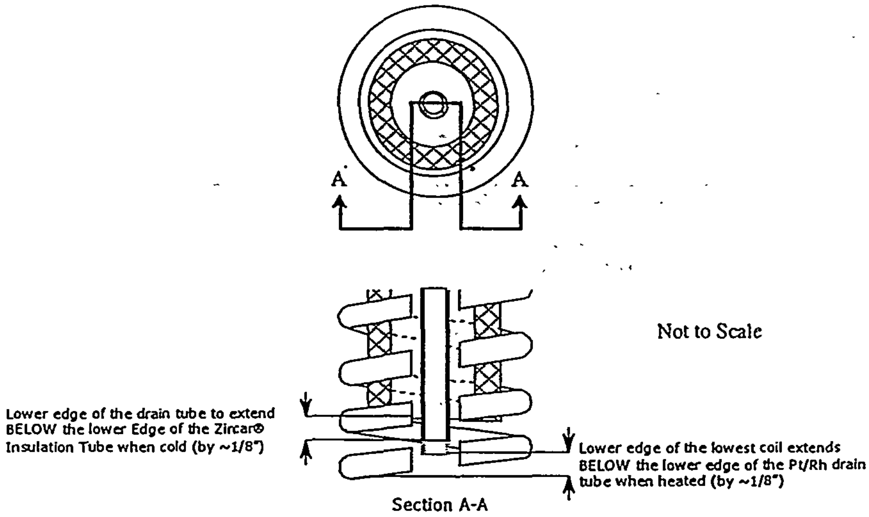
As discussed above, the drain tube sequence is controlled by power to the induction coil. In the Pilot System, temperature measurement devices are also used. However, these devices are somewhat unreliable do to movement of the drain tube during the processing cycle. The Design Authority will determine whether these devices are included in the MPPF design.

- Tube Wall Temperatures (see Figure XI-2) for pilot facility only

  One (1) Mikron® Fiber Optic Infrared temperature transmitter 600 – 1700°C range is provided. Reliability due to slight movements of the tube through the heating process is questionable.

Two (2) Type-R Thermocouples (50 – 1760°C) using ceramic double-bore isolation tubes are spring loaded against the drain tube. One each is located at upper and lower elevations on the drain tube wall. All are considered unreliable.

FIGURE XI-3 -- Graphic Representation of Spacing Relationship of Drain Tube to Insulation Tube and to Coil



Services

- Cooling Air to Drain Tube Lower Holding Air Ports (lower air)
- Cooling Air to Drain Tube Upper Cooling Air Ports (upper air)

Recommended Alarms/Interlocks

- Alarm HIGH Temperature
  (as measured by the pyrometer): 1500°C*

- Interlock Power Off at HIGH-HIGH Temperature
  (as measured by the pyrometer): 1560°C*

*Assuming the pyrometer used is ranged 600 – 1700°C

Heating System

General

The induction system is comprised of an Ameritherm 5 kW Power Supply, a heat station and an induction coil. This section is a general description of the Drain Tube Induction heating system using a single coil on the tube only.

Note: Although additional configurations of the drain tube induction coil have been tested, this section addresses only the single, drain tube coil option.

Design Bases

Drain Tube Induction Coil Configuration – Dimensional Requirements (see Figure XI-4)

- Material of Construction: 3/16" O.D. Coated Round Copper Tubing The copper tubing supplied by Ameritherm, Inc.® is coated with Gyptol® for electrical isolation and corrosion resistance. The coating for the copper coils in the MPPF will be specified by Design.

- Drain Tube Induction Heater Power Supply (Ameritherm® XP-5 Power Supply)
  - 5 kW
  - 300 Volts dc
  - 20 Amps dc
  - 50 – 450 kHz (auto load tuning)*

  * Frequency operates at ~217 kHz for 5" CIM configuration.

Services

- Chilled Water Total: ~1.0 GPM @ 40 – 60 psi

  Chilled Water to XP-5 Power Supply
  >0.5 GPM @ 40 – 60 psi required
  Chilled Water to Heat Station/Induction Coil
  >0.25 GPM @ 40 – 60 psi required

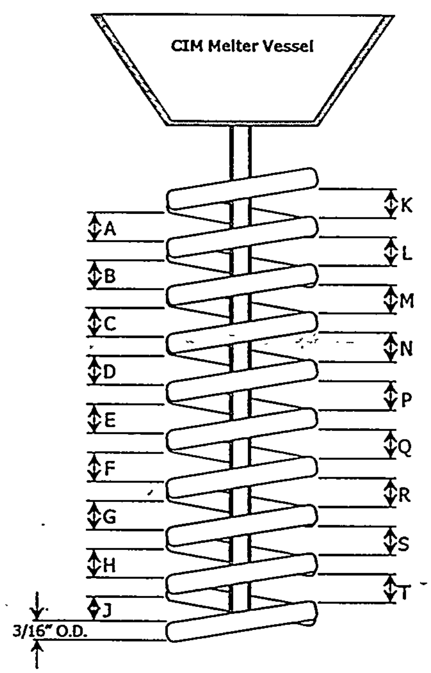
- Power Supply: 480 volts – 3-phase required

Minimum Real Time Monitoring Parameters

- Chilled Water Supply Temperature: Range: 50 – 120°C
- Chilled Water Pump Discharge Pressure: Range: 0 – 100 psig
- Chilled Water Flow to Power Supply: Range: 0 – 2 GPM

- Chilled Water Flow to Heat Station/Induction Coil: Range: 0 – 1 GPM
- Temp of Chilled Water Exiting Induction Coil: Range: 50 – 120°F
- Power: Range: 0 – 5 kW
- Voltage: Range: 0 – 300 volts
- Amperage: Range: 0 – 20 amps
- Frequency: Range: 0 – 450 kHz

FIGURE XI-4 – Drain Tube Induction Coil Dimensions



Drain Tube Induction Coil Spacing

A - 3/32"	K - 1/8"
B - 7/16"	L - 1/4"
C - 9/16"	M - 7/16"
D - 17/32"	N - 1/2"
E - 15/32"	P - 1/2"
F - 17/32"	Q - 15/32"
G - 9/16"	R - 7/16"
H - 1/4"	S - 7/16"
J - 3/8"	T - 11/32"

Recommended Alarms/Interlocks

- Alarm LOW Chilled Water Flow to Power Supply
- Interlock Power Off at LOW-LOW Chilled Water Flow to Power Supply
- Alarm LOW Chilled Water Flow to Heat Station/Induction Coil
- Interlock Power Off at LOW-LOW Chilled Water Flow to Heat Station
- Alarm HIGH Power: ≥ 1.2 kW
- Interlock Power Off at HIGH-HIGH Power: ≥ 1.4 kW

Power Ramp Limitation

- Established at a maximum of 2% full power/min (80/4095 per minute)

Cooling Water Heat Exchanger Unit

See Section X - Cooling Water Heat Exchanger Unit

XII. MELTER OFF-GAS TREATMENT

General

The current concept for the melter off-gas system consists of a hood located above and to the side of the circular top opening of the melter vessel. The exact location (distance above and radial distance away from the circular cross section of the melter vessel) and the cross sectional area of the hood, are to be determined by design to meet the design bases. This hood is open to the cell atmosphere and is to be designed to sweep process gasses and entrainment exiting the melter into the off-gas system.

The melter off-gas drawn into the hood passes through an off-gas line to a moisture separator. This moisture separator removes any water that may condense prior to addition of dry dilution air into the off-gas stream. Downstream of the moisture separator, a dry air stream is added to the off-gas to reduce the dew point of the off-gas to at least 10°C below the off-gas temperature (after mixing with the dry air). The off-gas is then passed through a HEPA filter before discharge into the appropriate MPPF Process Vessel Ventilation System.

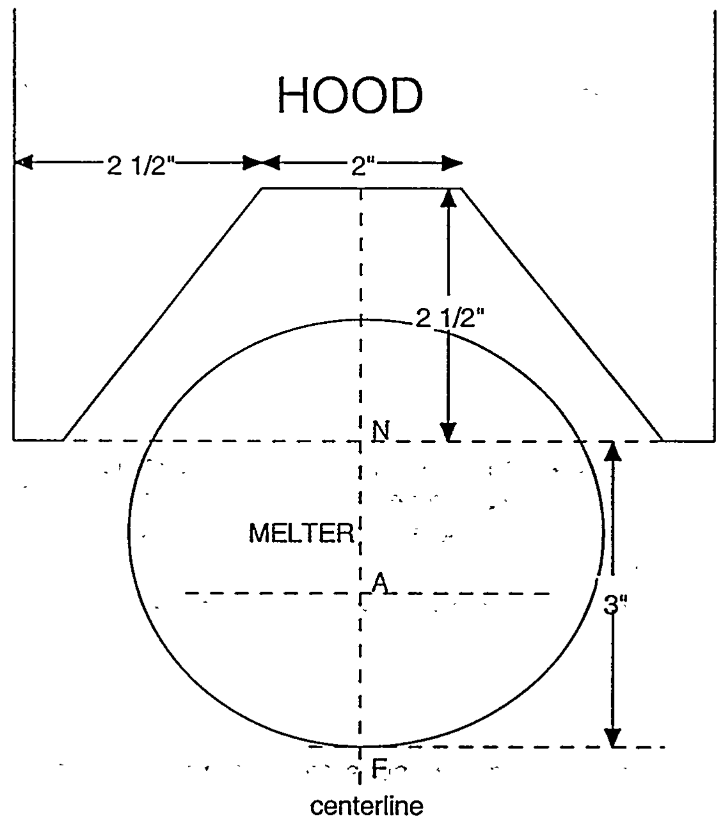
Note: Design Basis Decontamination Factor across Melter Off-Gas System to be specified by the Design Authority.

Melter Ventilation Exhaust Hood

Design Bases

- Minimum Centerline Horizontal Air Velocity Across Melter Top – 250 ft/min

  This velocity is defined as the arithmetic average of the centerline velocity at the near (N) and far (F) edges of the melter top, as shown below.



- Minimum Volumetric Flow into Hood – 30 scfm at 100% relative humidity

Note: Hood flows currently in use at TNX range from 55 to 65 scfm.

Note: The temperature of the cell air entering the hood, prior to mixing with the melter off-gas, for design calculations is assumed to be at 20°C although the actual temperature is more likely to be near 38°C (100°F). The lower temperature is assumed because a lower temperature results in a higher (more conservative) dry dilution air requirement due to the water evolved from the melter (even though the water content of 100% RH air at 20°C is less than that at 38°C).

- Entrainment from Melter – < 1.0 wt% of calcine

Note: Preliminary results from off-gas sampling tests conducted by ORNL during process simulations conducted with the 3-inch CIM indicated no measurable entrainment. Off-gas sampling results for the 5-inch CIM indicate less than 0.1 weight percent entrainment during the course of the entire run. Consequently, since the 1% entrainment assumption appears to be conservative based on the 3-inch and 5-inch CIM results, the material balance will not be changed at this time.

- Melter Exit Vapor Temperature – see Stream 61b, Material Balance
- Material of Construction – Design Authority to specify
- Position Relative to Top of Melter – shown above
- Dimensions of Hood – to be determined by Design to meet requirements

Moisture Separator (Optional)

Design Bases

There are two options available for the off-gas system.

The first is the use of a moisture separator (cyclone separator) before the HEPA filter. Dilution air would be added between the moisture separator and the HEPA. This is how the pilot system is currently setup. If a moisture separator is used, then it should remove any water droplets present that could impact the performance or integrity of the HEPA filter.

The second option is to move the dry dilution air piping immediately after the hood so that condensation cannot occur anywhere in the off-gas line. With this configuration, the moisture separator would not be needed. Also, with this configuration, the hood air flowrate could not be directly measured, but it can be calculated from the difference between the dry dilution air flowrate and the total flowrate exiting the HEPA filter; therefore, a flow measurement of the total flow exiting the HEPA filter is required.

Design is to evaluate the advantages and disadvantages of the two options and the Design Authority is responsible for selecting the preferred option.

Dilution Air

Design Bases

- The dilution air must have a dew point of no greater than -20°C.
- The required flowrate is that amount of dry air that will reduce the dew point of the resulting mixture of the hood exhaust and the dilution air to at least 10°C below the temperature of the off-gas entering the HEPA filter.
- Hood Flow - 100 scfm for a cell air temperature entering the hood of 20°C and at a relative humidity of 100%.

  Note: The worst case for the dilution air is where most of the free water is evolved from the melter. The temperature of the off-gas exiting the melter during this stage is assumed to be 200°C.

When this off-gas is mixed with the hood (cell) air, a vapor stream that is above saturation at 21.35°C results. This stream is then diluted with the dry dilution air to give an off-gas at 20.45°C and a dew point of 10.37°C.

For other melter off-gas temperatures or cell air temperatures, a material and energy balance must be performed to determine a new required dilution airflow.

High Efficiency Particulate Air (HEPA) Filter

Design Bases

- Dimensions – limit clean delta P to 3.0 in w.c. at the total off-gas + dilution air flowrate (nominally 200 scfm as calculated above)
- Particulate Removal Efficiency – use standard nuclear grade HEPA filters - nominally 99.97% removal for particles at 0.3 micron in diameter

Exhauster

Design Bases

Capable of maintaining the design basis centerline air velocity across the melter top at the total vessel vent flow.

XIII. PROCESS CONTROL/DATA ACQUISITION SYSTEM

The following is a process control/data acquisition system description for the pilot system at TNX [Ref. 11]. It is given for informational purposes only and is not intended to specify the system to be used in the MPPF.

A Modicon® 984 Programmable Logic Controller (PLC) performs process control functions at the TNX pilot system. Operator interface functions are performed using a PC workstation. The workstation operates under Windows NT® operating system, using a software package by US DATA Corporation (Factorylink®) for operator interface to the process.

General Requirements

All control functions are performed via the Modicon, in that loss of communication between the Modicon and the workstation will not cause loss of control of the process. Resumption of communication will also not cause the loss or upset of control functions performed by the Modicon. All process set points are provided to the Modicon from the workstation. Initial values for interlock set points and controlled process equipment (i. e. valve positions etc.) are set to allow for safe process startup.

Hardwired interlocks are provided to stop the process in the event of an emergency requiring shut down.

Induction Power Controls

Three heating zones are now available. These are defined as: the "melter or wall" zone which supplies heat to the vertical walls of the melter, the "cone" zone which supplies heat to the sloped bottom of the melter, and the "tip or drain tube" zone which supplies heat to the drain tube. Control of each of the zones is completely independent even though interaction between them is significant.

Power Station Status

The condition of each of the power stations is read using the RS-232 communication capability of the station. Data transmitted to the workstation includes: amps, volts, power, hertz, and status. The status message may be READY, HEATON, or FAULT.

Melter Controls

The power to the melter can be controllable in two modes: 1) manual control from the workstation and 2) temperature ramp control from the workstation.

Mode 1

In this mode, the power supplied to the melter is completely controlled by operator input at the workstation. Operator input is sent to the Modicon which sends the output to the power control cabinet.

Mode 2

In this mode, the power to the melter is incremented (up or down) once each minute by an amount specified by the operator to attain a temperature set point also supplied by the operator from the workstation. A subroutine running at the workstation is used to increment the output up or down. The operator also has the ability to select one of the five thermocouples of the melter upon which to compare the set point to the process reading. The operator also enters a cutoff temperature set point at the workstation. In the event any one of the five melter thermocouples exceeds this cutoff temperature set point, the output power is reduced by 0.5% once a minute until all temperatures are below the cutoff temperature. An alarm is also sounded to the alert the operator.

In the event of loss of communication between the workstation and the Modicon, the power output is frozen at the last value sent by the workstation. Restart of the work station results in the ramp function turned off, but the power output is at the value set prior to loss of communication.

Cone Power Control

The cone power control has Modes 1 and 2 above and works identically to the melter controls. The operator selects one of the two thermocouples or an optical pyrometer in the cone section for Mode 2 control. Use of the optical pyrometer for Mode 2 control at temperatures below its range of 600°C is not possible.

Pour Tip Power Control

The pour tip power control has Modes 1 and 2 above and works identically to the melter controls. The operator selects one of the two thermocouples located on the drain tube or the optical pyrometer to control from.

Recommended Alarms/Interlocks

Process alarms in the form of warnings are displayed on the workstation. These warnings indicate the approach to interlock conditions. Interlocks are also displayed at the workstation, but the Modicon performs interlock actions. The ability to disable individual interlocks from the workstation is also provided to allow for instrument calibrations and malfunctions.

Data Collection

All process data is collected each minute in a text file on the hard drive of the workstation. Process operations that require faster collection rates (i. e. during pouring) are collected using the report generator of Factorylink. Data collection for the pouring sequence is triggered by the start of the pouring sequence.

Process Operations Logging

All operator process actions, (i. e. Set point changes) are logged to the alarm printer with a time stamp and the new process set point.

Glass Pouring Control

A program running on the workstation performs the pouring sequence and generates a report of pour parameters. The pouring sequence shuts off the holding air to the pour tip to start the pour. At the completion of the pour, the operator issues the stop pouring command at the workstation. The program then opens the top pour tip cooling air for a specified number of seconds. The lower tip holding air comes on a specified number of seconds after the top pour tip air has been on and remains on. Top pour tip air shuts off at the specified time. The report continues to run for a specified period after the completion of the pouring sequence. When completed the report file is automatically printed to the letter quality printer at the workstation.

XIV. REFERENCES

1. "Defense Nuclear Facilities Safety Board Recommendation 94-1 to the Secretary of Energy", May 26, 1994.

2. Memo from R. M. Bigler to A. Gunter, "Meeting Minutes – Am/Cm Stabilization (U)", October 4, 1994.

3. Memo from A. L. Schwallie to M. P. Fiori, Defense Nuclear Safety Board Recommendation 94-1, "Improved Schedule for Remediation in the Defense Nuclear Facilities Complex", WSR-94-0082, July 12, 1994.

4. J. E. Marra, "Am-Cm Stabilization Development Program Plan", SRT-AMC-98-0048, Rev. 3, November 30, 1998.

5. M. E. Smith, et al., "Americium/Curium Preliminary Design Basis (U)," SRT-AMC-98-0225, Rev. 0, September 30, 1998.

6. J. E. Marra, "Completion of 5" Cylindrical Induction Melter Demonstration Runs (U)," SRT-AMC-98-0300, December 10, 1998.

7. Rudisill, T. S., "Americium/Curium Extraction from a Lanthanide Borosilicate Glass (U)", SRT-CHT-97-0043, May 8, 1997.

8. Marek, J. C., "Hydrogen Generation from Am/Cm Vessels (U)," S-CLC-F-00196, July 11, 1997.
   Smith, J. R., "Radiolysis Gases from Nitric Acid Solutions Containing HSA and HAN (U)", WSRC-TR-94-0525, October 28, 1994.

9. "Am/Cm Disposition Packaging and Transportation Options and Evaluation, Final Draft", SRT-PTG-98-0094, July 28, 1998.

10. Marra, J. E., "R&D Action Items 0.1.1 and 4.18 (U)", SRT-AMC-98-0228, September 18, 1998.

11. Baich, M. A., "Cylindrical Induction Melter (CIM) Control System Functional Basis", SRT-AMC-98-0017, Rev. 3, April 20, 1998.

Laboratory Notebooks

The following Laboratory Notebooks have been used throughout the experimental program to develop the batch process and equipment. These notebooks contain the raw data used to generate this report.

Glass Formulation Studies

WSRC-NB-96-616	Am/Cm Batch Process - SrABS I
WSRC-NB-98-00141	Am/Cm Batch Process - SrABS II
WSRC-NB-98-00200	Am/Cm Batch Process - SrABS III
WSRC-NB-98-00207	Am/Cm Batch Process - SrABS IV
WSRC-NB-98-00208	Am/Cm SrABS Variability Study

Precipitation/Process Equipment Development

WSRC-NB-94-237	Am/Cm Feed Preparation
WSRC-NB-98-00233	Coupled Precipitator
WSRC-NB-98-00271	Coupled Precipitator One

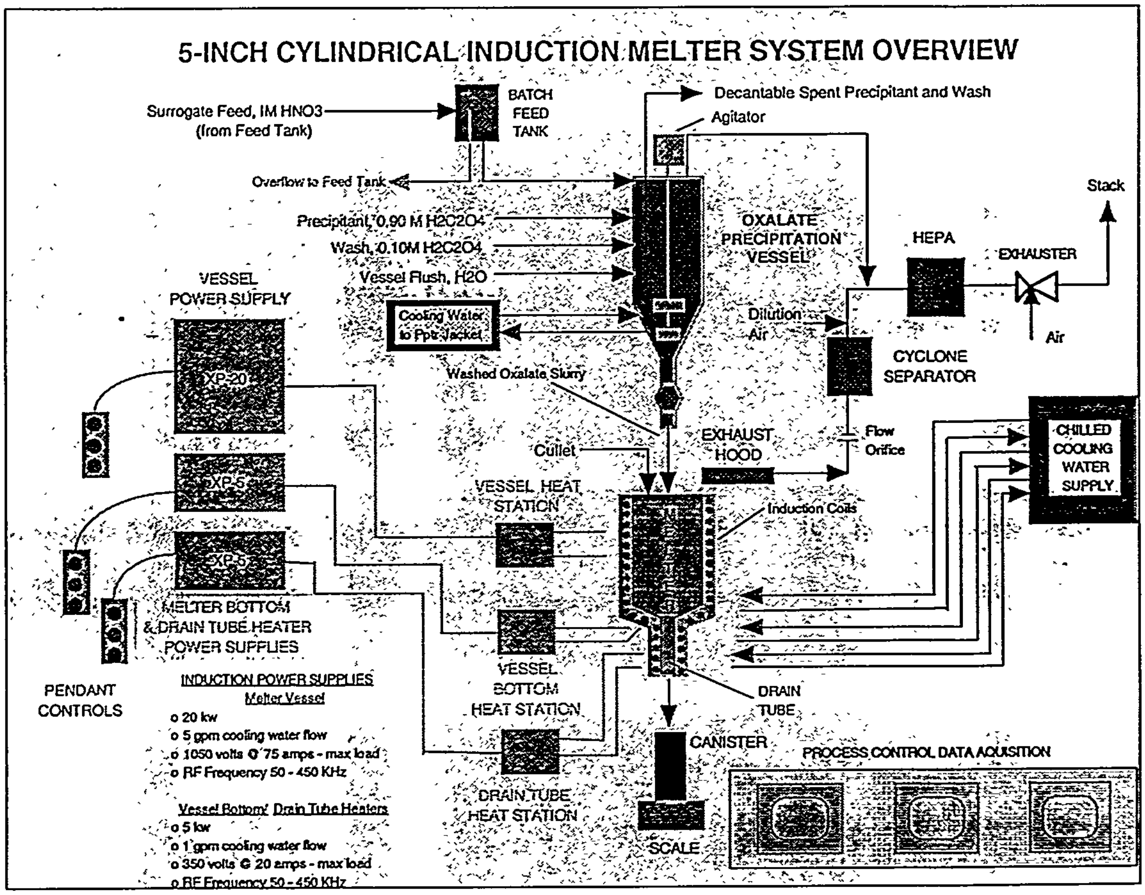
Drain Tube Test Stand

WSRC-NB-96-691	Am/Cm Development – Drain Tube Test Stand
WSRC-NB-97-243	Am/Cm Development – Drain Tube Test Stand
WSRC-NB-97-239	Am/Cm Development – Drain Tube Test Stand
WSRC-NB-97-242	Am/Cm Development – Drain Tube Test Stand

Cylindrical Induction Melter

WSRC-NB- 97-246	Am/Cm Cylindrical Induction Melter – No. 1
WSRC-NB- 97-245	Am/Cm Cylindrical Induction Melter – No. 2
WSRC-NB- 98-00244	5" Cylindrical Induction Melter Development

Attachment 1 – Schematic Diagram of 5-Inch Cylindrical Induction Melter System



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