Analysis of Cascade Impactor and EPA Method 29 Data from the Americium/Curium Pilot Melter System

by

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ANALYSIS OF CASCADE IMPACTOR AND EPA METHOD 29 DATA FROM THE AMERICIUM/CURIUM PILOT MELTER SYSTEM (U)

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SUMMARY

The offgas system of the Am/Cm pilot melter at TNX was characterized by measuring the particulate evolution using a cascade impactor and EPA Method 29. This sampling work was performed by John Harden of the Clemson Environmental Technologies Laboratory, under SCUREF Task SC0056. Elemental analyses were performed by the SRTC Mobile Laboratory.

Operation of the Am/Cm melter with B2000 frit has resulted in deposition of PbO and boron compounds in the offgas system that has contributed to pluggage of the High Efficiency Mist Eliminator (HEME). Sampling of the offgas system was performed to quantify the amount of particulate in the offgas system under several sets of conditions. Particulate concentration and particle size distribution were measured just downstream of the melter pressure control air addition port and at the HEME inlet. At both locations, the particulate was measured with and without steam to the film cooler while the melter was idled at about 1450°C. Additional determinations were made at the melter location during feeding and during idling at 1150°C rather than 1450°C (both with no steam to the film cooler). Deposition of particulates upstream of the melter sample point may have, and most likely did occur in each run, so the particulate concentrations measured do not necessarily reflect the total particulate emission at the melt surface. However, the data may be used in a relative sense to judge the system performance.

During idling of the melter at 1450°C, 63% of the particulate emitted was found to be PbO. Most of the remainder was probably boron compounds, but this could not be determined conclusively due to difficulties with the analytical measurements of boron. The total and PbO emission rates were 9.00 and 5.65 mg/min, respectively. Idling at 1150°C reduced the total particulate emissions from 9.00 mg/min to 0.21 mg/min or less. Although no PbO was detected in the sample (below detection limit) at 1150°C, it is likely that about ½ of the particulate was PbO. The particle size of the PbO emissions during idling was generally less than about 0.3 µm.

During feeding of coupled surrogate feed/frit, about 85 wt% of the particulate collected was larger than 1 µm and the total particulate emission rate was about 10X the rate measured during idling at 1450°C. During feeding, most of the particulate measured by elemental analysis was entrained feed surrogate. The remainder is volatilized PbO (and probably boron compounds). The presence of the cold cap during feeding reduced the evolution of PbO from 5.65 to 2.21 mg/min. The reduction in evolution of PbO during feeding is most likely due to the reduced glass surface temperature and the coverage of the glass surface by the cold cap.

The use of steam to the film cooler was found to decrease the PbO emissions during idling. The most likely reason for this behavior is that the steam cooled the melt surface more than the equivalent amount of air. The reduction in total emissions was found to be about 1.5-2X. The use of steam to the film cooler was also found to remove deposits on the film cooler and offgas line; "cleaned" material from the previous run with feed

was found in the sampling train; inspection of the offgas line after use of steam to the film cooler showed few deposits. This result is consistent with visual observations of the system after previous inspections.

The use of steam to the film cooler increases the efficiency of particulate removal prior to the HEME from about 10% to 60-70%. This increase appears to be due to an increase in the efficiency of the quencher/scrubber.

BACKGROUND

Offgas samples were taken at the exit of the melter downstream of the film cooler and the control air addition port, and downstream of the condensate tank just prior to the High Efficiency Mist Eliminator (HEME), as shown in Figure 1. These analyses were desired due to a significant problem with plugging of the HEME during operation. The current design basis frit for the Am/Cm project, B2000, contains a substantial amount of lead oxide (PbO), which is easily volatilized at the melter operating temperature. The composition of the B2000 frit is shown in Table I.

Table I. B2000 Frit Composition

Oxide	Weight Percent
SiO ₂	43.96
B ₂ O ₃	9.72
Al ₂ O ₃	5.63
La ₂ O ₃	7.22
PbO	24.15
BaO	9.32

The normal operating temperature of the melter is 1450°C, as measured at the melter wall. The actual glass temperature has been estimated to be about 30 to 50°C less than the measured temperature. The temperatures referred to herein are the measured temperatures at the melter wall.

Plugging of the clean HEME occurred within 3 to 5 hours of operation both during feeding of coupled surrogate feed/frit and idling at normal operating temperature. Therefore, it was desired that quantification of the evolution of particulate material during both idling and feeding be conducted. The use of steam to the film cooler had been hypothesized as a method to reduce particulate buildup in the offgas system, so quantification with and without steam was also desired. In addition to determining the total particulate evolution, the particle size distribution and elemental composition of the particulate in total and as a function of particle size was desired. Therefore, a cascade impactor, which separates particles by aerodynamic size, and the EPA Method 29 sampling train, which is used to determine the elemental composition of particulate metals, were combined and used to sample the process.

Figure 1. Simplified Schematic of the Am/Cm Offgas System

EXPERIMENTAL

A diagram of the experimental sampling equipment is shown in Figure 2. The offgas system sampling points consisted of approximately 3/8" slots cut in the 2" sch. 40 offgas line into which a "buttonhook" sampling probe was installed. This sample probe is designed to face directly into the process stream, so isokinetic (equal velocity) sampling can be conducted. The probe used had an inside diameter of 5/16".

Figure 2. Offgas Sampling System

The offgas sample from the sampling probe was conveyed through an approximately 1/2" I.D. stainless steel tube to the cascade impactor.^{1,2} The cascade impactor separates the incoming particles by their aerodynamic size and collects them on filter paper media. The impactor used had seven stages that separated the particles into the particle size ranges shown in Table II (cut size means particles greater than this size). The last "stage" of the impactor is an absolute filter that removes about 99+% of all particles larger than 0.3-0.4 μ m (it removes smaller particles at lower efficiency). The impactor was maintained at a temperature of approximately 300°F throughout sampling to avoid condensation of water.

Table II. Cascade Impactor Cut Sizes

Stage	Cut Size, μ m
top	>11.1-13.2
1	>8.2-9.8
2	>3.0-3.5
3	>1.4-1.7
4	>0.80-0.97
5	>0.39-0.48
6	>0.18-0.23
Absolute	>(0)

The sample passes out of the impactor to the EPA Method 29 sampling train.³ This sampling train normally consists of an absolute filter paper followed by a series of impingers. Since the cascade impactor has an absolute filter, the Method 29 absolute filter was removed. The impingers contained solution of HNO₃ and H₂O₂ designed to scrub out volatile (i.e., non-particulate) metals. Following the impingers was a silica gel impinger and an air pump. The sample flowrate is adjusted manually using a throttling valve to maintain the desired sample flowrate. The sample flowrate is monitored by both a differential pressure orifice meter in the sample line and by calculating the flow from the dry gas meter readings. The total dry volume of sample is measured with a dry gas meter at the pump. To calculate the volume sampled at the actual conditions, this volume is adjusted for the process temperature and water content. The sample flow rate was adjusted to maintain isokinetic conditions based on process flow measurements by a pitot tube inserted in the offgas line. However, the pitot tube measurement was troublesome in that it appeared to periodically become plugged with either water or particulate and give erroneous readings. These types of problems with pitot tubes are not uncommon. Use of the process flowrates measured by the meter control system would have been more accurate and reliable and is recommended for future sampling.

The filter papers in the cascade impactor were weighed before and after sampling to determine the total particulate loading on each filter. These filters were also analyzed by dissolving completely by a microwave digestion and analyzing by Inductively Coupled Plasma- Atomic Emission Spectroscopy (ICP-AES) for elemental composition (per EPA Method 29). The impinger solutions were also analyzed by ICP-AES after preparation following EPA Method 29 procedures. The buttonhook sample line and the line to the

cascade impactor was washed with 0.1N HNO₃, acetone (Method 29) to remove any adhered particulate. This material was also analyzed by ICP-AES. The digestions and ICP-AES measurements were conducted by the SRTC Mobile Laboratory. All filter paper mass analyses, washing, and sample preparation were performed by John Harden of Clemson.

The elements determined by ICP-AES are as given below. The elements for which Method 29 is approved for regulatory measurements are given first. The second list gives additional elements that were measured.

Method 29: Pb, Ag, As, Ba, Cd, Cr, Cu, Mn, Ni, Se, Sr

Additional: Al, B, Ca, Ce, Er, Eu, Fe, Gd, La, Nd, Pr, Sm

Previous Clemson tests have shown that EPA Method 29 can be used to reliably measure some elements not covered by the method. The elements Si, Na, and K were not measured. The filter papers used were composed of quartz (SiO₂), so reliable measurement of Si would be difficult. The amounts of Na and K in the melter feed were small, so measurement of these in the offgas samples would be difficult, especially considering that Na and K are relatively common contaminants.

Background estimation was performed by dissolving and analyzing several unused filter papers of both sizes (disk and annular shapes). However, the amounts of some background materials found were too low to properly adjust some of the measured values; e.g., for Run 3, where essentially no material was collected (0.2 mg), as determined by the total sample mass, the analyses for Ca and Al indicated ten times this mass even when the background was subtracted.

The Pyrex glassware and stainless steel parts used in the sample train probably also contributed to the background amounts of several elements found in the analyses. Pyrex contains Si, Na, B, Al, Ca and the stainless steel contained Ni, Fe, and Cr. The amounts of background Al and Ca found in most samples made reliable determination of these impossible, so neither of these elements are reported; the amount of Al expected in the offgas is small as Al₂O₃ is non-volatile, and the amount of Ca expected is also small since there was little in the feed. Background boron was found in all samples at levels too high to make reliable estimation of the amount collected possible. Background boron was probably also present from the ICP-AES equipment. This equipment uses borosilicate glass parts that were probably etched by the HF/HNO₃ dissolution mixture.

To summarize, the elements that are present in the surrogate or frit that were not measured or were not reliably measured are Al, B, Ca, Fe, Na, K, Ni, and Cr.

The accuracy of the data presented depends on three factors: the accuracy and reproducibility of the sampling techniques, the error in sample preparation, and the error in the analytical measurements. The reproducibility of the sampling methods is

the most likely cause of error. This error would have to be determined by replicate sampling at the same process conditions. Replicate sampling was not performed.

The total particulate was determined by weighing of the filter papers. The weights were determined to the nearest 0.0001 g. The error in this weighing appears to be about ± 0.0002 g, based on weighing of filter papers before and after sampling. A number of samples showed weight losses of up to 0.0002 g, which has been used as an indication of the error in weighing. This weight loss could be due to differences in the amount of water absorbed on the filters.

The accuracy of the elemental analyses by ICP-AES is difficult to determine without replicate analyses. Possible errors would be due to the sample preparation and the ICP-AES measurement itself. Since each filter paper was completely dissolved and analyzed, the accuracy of the sample preparation cannot be determined on actual samples. The accuracy of the ICP-AES method was not determined.

The composition of the initial glass in the melter is shown in Table III (Frit B1000). The composition of the melter feed surrogate is given in Table IV.

Table III. Initial Glass Composition

Oxide	Weight Percent
SiO ₂	26.6
B ₂ O ₃	3.3
Al ₂ O ₃	14.1
La ₂ O ₃	16.5
PbO	11.0
Nd ₂ O ₃	17.6
CeO ₂	7.3
BaO	3.6

Table IV. Melter Feed Surrogate Composition (Oxide Basis)

Oxide	Weight Percent	Oxide	Weight Percent
La ₂ O ₃	11.22	Al ₂ O ₃	0.64
Ce ₂ O ₃	12.89	CaO	0.03
Pr ₂ O ₃	12.89	Cr ₂ O ₃	0.25
Nd ₂ O ₃	27.32	Fe ₂ O ₃	2.20
Sm ₂ O ₃	6.33	MnO	8.43
Eu ₂ O ₃	1.25	Na ₂ O	0.28
Gd ₂ O ₃	3.22	K ₂ O	0.08
Er ₂ O ₃	12.89	NiO	0.09

RESULTS AND DISCUSSION

The process was sampled from the melter offgas line downstream of the film cooler and control air addition ports and from the offgas line between the condensate tank and the HEME. Table V shows the locations and conditions used for the six tests performed.

Table V. Test Summary and Process Conditions

Location		Run 1 Melter	Run 2 HEME	Run 3 Melter	Run 4 Melter	Run 5 Melter	Run 6 HEME
Melter Temperature	°C	1450	1450	1150	1450	1450	1450
Film Cooler Steam		No	No	No	No	Yes	Yes
Feeding		No	No	No	Yes	No	No
Temperature at Sample	°C	100	35	77	103	99	48
Saturation Temp. at Melter	°C	NA	35	NA	31	71	71
Process Flowrate	acfm	61.5	50.2	53.9	55.0	69.0	60.7
Total Sample (wet)	scf	24.0	43.5	40.4	41.2	35.3	40.9
Sampling Time	min	29	60	62	59	39	43
Sample Flowrate (wet)	acfm	1.13	0.82	0.84	0.96	1.23	1.12
(at nozzle)							
Process Velocity	ft/sec	44.0	38.0	38.6	39.4	49.3	33.6
Sample Velocity	ft/sec	35.4	25.6	26.1	30.0	38.6	35.0
% Isokinetic		81	67	68	76	78	104
Total Offgas Flow	lb/hr	219	216	210	191	194	193
(Measured)							
Total Offgas Flow @ HEPA	lb/hr	226	223	211	192	180	184
(Calculated)							
Total Offgas Flow @ HEPA	lb/hr	240	240	220	203	195	195
(Calculated-MEB *)							
Offgas Flow at Melter	lb/hr	218	216	203	185	215	219
(Calculated)							
Film Cooler Air	lb/hr	131	131	132	132	87	86
Control Air	lb/hr	87	85	71	53	79	83
FC Steam	lb/hr	0	0	0	0	50	50
Surrogate Feedrate	liter/hr	0	0	0	2.5	0	0
Frit Feedrate	kg/hr	0	0	0	0.5	0	0
HNO ₃ Generated	lb/hr	0	0	0	0.97	0	0
NO Generated	lb/hr	0	0	0	0.34	0	0
Water Generated	lb/hr	0	0	0	5.2	0	0

* Calculated by more detailed material and energy balance (see Appendix B).

acfm = actual cubic feet per minute, scf = standard cubic feet

For Runs 1, 3, and 5, the offgas flow at the melter was assumed to be the sum of the film cooler air, film cooler steam, and control air flows. The air inleakage was assumed to be negligible. This flow was calculated since it was not directly measured by the process flow monitoring system.

For Runs 2 and 6, the offgas flow at the HEME was calculated assuming that the gas leaving the HEME was saturated with water at the temperature of the condensate tank. The offgas flow meter at the HEPA is not necessarily accurate for the actual flow conditions since it was not calibrated for an air/water mixture.

For Run 4, the melter offgas was calculated to be the sum of the film cooler air and steam, the control air, the water evaporated from the feed, the HNO_3 evaporated from the feed, and the NO evolved from feed nitrate decomposition (all nitrates were assumed to decompose to NO).

A more detailed material and energy balance was performed by A. S. Choi (see Appendix B) and gave calculated offgas flows that are 4.1-7.7% higher than those calculated in this analysis.

It was assumed that all of the particulate deposited in the sampling system was in the form of oxides, except for Run 4. The elemental analyses were used to calculate the amount of oxides, where the oxide forms assumed were the same as those in the glass. For Run 4, it was determined that much of the particulate was due to feed entrainment, so the feed elements were assumed to be present as nitrates rather than oxides; the frit components were still assumed to be oxides. The assumption of entrainment of nitrates rather than emission as oxides improved the calculated mass/measured mass ratio.

Table V also shows the percent isokinetic for each of the samples taken (percent isokinetic is a measure of the relative velocity in the sampling tube to the velocity in the process). This value is an average for each run; the actual percent isokinetic most likely varied around the stated values. For a particulate sample to accurately represent the particle size distribution in the actual process, the percent isokinetic should be between 90-110%. Only Run 6 falls within this range. However, for all runs except Run 4, the lack of truly isokinetic sampling is not significant, since the importance of maintaining isokinetic conditions diminishes as the particle size decreases. At particle sizes less than about $2\text{ }\mu\text{m}$, lack of isokinetic conditions does not bias the sample. In Run 4, where most of the particles in the sample were in the $1\text{-}10\text{ }\mu\text{m}$ and greater range, the 76% isokinetic value indicates that the sample velocity was too low. Too low a sample velocity results in a higher measured concentration of particulate than actual and biases the size distribution towards larger particles. Therefore, the true particle size distribution probably should have a smaller percentage of particles at sizes above $2\text{-}3\text{ }\mu\text{m}$.

The method used to control the sampling rate was measurement of the process velocity by a pitot tube inserted into the process stream.⁴ As mentioned in the Experimental section, the pitot tube periodically gave erroneous readings. For future work, the calculated "Total Offgas Flow @ HEPA" (Table V) should be used to set the sampling rate. This quantity can easily be calculated with a simple spreadsheet and process inputs from the melter control system.

The data in Table VI indicates that about 40 to 60% of the materials collected on the filter papers for each run were not accounted for by the elemental analyses of the filter

papers. Some of the unmeasured mass in these data could be accounted for if the amounts of the unmeasured and unreliably measured elements (Al, B, Ca, Fe, Na, K, Ni, and Cr) were added in.

Table VI. Calculated Mass/ Measured Mass Ratio

Run	Ratio (%)
1	64
2	61
4	45
5	44
6	37

The results of each test will be discussed next. Then, the results of the tests will be compared.

Run 1 - Melter Location - Melter Idling @ 1450°C

The results for Run 1 show that virtually all of the particulate collected is in the sub-micron range and that about 63% of the particulate was PbO. Figure 3 shows the particle size distribution for the total mass measured. For this run, only the absolute filter at the end of the cascade impactor train was analyzed for elemental composition. Also note that this filter paper was inadvertently analyzed together with the sample line sample. The elemental analysis of these combined samples showed the presence of only Pb.

Figure 3. Total Particle Size Distribution for Run 1.

The total particulate and PbO concentrations in the offgas for Run 1 were 0.200 mg/dscf and 0.125 mg/dscf, respectively. The offgas contained no water, so concentrations in

mg/wet scf do not apply. The total particulate concentration is based on the total particulate weight measured on the filter papers; it does not contain the weight of particulate deposited on the sample line or any amount accumulated in the impingers, so the actual total particulate concentration may be higher than reported. Moreover, any particulate accumulated on the film cooler and the offgas line up to the sampling point was not be accounted for either; material deposited prior to the sample system is not accounted for in any of the runs. The PbO concentrations include the elemental Pb detected in the sample line, impactor filter papers, and the impingers. The PbO mass was calculated from the analyzed total mass of Pb.

Run 2 - HEME Location - Melter Idling @ 1450°C

Run 2 results are very similar to those for Run 1. Greater than 75 wt% of the total particulate was found to be less than 0.22 μm . PbO accounted for about 56% of the total. For this run, the absolute filter paper and the sample line samples were again combined. Figure 4 shows the total particle size distribution. The particulate concentration was 0.170 mg/wet scf (0.180 mg/dscf) and the PbO concentration was 0.104 mg/wet scf (0.110 mg/dscf).

Figure 4. Total Particle Size Distribution for Run 2.

Run 3 - Melter Location - Melter Idling @ 1150°C

Very little particulate was collected in this run, where the melter temperature was 1150°C at idle. The total particulate collected was only 0.0002 g, which was barely detectable and is on the order of the analytical error (accuracy of weighing a filter paper was about ± 0.0002 g), so the actual amount collected might be considered to be zero. No Pb was detected in any of the filter paper samples; detection of B was inconclusive due to high background B. The detection limit for Pb on the filter papers was around 22 μg . If the entire 0.0002 g of total particulate were PbO, the Pb analysis would have been

about 186 μg detected. The lack of detected Pb supports the possibility that the actual total emission was essentially zero. The impingers and sample line were not analyzed. All of the particulate was detected on the absolute filter, and was therefore less than 0.24 μm . The concentration of total particulate in the offgas is estimated to be 0.005 mg/dry scf or less and the evolution rate was 0.21 mg/min or less. The ratio of particulate evolution at idling at 1450°C to that at 1150°C, which is an indication of relative volatility, was about 43 or greater.

Run 4 - Melter Location - Melter Feeding @ 1450°C

A much more significant amount of particulate was collected during this run in which the melter was fed with surrogate and frit. Figure 5 shows the total particle size distribution based on the filter paper mass measurements:

Figure 5. Total Particle Size Distribution for Run 4.

For this run, 85 wt% of the particulate was found to be larger than 1 μm . The fraction smaller than 1 μm consisted of about 49 wt% PbO and 44 wt% lanthanide oxides, and 7 wt% others (of the elements measured). The odd distribution at the two large sizes is probably real and is due to some particles that were lodged in the jet plate between stage 1 and 2. These particles were removed from the jet plate and weighed with stage 1, but probably should have been put with stage 2. Figure 6 shows the total particle size distribution for the oxides/nitrates calculated from the elemental analyses. This distribution is very similar to Figure 5 except for the two largest size fractions. The difference at these fractions could be due to the presence of Si in the largest fraction; Si is expected to be present only from entrainment of glass and entrainment of glass generally results in large particles. Therefore, the calculated total mass at >12.6 μm including SiO_2 would be greater than that shown in Figure 6. The oxide/nitrate particle size distribution would be identical to the total particulate distribution if all elements

were measured and were measured accurately. The only element detected in the impingers was boron, but measurement of this element was unreliable.

Figure 6. Oxide/Nitrate Particle Size Distribution for Run 4 (Excluding Impingers).

The weight percent of each oxide/nitrate in the combined filter paper + impingers + sample line is compared with the distribution of the nitrates in the surrogate feed in Figure 7. (The sample line weight is the material collected on the sample line entering the cascade impactor.) Except for Pb, the distributions are very similar. Figure 8 shows this same comparison, with the Pb subtracted from the sample oxide/nitrate weight.

Figures 7 and 8 clearly show that the total material collected on the filter papers was essentially entrained surrogate feed plus the volatile glass (frit) component Pb. This behavior was expected.

The distribution of the oxides/nitrates by element for the sample line deposits, and the filter papers + impingers is given in Figure 9. All of the lanthanides are most prevalent in the sample line, while Ba, Cr, Fe, and Mn were about equal in the sample line and filter papers + impingers. The Pb was found mostly in the filter papers.

Figure 7. Run 4 Comparison of Sample and Feed Oxide/Nitrate Distribution

Figure 8. Run 4 Sample and Feed Oxide/Nitrate Distribution (excluding Pb)

Figure 9. Run 4 Distribution of Oxides/Nitrates by Element in the Sampling Train

Table VII shows the concentrations of the surrogate feed + frit PbO and offgas samples, and the offgas emissions rates for Run 4. The element with the highest emission rate was Nd. Next highest were Ce, Er, La, and Pr. The emission rate of Pb was lower than most of the feed components, indicating that feed entrainment was the most significant contributor to the offgas emissions and that the presence of the cold cap inhibited the volatility of Pb, as expected. Distribution of the oxides/nitrates versus particle size graphs are given in Appendix A.

The total particulate concentration based on the filter papers only was 1.99 mg/dscf (1.90 mg/wet scf). The total particulate concentration based on the elemental analyses of the combined sample line, filter papers, impingers was 2.32 mg/dscf (2.42 mg/wet scf). The PbO concentration was 0.0878 mg/dscf (0.0840 mg/wet scf).

Run 5 - Melter Location - Melter Idling @ 1450°C - Film Cooler Steam

The particle size distribution for this run is shown in Figure 10. These data show that most of the mass of the particles was greater than about 11 μm , which would not be expected during idling; the distribution was expected to be similar to Run 1. This run was performed soon after Run 4, in which the melter had been fed. It appears that the injection of steam to the film cooler "cleaned" the film cooler and removed some of the deposited material. Inspection of the film cooler and offgas line after feeding in previous runs has shown deposition of solids on both the film cooler and offgas line. Inspection of the film cooler and offgas line after the current tests showed that virtually all of the deposits had been removed during operation with steam. This result is consistent with visual observations of the system after previous inspections.

Table VII. Run 4 Feed + Frit Pb, Offgas Compositions, Offgas Emissions Rates

	Surrogate + Pb (wt %)	Offgas Solids (wt %)	Offgas (mg/dscf)	Offgas (mg/wet scf)
La(NO ₃) ₃	9.72	14.30	0.330	0.345
Ce(NO ₃) ₃	11.12	10.98	0.253	0.265
Pr(NO ₃) ₃	11.09	12.41	0.286	0.299
Nd(NO ₃) ₃	23.21	28.14	0.649	0.678
Sm(NO ₃) ₃	5.27	6.37	0.147	0.154
Eu(NO ₃) ₃	1.03	1.03	0.0237	0.0248
Gd(NO ₃) ₃	2.61	2.78	0.0641	0.0670
Er(NO ₃) ₃	9.74	9.66	0.223	0.233
Al(NO ₃) ₃	0.87			
Ca(NO ₃) ₂	0.03			
Cr(NO ₃) ₃	0.42	0.68	0.0157	0.0164
Fe(NO ₃) ₃	2.17	2.71	0.0626	0.0654
Mn(NO ₃) ₂	6.93	7.30	0.168	0.176
Ni(NO ₃) ₂	0.07			
PbO	15.71	3.64	0.0840	0.0878
BaO		0.57	0.0132	0.0138
Total			2.32	2.42

Figure 10. Total Particle Size Distribution for Run 5

The elemental analysis of the impactor samples shows that the top filter sample (>11.2 μm) contains lanthanides (Er, La, Nd, Pr, Sm) in proportions similar to the feed and also some Pb. The only other stages on which oxides were detected were those <0.8 μm; however, some oxides must have been present on the 8.3-11.2 μm stage. If the presence of the "cleaned" material on the first two stages is ignored, the distribution looks similar to Run 1. The oxide distribution is shown in Figure 11. The total particulate

concentration was 0.302 mg/dscf (0.204 mg/wet scf) and the PbO was 0.049 mg/dscf (0.033 mg/wet scf). These values exclude the material on the first two filter papers.

Figure 11. Oxide/Nitrate Particle Size Distribution for Run 5

Run 6 - HEME Location - Melter Idling @ 1450°C - Film Cooler Steam

The total particle size distribution for this run is shown in Figure 12. As in the other runs at idling, most of the particulate collected was in the $<0.2 \mu\text{m}$ (bottom) stage. Some particulate was detected at $>11.1 \mu\text{m}$ and at $0.8\text{-}2.9 \mu\text{m}$ by weighing, but essentially none was detected by the elemental analysis. Figure 13 shows the distribution for the oxides.

Figure 12. Total Particle Size Distribution for Run 6

Figure 13. Oxide Particle Size Distribution for Run 6

The elemental analysis of the 0.18-0.39 μm and <0.18 μm filter paper stages showed that only PbO was present. No material was collected in the impingers. The total particulate concentration was 0.0447 mg/dscf (0.0392 mg/wet scf) and the PbO was 0.0167 mg/dscf (0.0146 mg/wet scf).

Comparison of Runs

The runs can be divided into the following comparison categories based on the experimental conditions:

Runs	Effect
1 vs. 5	Steam to Film Cooler (Melter Location)
2 vs. 6	Steam to Film Cooler (HEME Location)
1 vs. 2 & 5 vs. 6	Melter vs. HEME
1 vs. 3	1450°C vs. 1150°C
1 vs. 4	Feeding vs. Idling

These comparisons are made in Tables VIII-XII. The total particulate collected on the filter papers, the calculated amounts of oxides (or nitrates) on the filter papers, sample line, and impingers, and the calculated amount of PbO are given in these tables. The evolution rate rather than the concentrations are compared since the offgas flowrates were not necessarily the same between runs. The total concentrations are also given for reference.

Comparison of Runs 1 and 5 (see Table VIII) shows that both the total particulate and PbO collected at the melter location were decreased by use of steam to the film cooler. For both of these runs, Pb was the most prevalent particulate collected and was

captured on the later stages of the impactor, indicating a particle size of less than about 0.3 μm . Note that the total particulate reported for Run 5 excludes the particulate collected on the first two stages of the impactor; these were excluded since it was determined that the particulate collected on these stages was mostly lanthanides that were apparently "cleaned" from the deposits on the film cooler and/or offgas line from Run 4, during which the melter was fed.

The most likely explanation for the decrease in PbO evolution during steam use is cooling of the surface of the glass. Visual observations have shown that when the air flow to the film cooler is increased, the surface of the glass becomes darker red, indicating it is being cooled more. The amount of cooling provided by steam is greater than that provided by air due to its higher heat capacity and absorption of infrared radiation, so use of steam should result in more cooling than an equivalent amount of air. The decreases in total particulate and PbO evolution were about 1.5X and 2X, respectively.

Table VIII. Comparison of Runs 1 and 5: Melter Location No Steam vs. Steam

Run and Conditions	Sample Line (mg/min)	Filters (mg/min)	Impingers (mg/min)	Total (mg/min)	Concentration (mg/wet scf)
Total Particulate					
1 No Steam		9.00		9.00	0.200
5 Steam		5.74 ^a		5.74	0.0764
Total Oxides					
1 No Steam	NA ^c	5.72	0	5.72	0.127
5 Steam ^b	0.703	2.49	0.160	3.35	0.0446
PbO					
1 No Steam	NA ^c	5.65	0	5.65	0.126
5 Steam	0.385	2.41	0	2.85	0.0380

^a Stages 1 & 2 not included since they contained material "cleaned" from the film cooler and offgas line.

^b Boron not included in calculated oxides.

^c Sample Line amounts are included with the Filters.

Comparison of Runs 2 and 6 (Table IX) for sampling from the HEME location with and without steam to the film cooler resulted in similar conclusions. The amount of total particulate, total oxides, and PbO are all much less when steam is used. The decrease resulting from steam use is about 4X.

Table IX. Comparison of Runs 2 and 6: HEME Location No Steam vs. Steam

Run and Conditions	Sample Line (mg/min)	Filters (mg/min)	Impingers (mg/min)	Total (mg/min)	Concentration (mg/wet scf)
Total Particulate					
2 No Steam		8.03		8.03	0.170
6 Steam		2.30		2.30	0.0392
Total Oxides					
2 No Steam	NA ^c	4.89	0	4.89	0.104
6 Steam	0.180	0.860	0	1.039	0.0177
PbO					
2 No Steam	NA ^c	4.89	0	4.89	0.104
6 Steam	0.0447	0.860	0	0.904	0.0154

^c Sample Line amounts are included with the Filters.

Comparison of Runs 1 and 2 (Table X) shows that there was about a 10% decrease in the amount of particulate from the melter to the HEME, which indicates that the quencher/scrubber, as expected, is not an efficient device for removal of particulate smaller than about 10 μm . This decrease was seen for the total particulate, total oxides, and the PbO. When steam was used, the absolute concentrations all were decreased, as noted before. In addition, the decrease from the melter to the HEME was higher than when steam was not used. A 60-70% decrease was found when steam was used, indicating that injection of steam apparently increases the efficiency of particulate removal from the system. The data tend to lead to the conclusion that the scrubber efficiency is improved by the use of steam. However, the apparent efficiency would also have increased if introduction of steam caused PbO to become less likely to precipitate out of the vapor phase as a particulate. (Whether or not PbO precipitation was affected by steam is a supposition; however, it would result in the same apparent increase in scrubbing efficiency as the assumption of increased scrubber efficiency. The data are not sufficient to determine which alternative is most likely to be correct.) The PbO would then not be removed by the filter papers and may also not be removed by the Method 29 impingers, such that the measured concentration would be less than the actual. Decreased likelihood of removal of the PbO would not reduce the actual concentration in the offgas system, but would have the desired effect of decreasing the possibility of plugging the HEME.

**Table X. Comparison of Runs 1 and 2: Melter vs. HEME and
Runs 5 and 6: Melter vs. HEME, Both With Steam**

Run, Location, and Conditions	Sample Line (mg/min)	Filters (mg/min)	Impingers (mg/min)	Total (mg/min)	Concentration (mg/wet scf)
Total Particulate					
1 Melter No Steam		9.00		9.00	0.200
2 HEME No Steam		8.03		8.03	0.170
5 Melter Steam		5.74 ^a		5.74	0.0764
6 HEME Steam		2.30		2.30	0.0392
Total Oxides					
1 Melter No Steam	NA ^c	5.72	0	5.72	0.127
2 HEME No Steam	NA ^c	4.89	0	4.89	0.104
5 Melter Steam ^b	0.703	2.49	0.160	3.35	0.0446
6 HEME Steam	0.180	0.860	0	1.039	0.0177
PbO					
1 Melter No Steam	NA ^c	5.65	0	5.65	0.126
2 HEME No Steam	NA ^c	4.89	0	4.89	0.104
5 Melter Steam	0.385	2.41	0	2.85	0.0380
6 HEME Steam	0.0447	0.860	0	0.904	0.0154

^a Stages 1 & 2 not included since they contained material "cleaned" from the film cooler and offgas line.

^b Boron not included in calculated oxides.

^c Sample Line amounts are included with the Filters.

The total particulate emissions versus idling temperature are shown in Table XI. The reduction in emissions was approximately 43X. The reduction in PbO emissions was not calculated since the Pb detected at the lower temperature was zero.

Total particulate evolution during feeding was found to be about 10X the amount determined during idling, as shown in Table XII. As previously discussed, this particulate essentially all consists of entrained surrogate feed. As noted before, the evolution of PbO is decreased by the presence of the cold cap, which both cools the surface of the glass and reduces the exposed glass surface area.

Table XI. Comparison of Runs 1 and 3: Effect of Temperature

Run, Location, and Conditions	Filters (mg/min)	Total (mg/min)	Concentration (mg/wet scf)
Total Particulate			
1 Melter 1450°C	9.00	9.00	0.200
3 Melter 1150°C	0.208	0.208	0.00495

Table XIII summarizes the data for the six runs presented in Tables VIII-XII.

Table XII. Comparison of Runs 1 and 4: Melter Location No Feeding vs. Feeding

Run and Conditions	Sample Line (mg/min)	Filters (mg/min)	Impingers (mg/min)	Total (mg/min)	Concentration (mg/wet scf)
Total Particulate					
1 Not Feeding		9.00		9.00	0.200
4 Feeding		79.5		79.5	1.90
Total Oxide/Nitrate					
1 Not Feeding	NA ^c	5.72	0	5.72	0.127
4 Feeding	61.4	35.6	0.032	97.0	2.32
PbO					
1 Not Feeding	NA ^c	5.65	0	5.65	0.126
4 Feeding	1.30	2.21	0	3.51	0.084

^c Sample Line amounts are included with the Filters.

Table XIII. Total Particulate, Oxide/Nitrate and PbO Summary

Run, Location, and Conditions	Sample Line (mg/min)	Filters (mg/min)	Impingers (mg/min)	Total (mg/min)	Concentration (mg/wet scf)
Total Particulate					
1 Melter No Steam		9.00		9.00	0.200
2 HEME No Steam		8.03		8.03	0.170
3 Melter Low Temp		0.208		0.208	0.00495
4 Melter Feeding		79.5		79.5	1.90
5 Melter Steam		5.74 ^a		5.74	0.0764
6 HEME Steam		2.30		2.30	0.0392
Total Oxide/Nitrate					
1 Melter No Steam	NA ^c	5.72	0	5.72	0.127
2 HEME No Steam	NA ^c	4.89	0	4.89	0.104
3 Melter Low Temp	NA	0	0	0	0
4 Melter Feeding	61.4	35.6	0.032	97.0	2.32
5 Melter Steam ^b	0.703	2.49	0.160	3.35	0.0446
6 HEME Steam	0.180	0.860	0	1.039	0.0177
PbO					
1 Melter No Steam	NA ^c	5.65	0	5.65	0.126
2 HEME No Steam	NA ^c	4.89	0	4.89	0.104
3 Melter Low Temp	NA	0	0	0	0
4 Melter Feeding	1.30	2.21	0	3.51	0.084
5 Melter Steam	0.385	2.41	0	2.85	0.0380
6 HEME Steam	0.0447	0.860	0	0.904	0.0154

^a Stages 1 & 2 not included since they contained material "cleaned" from the film cooler and offgas line.

^b Boron not included in calculated oxides.

^c Sample Line amounts are included with the Filters.

The distribution of the collected material on the sample line, filter papers, and impingers for Runs 4-6 is given in Table XIV.

Table XIV. Distribution of Particulate in the Sampling System (Wt %)

	Run 4			Run 5			Run 6	
	Sample Line	Filter Papers	Impingers	Sample Line	Filter Papers	Impingers	Sample Line	Filter Papers
Pb	37.0	63.0	0.0	13.5	86.5	0.0	4.9	95.1
B	4.4	47.9	47.7	3.3	68.1	28.7	100	0
Ba	37.6	62.4	0.0	100.0	0.0	0.0		
Ce	67.2	32.8	0.0	19.6	80.4	0.0	100	0
Cr	58.9	41.1	0.0	100.0	0.0	0.0	100	0
Er	67.1	32.9	0.0	0.0	100.0	0.0		
Eu	65.0	35.0	0.0					
Fe	51.3	48.6	0.1	75.9	0.0	24.1	100	0
Gd	72.4	27.6	0.0					
La	66.5	33.5	0.0	0.0	100.0	0.0		
Mn	47.7	52.0	0.3	72.7	23.2	4.1	100	0
Nd	66.1	33.9	0.0	4.0	96.0	0.0		
Pr	63.4	36.6	0.0	3.1	96.9	0.0		
Sm	67.3	32.7	0.0	0.0	100.0	0.0		
Total	59.1	37.5	3.4	7.3	73.0	19.7	17.3	82.7

CONCLUSIONS

Note: The particulate evolution rates given are based on the particulate measured at the sample point. Deposition of particulate in the offgas line prior to the sample point is not quantified and therefore not included. Due to high uncertainties in background data, the results of elemental analyses of B, Ca, Al, Fe, etc. were discarded, while those of Pb and lanthanides were retained.

- During idling of the melter at 1450°C, about 63 wt% of the particulate emitted was PbO. The emission rate of PbO was 5.65 mg/min (0.126 mg/wet scf).
- Idling at 1150°C reduced the total particulate emissions from 9.00 mg/min to 0.21 mg/min.
- The particle size of the PbO emissions during idling is less than about 0.3 μm .
- During feeding of coupled surrogate feed/frit, about 85 wt% of the particulate was 1 μm or larger. The particulate rate was about 10X the rate during idling at 1450°C.
- During feeding, most of the offgas particulate is surrogate feed entrained most likely as nitrates. The remainder is mostly volatilized PbO.

- The presence of the cold cap during feeding reduced the evolution of PbO. This reduction is due to reduced glass surface temperature and coverage of the glass surface by the cold cap.
- The use of steam to the film cooler decreases the PbO emissions during idling by cooling the melt surface more than an equivalent amount of air. The reduction seen was about 1.5-2X.
- The use of steam to the film cooler removes offgas deposits on the film cooler and offgas line.
- The addition of steam to the film cooler increases the efficiency of particulate removal (apparently in the venturi scrubber) prior to the HEME from about 10% to 60-70%.

REFERENCES

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- [2] **Atmospheric Environment**, Vol. 4, pp. 671-679, Pergamon Press, 1970. .
- [3] *Method 29 - Determination of Metals Emissions from Stationary Sources*, U. S. Environmental Protection Agency, 40 CFR 60.759.
- [4] J. M. Harden, *Offgas Sampling of the Am/Cm Melter*, Clemson Environmental Technologies Laboratory Report performed under SCUREF Task Order SC0055, August 1997.

APPENDIX A: Oxide Particle Size Distributions for Run 4

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
BASES:				
liquid feed temp (oC) =	50	50	50	50
feed solids content, S (g/liter) =	187.8420052	187.8420052	187.8420052	187.8420052
oxide equiv. in feed (g/liter) =	95.24526536	95.24526536	95.24526536	95.24526536
HNO ₃ conc in feed, M (molar) =	2.763352629	2.763352629	2.763352629	2.763352629
operating cycle @ 100% attainment (hr) =	5	5	5	5
duration of feeding (hr) =	2	2	2	2
dur of pouring & idling (hr) =	3	3	3	3
instantaneous glass prod. rate (kg/hr) =	0	0	0.7	0
target waste loading in glass (wt%) =	35	35	35	35
melt density @ 1450 oC (g/ml) =	3.7	3.7	3.7	3.7
wt% glass entrainment =	2	2	2	2
wt% Cs volatilized =	20	20	20	20
CALCULATED RESULTS:				
melter feeds:				
assumed liquid feed density (g/ml) =	1.211	1.211	1.211	1.211
cal'd volatile density at fixed M, S (g/ml) =	1.080587931	1.080587931	1.080587931	1.080587931
cal'd liquid feed density (g/ml) =	1.210994504	1.210994504	1.210994504	1.210994504
instantaneous liquid feed rate (liter/hr) =	0	0	2.624802388	0
(gpm) =	0	0	0.011556693	0
(kg/hr) =	0	0	3.178621267	0
component liquid feed rates (kg/hr)				
salts =	0	0	0.493048144	0
HNO ₃ =	0	0	0.456955039	0
H ₂ O =	0	0	2.228618085	0
instantaneous frit B2000 feed rate (kg/hr) =	0	0	0.464285714	0
avg. liquid feed rate over cycle (liter/hr) =	0	0	1.049920955	0
average frit feed rate over cycle (kg/hr) =	0	0	0.185714286	0
avg. glass prod. rate over cycle (kg/hr) =	0	0	0.28	0
Pb/B volatilization & glass entrainment:				
instant. rate of PbO volatilization (g/hr) =	2.241780962	2.241780962	2.241780962	2.241780962
average rate of PbO volatilization (g/hr) =	1.681335722	1.681335722	1.681335722	1.681335722
total PbO volatilized per cycle (% fed) =	N/A	N/A	3.748797596	N/A
instant. rate of B ₂ O ₃ volatilization (g/hr) =	0.618034907	0.618034907	0.618034907	0.618034907
average rate of B ₂ O ₃ volatilization (g/hr) =	0.463526181	0.463526181	0.463526181	0.463526181
total B ₂ O ₃ volatilized per cycle (% fed) =	N/A	N/A	2.567808851	N/A
total Na ₂ O req'd to form NaBO ₂ (% fed) =	N/A	N/A	229.6316219	N/A
actual Na ₂ O used to form NaBO ₂ (% fed) =	N/A	N/A	50	N/A
total K ₂ O req'd to form KBO ₂ (% fed) =	N/A	N/A	229.6316219	N/A
actual K ₂ O used to form KBO ₂ (% fed) =	N/A	N/A	50	N/A
instantaneous glass pour rate (kg/hr) =	N/A	N/A	0.698336229	N/A
avg. glass pour rate over cycle (kg/hr) =	N/A	N/A	0.277754565	N/A
air Inleakage & purge (kg/hr) =	4.55	4.55	4.55	4.55

All mass rates shown represent instantaneous values during feeding or idling, except for PbO and borates whose rates are averaged over a cycle.

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
melter off-gas:				
off-gas to film cooler (kg/hr):				
H2O =	0.13195	0.13195	2.360569272	0.13195
HNO3 =	0	0	0.456955039	0
NOx =	0	0	0.167392472	0
SO2 =	0	0	0.003804961	0
FeCl3 =	0	0	0.000911154	0
NaF =	0	0	2.98547E-05	0
PbO =	0.002241781	0.002241781	0.001681336	0.002241781
(Na,K)BO2 =	0.000718608	0.000718608	0.0005641	0.000718608
O2 =	1.029448544	1.029448544	1.099784936	1.029448544
N2 =	3.388601456	3.388601456	3.388601456	3.388601456
glass =	0	0	0.014276172	0
total off-gas (kg/hr) =	4.552960389	4.552960389	7.494570752	4.552960389
(lb/hr) =	10.03755937	10.03755937	16.52270006	10.03755937
OG w/o particulate (lb/hr) =	10.03103283	10.03103283	16.48420158	10.03103283
assumed temp (oC) =	500	300	300	350
pressure ("wc vac) =	3	3	3	3
MW (lb/lbmole) =	28.34640756	28.34640756	25.06498056	28.34640756
MW dry (lb/lbmole) =	28.84	28.84	29.11175227	28.84
Cp (Btu/lb/F) =	0.257578397	0.257578397	0.337238229	0.257578397
volumetric flow (acfm) =	6.066491402	4.497199181	8.35785905	4.889522237
(scfm) =	2.11694394	2.11694394	3.934252932	2.11694394
solids loading (grain/scf) =	0.359683503	0.359683503	1.141637096	0.359683503
residence time (sec) =	0.494519781	0.667081861	0.358943598	0.613556878
heat loss due to OG flow (Btu/hr) =	4244.4	2566.08	9164.494946	1038.96
film cooler:				
FC air flow @ 25 psig (lb/hr) =	131	132	132	87
assumed temp (oC) =	110	80	95	50
Cp (Btu/lb/F) =	0.24	0.24	0.24	0.24
FC steam flow @ 65 psig (lb/hr) =	0	0	0	50
assumed temp (oC) =	156	156	156	167
Cp (Btu/lb/F) =	0.48	0.48	0.48	0.48
check for possible condensation in manifold (A):				
assumed vapor outlet temp (oC) =	42	39	41	81.7
temperature approach (oC) =	0	0	0	0
H2O PS eqn slope (psia/oC) =	0.0807	0.0807	0.0807	0.279
H2O PS eqn intercept (psia) =	-2.157	-2.157	-2.157	-15.335
estimated condensation (lb/hr) =	-3.534696649	-2.004171657	-3.03626688	-2.758342156
parameter L =	609	609	609	609
parameter U =	82.75134483	83.38303448	83.38303448	104.957
parameter A =	6.009785434	6.055661659	6.055661659	27.74868156
parameter B =	-4993.634107	-4955.056171	-4993.404811	-21820.14009
parameter C =	200281.9878	185910.0481	193860.453	1597453.655

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
cal'd vapor outlet temp (oC) =	42.25641793	39.41817916	40.84668466	81.69812602
cal'd liquid outlet temp (oC) =	42.25641793	39.41817916	40.84668466	81.69812602
moisture condensed (lb/hr) =	N/A	N/A	N/A	-2.750405252
% moisture condensed =	N/A	N/A	N/A	-5.500810504
total film cooling medium (lb/hr) =	131	132	132	137
temp (oC) =	110	80	95	112.5668449
Cp (Btu/lb/F) =	0.24	0.24	0.24	0.327591241
MW (lb/lbmole) =	28.84	28.84	28.84	23.65601733
next calc valid when FC medium T < 100 oC				
check for possible condensation @ FC exit (A):				
assumed vapor outlet temp (oC) =	45	40.9	51.5	80.6
temperature approach (oC) =	0	0	0	0
H2O PS eqn slope (psia/oC) =	0.0807	0.0807	0.0807	0.279
H2O PS eqn intercept (psia) =	-2.157	-2.157	-2.157	-15.335
estimated condensation (lb/hr) =	-5.541626207	-3.218984785	-4.763396092	-3.92280986
parameter L =	609	609	609	609
parameter U =	89.65436647	90.29007313	103.1885732	111.6832735
parameter A =	6.507974667	6.554019461	7.335400892	29.44540321
parameter B =	-5490.323002	-5410.244826	-6263.654917	-23348.43229
parameter C =	233545.8638	210533.546	302909.4323	1689899.317
cal'd vapor outlet temp (oC) =	44.93067916	40.94476188	51.4612448	80.56256579
cal'd liquid outlet temp (oC) =	44.93067916	40.94476188	51.4612448	80.56256579
moisture condensed (lb/hr) =	-5.500988662	-3.244142761	-4.736561499	-3.760342646
% moisture condensed =	-1891.024258	-1115.209108	-76.25375828	-1292.658393
off-gas at film cooler exit (lb/hr) =	141.0375594	142.0375594	148.5227001	147.0375594
H2O =	4.089899952	4.118899952	9.032164366	52.81389995
H2O l =	0	0	0	0
HNO3 =	0	0	1.007413405	0
HNO3 l =	0	0	0	0
NOx =	0	0	0.369037226	0
SO2 =	0	0	0.008388503	0
FeCl3 =	0	0	0.002008752	0
NaF =	0	0	6.58182E-05	0
PbO =	0.004942281	0.004942281	0.003706711	0.004942281
(Na,K)BO2 =	0.00158426	0.00158426	0.001243627	0.00158426
O2 =	31.90861349	32.13486591	32.28993111	21.95350669
N2 =	105.0325194	105.777267	105.777267	72.26362619
glass =	0	0	0.03147357	0
temp @ FC exit (oC) =	139.6167341	96.58985267	125.6026734	125.4919521
pressure ("wc vac) =	3.5	3.5	3.5	3.5
MW (lb/lbmole) =	28.34640756	28.34640756	27.94032485	23.72333052
MW dry (lb/lbmole) =	28.84	28.84	28.8599897	28.84
Cp (Btu/lb/F) =	0.25767157	0.25767162	0.266514477	0.333272031
total moisture (lb/hr) =	4.089899952	4.118899952	10.03957777	52.81389995

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
volumetric flow (acfm) =	45.59190947	41.12897771	47.04558114	54.85077678
(scfm) =	29.76311566	29.97415514	31.79146413	37.07618846
solids loading (grain/scf) =	0.025583001	0.025402878	0.141279718	0.020536896
effective film cooler I.D. (in) =	2.067	2.067	2.067	2.067
off-gas velocity @ FC exit (ft/sec) =	32.60832986	29.41634355	33.64802759	39.23047406
check max moisture content:				
H2O PS eqn slope (psia/oC) =	0.279	0.279	0.279	0.279
H2O PS eqn intercept (psia) =	-15.335	-15.335	-15.335	-15.335
max moisture limit (lb/hr) =	No Limit	338.0995926	No Limit	No Limit
melter pressure control air:				
25 psig control air flow (lb/hr) =	89	71	53	79
temp (oC) =	35	35	35	35
Cp (Btu/lb/F) =	0.24	0.24	0.24	0.24
check for possible condensation (A or C):				
assumed vapor outlet temp (oC) =	41.5	39.2	47.6	73.4
temperature approach (oC) =	0	0	0	0
H2O PS eqn slope (psia/oC) =	0.0807	0.0807	0.0807	0.279
H2O PS eqn intercept (psia) =	-2.157	-2.157	-2.157	-15.335
estimated condensation (lb/hr) =	-5.795397988	-3.435783107	-4.995183219	-3.374582915
parameter L =	609	607.2267234	609	609
parameter U =	146.2363369	135.4293238	138.037497	161.9081774
parameter A =	10.79316215	10.01182732	10.01349392	42.45145659
parameter B =	-8834.518735	-8063.966266	-8336.707475	-33148.74632
parameter C =	348344.5952	300893.1471	374253.7153	2203452.887
cal'd vapor outlet temp (oC) =	41.53786604	39.22338898	47.61552341	73.36451036
cal'd liquid outlet temp (oC) =	41.53786604	39.22338898	47.61552341	73.36451036
moisture condensed (lb/hr) =	-5.83021747	-3.455156471	-5.009125247	-3.200551526
% moisture condensed =	-142.5515914	-83.8854187	-49.893784	-6.060055267
off-gas flow to steam jet (lb/hr) =	230.0375594	213.0375594	201.5227001	226.0375594
H2O =	6.670899952	6.177899952	10.56916437	55.10489995
H2O l =	0	0	0	0
HNO3 =	0	0	1.007413405	0
HNO3 l =	0	0	0	0
NOx =	0	0	0.369037226	0
SO2 =	0	0	0.008388503	0
FeCl3 =	0	0	0.002008752	0
NaF =	0	0	6.58182E-05	0
PbO =	0.004942281	0.004942281	0.003706711	0.004942281
(Na,K)BO2 =	0.00158426	0.00158426	0.001243627	0.00158426
O2 =	52.04507951	48.19878824	44.28130976	39.82744844
N2 =	171.3150534	158.6543446	145.2488883	131.0986844
glass =	0	0	0.03147357	0
temp w/ ctrl air (oC) =	100.8895173	77.02404886	103.5684479	100.2471184
pressure ("wc vac) =	4.5	4.5	4.5	4.5

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
MW (lb/lbmole) =	28.34640756	28.34640756	28.04601207	25.15735688
MW dry (lb/lbmole) =	28.84	28.84	28.85456996	28.84
Cp (Btu/lb/F) =	0.258126824	0.258126473	0.264629863	0.307204604
total moisture (lb/hr) =	6.670899952	6.177899952	11.57657777	55.10489995
volumetric flow (acfm) =	67.55458129	58.5703366	60.23316533	74.6660088
(scfm) =	48.54562927	44.95795813	42.9765565	53.74830728
solids loading (grain/scf) =	0.015684827	0.016936486	0.104510213	0.014166582
off-gas line I.D. (in) =	2.067	2.067	2.067	2.067
off-gas velocity (ft/sec) =	48.31651264	41.89078453	43.08007597	53.40276097
check max moisture content:				
H2O PS eqn slope (psia/oC) =	0.279	0.279	0.279	0.279
H2O PS eqn intercept (psia) =	-15.335	-15.335	-15.335	-15.335
max moisture limit (lb/hr) =	No Limit	94.89683072	No Limit	No Limit
steam jet:				
steam supply pressure (psig) =	25	25	25	25
pressure ratio =	347.5103878	347.5103878	347.5103878	347.5103878
max mass ratio =	8.974932376	8.974932376	8.974932376	8.974932376
excess steam (%min) =	0	0	0	0
actual steam flow (lb/hr) =	25.63111896	23.73695427	22.45395192	25.18543315
temp (oC) =	131	131	131	131
Cp (Btu/lb/F) =	0.48	0.48	0.48	0.48
check for possible condensation (E), Tvo<100:				
assumed vapor outlet temp (oC) =	61.4	60.4	64	78
temperature approach (oC) =	0	0	0	0
H2O PS eqn slope (psia/oC) =	0.163	0.163	0.163	0.279
H2O PS eqn intercept (psia) =	-6.89	-6.89	-6.89	-15.335
estimated condensation (lb/hr) =	-5.568672651	-2.858938645	-4.745683922	-3.596460997
parameter L =	609	609	609	609
parameter U =	171.8674559	159.166278	155.1952497	187.0936106
parameter A =	26.25161923	24.31158635	23.60240367	49.89007257
parameter B =	-20702.26451	-18958.426	-18728.71472	-38716.51334
parameter C =	1172009.015	1057180.315	1103066.273	2717512.081
cal'd vapor outlet temp (oC) =	61.39184888	60.44893393	64.07029035	78.03734802
cal'd liquid outlet temp (oC) =	61.39184888	60.44893393	64.07029035	78.03734802
moisture condensed (lb/hr) =	-5.548160178	-2.969902655	-4.911426249	-3.839599662
% moisture condensed =	-21.64618793	-12.5117259	-21.87332665	-15.24531914
check for possible evaporation (F), Tvo<100:				
assumed vapor outlet temp (oC) =	54.9	57.5	59.3	76.8
temperature approach (oC) =	0	0	0	0
H2O PS eqn slope (psia/oC) =	0.0807	0.163	0.163	0.279
H2O PS eqn intercept (psia) =	-2.157	-6.89	-6.89	-15.335
estimated evaporation (lb/hr) =	6.5818486	3.456534354	5.608575194	3.899008471
parameter L =	N/A	N/A	N/A	N/A
parameter U =	171.8674559	159.166278	155.1952497	187.0936106

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
parameter A =	5.784721392	10.82065263	10.44805431	22.74653155
parameter B =	5910.041256	12089.92465	11581.9499	24249.55064
parameter C =	-341884.5172	-731118.7793	-723441.0135	-1995579.099
cal'd vapor outlet temp (oC) =	54.89817334	57.5129236	59.29149096	76.7657245
cal'd liquid outlet temp (oC) =	54.89817334	57.5129236	59.29149096	76.7657245
liquid H2O vaporized (lb/hr) =	6.583823643	3.429482306	5.626105279	4.104454912
% liquid H2O vaporized =	0	0	0	0
if all liq H2O is vaporized @ Tvo>100, (D):				
cal'd vapor outlet temp (oC) =	106.057459	86.28809445	108.1803509	104.8071252
vapor flow @ jet discharge (lb/hr) =	255.6686783	236.7745136	223.976652	251.2229925
H2O =	32.30201891	29.91485422	33.02311629	80.2903331
H2O I =	0	0	0	0
HNO3 =	0	0	1.007413405	0
HNO3 I =	0	0	0	0
NOx =	0	0	0.369037226	0
SO2 =	0	0	0.008388503	0
FeCl3 =	0	0	0.002008752	0
NaF =	0	0	6.58182E-05	0
PbO =	0.004942281	0.004942281	0.003706711	0.004942281
(Na,K)BO2 =	0.00158426	0.00158426	0.001243627	0.00158426
O2 =	52.04507951	48.19878824	44.28130976	39.82744844
N2 =	171.3150534	158.6543446	145.2488883	131.0986844
glass * =	0	0	0.03147357	0
temp (oC) =	106.057459	86.28809445	108.1809501	104.8071252
pressure ("wc vac) =	2.5	2.5	2.5	2.5
MW (lb/lbmole) =	26.8063623	26.80635933	26.56406508	24.19654725
MW dry (lb/lbmole) =	28.84	28.84	28.85456996	28.84
Cp (Btu/lb/F) =	0.280369899	0.280369584	0.286224035	0.324527568
total moisture (lb/hr) =	32.30201891	29.91485422	34.03052969	80.2903331
moisture (wt%) =	12.63465033	12.63467016	15.19639649	31.96061723
lb H2O / lb dry gas =	0.144618552	0.144618811	0.179195174	0.469737025
volumetric flow (acfm) =	80.09254046	70.30656685	71.19053454	86.90082142
(scfm) =	57.05455068	52.83806195	50.43073408	62.10927161
solids loading (grain/scf) =	0.013345646	0.014410631	0.089062536	0.012259519
off-gas line I.D. (in) =	2.067	2.067	2.067	2.067
off-gas velocity (ft/sec) =	57.28393499	50.28479284	50.91702584	62.1533663
check max moisture content:				
H2O PS eqn slope (psia/oC) =	0.279	0.279	0.279	0.279
H2O PS eqn intercept (psia) =	-15.335	-15.335	-15.335	-15.335
max moisture limit (lb/hr) =	No Limit	192.4200312	No Limit	No Limit
gamma emitter loading (grain/scf):				
Cs-137 =	0	0	8.47306E-07	6.12127E-07
Eu-154 =	0	0	7.98622E-06	0

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
Am-241 =	0	0	0.000102427	0
Np-239 =	0	0	6.38325E-11	0
total gamma to scrubber (Ci/hr) =	0	0	0.508874048	0.012823125
alpha emitter loading (grain/scf):				
Cm-244	0	0	0.000570102	0
Cm-242	0	0	4.36707E-09	0
Pu-238	0	0	1.89564E-06	0
Pu-239	0	0	8.13162E-07	0
Pu-240	0	0	2.82384E-05	0
total alpha to scrubber (Ci/hr) =	0	0	9.05143732	0
Quencher / Scrubber:				
pressure drop in quencher ("wc) =	0.5	-0.5	-1	0
quencher outlet pressure (psia) =	14.5195	14.5556	14.57365	14.53755
temperature approach (oC) =	0	0	0	0
wt% overall dust removal =	75	75	75	75
overall DF =	4	4	4	4
wt% semivolatile removal =	0	0	0	0
semi-volatile DF =	1	1	1	1
fresh motive fluid flow (lb/hr) =				
	1100	1100	1500	1500
(gpm) =	2.197802198	2.197802198	2.997002997	2.997002997
fresh motive fluid temp (oC) =	35	35	35	35
assumed outlet vapor T (oC) =				
	46.7	45.4	45.5	59
H2O PS eqn slope (psia/oC) =	0.0807	0.0807	0.0807	0.163
H2O PS eqn intercept (psia) =	-2.157	-2.157	-2.157	-6.89
estimated condensation (lb/hr) =	14.87565308	14.98986787	19.97282192	55.62996269
parameter L =	609	601.8698091	609	609
parameter U =	171.8674559	159.166278	155.2153297	187.0936106
parameter A =	101.7669673	100.8064725	132.7369314	273.6472467
parameter B =	-32143.32214	-31198.32818	-39025.20502	-63688.08649
parameter C =	1280220.407	1207874.2	1500315.536	2803926.979
cal'd vapor outlet temp (oC) =	46.74726736	45.36591019	45.48023436	58.96484714
cal'd liquid outlet temp (oC) =	46.74726736	45.36591019	45.48023436	58.96484714
moisture condensed (lb/hr) =	14.82924563	15.02025779	19.98933931	55.69371167
% moisture condensed =	45.90810771	50.21003172	58.73943041	69.36540118
total vapor discharge (lb/hr) =				
	240.8394327	221.7542558	203.9637075	195.5292809
H2O =	17.47277328	14.89459643	14.04119038	24.59662143
HNO3 =	0	0	0	0
NOx =	0	0	0.369037226	0
SO2 =	0	0	0.008388503	0
FeCl3 =	0	0	0.002008752	0
NaF =	0	0	6.58182E-05	0
PbO =	0.004942281	0.004942281	0.003706711	0.004942281
(Na,K)BO2 =	0.00158426	0.00158426	0.001243627	0.00158426

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
O ₂ =	52.04507951	48.19878824	44.28130976	39.82744844
N ₂ =	171.3150534	158.6543446	145.2488883	131.0986844
glass * =	0	0	0.007868393	0
MW (lb/lbmole) =	27.63608717	27.72193866	27.70763424	26.81455169
C _p (Btu/lb/F) =	0.257311637	0.256193092	0.256479212	0.268372928
volumetric flow (acfm) =	61.81245663	56.35266561	51.81055551	53.62924689
(scfm) =	52.1315941	47.85169388	44.03352682	43.62028499
solids loading (grain/scf) =	0.014605918	0.015912285	0.039459744	0.017455865
gamma emitter loading (grain/scf):				
Cs-137 =	0	0	9.70403E-07	8.71585E-07
Eu-154 =	0	0	2.28662E-06	0
Am-241 =	0	0	2.93269E-05	0
Np-239 =	0	0	1.82765E-11	0
total gamma to HEME (Ci/hr) =	0	0	0.138027683	0.012823125
alpha emitter loading (grain/scf):				
Cm-244	0	0	0.000163232	0
Cm-242	0	0	1.25038E-09	0
Pu-238	0	0	5.42758E-07	0
Pu-239	0	0	2.32825E-07	0
Pu-240	0	0	8.08523E-06	0
total alpha to HEME (Ci/hr) =	0	0	2.26285933	0
condensate collection:				
total liquid discharge (lb/hr) =	1114.829246	1115.020258	1519.989339	1555.693712
HNO ₃ in condensate (wt%) =	0	0	0.066277663	0
(molar) =	0	0	0.010515762	0
max HNO ₃ in condensate (wt%) =	0	0	0.108396337	0
nominal condensate pH w/ once-thru =	7	7	1.978159266	7
min condensate pH w/ once-thru =	7	7	1.764511843	7
nominal cond pH w/ recirc =	7	7	0.097117164	7
min condensate pH w/ recirc =	7	7	-0.116530259	7
solids scrubbed out (lb/hr) =	0	0	0.023605178	0
solids concentration (g/liter) =	0	0	0.015523185	0
check heat balance @ quencher:				
heat loss (Btu/hr) =	23011.03996	20350.46292	28081.3122	64533.64768
heat gain (Btu/hr) =	23259.58937	20524.50217	28296.63276	64705.08727
condensate overflow tank (COT):				
aqueous feed batch size (liter) =	30	30	30	30
duration of one feed batch (hr) =	N/A	N/A	11.42943184	N/A
max COT liquid volume (liter) =	110	110	110	110
calc's below pertain to Pu project:				
max solids in COT(g/liter):				
after each feed batch =	N/A	N/A	1.112531403	N/A
between HNO ₃ additions =	N/A	N/A	150.8180006	N/A

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
max elemental in COT after 1 feed batch (g/liter): (assuming 100% carryover)				
Pu =	N/A	N/A	0.033194919	N/A
Am/Cm =	N/A	N/A	2.314553398	N/A
max successive feed batches =	N/A	N/A	135.5629155	N/A
condensate collection tank (CCT):				
nominal liquid volume (liter) =	110	110	110	110
max allow. liquid volume (liter) =	180	180	180	180
total condensate per batch (liter) =	N/A	N/A	7887.995854	N/A
req'd transfer rate (gal/min) =	N/A	N/A	3.038638271	N/A
max time w/o transfer (min) =	N/A	N/A	6.085654028	N/A
OG temperature drop in COT (oC) =	10	10	10	10
COT pressure control:				
25 psig control air flow (lb/hr) =	0	0	0	0
@ temp (oC) =	35	35	35	35
off-gas flow to HEME (lb/hr) =	240.8394327	221.7542558	203.9637075	195.5292809
H2O =	17.47277328	14.89459643	14.04119038	24.59662143
NOx =	0	0	0.369037226	0
SO2 =	0	0	0.008388503	0
FeCl3 =	0	0	0.002008752	0
NaF =	0	0	6.58182E-05	0
PbO =	0.004942281	0.004942281	0.003706711	0.004942281
(Na,K)BO2 =	0.00158426	0.00158426	0.001243627	0.00158426
O2 =	52.04507951	48.19878824	44.28130976	39.82744844
N2 =	171.3150534	158.6543446	145.2488883	131.0986844
glass * =	0	0	0.007868393	0
temp (oC) =	36.74726736	35.36591019	35.48023436	48.96484714
Cp (Btu/lb/F) =	0.257311637	0.256193092	0.256469317	0.268372928
pressure ("wc vac) =	4	3	2.5	3.5
MW (lb/lbmole) =	27.63608717	27.72193866	27.70763424	26.81455169
MW dry (lb/lbmole) =	28.84	28.84	28.85456996	28.84
volumetric flow (acfm) =	60.02944894	54.71915097	50.30913478	52.14395186
(dry acfm) =	53.35013066	49.06486563	44.98346479	42.38287244
(scfm) =	52.1315941	47.85169388	44.03352682	43.62028499
solids loading (grain/scf) =	0.014605918	0.015912285	0.039459744	0.017455865
off-gas line I.D. (in) =	2.067	2.067	2.067	2.067
off-gas velocity (ft/sec) =	42.93437355	39.13633241	35.98219247	37.29449374
gamma emitter loading (grain/scf):				
Cs-137 =	0	0	9.70403E-07	8.71585E-07
Eu-154 =	0	0	2.28662E-06	0
Am-241 =	0	0	2.93269E-05	0
Np-239 =	0	0	1.82765E-11	0
total gamma to HEME (Ci/hr) =	0	0	0.138027683	0.012823125
alpha emitter loading (grain/scf):				

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
Cm-244	0	0	0.000163232	0
Cm-242	0	0	1.25038E-09	0
Pu-238	0	0	5.42758E-07	0
Pu-239	0	0	2.32825E-07	0
Pu-240	0	0	8.08523E-06	0
total alpha to HEME (Ci/hr) =	0	0	2.26285933	0
High Efficiency Mist Eliminator:				
overall dust DF =	40	40	40	40
semivolatiles DF =	40	40	40	40
add water flush ? (0=false, 1=true):	0	0	0	0
water flush (lb/hr) =	0	0	0	0
atomizing air flow (lb/hr) =	0	0	0	0
HEME outlet pressure ("wc vac)=	13	12	11.5	12.5
check for possible condensation (I):				
assumed outlet vapor T (oC) =	45.4	44	44.4	58.2
temperature approach (oC) =	0	0	0	0
H2O PS eqn slope (psia/oC) =	0.0807	0.0807	0.0807	0.163
H2O PS eqn intercept (psia) =	-2.157	-2.157	-2.157	-6.89
estimated condensation (lb/hr) =	0.945287317	0.90014024	0.887091603	0.796259241
parameter L =	576.108579	575.3902733	575.4497219	582.4617205
parameter U =	157.0382103	144.1460202	132.6499155	131.3998989
parameter A =	11.5909941	10.63366461	9.787972984	19.69084222
parameter B =	-8805.786131	-8060.664866	-7423.04543	-14656.36279
parameter C =	375714.3635	334170.2425	310588.4765	785779.2919
cal'd vapor outlet temp (oC) =	45.37711596	44.01231802	44.44591154	58.15767034
cal'd liquid outlet temp (oC) =	45.37711596	44.01231802	44.44591154	58.15767034
moisture condensed (lb/hr) =	0.967939266	0.889077813	0.849115185	0.873549449
liquid return to COT (lb/hr) =	0.967939266	0.889077813	0.849115185	0.873549449
off-gas to HEPA heater (lb/hr) =	239.8651301	220.8588147	203.1000713	194.649368
H2O =	16.50483401	14.00551862	13.1920752	23.72307198
NOx =	0	0	0.369037226	0
SO2 =	0	0	0.008388503	0
FeCl3 =	0	0	5.02188E-05	0
NaF =	0	0	1.64546E-06	0
PbO =	0.000123557	0.000123557	9.26678E-05	0.000123557
(Na,K)BO2 =	3.96065E-05	3.96065E-05	3.10907E-05	3.96065E-05
O2 =	52.04507951	48.19878824	44.28130976	39.82744844
N2 =	171.3150534	158.6543446	145.2488883	131.0986844
glass * =	0	0	0.00019671	0
temp (oC) =	36.74726736	35.36591019	35.48023436	48.96484714
Cp (Btu/lb/F) =	0.256538155	0.255417315	0.255671858	0.267563213
MW (lb/lbmole) =	27.69572717	27.78215231	27.77001727	26.87341119
volumetric flow (acfm) =	61.02846043	55.62637991	51.12983602	52.98438385
(scfm) =	51.8102613	47.55654121	43.75169296	43.33028737
solids loading (grain/scf) =	0.000367413	0.000400276	0.000992848	0.000439317

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
gamma emitter loading (grain/scf):				
Cs-137 =	0	0	2.44163E-08	2.19355E-08
Eu-154 =	0	0	5.75336E-08	0
Am-241 =	0	0	7.37895E-07	0
Np-239 =	0	0	4.59857E-13	0
total gamma to HEPA (Ci/hr) =	0	0	0.003450692	0.000320578
alpha emitter loading (grain/scf):				
Cm-244	0	0	4.10708E-06	0
Cm-242	0	0	3.14609E-11	0
Pu-238	0	0	1.36564E-08	0
Pu-239	0	0	5.85811E-09	0
Pu-240	0	0	2.03433E-07	0
total alpha to HEPA (Ci/hr) =	0	0	0.056571483	0
HEPA Preheater:				
desired gas temp increase (oC) =	10	10	10	10
req'd heater duty (Btu/hr) =	1107.622043	1015.400979	934.6855068	937.4581862
HEPA:				
overall DF =	500	500	500	500
semivolatiles DF =	200	200	200	200
HEPA outlet pressure ("wc vac)=	16	15	14.5	15.5
off-gas flow to air-jet (lb/hr):				
H2O =	239.8649677	220.8586523	203.0997003	194.6492057
NOx =	16.50483401	14.00551862	13.1920752	23.72307198
SO2 =	0	0	0.369037226	0
FeCl3 =	0	0	0.008388503	0
NaF =	0	0	2.51094E-07	0
PbO =	0	0	8.22728E-09	0
PbO =	6.17785E-07	6.17785E-07	4.63339E-07	6.17785E-07
(Na,K)BO2 =	1.98033E-07	1.98033E-07	1.55453E-07	1.98033E-07
O2 =	52.04507951	48.19878824	44.28130976	39.82744844
N2 =	171.3150534	158.6543446	145.2488883	131.0986844
glass * =	0	0	3.9342E-07	0
temp (oC) =	46.74726736	45.36591019	45.48023436	58.96484714
Cp (Btu/lb/F) =	0.256538259	0.255417427	0.255671901	0.26756335
MW (lb/lbmole) =	27.69572717	27.78215231	27.77001727	26.87341119
volumetric flow (acfm) =	63.48336464	57.87094683	53.19182597	55.04982123
(scfm) =	51.8102613	47.55654121	43.75169296	43.33028737
solids loading (grain/scf) =	1.83706E-06	2.00138E-06	3.39062E-06	2.19659E-06
gamma emitter loading (grain/scf):				
Cs-137 =	0	0	1.22082E-10	1.09677E-10
Eu-154 =	0	0	1.15067E-10	0
Am-241 =	0	0	1.47579E-09	0
Np-239 =	0	0	9.19713E-16	0
total gamma to air jet (Ci/hr) =	0	0	7.9823E-06	1.60289E-06
alpha emitter loading (grain/scf):				

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

(8/97, A.S. Choi)

	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
Cm-244	0	0	8.21416E-09	0
Cm-242	0	0	6.29217E-14	0
Pu-238	0	0	2.73127E-11	0
Pu-239	0	0	1.17162E-11	0
Pu-240	0	0	4.06866E-10	0
total alpha to air jet (Ci/hr) =	0	0	0.000113143	0
air-jet pump:				
air supply pressure (psig) =	25	25	25	25
discharge pressure ("wc vac) =	0	0	0	0
pressure ratio =	43.28254848	46.16805171	47.76005349	44.67875972
max mass ratio =	2.738315936	2.841618931	2.896540454	2.788933689
excess air (%min) =	70	70	70	70
air supply to jet pump (lb/hr) =	148.9128554	132.1288034	119.200645	118.6488051
vapor discharge to PVVS (lb/hr) =	388.7778231	352.9874557	322.3003453	313.2980108
H2O =	20.82330682	17.83725391	16.6488939	27.16388733
NOx =	0	0	0.369037226	0
SO2 =	0	0	0.008388503	0
FeCl3 =	0	0	2.51094E-07	0
NaF =	0	0	8.22728E-09	0
PbO =	6.17785E-07	6.17785E-07	4.63339E-07	6.17785E-07
(Na,K)BO2 =	1.98033E-07	1.98033E-07	1.55453E-07	1.98033E-07
O2 =	85.73697449	78.0932507	71.25074502	66.67202857
N2 =	282.217541	257.0569502	234.0232794	219.462094
glass *	0	0	3.9342E-07	0
temp (oC) =	42.33835081	41.55446326	41.67568991	50.30719785
Cp (Btu/lb/F) =	0.253370394	0.252741163	0.252933499	0.260255904
MW (lb/lbmole) =	27.94139511	27.9907117	27.98043919	27.41287709
volumetric flow (acfm) =	96.61300108	87.34681644	79.81329757	81.36145115
(scfm) =	83.2367527	75.440935	68.90773496	68.36986935
solids loading (grain/scf) =	1.14347E-06	1.26163E-06	2.15281E-06	1.39212E-06
NOx content (ppm) =	0	0	882.2028234	0
gamma emitter loading (grain/scf):				
Cs-137 =	0	0	7.75135E-11	6.95094E-11
Eu-154 =	0	0	7.30598E-11	0
Am-241 =	0	0	9.37026E-10	0
Np-239 =	0	0	5.83955E-16	0
total gamma to PVVS (Ci/hr) =	0	0	7.9823E-06	1.60289E-06
alpha emitter loading (grain/scf):				
Cm-244	0	0	5.21543E-09	0
Cm-242	0	0	3.9951E-14	0
Pu-238	0	0	1.73417E-11	0
Pu-239	0	0	7.439E-12	0
Pu-240	0	0	2.58332E-10	0
total alpha to PVVS (Ci/hr) =	0	0	0.000113143	0
miscellaneous calculations:				

Appendix B. Results of Am/Cm Vitrification Flowsheet Calculations

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	Idling @ 1450 oC (Clemson Run 1&2)	Idling @ 1150 oC (Clemson Run 3)	Feed @ 1450 oC (Clemson Run 4)	Idling w/ FC Stm (Clemson Run 5&6)
campaign duration @ 100% attain. (hr) =	N/A	N/A	1135.232039	N/A
total glass produced (kg) =	N/A	N/A	317.1094645	N/A
total NOx release to PVVS (lb) =	N/A	N/A	167.5771529	N/A
total Pb release to PVVS (lb) =	N/A	N/A	0.000488291	N/A
total gamma to PVVS (Ci) =	N/A	N/A	0.004851797	N/A
Cs-137 =	N/A	N/A	0.002045153	N/A
Eu-154 =	N/A	N/A	0.002400723	N/A
Am-241 =	N/A	N/A	0.000389411	N/A
Np-239 =	N/A	N/A	1.65103E-05	N/A
total alpha to PVVS (Ci) =	N/A	N/A	0.051377408	N/A
Cm-244	N/A	N/A	0.051318036	N/A
Cm-242	N/A	N/A	1.61072E-05	N/A
Pu-238	N/A	N/A	3.61189E-05	N/A
Pu-239	N/A	N/A	5.54952E-08	N/A
Pu-240	N/A	N/A	7.09016E-06	N/A