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7. Abstract

This CSER justifies the Limited Control Facility designation for the closed Burning Hood in the PFP 232-Z Incinerator Facility. If the Burning Hood is opened to characterize the plutonium distribution and geometric integrity of the internals or or for disassembly of the internals, then the more rigorous Fissionable Material Facility classification is required. Two sets of requirements apply for personnel access, criticality firefighting category for water use, and fissile material movement for the two states of the Burning Hood. The parameters used in the criticality analysis are listed to establish the limits under which this CSER is valid. Determination that the Burning Hood fissile material, moderation, or internal arrangements are outside these limits requires reevaluation of these parameter values and activities at the 232-Z Incinerator Facility. When the Burning Hood is open, water entry is to be prevented by two physical barriers for each water source.

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CSER 94-013

Title: CLASSIFICATION AND ACCESS TO PFP 232-Z INCINERATOR FACILITY AND
LIMITS ON CHARACTERIZATION AND DISASSEMBLY ACTIVITIES IN 232-Z
BURNING HOOD

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1.0 PURPOSE

This Criticality Safety Evaluation Report (CSER) 94-013 addresses the three specific areas listed below:

- 1) Criticality classification of the PFP 232-Z Incinerator Facility including 232-Z building and process room areas
- 2) Restrictions on access to the PFP 232-Z Incinerator Facility including 232-Z Building and process room areas
- 3) Limitations on characterization and disassembly activities at the 232-Z Burning Hood

The criticality classification of the PFP Incinerator 232-Z Facility was based in part on the plutonium holdup in the 232-Z Building Burning Hood. Recently, the Nondestructive Assay (NDA) upper estimate of the holdup was revised from 20 grams (Reference 1) to 5.9 kg (Reference 2). This increase in plutonium inventory assessment required a reevaluation of the criticality safety of the Burning Hood. In addition, if intrusive characterization and disassembly activities at the 232-Z Burning Hood are undertaken that have the potential to displace significant amounts of plutonium or of Burning Hood interior refractory insulation, then the criticality classification for the a Burning Hood needs to be different than that when no activity internal to the Burning Hood is allowed.

2.0 SUMMARY

2.1 CLASSIFICATION AND RESTRICTIONS

This CSER establishes the classification for the PFP 232-Z Incinerator Facility and sets limits on activities at the Burning Hood. The activities include stabilization and characterization external to the hood and characterization and disassembly internal to the hood.

The classifications and limitations for activities at the Burning Hood are in two sets in response to two conditions. In one condition the Burning Hood remains closed and in the other the hood is opened for characterization and disassembly of the internals. The two sets of classifications and limitations are summarized in the table below.

BURNING HOOD	CLOSED	OPENED
CLASSIFICATION	LIMITED CONTROL FACILITY	FISSIONABLE MATERIAL FACILITY
PERSONNEL ACCESS	UNLIMITED	NOTE 1 BELOW
WATER RESTRICTIONS	FIREFIGHTING CATEGORY B	NOTE 2 BELOW
FISSILE MATERIAL MOVEMENT	LIMITED TO 35 GRAMS IN SOURCES AND DETECTORS	LIMITS IN NOTE 3 BELOW

Note 1 Restrict personnel entry to minimum number required for intrusive Burning Hood characterization or disassembly.

Note 2 Firefighting Category D. Take positive actions to preclude any water entry into the open Burning Hood by having two physical barriers in place from each possible water source. Specifically, sprinklers are to be blanked off to the Burning Hood area and a second specific action taken to preclude water entry, such as a greenhouse. Administrative controls are to preclude personnel from bringing water near and into the Burning Hood except two damp rags at a time and less than a half liter of lubricating fluid or paste for cutting may be used in the Burning Hood.

Note 3 Activities at or inside the Burning Hood are limited by the following requirements:

- 1) Limit observable, loose power or ash to 1/8 inch depth. Remove excess to 1/2 liter containers and remove containers from inside Burning Hood before proceeding with removal or movement of Burning Hood internals. Maintain 3 foot spacing between containers and between containers and packaged internals inside the Burning Hood. (This is a criticality limit only; radiological considerations may limit loose ash to significantly less loose surface contamination.)
- 2) Remove only one segment of tubing at a time.
- 3) Cap each tubing segment when opened to prevent spilling liquid or powder into the Burning Hood.
- 4) Remove insulation in a manner to prevent collapse of insulation around the lower combustion chamber.
- 5) Allowed plutonium containers:
 - 1/2 liter can/jar for cleanup
 - sections of tubing sealed with caps, double wrapped in plastic, and taped or constrained to maintain a geometrically favorable shape
 - Burning Hood internal refractory insulation double wrapped in plastic and taped or constrained to approximate the shape of pieces of insulation or internals. Each package is limited to two square feet of 1/8 inch depth of powder or equivalent volume of powder (0.5 liters).
 - Other containers approved by the PFP CSR in the CPS for the Burning Hood work.

- 6) Use of plastic shall conform to Section G of CPS-Z-165-80010, Rev./Mod. C-2.
- 7) Handling of nonapproved containers shall conform to CPS-Z-165-80330, Rev./Mod. B-0, entitled "200 Gram Plutonium Storage Limit for Nonapproved Containers."
- 8) All items removed from the Burning Hood are to be assayed to monitor the total amount of plutonium that is being found.

If any of the following parameters used to establish this CSER's conclusions are found to be exceeded, stop activities at the incinerator until a criticality evaluation can be preformed.

- 1) Total mass of plutonium removed from the upper part of the Burning Hood exceeds 5 kg or if the total mass of plutonium removed from the Burning Hood exceeds 10 kg at any time during characterization or disassembly.
- 2) 2 inch or thicker ash or powder layer anywhere
- 3) Any section of tubing contains greater than 1 kg of plutonium
- 4) More than 0.5 liter of free liquid
- 5) Internal tubing deposit is a loose powder
- 6) Deposits inside or outside tubing are a paste or wetter
- 7) Assay of powder or ash samples are:
 - $H/Pu > 100$
 - $C/Pu > 48$
 - $PuO_2 > 0.4 \text{ g/cc}$
 - Fissile matrix (ash or slag separated from plutonium) $> 1.5 \text{ g/cc}$

2.2 NDA PLUTONIUM INVENTORY ASSESSMENT

The WHC Internal Memo to E. C. Vogt from G. A. Westsik (Reference 2), attached as Appendix A, assesses a conservative plutonium inventory of 6.5 kg for the PFP 232-Z Incinerator Facility. This amount is divided into 5.9 kg in the Burning Hood and 0.6 kg in balance of the facility. The distribution of the 0.6 kg of plutonium in the exhaust ducting, scrubber cell, and other hoods and gloveboxes in the facility is listed in Figure 1 based on Reference 3. The conservative value of 5.9 kg of plutonium holdup in the Burning Hood will be used as specified in Reference 2 and is the upper value in the uncertainty range. The assessment has two divergent values based on different techniques. The neutron method gives the 5.9 value, while the gamma ray method and holdup model used gave an upper value in the uncertainty range of 1.3 kg for the Burning Hood. The holdup in the balance of the facility was assessed by the gamma ray method.

2.3 CRITICALITY ASSESSMENT

This CSER justifies the classification of the PFP 232-Z Incinerator Facility as a Limited Control Facility when the Burning Hood is closed and that there is sufficient margin of safety for intrusive characterization and disassembly activities at the Burning Hood. Westinghouse Hanford Company (WHC) and Battelle Pacific Northwest Laboratories (PNL) both have analyzed the Burning Hood for criticality safety. The WHC analysis analyzed for the plutonium oxide mixed with refractory material and carbon with limited hydrogen moderator. The PNL analysis analyzed for plutonium oxide mixed with water. Together the two analyses show that the Burning Hood is safely subcritical by a wide margin for a plutonium inventory of 10 kg or less mixed with water, carbon, and slag that is confined within the combustion chambers and flues and for an incinerator that has maintained its original internal insulation geometry. For plutonium with an $H/Pu < 20$, the Burning Hood is safe even with a limited amount of plutonium mixed with carbon and slag outside the combustion chambers and flues or with the internal insulation collapsed into the void spaces around the combustion chambers. The results of these two analyses were sent to PFP as soon as available, the WHC analysis by Reference 4 and the PNL by Reference 5. The two analyses are presented below.

3.0 WHC CRITICALITY ANALYSIS

3.1 MODEL

3.1.1 Geometry

A simplified model of the incinerator was developed from the design drawings of References 6 thru 11. The first five items in Appendix B depicts the Burning Hood in the two sketches, a picture of the internal tubing, and two computer generated depictions of the tubing and insulation contained. Reference 12, a written description of the construction and operation of the incinerator up to 1969, is also reproduced in Appendix B. The model is conservative because it used the most reactive configuration from the

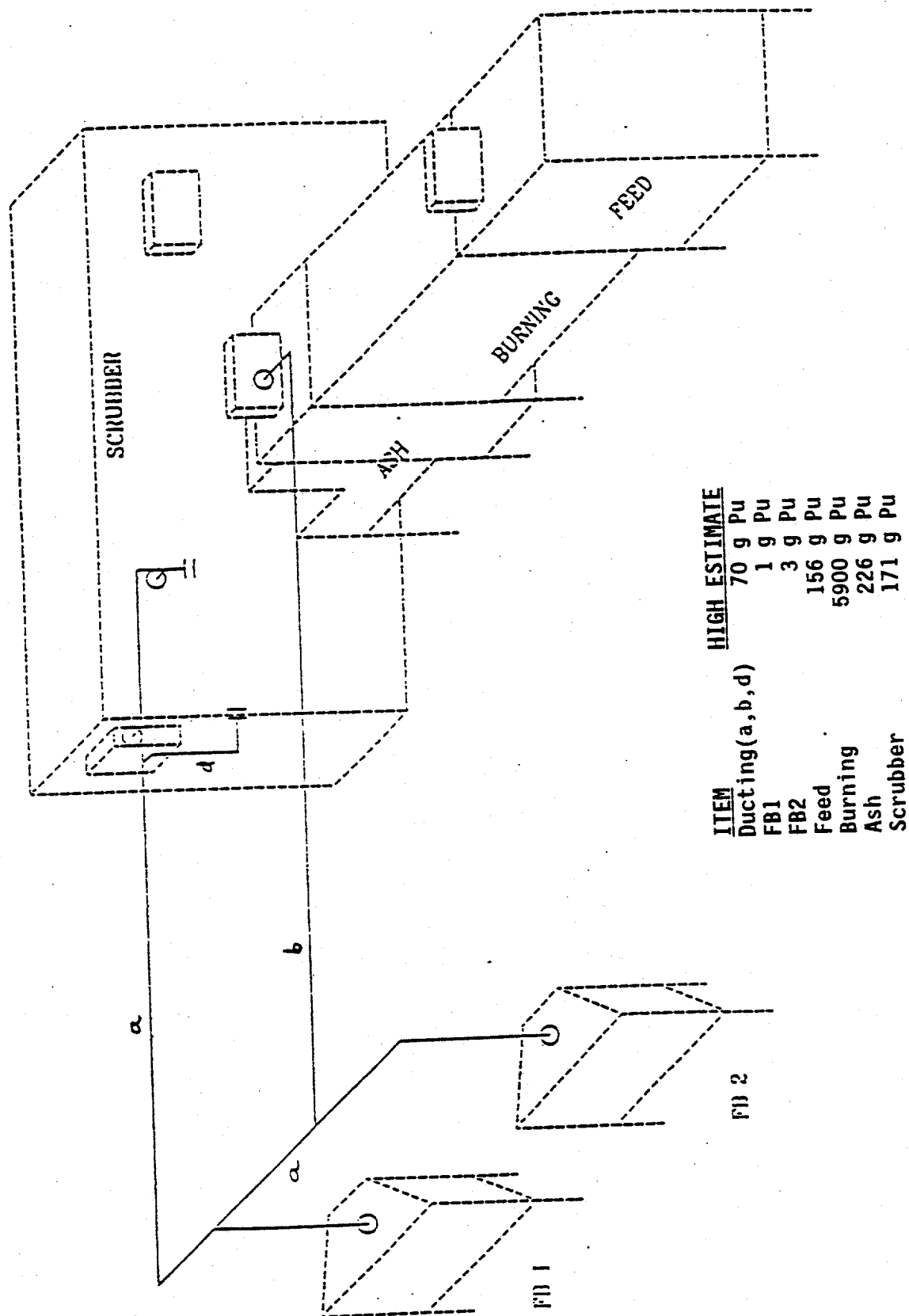


FIGURE 1 10/94 HIGH Pu HOLDUP ESTIMATES FOR THE 232-Z BUILDING INCINERATOR

numerous sizes of combustion chambers and flues, void spaces, and refractory insulation materials comprising the incinerator. The upper combustion chamber has an ID of 12.065 cm (4.75") and the lower is a half tube ("D" shaped hemitube) of 20.0025 cm (7.875") ID (Reference 7). The lower has a cross sectional area of 0.412 ℓ per 2.54 cm (per inch) while the upper has 0.29 ℓ per 2.54 cm (per inch). The vertical tubes are only 4.7625 cm (1.875") ID (Reference 7).

The larger combustion chamber was used to model both upper and lower combustion chambers. The void space was replaced with the densest refractory insulation. The model has significantly greater neutron reflection around the primary combustion chamber because the modelled material surrounding the primary combustion chamber is more dense and closer than that in the actual incinerator. The entire Burning Hood was surrounded by 2.54 cm (1") of water to model room reflection.

The vertical flues were not modelled. To compensate for this and account for erosion, tolerances, and additional volume at intersections of the lower tube and the vertical flues, the primary combustion chamber radius was increased by 0.3175 cm (1/8") to an ID of 20.32 cm (8.0") and cases were run with plutonium around the outside of the primary combustion chamber. The neutron absorbing tube wall was decreased from an actual 0.9525 cm (3/8") to 0.635 cm (1/4") in the model as was the plate making up the bottom half of the lower combustion chamber. The loss of close reflection of the thinner tubing is not expected to be significant because this model has dense, close reflector directly under the tube and at a 16.51 cm (6.5") radius, where the PNL model has void.

The combustion chamber is surrounded by refractory materials at different densities which are composed of predominately aluminum, silicon, and oxygen. Data from documents specifying pertinent parameters for the refractory materials in the Burning Hood (References 13-16) are summarized in Appendix C. Brick at a density of 2.1 g/cc is below the half tube for 7.5". Reference 14 specifies Johns-Manville Co. Insulating Firebrick designated JM 23 "composed largely of refractory clays." The properties and composition of "Bricks(fire clay)" from the COMMONLY USED MATERIALS table on page II.F.1-1 of Volume I of ARH-600 (Reference 17) are used. Reference 14 gives the density of the JM 23 firebrick as 0.73 -0.75 g/cc. The denser material used in the model is conservative because it acts as a better close reflector. A flexible refractory, CERAFELT, of 0.16 g/cc per Reference 14 covers the tube to a radius of 16.51 cm (6.5"), then a castable refractory of 1.5 g/cc, rounded up from densities in References 13 and 14, goes out to 43.18 cm (17") radius and to 30.48 cm (12") below the tube center line. A 2.54 cm (one inch) layer of water surrounds the entire model to give a nominal reflection at the boundary.

The incinerator exterior stainless steel plates are left off as they are neutron absorbers and the water acts as the reflector. The tube is modelled as infinitely long by having spectral reflection at each end of its 50.8 cm (20") explicitly modelled length. An incinerator length of 241.3 cm (95") was used to calculate the total plutonium inventory of the incinerator reported for each computer case.

To test the effect of including the upper combustion chamber on reactivity, a model was composed with a 22.86 cm (9") wide void vertically to 41.275 cm (16.25") above the center line of the lower combustion chamber. The bottom chamber was mirrored to make a conservative model of the upper chamber. The distance between the center lines of the two combustion chambers is 82.8675 cm (32-5/8"). The 22.86 cm (9") wide vertical void is conservative in that in most places in the incinerator the void space is actually about 40.64 cm (16") wide which would allow more neutron leakage. In addition, there is at least 22.86 cm (9") of 1.5 g/cc refractory insulation between the two combustion chambers.

A third model was made to test the affect of filling the void space in the Burning Hood with a mixture of plutonium and carbon boxed in by refractory insulation. The void space was conservatively modelled as 40.64 cm (16") wide, 50.8 cm (20") high, and 193.04 cm (76") long. The Burning Hood outside dimensions were modelled as 91.44 cm (36") wide, 96.52 cm (38") high, and 243.84 cm (96") long that surrounded the fuel region with 1.5 g/cc refractory insulation. This was then surrounded by 2.54 cm (1") of water. In addition, two runs were made where spectral reflection was used to model the upper void space filled with the fissile mixture. The upper void space was conservatively modelled as the larger and better reflected lower space. The model included the 24.13 cm (9.5") refractory insulation (1.5 g/cc) between the two chambers.

3.1.2 Fissile Material

Records of plutonium in the incinerator ash for 1967 and 1968 (Reference 18) gave values of less than 90 g Pu/l. The normal value given by PFP personnel (References 19 and 20) for plutonium content of ash from the incinerator was 10%. Figures 1 and 2 of Reference 21 shows the weight per cent of plutonium in incinerator ash as about 6% with an upper limit of 9% and 12%, respectively. If an average PuO₂ density of 4 g/cc is used with the 10%, a value of 353 g Pu/l is calculated for the density of PuO₂ in the ash which is about 4 times the measured value in Reference 18. This is the conservative density of PuO₂ that is used for the fissile mixture in the base cases of the incinerator model. The 4.0 g/cc density of PuO₂ is consistent with density values for PuO₂ formed by calcining nitrate, peroxide, oxalate, hydroxide, and by burning metal listed on Page II.C.2-2 of Volume 1 of ARH-600 (Reference 17). All plutonium is conservatively modelled as plutonium-239. Reference 22 gives the Pu-240 content of the plutonium in 232-Z incinerator as over 9 wt%. Modelling all plutonium as Pu-239 introduces a significant conservatism to the k_{eff} values calculated by the criticality codes. The page of PuO₂ densities and Reference 22 are reproduced in Appendix D.

The neutron analysis of the Burning Hood plutonium content found a total inventory of 5.9 kg (Reference 2). The data also indicates that the plutonium was relatively uniformly distributed throughout the Burning Hood (Reference 23). Readings were taken in 7 volumes 15 inches long from the inlet to the outlet end and divided into an upper and lower halves. In 9 of the 14 volumes the readings were 9.7 to 12 in arbitrary units. The lower inlet volume has a reading of 6.8 and is the lowest reading. The two lower volumes that include the two flues closest to the outlet end read 16.8 and

16.0, while the volume above the 16.8 reading is 14.5. The WHC and PNL criticality analyses have modeled the plutonium distribution as uniform, but at concentrations greater than that corresponding to maximum concentration resulting from the nonuniform distribution of plutonium in the Burning Hood.

To test the limits on the maximum safe plutonium concentration, the 10% was raised to 20% and 30% in special cases. These larger values are not expected to exist in the actual incinerator. This increase in plutonium concentration was made without displacing any matrix material (slag). The H/Pu ratio was also maintained at 20. Thus the total material in the cases where more plutonium was added had a higher density than the base case or is expected to be in the incinerator combustion chambers.

For the case with fissile material filling the void around the hemicylinder, plutonium-239 was mixed with carbon. A carbon density of 1.71 g/cc from page II.F.1-2 of ARH-600 (Reference 17) is used in the analysis. The plutonium density depends on the C/Pu ratio and ranges from 0.085 g Pu/cc at C/Pu of 400 to 0.017 g Pu/cc at a C/Pu of 2000.

3.1.3 Moderator

As a result of operating the incinerator up to the 820°C limit, the material mixed with the plutonium is expected to be a refractory (Reference 24, reproduced in Appendix E, says that material buildup in the tubing had to be crushed out periodically when operating.). The moderator material mixture was assumed to have a chemical composition of the refractory insulation used in the incinerator (Reference 13), a mixture of 57% Al₂O₃ and 32% SiO₂. One per cent Beryllium was included based on analysis of the slag in the incinerator (Reference 25) and personal communications with PFP personnel (References 19 and 20). Analysis of slag (See Appendix E.) from the incinerator during its operation found many other metals present in the slag (Reference 25). They were not included because they have higher neutron absorption than Al and Si, which have low absorption cross sections.

Work at PFP by F. D. Fisher (References 26 and 27) indicates that an average 10% PuO₂-salt waste mixture absorbs less than 2% water when left out in the air after having been dried by heating. This is an H/Pu of 6. The maximum absorption was 6.6%, which is an H/Pu of 20. Water was added to the fissile mixture to give an H/Pu of 20. Adding hydrogen to an undermoderated material increases reactivity. References 26 and 27 are reproduced in Appendix F.

References 19 and 20 gave the carbon content of the ash produced by the incinerator having a C/Pu ratio of 30 and 12, respectively. Carbon at C/Pu ratios of 12 and 60 was added to the mixture to determine its effect. Both the water and carbon were added without displacing other material. They also increased the density of the fissile mixture. To further explore the effect of carbon, a second mixture was made up of the 10% PuO₂, 50% carbon at 1.71 g/cc, 20% Al₂O₃, 19% SiO₂, 1% BeO, and H/Pu = 20. Carbon is expected to be a better moderator than oxygen so a more reactive mixture is expected.

3.1.4 Reflector

The reflector as described above in the model section is three densities of refractory surrounded by 1" of water. The refractory is composed by atom ratios of 127 atoms of oxygen, 38 atoms of silicon, 32 atoms of aluminum, and 1 atom of each of calcium, iron, and magnesium from page II.F.1-2 of ARH-600 (Reference 17). In cases to find the effect of close water reflection, the model had water surrounding the half tube to 2.8575 cm (1.125") below the bottom plate and to 16.51 cm (6.5"), 25.4 cm (10"), and 38.1 cm (15") radial around the upper part of the half tube. The brick below the half tube is in a square wave pattern in the direction of the "D" tube centerline (See figures in Appendix B) where the average void depth is 2.8575 cm (1.125"). This space is filled with brick, water, or fissile material in different cases to find the effect of the change on the base case. The 2.1 g/cc brick is the densest reflector. In one case, all the refractory except the brick is modelled as the 0.16 g/cc refractory to investigate the effect of the large open spaces between the heaters and the combustion chambers.

3.2 RESULTS

The sections below explore the effect of increasing the reactivity in several ways. Table 1 lists the k_{eff} for each model analyzed using the MONK6B criticality computer code. This code prints cross sections of the entered model that shows the arrangement of materials comprising the model. Appendix G reproduces the input listings for some of the cases in Table 1 and selected cross sections to illustrate the geometry.

3.2.1 Calculational Method

The MONK6B criticality computer code was used for calculating k_{eff} in this analysis. References 28 and 29 documents the validity of the MONK6B criticality computer code for plutonium systems and establishes the safety limit which includes the code bias and uncertainties as 0.935. Appendix H explains the MONK6B validation. All k_{eff} values have a standard deviation of less than 0.003.

3.2.2 Plutonium Density

The base case, the computer run incin01, of 10% PuO₂ in slag with an H/Pu of 20, with a base case geometry, and with a plutonium inventory of 13.8 kg has a $k_{eff} = 0.427$. This represents the results for a conservative configuration and fissile content of the incinerator. This is a low value and gives large conservatism for deviations and contingencies from the assumptions made for this model. The plutonium density (and Hydrogen content) was doubled, case incin02, and tripled, case incin03, from that in the base case incin01. (The oxygen content from increased Pu and H was not increased.) The Pu inventories are 27.6 and 41.4 kg of Pu, respectively. The resulting k_{eff} 's

are 0.739 and 0.955. It takes 40 kg of plutonium evenly distributed in the lower combustion chamber with a H/Pu of 20 to exceed the allowable limit 0.935, on k_{eff} . It should be noted that adding Pu to a density of 1.06 g/cc and hydrogen to a density of 80% of water without removing any refractory material already modelled is unrealistic and creates a material with the density of aluminum. The reactivity increases with an increase of plutonium and moderator density. Modelling the increase in plutonium and hydrogen moderation is thus conservative.

3.2.3 Plutonium Distribution

An extensive accumulation of Pu outside the combustion chambers was modelled by putting an 1-1/8" of the 10% PuO₂ fissile mixture below the primary combustion chamber bottom plate and out to 6.5" radially from the chambers half tube. The total plutonium inventory, in, around, and below the combustion chamber is 39.9 kg. The resulting k_{eff} for case incin06 is 0.796. Although the 6.5" radius is an arbitrary dimension and there is room for a larger deposition, the incredible large inventory resulting in a k_{eff} of less than 0.8 shows the situation to have considerable margin of safety even if, contrary to all operating evidence, plutonium was not confined to the incinerator tubing. This run shows that a 2-1/2 inch deposit of plutonium even when on the lower combustion chamber is also filled with fissile material has a k_{eff} significantly below the allowable limit.

The internal parts with the largest horizontal surface are some of the heater blocks. Their 10 x 30 inch surface is about 2 square feet. An 1/8 inch layer of ash would make a volume of half a liter. At 100 grams of plutonium per liter in the ash per Reference 18, the deposit would contain only 50 grams of plutonium (1/10 of a minimum critical mass).

3.2.4 Upper Combustion Chamber

Using the model described above for two chambers and the 1.5 g/cc refractory insulation in most of the space, case incin08 found a k_{eff} of 0.480 for an inventory of 13.7 kg of Pu in each of the two tubes. This is only an increase of about 0.06 from the case of a single tube. The second chamber has little effect. The actual arrangement in the incinerator has a lateral void of 16" and has 9" refractory insulation between combustion chambers for 76" of the 95" length of the incinerator. Both increased void and refractory between combustion chambers decreases the incinerator reactivity by increasing leakage and decreasing interaction.

Case incin09 models an increase in void space by decreasing the refractory insulation from 1.5 to 0.16 g/cc. The k_{eff} decreases to 0.314. Even with 27.4 kg of Pu, the k_{eff} is extremely low. This is especially significant in that this model is the closest to the average geometry of the actual incinerator that is analyzed.

TABLE 1 k_{eff} FOR MODELS OF 232-Z INCINERATOR CALCULATED USING THE MONK6B CRITICALITY COMPUTER CODE

CASE	FISSILE GEOMETRY	MODERATOR	REFLECTOR: REGION (OUTER RADII)/	Pu, kg	DENSITY g PuO ₂ /cc	H/Pu	C/Pu	keff
incin01	HEMITUBE WITH 10% PuO ₂	SLAG (57% Al ₂ O ₃ / 32% SiO ₂)	CERAFELT(6.5")/ KAST-O-LITE(17")/ WATER(18")	13.8	0.4	20	0	0.427
incin02	" " 20% PuO ₂	"	"	27.6	0.8	"	"	0.739
incin03	" " 30% PuO ₂	"	"	41.4	1.2	"	"	0.955
incin04	" " 10% PuO ₂	"	"	13.8	0.4	"	12	0.444
incin05	" " " "	"	"	"	"	"	60	0.523
incin06	HEMITUBE WITH 10% PuO ₂ TO 6.5" RADIUS & 1.125" BELOW	"	KAST-O-LITE(17")/ WATER(18")	39.9	"	"	0	0.796
incin07	" " " " "	"	"	"	"	"	60	0.938
incin08	2 HEMITUBES WITH 10% PuO ₂ 32-5/8" AXIS-TO-AXIS	"	VOID(6.5")/ KAST-O-LITE(17")/ WATER(18")	27.6	"	"	0	0.480
incin09	" " " " "	"	VOID/CERAFELT/ WATER(1")	"	"	"	"	0.314
incin10	HEMITUBE WITH 10% PuO ₂	"	WATER(6.5")/ KAST-O-LITE(17")/ WATER(18")	13.8	"	"	"	0.545
incin11	" " " " "	"	WATER(10")/ KAST-O-LITE(17")/ WATER(18")	"	"	"	"	0.529
incin12	" " " " "	"	WATER(15")/ KAST-O-LITE(17")/ WATER(18")	"	"	"	"	0.529

NOTES: 1) All keff values standard deviations are less than 0.0030

TABLE 1 k_{eff} FOR MODELS OF 232-Z INCINERATOR CALCULATED USING THE MONK6B CRITICALITY COMPUTER CODE
(CONTINUED)

CASE	FISSILE GEOMETRY	MODERATOR	REFLECTOR: REGION (OUTER RADII)/	Pu, kg	DENSITY g PuO ₂ /cc	H/Pu	C/Pu	keff
incin21	HEMITUBE WITH 10% PuO ₂	50% C/39% SLAG (20% Al ₂ O ₃ / 19% SiO ₂)	CERAFELT(6.5")/ KAST-O-LITE(17")/ WATER(18")	13.8	0.4	20	48	0.470
incin22	" " 20% PuO ₂	"	"	27.6	0.8	"	24	0.781
incin26	HEMITUBE WITH 10% PuO ₂ TO 6.5" RADIUS & 1.125" BELOW	"	KAST-O-LITE(17")/ WATER(18")	39.9	0.4	"	48	0.864
incin51	PRI COMBUSTION CHAMBER & VOID FILLED WITH PuO ₂ & CARBON	CARBON	NOTE 2	34.0	0.0851	0	400	0.688
incin53	" " " " "	"	"	17.0	0.0425	"	800	0.610
incin55	" " " " "	"	"	11.0	0.0283	"	1200	0.585
incin57	" " " " "	"	"	8.5	0.0213	"	1600	0.560
incin59	" " " " "	"	"	6.8	0.0170	"	2000	0.546
incin52	PRI & SEC COMBUSTION CHAMBERS & VOID FILLED WITH PuO ₂ & CARBON	"	NOTE 3	64.0	0.0851	"	400	0.791
incin54	" " " " "	"	"	32.0	0.0425	"	800	0.720

NOTES: 1) All keff valves standard deviations are less than 0.0030
2) KAST-O-LITE surrounds 76"x20"x16" PuO₂-C to 96"x38"x36" with water to 98"x40"x38".
3) Same as Notes 2 except plane of symmetry is 4.74" above PuO₂-C slab.

3.2.5 Added Carbon Moderation

Two means were adopted to test the effect of carbon on the multiplication factor of the incinerator system, 1) carbon was added to the 10% PuO₂-Slag fissile material, and separately 2) a new material was composed of 50% carbon as described above. When carbon was added to the 10% PuO₂-Slag to achieve a C/Pu of 12 and 60, the k_{eff} rose from the base case incin01 value of 0.427 to 0.444 and 0.523 for cases incin04 and incin05, respectively. The 0.1 increase in k_{eff} for a C/Pu of 60 may be due more to the increased scatterer density of the medium rather than the moderating affect of carbon. Adding 60 atoms of carbon to the plutonium mixture is adding carbon at a density of 1.06 g/cc, and the total material packing is physically not attainable. This is greater than that of carbon in the 10% PuO₂, 50% C, 39% Slag where the carbon density is 0.855 g/cc (C/Pu=48).

The effect of increasing the carbon density is also demonstrated by adding carbon of C/Pu = 60 to case incin06 where the plutonium mixture is in, below, and around the primary combustion chamber. The k_{eff} rose from 0.796 to 0.938. Although an unrealistic model of expected plutonium inventory (39.9 kg of Pu), plutonium distribution, and moderator density, the case illustrates the effect of increased moderator to fissile ratio.

When three cases [(1)the base case incin01, (2)the case with 20% PuO₂, incin02, and (3)the case incin06 where fissile material is in, around, and below the primary combustion camber] were repeated using the 50% carbon fissile mixture, the k_{eff} increases were only about 0.03, 0.04, and 0.07. This gave the k_{eff} values of to 0.470, 0.781, and 0.864 for cases incin21, incin22, and incin26, respectively, in Table 1, page 12. The plutonium inventories were 13.7, 27.6, and 39.9 kgs. Although carbon is a more efficient moderator than oxygen, the affect is not dramatic and the k_{eff} 's are low for credible moderator densities and plutonium inventories.

There are ratios of plutonium-carbon-water that are more reactive than those used in these analyses, but the plutonium is more dilute and for the diameters of the incinerator tubing the plutonium-carbon-water mixtures could not be critical. It would take extensive intrusion into the void space to reach a critical volume.

3.2.6 Reflection

Three cases were run where the refractory radially around the primary combustion chamber half tube was replaced by water out to 6.5, 10, and 15 inches. This close water reflector increased the 0.427 k_{eff} of the base case incin01 to 0.545, to 0.529, and to 0.529 for cases incin10, incin11, and incin12, respectively. Note that increasing the density adjacent to the tube from 0.16 to 0.988 g/cc increased the k_{eff} , but substituting water for refractory insulation at 1.5 g/cc lowered the k_{eff} in the latter two cases by allowing more neutron leakage. Flooding the interior of the incinerator, but not the inside of the combustion cambers, increases the k_{eff} significantly, by 0.12, but to approach a limiting condition significantly more plutonium must be present than the 5.9 kg measured in the Burning Hood.

3.2.7 Void Space Model

The interior of the Burning Hood has a large void space. This space is between the heaters and the combustion chambers so it is not believable that the space in front of the heaters could fill with a fissile mixture and that the incinerator could still operate. However, to test the reactivity of a more dilute plutonium-carbon mixture than run in the other cases, the large space is filled with fissile mixtures with C/Pu between 400 and 2000. As the plutonium concentration decreases, so does the k_{eff} as shown by runs incin51, incin53, incin55, incin57 and incin59 using the single chamber model. The same is true with the two chamber cases incin52 and incin54. When the volume is doubled from 400 to 800 ℓ , the k_{eff} increases but only by 0.10. However, there is 24.13 cm (9.5") of 1.5 g/cc refractory between the two volumes modelling the void around each of the two combustion chambers. Even with both void chambers filled, the maximum k_{eff} is only 0.79 for 64 kg of plutonium in 800 ℓ at a C/Pu of 400. Comparing run incin21 with incin55, incin57, and incin59, a larger k_{eff} is attained with less plutonium, but only by occupying unreasonably large volumes that are not actually available in the incinerator. Dilution of plutonium in a large volume of carbon in the incinerator is not a concern for a measured inventory of 5.9 kg or less of plutonium.

4.0 PNL CRITICALITY ANALYSIS

PNL did an independent criticality analysis of the Burning Hood. The cover letter by A. W. Prichard (Reference 5) and the criticality report (Reference 30) on the subject of PFP Waste Incinerator Criticality Analysis are reproduced in Appendix I. The PNL analysis complemented the WHC analysis in several ways. The PNL analysis used a detailed model of the incinerator that included both combustion chambers and all flues with actual dimensions and numerous types of refractory insulation in the actual complicated arrangement while WHC modelled a simplified worst case. The PNL analysis looked at wet PuO₂ (H/Pu of 0 to 599) while the WHC analysis looked at PuO₂ in slag and carbon with an H/Pu of 20. The PNL analysis further determined the optimum H/Pu ratio for PuO₂ in water confined to the incinerator piping and determined k_{eff} for 10 - 20 kg of PuO₂ dry and wet entirely in the primary combustion chamber and for 3.1 -18.1 kg of PuO₂-H₂O throughout the incinerator combustion chambers and flues.

Table 2 below from the PNL report summarizes the incinerator cases run. The incinerator is found safely subcritical for all cases except 13 and 14 where the refractory insulation is modelled as replacing the cerafelt and void next to the combustion chambers and flues to simulate collapsed interior insulation in the incinerator.

The PNL authors conclude that the Burning Hood is safe to approach, to make measurements, and to dismantle as long as the Burning Hood contains less than 10 kg of plutonium. This result allows activities around the Burning Hood while unopened, the intrusive activities to characterize the amount and distribution of plutonium inside the hood, and to determine the integrity of the refractory insulation inside the hood. The report also cautions that if plutonium is found outside the piping or the insulation has collapsed, further criticality analysis is needed to document that the Burning Hood would be sufficiently subcritical during planned activities at the incinerator under these unexpected conditions.

Table 2 PFP Waste Incinerator Criticality Analysis Results

Case	Geometry	H/Pu	kg Pu	Density PuO ₂ g/cc	Pu form	KENO keff	KENO Uncert ainty	K95/95
1	Line hemicylindrical pipe with 0.47 cm material	0	10.0	2.00	PuO ₂	0.064	0.001	0.109
2	Line hemicylindrical pipe with 0.47 cm material	12	10.0	2.00	PuO ₂ + H ₂ O	0.108	0.002	0.153
3	Line hemicylindrical pipe with 0.98 cm material	12	20.0	2.00	"	0.260	0.003	0.306
4	Cylinder in middle of hemicylinder	12	10.0	2.00	"	0.251	0.003	0.296
5	Line hemicylindrical pipe with 2.16 cm material	58	10.0	0.50	"	0.296	0.003	0.342
6	Fill hemicylindrical pipe	58	16.8	0.50	"	0.837	0.005	0.882
7	Line all pipes and flues with 2.16 cm material	58	18.1	0.50	"	0.586	0.005	0.631
8	Fill hemicylindrical pipe	98	10.0	0.30	"	0.810	0.006	0.855
9	Fill all pipes and flues	182	10.0	0.16	"	0.889	0.005	0.934
10	Fill all pipes and flues	298	6.2	0.10	"	0.849	0.006	0.894
11	Fill all pipes and flues	599	3.1	0.05	"	0.757	0.005	0.802
12	Case 11 + replace Inconel with void	599	3.1	0.05	"	0.695	0.005	0.740
13	Case 9 + replace void regions with Kast-0-Lite	182	10.0	0.16	"	0.978	0.006	1.023
14	Case 13 + replace Inconel with void	182	10.0	0.16	"	0.949	0.006	0.994
15	Case 9 + 5 wt% Pu240	182	10.0	0.16	"	0.824	0.005	0.870
16	Case 9 + external water reflector	182	10.0	0.16	"	0.935	0.005	0.980

Bias = -0.0056

Standard Deviation = 0.019

Variance = 0.00036

The basis for this CSER's limit on H/Pu of 100 is the PNL cases 8-11 that show that the optimum H/Pu ratio is 182 for plutonium oxide confined to incinerator piping and where the incinerator insulation geometry is intact. A limit of 100 gives additional margin. Water content above 20 H/Pu is not expected, but a limit is set to require additional analysis if the situation in the Burning Hood is different than available information indicates. Note that because the primary combustion chamber is open at both ends, it is not expected that it would hold a PuO₂-H₂O mixture with an H/Pu as great as 100. The solution would spill out the ends.

5.0 REVIEWER'S COMMENTS

A. L. Hess of Criticality and Radiological Analyses carried out the independent, technical review of this CSER, for which the following comments were provided:

On a cross-sectional area basis, the hemicylindrical furnace tube is equivalent to an $8/\sqrt{2} = 5.66$ -inch diameter cylinder. Per chart # III.A.7(100)-3 in ARH-600, criticality for a pure mixture of ²³⁹Pu and water in an infinite cylinder of 5.66-in. diameter requires a concentration of at least 1000 g/l Pu plus full reflection by water. This means about 5 kg of Pu per foot over a substantial length of the tube. At that, the equivalence assumption is conservative because the real tube has a greater surface area to provide a higher neutron leakage fraction. And the real reflector is appreciably less effective. On this basis, the adopted design was originally assessed as geometrically favorable for criticality safety for foreseen operational conditions. Certainly, the open ended tube would never be full of material, and to achieve criticality with fissile slag caked on the inside surface would require even higher Pu concentrations and tube linear loadings. The initial seven cases of the PNL study (Table 2) show the latter aspect quite clearly.

The reported WHC and PNL analyses are complimentary, with the slag-lined tube scenarios done by PNL and the exterior-to-tube fissile accumulations studied by WHC. Both studies also cover tube fillings of highly moderated plutonium. However, for most of the cases giving calculated k-effective values in excess of 0.80 the modelled configurations are not physically realizable. For the later PNL KENO cases in Table 2, using PuO₂ mixed homogeneously with water, the represented H₂O content exceeds 95 volume percent at PuO₂ concentrations of 0.5 g/cm³ or less. Such liquid mixtures would surely drain out. For the MONK6 cases incin03, incin05, incin07 and incin22 (in the Table 1 results of WHC calculations), giving k_{eff} values of 0.96, 0.52, 0.94 and 0.78, respectively, the assumed PuO₂ content plus volume fractions of water or graphite required to achieve the cited H/Pu or C/Pu ratios add up to mixture total volume fractions of about 130 %.

The more significant plausible configurations modelled in the MONK6 calculations are for cases incin02 (k_{eff} = 0.739), incin06 (k_{eff} = 0.796), and incin26 (k_{eff} = 0.864). They well demonstrate that over 40 kg of Pu would have to be configured in the incinerator before the k_{eff} could approach 0.90. It is not reasonable for so much to be present, or that if so the NDA assessments would be so far off.

The essence of criticality safety control for the cited operations and future decontamination/dismantling operations is the exclusion of water or other hydrogenous liquids. It is not so much a matter of keeping material inside the chambers dry, but preventing washout of Pu-bearing sludge, powder or whatever into a configuration of not-geometrically favorable proportions containing the resulting liquid mixture. The blank-off of the room overhead fire sprinkler system is appropriate, presuming of course that other fire control measures are adopted to handle the potential fire loading of the added equipment and greenhouse plastic used in the operations.

The reviewer concurs in the conclusions of this evaluation. The provisions recommended as CPS limits will provide ample assurance of criticality safety during the Building 232-Z incinerator holdup characterization, the dismantling of the furnace tubing and insulation, and the removal of contamination to reduce the source term of the Burning Hood. In addition to the continued exclusion of water, the sectioning and waste container loadout processes need controls like those recommended in the previous CSER (reference 1) for removing the ducting between the various room gloveboxes and hoods.

Reviewer's editorial comments and suggested inclusions and/or simplifications were incorporated into the report. Selected inputs for the WHC and PNL calculations were reviewed to verify that the modelling was as described in the results tables.

6.0 REFERENCES

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3. Telecon between G. A. Westsik and E. M. Miller on October 20, 1994, listing the amount of plutonium in ducting and gloveboxes other than the Burning Hood in Building 232-Z.
4. WHC Internal Memo # EMM-80D150-001, Criticality & Radiological Analyses to L. H. Rodgers, "PLUTONIUM FINISHING PLANT (PFP) 232-Z INCINERATOR CRITICALITY CHARACTERIZATION," September 23, 1994.
5. Letter to Dr. L. H. Rodgers from A. W. Prichard of Pacific Northwest Laboratories, dated September 30, 1994.
6. WHC drawing, "Incinerator Hood Frame Assembly and Details," H-2-24680, Rev. 2, (As Built/ 9-27-66).
7. WHC drawing, "Incinerator Combustion Chamber Arrangement and Details," H-2-25883 Sheets 1 (Rev. 6, 7-10-70), 2 (Rev. 5, 5-15-69), and 3 (Rev. 3, 11-17-67).
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9. WHC drawing H-2-24718 Sheet 1 (Rev. 0, "Insulation Plan & B. M. Incinerator Repair"), Sheet 2 (Rev. 1, "Insulation Elevations - Details Incinerator Repair," 9-1-65), and Sheet 3 (Rev. 1, "Insulation Details - Incinerator Repair," 9-2-65).
10. WHC drawing, "Incinerator Heating Element Plug Assembly & Details," H-2-26147 Sheets 1 (Rev. 0, 6-3-66) and 2 (Rev. 1, 12-6-66).
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13. Fax, AP Green Industries, Inc. to E. M. Miller, September 7, 1994. Six pages of technical data on the AP Green product line "KAST-O-LITE."
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18. RE 5.6.6.1, Incinerator Operation Log for 1965 to 1968. The grams of plutonium per number of 0.5 l cans is recorded for 1967 and 1968.
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24. Felt, R. E., Process Test PRF-73-3, entitled: "INCINERATOR FLU PLUGGAGE," dated February 16, 1973 and Addendum to Process Test PRF-73-3 dated March 13, 1973.
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29. WHC-SD-SQA-CSWD-20019, CCVR 94-001; "MONK6B Pu Validation," Miller, E. M., June 14, 1994.
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APPENDIX A NDA INTERNAL MEMO
^^

From: PFP Analytical Laboratories
Phone: 373-1947
Date: October 17, 1994
Subject: NONDESTRUCTIVE ASSAY OF THE 232-Z BUILDING INCINERATOR

To: E. C. Vogt

cc: L. E. Ebbeson T5-04
C. M. Kronvall T5-53
W. L. Louk T5-05
D. J. McBride T5-54
L. T. Nirider T5-53
A. L. Ramble H4-68
R. D. Redekopp T5-50
L. H. Rodgers T5-54
C. R. Stallbaum T5-05
GAW/LB

Process equipment in the 232-Z Building has been assayed for residual plutonium using nondestructive assay techniques. Efforts have been concentrated on evaluating the Burning Hood by both gamma ray and neutron measurement methods. Additional measurements were performed to locate any plutonium holdup that had not been previously measured.

Based on gamma ray measurements and the holdup model used, the Burning Hood is estimated to contain 0.6 kg of plutonium with an uncertainty range of 0.1 kg to 1.2 kg. (A similar model developed by one of the Overview Team members yields a slightly higher best value within an uncertainty range up to 1.3 kg.) This is in addition to the 0.4 kg measured in the remaining process equipment, scrubber cell, and exhaust ventilation ductwork. The uncertainty range for the remaining process equipment is 0.2 kg to 0.6 kg plutonium. The total holdup in the 232-Z Building, using a gamma ray measurement model, is then 1 kg with a range of 0.3 kg to 1.9 kg plutonium.

Based on neutron measurements, the Burning Hood is estimated to contain, at most, 5.9 kg of plutonium. This calculation was performed by Pajarito Scientific Corporation personnel. Since this value is higher than the gamma ray based value, it should be used for safety analysis calculations.

Due to the disparity between the gamma ray and neutron assay values, additional measurements are being performed to better define the best assay value. In addition, radiation modeling is being used to try to reconcile the divergent results.

G. A. Westsik
Principal Scientist

lrg

APPENDIX B DEPICTIONS OF BURNING HOOD

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CONTAMINATED WASTE RECOVERY FACILITY

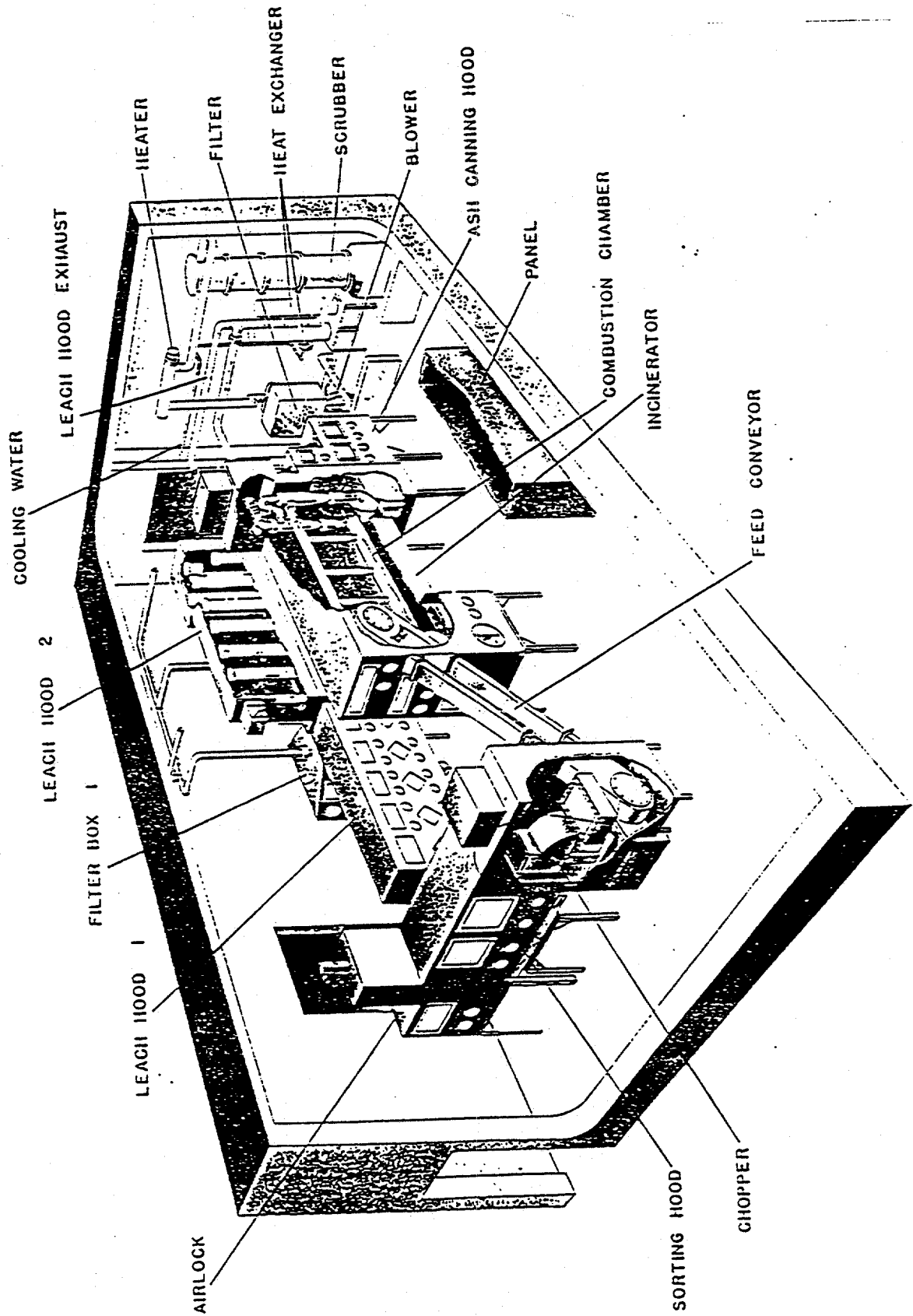


FIGURE B.1

INCINERATOR FOR PLUTONIUM RECOVERY

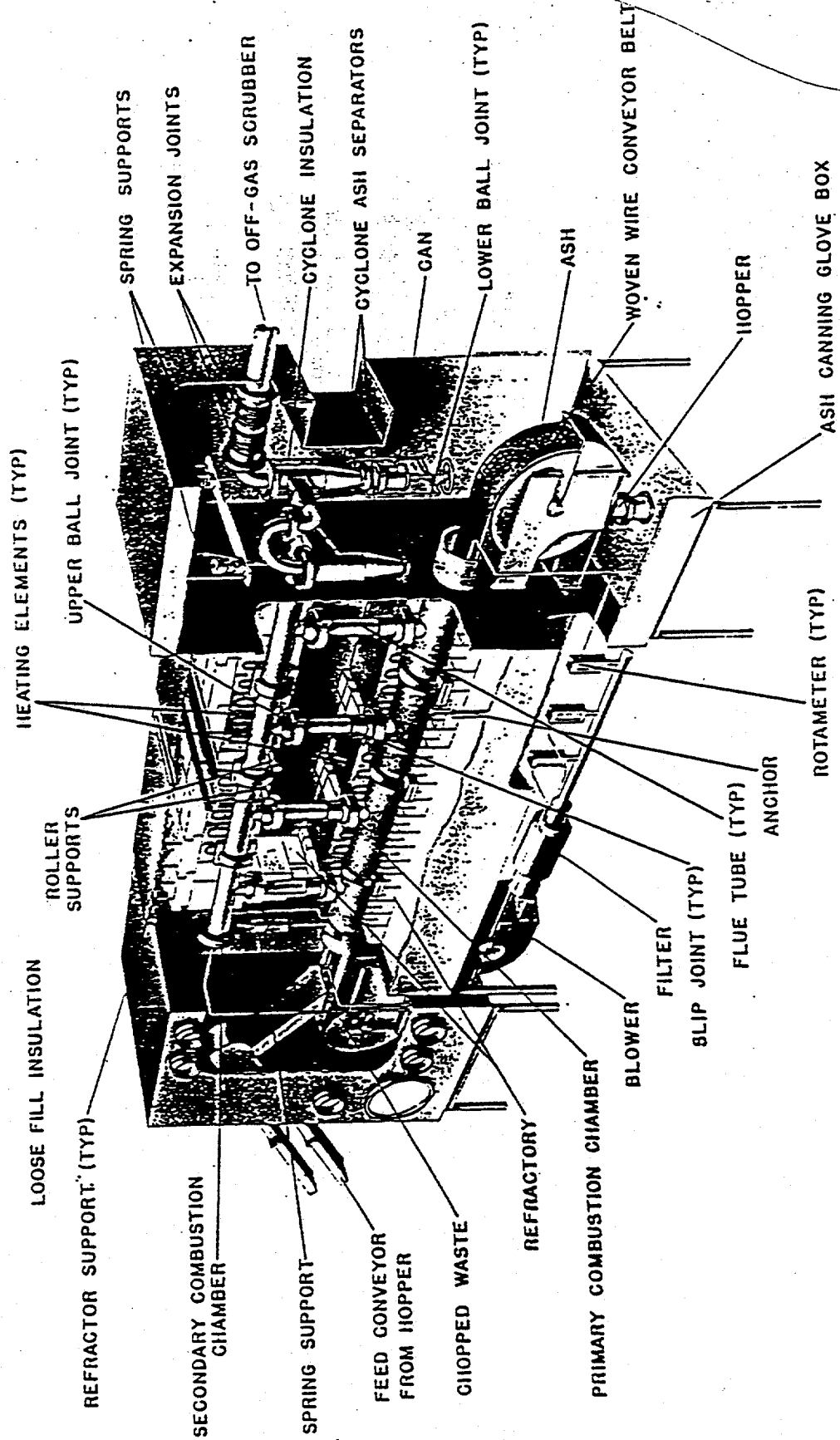


FIGURE B.2

FIGURE B.3 INCINERATOR TUBING

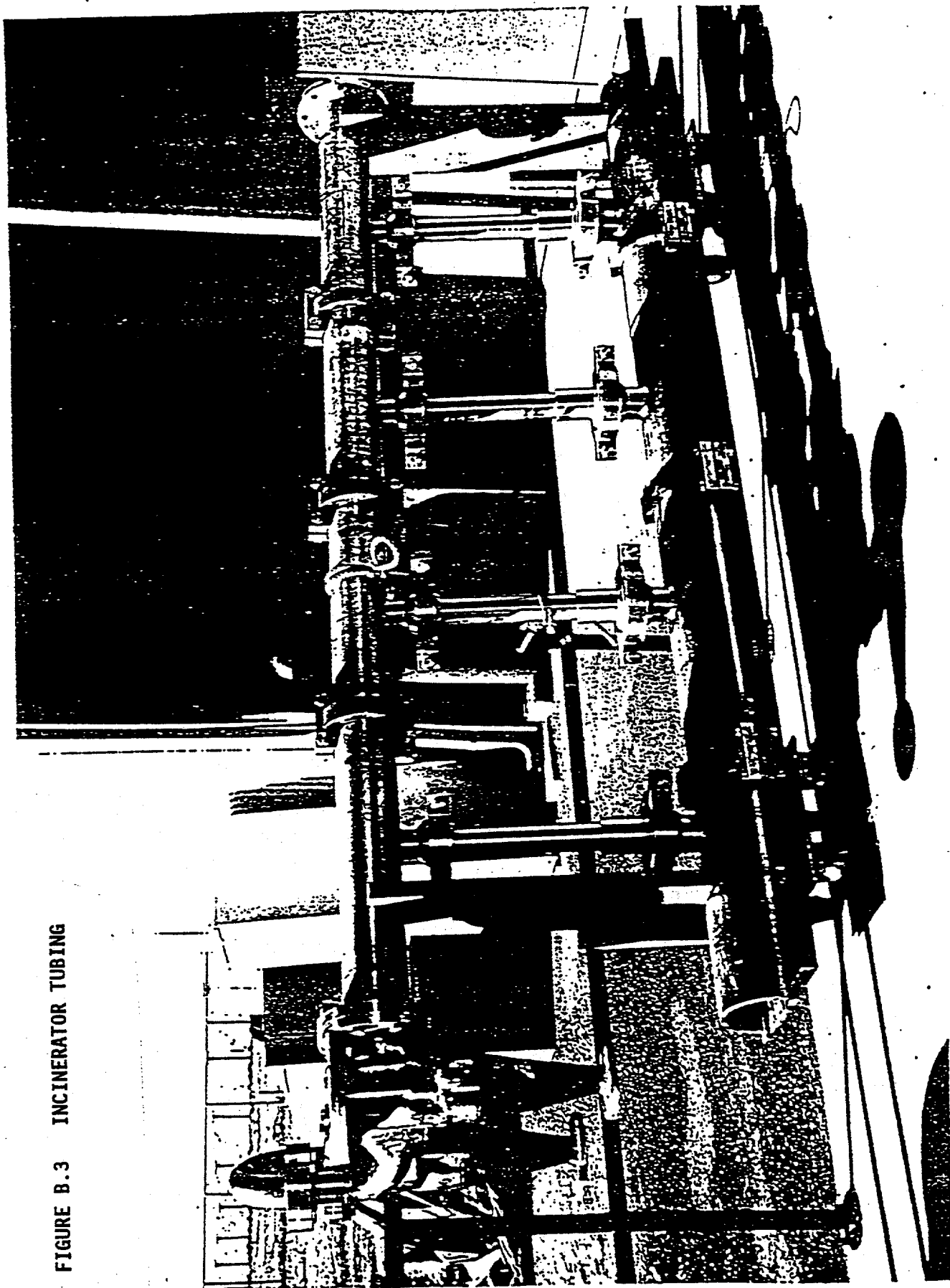


FIGURE B.4 CUT AWAY OF INCINERATOR TUBING AND INSULATION

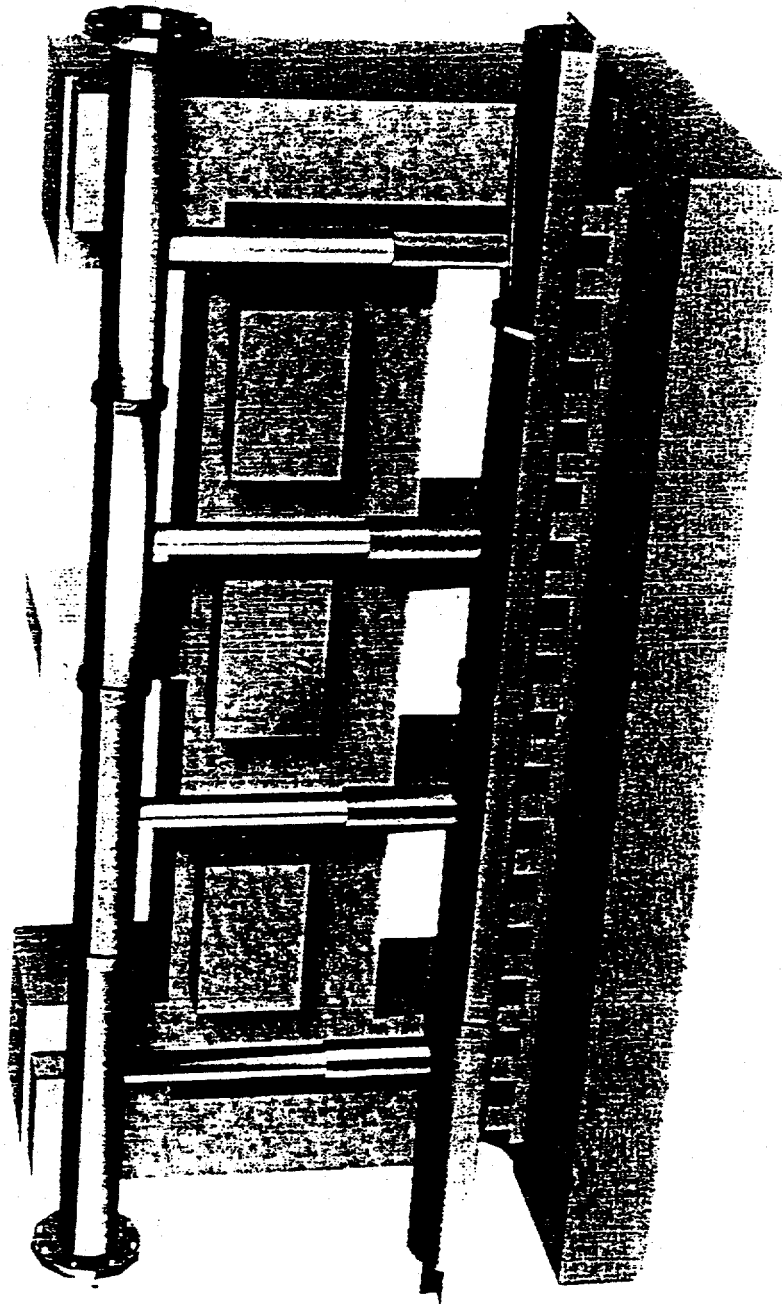
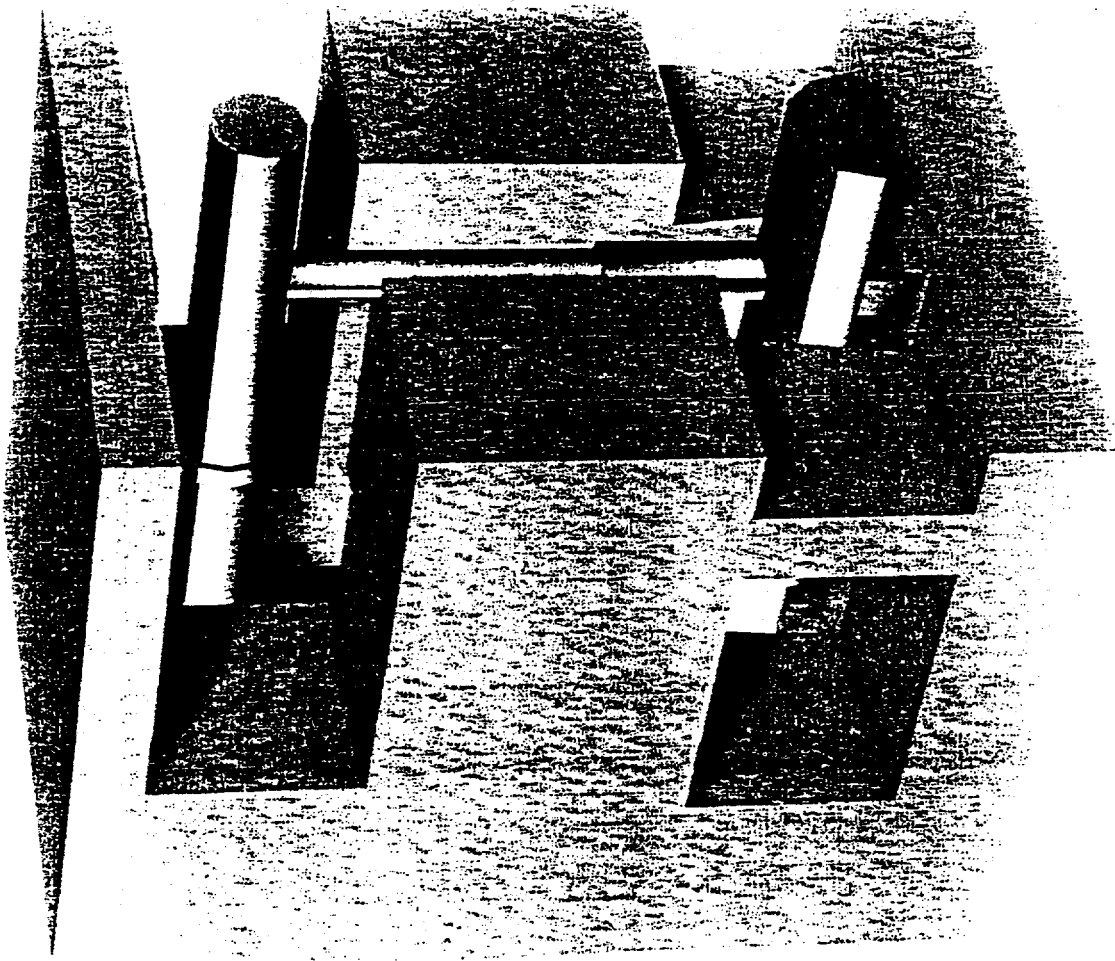


FIGURE B.5 PERSPECTIVE OF INCINERATOR CROSS SECTION



ITEM B.6 DESCRIPTION OF 232-Z INCINERATOR CONSTRUCTION AND OPERATION

APH-CA-39

Sept. 15, 1969

THE CONTINUOUS INCINERATION OF PLUTONIUM-BEARING SCRAP

Lee M. Knights

Atlantic Richfield Hanford Company
Richland, Washington, U.S.A.

INTRODUCTION

The Atlantic Richfield Hanford Company at Richland, Washington, has a contract to operate the chemical processing facilities for the Atomic Energy Commission. Irradiated fuels and target materials are dissolved and elements of interest are separated and purified by the Purex process. Much of the plutonium nitrate solution produced is processed further to oxides or metal. Plutonium-bearing scrap, much of which is bulky and incinerable, is a normal by-product of the processing, and the quantities of plutonium are often economically attractive to recover. A Contaminated Waste Recovery Facility, which included both incineration and leaching equipment, was built in 1961 to recover plutonium from these scrap materials. During eight years of operation, a considerable amount of practical experience has been gained and used to improve the performance of the unit.

DESCRIPTION OF PROCESS

The incinerator was designed for continuous operation, with emphasis on (a) reducing the size of the unit to glove box proportions, (b) minimizing the problems of contamination control while charging feed, and (c) using geometric limitations wherever possible to assure criticality prevention.

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A flow diagram of the process is shown in the first slide. Waste-filled cartons are introduced through an airlock into a sorting hood. Sorting is manual. Leachables are fed to a leach hood. Some waste, tools, sharp objects, etc., are discarded after the absence of economically recoverable plutonium has been confirmed by gamma or neutron counting. Smooth metal objects, for instance, may be wiped with rags and discarded. The rags are then incinerated.

Most all of the plastic and rubber materials, including gloves, are treated as noncombustibles because of the large amount of soot formed in burning and because of the corrosion resulting from chloride release. The noncombustibles are leached in nitric acid in trays or in steam-heated pots. The leached scrap is discarded after evaluation of plutonium content.

Combustibles are shredded in the chopper and conveyed on a belt to the incinerator, where a second belt carries them through the primary combustion chambers. The off-gas passes through a secondary combustion chamber and then through two cyclone separators in series. Ash from the cyclones and combustion chamber is collected in small iron cans and transferred to dissolution and reprocessing facilities elsewhere. The off-gas is treated by scrubbing with a counter-current spray of sodium hydroxide to neutralize acidic gases. Small amounts of urea are used to neutralize hypochlorite, which is generated when burning some plastics. Cooling is effected in the scrubber by circulating the sodium hydroxide through water-cooled heat exchangers. When the scrubber solution is spent, the plutonium content associated with the fine solids in it approximate 0.05 to 0.1 gram per liter. Provisions were made for filtration of the plutonium-bearing fines in the leach hood.

The cooled off-gas from the scrubber is heated above its dew point by an electric heater to prevent condensation of moisture on the high-efficiency filters. The blower, pulling a slight vacuum on the entire system, discharges to the main building stack via two more high-efficiency filters in series.

DESCRIPTION OF EQUIPMENT AND CONTROLS

A cutaway of the Contaminated Waste Recovery Facility in the next slide shows the principal features of the incinerator, the leach hoods, and the off-gas system. The chopper is a rotating drum with blades set in the periphery, parallel to the axis. The chopper has given excellent service on rags, papers, plastic, wood, and asbestos filter elements.

ARM-SA-39

The feed conveyor is a conventional cleated rubber conveyor belt with a variable speed drive. The furnace belt, which is also equipped with a variable speed drive, is woven of Nichrome-V wire, an 80 percent nickel - 20 percent chromium alloy.

The furnace is three meters long and is fabricated of Incalloy 800 (32 percent nickel, 20.5 percent chromium, and 46 percent iron alloy) and 321 stainless steel (a steel of 17 - 19 percent chromium and 8 - 11 percent nickel). The lower horizontal member is a semicylinder 20.3 centimeters in diameter, with a flat bottom which serves as a floor for the furnace belt. This is the primary combustion chamber. Above this, four flue risers connect with the upper (or secondary) 12.7 centimeter diameter combustion chamber. The furnace is shielded by 45 centimeters of firebrick insulation and the whole unit contained in a stainless steel gloved box.

The incinerator target temperature of 700 - 800° C is controlled primarily by the voltage applied to three 32 kw resistance heating elements. Feed rates and the incinerator belt speed also have an effect on temperature control. Residence time in the combustion chamber averages eight minutes. Air flow to the primary and secondary combustion chambers, indicated by rotameters, is approximately 0.2 cubic meter/minute.

The incinerator off-gas discharges through a combustible gas analyzer set to alarm at one percent combustibles in the off-gas. There has been no confirmed alarm from this analyzer. The gas then discharges through two cyclone separators in series. A small adjoining room houses the off-gas scrubber, which is 0.35 meter inside diameter by 2.7 meters high, set on a 0.75 meter diameter by 0.70 meter high pump tank. The scrubber contains a quench spray section, two impingement baffles, and a high velocity baffle plate stage. The original moisture de-entrainer (vane type) has been replaced with a tetrafluoroethylene mesh de-entrainer. Construction is 316 stainless steel throughout (10 - 14 percent nickel, 16 - 18 percent chromium, 1.75 - 2.5 percent molybdenum steel). Two heat exchangers cool the circulating sodium hydroxide solution. Rated efficiency of the scrubber system is greater than 90 percent for all particles larger than 0.3 micron in diameter.

Air flow to the scrubber includes both the incinerator off-gas and the leach hood exhaust. It is regulated for proper scrubbing action by a butterfly valve in the leach hood exhaust line. Rotameters indicate

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the scrubber liquid flows to the top inlet, the plate spray, and the quench spray. Differential pressure gages on the scrubber are used to indicate plugging.

SAFETY CONSIDERATIONS

The many safety problems associated with a nuclear facility in which corrosive acids and high temperatures are involved required special attention in design. The prevention of criticality, fire, contamination spread, and personal injuries are among the more important.

Several techniques are used to provide for criticality prevention in the facility. The leach pots, conveyer, and incinerator are of limited geometry. The leach hood, chopper enclosure, and scrubber are equipped with neutron monitors and alarms. Administrative controls are also used successfully to prevent undetected accumulations of plutonium. These controls include maintenance of a running inventory, with clean-outs required at specified limits, frequent monitoring with portable gamma counters, and monthly inspection of pots and jackets.

Some question of the possibility of plutonium accumulating in the space between the incinerator and the surrounding firebrick has been raised by engineers since start-up. While accumulation of an amount sufficient to cause a nuclear incident is highly unlikely, during repairs to the incinerator proper, gamma and neutron surveys and inspection have been used to confirm this judgment. No accumulations of plutonium have been found in these areas.

The most difficult contamination control problem arises as a result of the frequent contact maintenance necessary on the off-gas system. This system, including the scrubber, is too large for containment in glove boxes. Physical entry into the contaminated room area is required, with attendant multiple layers of protective clothing and fresh-air masks. There are similar severe contamination control problems associated with repair of the incinerator proper. During these repair periods, temporary containment barriers of sheet plastic are constructed around the equipment being worked upon to control and limit the spread of contamination.

One of the most serious hazards in this facility is that of fire, and glove box fire protection equipment has been improved to a high degree of effectiveness. Despite all precautions, several brief localized glove box fires have occurred in the feed end of the

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incinerator and the chopper effluent hopper. These fires were caused by flashback from the incinerator. A wire screen placed in the feed end of the incinerator has been very effective in preventing flashback. Also, nitrogen is added at the primary combustion chamber inlet to help prevent flame blow-back.

The chopper enclosure is protected with heat sensing elements which activate an alarm when heated to 88° C. At the same time, a limited (by criticality prevention considerations) supply of water is applied automatically in the enclosure through four spray nozzles. The system may also be operated manually. All glove boxes are fitted with attachments to allow introduction of carbon dioxide or dry chemical (sodium carbonate) from external portable extinguishers. Glove ports near the incinerator are protected with heat shields at all times it is in operation.

The entire building is provided with fire detectors which activate alarms in appropriate locations, including the area's central fire department. In addition, there is an automatic CO₂ extinguishment system of the total flooding type which protects the storage room housing boxes of scrap awaiting processing.

Protection for the operator's hands was provided by equipping the chopper with two "start" buttons widely spaced on the exterior of the glove box. These must be pressed simultaneously to start the chopper. Thus, the operator must remove both hands from the vicinity of the chopper before he can start it.

MAINTENANCE

The more serious maintenance problems have included furnace failures, inadequate temperature control, accumulation of solids in the off-gas system, and short furnace belt life. In 1963, the original combustion chamber failed and was replaced.

The original incinerator was a one-piece unit welded from sections of cast high temperature, high nickel alloy steel. This incinerator was removed when massive fractures of the chamber occurred after one year of operation due to the effects of thermal expansion and contraction. After 22 more months, failure occurred a second time, prompting complete redesign of the combustion chamber to eliminate differential thermal expansion stresses between its various members. This is shown in the next slide. The redesign eliminated the all-welded construction, and in its place, ball and socket and slip joints

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were installed at the top and bottom of each of the flue tube risers. This unit performed for only nine months when stress corrosion cracking occurred. The furnace was constructed of Incalloy 800, both wrought and cast.

Investigation revealed that the cause of failure was high temperature and temperature cycling outside the 700 - 800° C range as a result of excessive feed rates. Further, in a portion of the combustion chambers, a rotationally cast Incalloy 800 material was used which had extremely large grain structure. These sections were replaced with wrought 321 stainless steel. In addition, temperature sensors were moved from the exterior wall of the incinerator and placed directly in the off-gas. This provided improved control because of its faster response. This incinerator has been running for two years without failure, with down time necessitated only by problems with the off-gas treatment equipment.

Stretching of the wire mesh furnace belt is a recurring problem, but has been reduced by selection of improved alloys. Addition of a positive belt drive was also helpful, and this was achieved by adding spots of weld metal on the drive drum. More careful attention during sorting, to keep tramp metal out of the choppers and belts, has been helpful. Belts currently in use cost about \$500 and are giving up to six months of service before replacement is necessary. Changing of the incinerator belts is accomplished by spot welding a new belt to the old belt and pulling the new belt into position as the old belt is removed.

A continuing problem has been the lack of good air flow control through the incinerator. There is no direct control here, since total air input varies as the leach hood exhaust is varied, and this greatly affects the collection efficiency of the cyclones.

De-entrainer pads were added to the scrubber to reduce liquid entrainment to the filters. With a constant sodium hydroxide spray, these must be replaced every three to four weeks. Plugging occurs in two weeks if the spray is not applied continuously.

Cleaning the flue risers in the incinerator without dismantling the whole system was accomplished with ingenuity. A spade-shaped piece of carbon steel, known as a "knocker head" in the boiler industry, was threaded on a short flexible shaft. Entering from the end of the top combustion chamber, a curved piece of pipe around the shaft guided the spade into the vertical flues. Sections of rod are added to the

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shaft to extend the spade to the furthest flues. Rotation of the spade is provided with a variable speed reversible motor and the flue is effectively freed of soot.

PERFORMANCE

Accurate assessment of the plutonium input is difficult because of the heterogeneous nature of the scrap. It is estimated that about 98 percent of the plutonium entering the facility is recovered in the ash and leach solutions. Unrecoverable plutonium is routed to underground storage. Only trace plutonium is found on the filters downstream of the scrubber through which air is exhausted to the stack. For the material actually incinerated, there is a volume reduction of 98 percent.

Leaching of the incinerator ash product in a mixture of boiling 9 - 10 molar nitric acid and 0.5 - 0.7 molar hydrofluoric acid has proved to be a fairly effective means of plutonium recovery. The filterability of the leached ash presents operating problems, as the residues are fine and have a pronounced tendency to blind filters. Filterability has not been consistently improved by use of various types of deflocculating agents or filter preccats. Recent experimental work indicates that poor filtration of ash leach solutions is caused in major part by incomplete combustion. When reburned for an additional 20 minutes, the ash loses about 25 - 30 percent of its weight. The ash from this re-ignition leaches more completely and is much more easily filtered.

Performance of the cyclone separators is variable and strongly dependent upon off-gas flow rates. Normally, it has been estimated that they remove about 98 percent of the solids in the off-gas. Occasionally their efficiency is almost negligible. Particle size data on these solids are not available.

Throughput rates are quite dependent on manpower availability because of the many hand operations in sorting, leaching, and belt-feeding. Full capacity operation requires a crew of four to five men per eight-hour shift. In this time, three 0.13 cubic meter boxes can be sorted and processed. Presently, the incineration and leaching of scrap is current with generation rates and excess capacity exists. It was estimated that economic payout of the facility was achieved during its first year of operation.

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On the basis of experience to date, there are two recommendations to be made in the design of a new facility. First, there should be improved access to the system for clean-out of the flues and combustion chambers. Second, more positive controls on air input to the incinerator are required to provide better control of off-gas handling and to provide uniformly high cyclone efficiency. Better air controls, coupled with increased residence time in the incinerator, would provide more complete combustion and, in turn, would enhance subsequent dissolution of the ash.

Taking into account the rugged nature of the process and the equipment requirements, it has been concluded that the large-scale incinerator and leaching facility described has contributed materially to the recovery of plutonium-bearing scrap in the Atlantic Richfield Hanford Company at Richland, Washington.

CONTAMINATED WASTE RECOVERY FACILITY

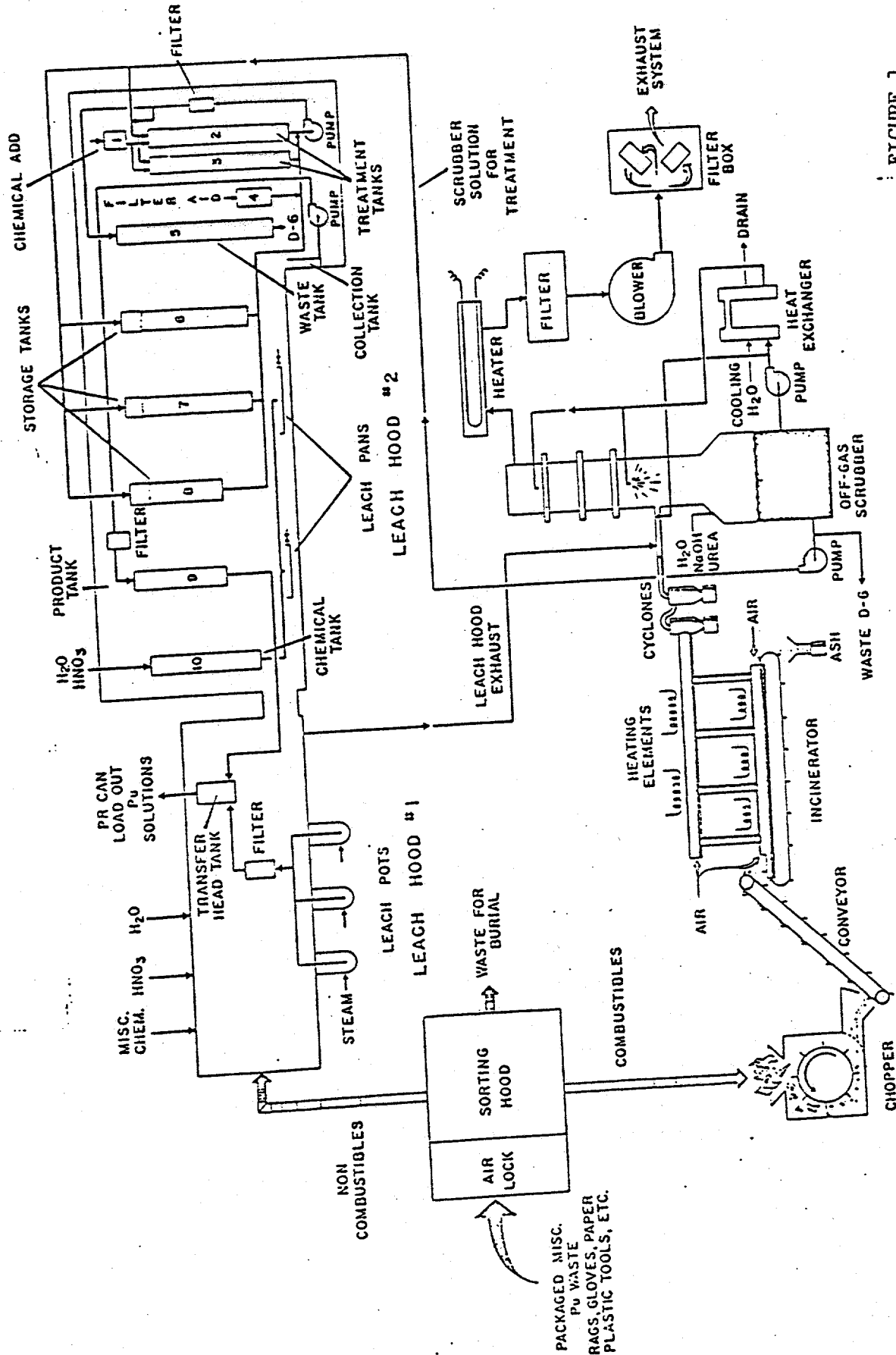


FIGURE 1

APPENDIX C PROPERTIES OF REFRACTORIES USED IN THE BURNING HOOD

PFP BURNING HOOD INSULATION MATERIAL PROPERTIES SUMMARY				
TRADE NAME	MSDS #	DENSITY g/cc	COMPOSITION	REFERENCE
Firebrick			JM 23, largely of refractory clay	14
G-23 IFB		0.74	40% Al ₂ O ₃ , 38% SiO ₂ , 11% CaO, 2% TiO	15
Min-K 1301		0.336		14
Min-K 2000	EPO-005	0.32	50-70% SiO ₂ & Al ₂ O ₃ , TiO ₂	16
Super X		0.324		14
SUPEREX 2000	3013	0.4	50-70% SiO ₂ & Al ₂ O ₃ , clay, calcium silicate	16
SUPEREX 1600	3014	0.21	Calcium Silicate, fibrous glass	16
Marinite		0.416	J-M Molten Metal Martinite # 36	14
MARTINITE # 36	ASO-091	0.58	Asbestos-Calcium Silicate (Ca ₃ SiO ₂)	16
Block		0.24		14
INSBLOK-19		.25-.3	12% Al ₂ O ₃ , 56% SiO ₂ , 24% CaO, 5% MgO	15
Castable		1.44		14
KAST-O-LITE		1.38-1.55	44-48% Al ₂ O ₃ , 36-40% SiO ₂ , 9-12% CaO, 1-3% TiO, 1-2% Fe ₂ O ₃	15
KAST-O-LITE 30 and 30 PLUS		1.39-1.49	34-38% SiO ₂ , 56-60% Al ₂ O ₃ , 4% CaO, 1-2% TiO, 1% Fe ₂ O ₃ , 1% Na ₂ O & K ₂ O	13
KAST-O-LITE 25 and 25 PLUS		1.30-1.46	36-40% SiO ₂ , 44-48% Al ₂ O ₃ , 9-12% CaO 2% TiO, 1% Fe ₂ O ₃ , 1% Na ₂ O & K ₂ O	13
KAST-O-LITE 22 and 22 PLUS		0.77-0.93	32-36% SiO ₂ , 39-43% Al ₂ O ₃ , 16-18% CaO 4% Fe ₂ O ₃ , 1% MgO, 2% TiO, 1-2% Na ₂ O	13
Cerafelt		0.167		14
CERAFELT	3111	2.6	60% SiO ₂ , 40% Al ₂ O ₃	16

APPENDIX D CHARACTERIZATION OF FISSILE MATERIAL

ITEM #	CONTENT	PAGES
D.1	DENSITIES OF PLUTONIUM OXIDE [PAGE II.C.2-2 FROM ARH-600, REF. 17]	40
D.2	PLUTONIUM ISOTROPIC DATA [REF. 22]	41

ITEM D.1 DENSITIES OF FISSILE MATERIAL

II.C.2-2

ARH-600

BULK AND TAP DENSITIES OF PLUTONIUM OXIDE PREPARED
IN SEVERAL DIFFERENT WAYS

<u>Starting Material</u>	<u>Decomposition Temperature</u>	<u>Bulk Density gPuO₂/cc</u>	<u>Tap Density gPuO₂/cc</u>
Pu Nitrate	240°C	1.7	2.1
"	400	1.9	2.4
"	600	1.7	1.8
"	800	2.9	3.6
"	1000	--	--
Pu Peroxide	240°C	3.5	4.1
"	400	3.3	4.3
"	600	3.9	4.4
"	800	4.5	4.8
"	1000	4.9	5.3
Pu(IV) Oxalate	240°C	1.0	1.4
"	400	1.1	1.5
"	600	1.2	1.5
"	800	1.4	1.7
"	1000	1.7	2.3
Pu Hydroxide	240°C *	2.9	3.2
"	400 *	3.7	4.2
"	600 *	3.5	4.0
"	800	3.2	3.7
"	1000	3.8	4.2
Pu Metal	Unknown	4.8	5.3

*Average of two or more measurements. Other data are single measurements.
RFP-503, "Properties of Plutonium Dioxide," I.D. Moseley and R. O. Wing.

Pu (IV) Oxalate -475° C** 2.0 2.5

**Maximum values for eight measurements, tapped to constant density.
From letter, R. D. Fox to G. W. Upington, ARHCO, August 30, 1972.

ITEM D.2 PLUTONIUM ISOTROPIC DATA

[5] From: Cheryl R Stallbaum at ~WHC167 12/22/94 10:27AM (1490 bytes: 29 ln)
To: Edward M Miller at ~WHC276
Receipt Requested
cc: Cheryl R Stallbaum, George A Westsik at ~WHC120
Subject: 232-Z Isotopic Information

Message Contents

Ed,

George Westsik requested that I send you the plutonium isotopics for the 232-Z Incinerator. These isotopics were calculated from data collected using non-destructive assay techniques and gamma-ray spectroscopy. Below is the average of three isotopic measurements and the standard deviation at 1 sigma for these measurements. The isotope value is reported in weight percent of the Isotopic to Total Pu.

Wt%	Pu-238	0.0199%	± 0.0051%
Wt%	Pu-239	90.5%	± 0.3%
Wt%	Pu-240	9.22%	± 0.29%
Wt%	Pu-241	0.269%	± 0.011%
** Wt%	Pu-242	0.0304%	± 0.0035%
Wt%	Am-241	0.793%	± 0.040%

**** The Pu-242 Weight Percent was calculated using an isotopic correlation of the weight percents from Pu-239, Pu-240 and Pu-241.**

If you need any more information or have any questions please feel free to contact me either by cc:Mail or at 373-2562.

If a formal report is necessary please notify either George Westsik or myself.

Cheryl Stallbaum
Advanced Scientist
Portable Nondestructive Assay of Plutonium
PFP Analytical Laboratory

APPENDIX E SLAG COMPOSITION

ITEM #	CONTENT	PAGES
E.1	ANALYSIS OF 232 INCINERATOR SLAG [REF. 25]	43-44
E.2	INCINERATOR FLU PLUGGAGE PROCESS TEST PRF-73-3 + ADDENDUM [REF. 24]	45-48

ITEM E.1 ANALYSIS OF 232 INCINERATOR SLAG

AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

Atlantic Richfield Manford Company

RE 5.6.6.1



Date: May 30, 1973

To: C. M. Peabody
R. E. Felt

From: V. L. Schuelein *V.L. Schuelein*

Subject: ANALYSIS OF 232 INCINERATOR SLAG

Manrich
NSTR term
"slag"
for R. E. Felt
5-6-77

The material which plugged the incinerator updraft tubes was analyzed for dissolution characteristics and content.

Four samples of incinerator slag were received for dissolution and submission to analysis by emission spec and X-ray fluorescence. The first slag material received was of two different types--one predominately green and the other predominately black. The second set, 232 slag, was also divided into two samples, 232G for green and 232T for black.

The slag is very hard, but crushes easily. The sample sent to X-ray fluorescence was ground into a fine powder. No diffraction pattern was found (amorphous). The slag was sent to the emission spec so that portion which dissolved in 12N HNO_3 :0.3N HF after one hour at 75 to 80 °C, and as the solid powder. The results are $\pm$ a factor of five because of quantity and matrix difficulties.

Sample #2, 232B and 232T, which weighed 160 g, was counted by D. L. Turner for total Pu. These results have already been reported.

VLS:e

cc: MH Campbell
LM Knights

Sample	Element	X-Ray Fluorescence Order of Magnitude		Emission Spec ppm Leachate		Emission Spec ppm Ground Solid	
		Green	Black	Green	Black	Green	Black
#1 The green was 50% dissolved or approximately 50 g slag/liter solution. The black was 30% dissolved or approximately 30 g slag/liter solution.	Al			1,000	20,000	40,000	15,000
	B			30	>2,000	150	150
	Be			<1	<10	<50	<10
	Bi			<5	<50	<50	<50
	Ca			200	1,000	20,000	40,000
	Cd	4	4	<10	<100	2,000	300
	Cr			40	2,000	4,000	10,000
	Cu	2	1	<100	2,000	1,000	1,000
	Fe			<10	<100	10,000	20,000
	Ga			50	200	7,500	10,000
	Mg			<10	<100	15,000	15,000
	Mn			<10	<100	<100	<100
	Mo			<100	<100	<1,000	<1,000
	Nb			50	<200	-	-
	Ni	3	2	>2,000	20,000	10,000	20,000
	Pb			>2,000	>2,000	>20,000	>20,000
	Si			50	1,000	100,000	15,000
	Ti			<5	<50	500	500
	Sn			<2	100	<20	<20
#2 Black was 50% dissolved and green was 42% dissolved. Each was approximately 34 g slag/liter of solution for emission spec analysis	V			<5	<50	-	-
	W			<20	<200	-	-
	Zn	1	3	>2,000	>2,000	20,000	20,000
	Zr			<10	200	-	-
	Al			1,500	1,500	15,000	40,000
	B			<1	<1	100	200
	Be			20	20	<10	<10
	Bi			20	20	<50	<50
	Ca			1,000	1,000	40,000	40,000
	Cr	4	5	10	10	10,000	10,000
	Cu	5	6	20	20	2,000	1,000
	Fe	3	1	200	200	20,000	10,000
	Ga			<10	<10	10,000	10,000
	Mg			180	800	15,000	15,000
	Mn			20	50	<100	<100
	Mo			<100	<100	<1,000	<1,000
	Nb			-	-	-	-
	Ni	2	2	2,000	1,500	20,000	10,000
	Pb			100	100	20,000	20,000
	Si			-	-	15,000	15,000
	Ti			20	20	500	500
	Sn			-	-	<20	<20
	V			<5	<5	-	-
	Zn	1	3	150	150	20,000	20,000
	Zr	6	4				
	Pu	7	7				
	U						

ITEM E.2 INCINERATOR FLU PLUGGAGE PROCESS TEST PRF-73-3 + ADDENDUM
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

RE 5.6.6.1

PROCESS TEST PRF-73-3

+ Addendum

INCINERATOR FLU PLUGGAGE

INTRODUCTION

The incinerator for combustible wastes requires periodic cleaning of the primary and secondary burning chambers as well as the four flues connecting them. The volatile material and fly ash from the combustion process pass from the primary combustion chamber through the four flues into the secondary combustion chamber where most of the remaining combustibles are burned. Fly ash and combustion residues collect on the walls of the flues and secondary combustion chamber, but usually spall off when the equipment is cooled. Intermittent "rodding" or cleaning of the primary and secondary chambers and flues keeps the system open and functional.

Recent operation has resulted in plugging the flues with a ceramic material which is difficult to remove by rodding or grinding. Three of the four flues have been partially opened by this means, but the holes through the flues are only the diameter of the rodding tool. The accessibility to the flues limits the extent of mechanical means of breaking loose the coating on the flues. The secondary burning chamber was easily cleaned because of the direct access to it.

OBJECT

The object of this test is to attempt to loosen the ceramic coating of the incinerator flues by thermal shock.

DISCUSSION

Preliminary physical examination of the solids removed from the secondary burning chamber showed the material to be highly sintered, and hard. The hardness suggests a significant component is aluminum oxide which has a hardness of 9+ on the Mohs scale (diamond = 10). Another significant physical property of alumina is its susceptibility to thermal shock. This in part could explain why the flues have remained open in the past.

There is no acceptable explanation as to why the flues should plug. The feed material to the incinerator has been generally random, with no specific type of material being prevalent. Further laboratory investigation should disclose the composition of the ceramic flue coating which could indicate a possible source.

The concept of thermally shocking the flues has been proposed to loosen the ceramic coating. The heating elements for the primary and secondary burning chambers can be electrically isolated. This would permit heating one chamber, while cooling the other chamber. The thermal gradient along the flues could cause the ceramic coating to crack and loosen. The flue construction permits it to absorb thermal expansion through the ball joints at each end and the slide joint in the flue tube.

PROCESS TEST PRF-13-3

Page 2

Consultation with E. L. Moore, Principal Metallurgist, indicated the Incoloy 600 metal in the incinerator chambers and flues could be thermally cycled to 1000°C without deleterious effects. The heating elements are capable of reaching this temperature.

SAFETY

The process test will be run with no combustibles in the burning chambers. The temperature control at 620°C will be bypassed to permit heating to 1000°C. All temperature indicators should be carefully monitored to detect any unusual temperature transients. Hood gloves should be secured and all combustibles removed from the vicinity of the heated portions of the incinerator.

PROCEDURE

1. Set the L & N and Barber Coleman temperature controllers to 200°C. Make sure that the instruments are operating correctly and are capable of controlling to 1000°C.
2. Isolate the power supplies to the heating elements of the primary and secondary chambers. Replace flange on secondary burning chambers.
3. Turn on the power to the secondary burning chamber.
4. When the set temperature has been reached, increase the temperature control settings to allow heating at not more than 100°C every 30 minutes until 1000°C is reached.
5. Start the scrubber cell equipment (See Section II - 2.06).
6. Start the input air blower and adjust the valves to the primary inlet at 5 cfm. Turn the air to the secondary chamber off.
7. Hold the 1000°C temperature for 15 minutes.
8. Turn off the power to the heaters and allow to cool to ambient temperature with the primary air flow on.
9. Repeat the procedure with the exception of heating the primary chamber instead of the secondary (turn off power to secondary chambers and turn on primary) and cooling the secondary instead of the primary burning chamber (turn off air flow to primary inlet and outlet rotometers and set secondary rotometer to 22 cfm).
10. Shut down the scrubber cell equipment (See Section 2.06).

Process Test PRF-73-3

Page 3

EVALUATION

The effect of the thermal shock would be noted by continuing mechanical clean out operations. OSED process control engineers should be notified of progress of solids removal.

Prepared by R. E. Felt

Approved *L. M. Knights* Date 2/16/73
L. M. Knights, Manager, Plutonium Process Engineering

Accepted *R. E. Olson* Date 2-16-73
R. E. Olson, Manager, Plutonium Reclamation
for

Planned.

This process test need to be changed to reflect the following steps:

- insert* {
- 1. place an asbestos blanket over the primary chamber inlet*
 - 2. heat both primary & secondary chambers simultaneously to 1000°C*
 - 3. Soak at 1000°C for 6 hours*
 - 4. Turn all heaters off & resume a normal cool down.*
- 2-16-73*

Thanks.
T. A. H. 2/15/73

ADDENDUM TO PROCESS TEST PRF-73-3

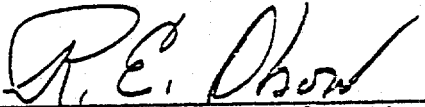
INCINERATOR FLUE PLUGGAGE

The intent of process test PRF-73-3 was to thermally shock the build-up in the flues. The flue material was found to be a mixture of condensed inorganic salts and refractory oxides. The temperature of the process test succeeded in melting a portion of the pluggage material. Three of the four flues were successfully unplugged. The purpose of this addendum is to permit additional heating in an attempt to unplug the final flue. The deviation from the process test is primarily heating both chambers simultaneously instead of separately. This will introduce no additional hazards over those delineated in the process test.

The following changes to the process test conditions are requested:

1. Place an asbestos blanket over the primary chamber inlet.
2. Heat both primary and secondary chambers simultaneously to 1000° C.
3. Soak at 1000° C for 6 hours.
4. Turn all heaters off and resume a normal cool down.

Approved by  Date 3/13/73
Manager, Plutonium Process Engineering

Accepted by  Date 3/13/73
Manager, Plutonium Reclamation

APPENDIX F WATER ABSORPTION IN BACKED PuO₂-SLAG FROM THE AIR

ITEM #	CONTENT	PAGES
F.1	THERMAL STABILIZATION OF PLUTONIUM FINISHING PLANT REACTIVE SCRAP - DEMONSTRATION TESTING, REF. 26]	50-52
F.2	LONG TERM WATER ABSORPTION DATA FROM DEMONSTRATION TESTS [REF. 27]	53-54

ITEM F.1 THERMAL STABILIZATION OF PLUTONIUM FINISHING PLANT REACTIVE
SCRAP - DEMONSTRATION TESTING
WHC-SA-2598-A

THERMAL STABILIZATION OF PLUTONIUM FINISHING PLANT REACTIVE SCRAP - DEMONSTRATION TESTING

Dr. Fred D. Fisher, Fellow Engineer

ABSTRACT

Twelve batches of plutonium-bearing reactive scrap materials, representing several hundred batches of those materials in inventory in the Plutonium Finishing Plant, were thermally stabilized. Most of the twelve test batches were heated at $3^{\circ}\text{C}/\text{min}$ in a furnace from ambient temperature to $1,000^{\circ}\text{C}$, held at $1,000^{\circ}\text{C}$ in the furnace for one hour, cooled in the furnace until furnace temperatures dropped to 300°C , and transferred to a Drierite¹ desiccator for cooling to ambient. Half of the contents of three test batches were heated in a furnace to 760°C at $2^{\circ}\text{C}/\text{min}$, held at 760°C in the furnace for one hour, partially cooled in the furnace, and transferred to a desiccator for cooling to ambient. All cooled batches were broken up as appropriate, exposed to ~50 percent relative humidity air for several days to weeks, and weighed to determine the weight gained from moisture pickup.

At issue was the extent and rapidity of moisture pickup. None of the fired batches gained weight so rapidly as to preclude ambient air weighing, grinding, and packaging operations after final cooling in dry air in the Drierite desiccator.

Foamover of the furnace boat during heating occurred in some batches containing deliquescent salts that were liquid at room temperature or became

¹Drierite is a trademark of W. A. Hammond Drierite Company.

Material	Pu/g <i>P_o</i> (g)	As-Received Appearance	Firing Cycle	Thermally Stabilized Appearance	Moisture/Pickup 1 hr w/o 24 hr w/o		Notes
PPSL-213 Centrifuge Sludge	18	Damp Rust	1 hr @ 760°C 1 hr @ 1000°C	Black Solids	0.131	0.80	Liquified ca. 150°C Liquified ca. 150°C
PPSL-214 Oxalate Sludge	29	Rusty Crystals	1 hr @ 760°C 1 hr @ 1000°C	Black friable cake	0.0095	0.40	Foamed over
					0.013	0.237	Foamed over
PPSL-215 Canyon Floor Sludge	16	Rust w/tape & vial lid	1 hr @ 760°C 1 hr @ 1000°C	Free flowing black powder	0.40	0.75	3.46 w/o @ 300 hr
					0.215	0.40	1.0 w/o @ 146 hr
PPSL-218 Oxalate Sludge	30	Loose rusty mud	1 hr @ 1000°C	Very friable cake	0.03	0.29	Foamed over
PPSL-219 Centrifuge Sludge	52	Damp, grey cake	1 hr @ 1000°C	Grayish, olive drab free flowing powder	-	0.242	-
PPSL-220 PRF Sludge	48	Rusty soup	1 hr @ 1000°C	Black friable cake	nil	0.046	Foamed over repeatedly
PPSL-221 PRF Oxide Sludgel	7	White clay-like cake	1 hr @ 1000°C	White lumps	0.005	0.024	Only 1/3 volume reduction

Material	Pu/g	As-Received Appearance	Firing Cycle	Thermally Stabilized Appearance	Moisture/Pickup 1 hr w/o 24 hr w/o		Notes
PPSL-222 PRF Solids/ Sludge	24	Cornflakes	1 hr @ 1000°C	Black powders very small volume	-	ca. 0.005	-
PPSL-223 Centrifuge Sludge	162	Large grey-green chunks	1 hr @ 1000°C	Black lumps w/white blooming	nil	nil	-
PPSL-224 PRF Oxide Sludge	189	Green "biscuit"	1 hr @ 1000°C	Small green chunks	nil	nil	-
PPSL-225 PRF Oxide Scrap	129	Grey-powder on top of very hard grey-black "biscuit"	1 hr @ 1000°C	Frangible olive drab tinted dark pieces	0.020	0.156	-
PPSL-232 RMC Sludge	117	Green chunks	1 hr @ 1000°C	Green-black pieces	nil	nil	-

ITEM F.2 LONG TERM WATER ABSORPTION DATA FROM DEMONSTRATION TESTS

SAMPLE ID	WT	DATE	TIME	GROSS WT	Elapsed Time	WT GAIN W/O
PPSL-224		8/23/94	0630	409.89		
1000°C		8/22/94	0630	409.89		
		Wt gain		0.00	24 hrs	0.00
PPSL-232		8/23/94	0630	388.39		
1000°C		8/24/94	0630	388.39		
				0.00	24 hrs	0.00
PPSL-223	427.96	7/27/94	0514	512.12		
1000°C		8/22/94	0630	512.14		
				0.02	600 hrs	0.005%
PPSL-225	498.15	7/27/94	0514	592.09		
1000°C		2/13/94	0530	588.22		
				3.87	336	0.776%
PPSL-221	207.22	7/7/94	0620	293.55		
1000°C		6/28/94	0605	293.46		
				0.09	216	0.043
PPSL-222	45.64	6/21/94	1310	132.10		
1000°C		6/16/94	0615	131.93		
				0.17	31	0.37
PPSL-220	119.52	6/24/94	0900	209.01		
1000°C		6/22/94	0500	208.92		
				0.09	51	0.075
PPSL-219	90.67	6/24/94	0900	174.25		
1000°C		6/14/94	0945	174.17		
				0.08	239	0.088
PPSL-218	134.18	6/28/94	0605	221.17		
1000°C		6/23/94	0630	219.00		
				2.17	120	1.62
PPSL-215A	71.08	4/6/94	1320	145.99		
1000°C		4/21/94	1045	148.45		
				2.46	358	3.46
PPSL-215B	74.55	4/21/94	0300	157.60		
760°C		4/27/94	1045	160.36		
				0.76	147	1.019
PPSL-214A	109.67	4/27/94	1020	193.60		
1000°C		5/21/94	0630	194.13		

1000°C		6/10/97	0615	151.12 0.17	31	0.37
PPSL-220	119.52	6/24/94	0900	209.01		
1000°C		6/22/94	0500	208.92 0.09	57	0.075
PPSL-219	90.67	6/24/94	0900	174.25		
1000°C		6/14/94	0945	174.17 0.08	237 239	0.088
PPSL-218	134.18	6/28/94	0605	221.17		
1000°C		6/23/94	0630	219.00 2.17	120	1.62
PPSL-215A	71.08	4/6/94	1320	145.99		
1000°C		4/21/94	1045	148.45 2.46	358	3.46
PPSL-215B	74.55	4/21/94	0300	159.60		
760°C		4/27/94	1045	160.36 0.76	147	1.019
PPSL-214A	109.67	4/27/94	1020	193.60		
1000°C		5/2/94	0630	194.13 0.53	140	0.483
PPSL-214B	105.11	4/5/94	0800	155.85		
760°C		4/27/94	1045	162.76 555	555	6.57

SAMPLE #	Net Wt	DATE	TIME	Gross Wt	Gross Time	Wt. Gain %
PPSL-213A	45.94	4/14/94	0738	131.23		
760°C		4/27/94	1045	133.97 2.74	315	5.96%
PPSL-213B	74.32	4/20/94	0740	159.78		
1000°C		4/27/94	1045	161.07 1.29	171	1.736

APPENDIX G MONK6B INPUT LISTINGS AND SELECTED INPUT MODEL CROSS SECTIONS

COMPUTER RUN INPUT FILE	# OF CROSS SECTIONS	PAGE
incin01	3	56
incin26	2	65
incin52	3	72

--- Verification Information V2.2 ---

```

sparc      : sun3
SunOS      : 4.1.3
monk6b     : Jun 7 16:02
dicedat1.dat : Jun 7 16:02
scan6d     : Jun 7 16:02
Custodian  : EM Miller
User       : W93290 ( Edward Miller )
Input File : incin01
Print File : incin01.prt
Batch File : incin01.run
Date       : 09/12/94
Time       : 09:05:55
  
```

INPUT DATA

INPUT READ FROM :

```

incin01
**
* File Name      : incin01
* Description    : PFP 232-Z INCINERATOR
* Author        : Edward Miller
* Date          : September 8, 1991
**
* For Report     : 6.022045e23
* Fissile        : 10% (Pu-239) PuO2 of density 4.0 g/cc
* Moderator      : 0.0
* Model          : Slag of Al2O3 and SiO2 with H/Pu of 20
*                : Half tube 4" IR, 1/4" INCOLOY 800 wall and bottom
*                : plate, 20" long, surrounded by refractory at different
*                : densities. Fire directly under tube for 7.5".
* Reflector      : 1" of water in radial directions; spectral reflection
*                : on each end to make and infinite half cylinder.
**
* Code           : MONK6B
* Computer       : SECC Sun SPARC 10 workstation with operating
*                : system SunOS 4.1.3
  
```

FISSION

MATERIAL DATA AND MAIN CONTROL DATA

Material #	Material Name	Symbol
1	PuO2 in Slag	F
2	INCOLOY 800	I
3	Firebrick	B
4	KAST-O-LITE	K
5	CERAFELT	-
6	Water	W
7	Polyethylene	P
8	Hanford concrete	C
9	304 Stainless Steel	4

* # Materials 6
* # Elements 15

* Pu239	Pu240	Iron	Chromium	HINH2O
* Oxygen	Nitrogen	Nickel	Manganese	Aluminum
* Calcium	Silicon	Sodium	Carbon	Beryllium
* 9161	402C	908A	446C	923A
* 933C	259A	907A	88A	935A
* 138E	25E	182E	902B	967A
* PuO2	In Slag	0.0	0.0	0.017774
* CONC	0.000887	0.0	0.0	0.0101
	0.0352	0.0	0.0	0.000361
	0.0	0.00452	0.0	
* Half Pipe and Plate:	INCOLOY 800			
* CONC	0.0	0.04018	0.01923	0.0
	0.0	0.02659	0.0	0.0
	0.0	0.0	0.0	0.0
* Fire Brick				
* ATOM	2.1	1	0	0
	127	0	1	32
	1	38	0	0
* Castable (KAST-O-LITE)				
* ATOM	1.5	1	0	0
	127	0	1	32
	1	38	0	0
* CERAFELT				
* ATOM	0.16	1	0	0
	127	0	1	32
	1	38	0	0
* Water				
* ATOM	0.988	0	0	2
	1	0	0	0
	0	0	0	0
* Slip Lid Container - assume polyethylene (max. H)				
* ATOM	0.92	0	0	2
	0	0	0	0
	0	0	0	0
	0	0	1	0
* Hanford Concrete				
* CONC	0.0	0.00035	0.0	0.01375
	0.04608	0.0	0.0	0.00175
	0.00152	0.01663	0.0	0
* 304 Stainless Steel				
* CONC	0.0	0.05986	0.01745	0.0
	0.0	0.008135	0.000869	0.0
	0.0	0.0	0.0	0.0
** Input units are centimeters.				
***** INCHES *****				
***** GEOMETRY DATA *****				
***** PART 1 *****				
***** CLUSTER 3 *****				
* *Body 1 - Radial Primary Combustion Camber & Radial Surroundings				
* 1 BOX ORIGIN	X Y Z	Mat. X Y Z		
	0.0 0.0 13.0	P2 36.0 20.0 18.0		
* *Body 2 - Cuboid Materials below the Primary Combustion Camber				
* 2 BOX	Mat. X Y Z	P3 36.0 20.0 13.0		
* *Body 3 - Outside Boundary of Primary Combustion Model				
* 3 BOX	Mat. X Y Z	0 36.0 20.0 31.0		
	ALBEDO	0 1.0 0 0 1.0 0		

```

* * PART 2
* CLUSTER 6
*
*Body 1 - Pu-Slag Inside Primary Combustion Camber
*   Mat. Radius Height
*   1 4.0 20.0
*   Body #'s Dominance #
*   2 3 4 5 6 5
*
*Body 2 - INCOLOY 800 Primary Combustion Camber Pipe
*   Mat. Radius Height
*   2 4.25 20.0
*   Body #'s Dominance #
*   1 3 4 5 6 4
*
*Body 3 - CERAFELT
*   Radius Height
*   5 6.5 20.0
*   Body #'s Dominance #
*   1 2 4 5 6 3
*
*Body 4 - CASTABLE (KAST-O-LITE)
*   Mat. Radius Height
*   4 17.0 20.0
*   Body #'s Dominance #
*   1 2 3 5 6 2
*
*Body 5 - Nominal 1" Water Reflector
*   Mat. Radius Height
*   6 18.0 20.0
*   Body #'s Dominance #
*   1 2 3 4 6 1
*
*Body 6 - Boundary Box for Radial Model
*   Mat. X Y Z MAT X Y Z
*   0 18.0 20.0 18.0 0.0 0.0 0.0
*   Body #'s Dominance #
*   5 1 2 3 4 5 6
*
* * PART 3
* NEST 4
* *Body 1 - INCOLOY 800 Bottom Plate of Primary Combustion Camber
*   X Y Z MAT X Y Z
*   1 BOX ORIGIN 13.75 0.0 12.75 2 8.5 20.0 0.25
*
* *Body 2 - Brick below Primary Combustion Camber
*   X Y Z MAT X Y Z
*   2 BOX ORIGIN 13.75 0.0 5.25 3 8.5 20.0 7.75
*
* *Body 3 - Castable (KAST-O-LITE)
*   X Y Z MAT X Y Z
*   3 BOX ORIGIN 1.0 0.0 1.0 4 34.0 20.0 12.0
*
* *Body 4 - 1" Nominal Water Reflector
*   X Y X MAT X Y X
*   4 BOX ORIGIN 0.0 0.0 0.0 6 36.0 20.0 13.0
*
* ***** CONTROL DATA *****
* ***** Override Default # Generations/ Multiplying Factor *****
* SUPERHIST 10 4.00
*
* * First Stage Last Stage Number/Stage Time SD Limit Pu Source
* -2 40 500 0 STDV 0.0030 -1
* ***** SOURCE *****
* ***** FISSILE *****
* ***** REGION 1 PART 2 / *****
* ***** END *****

```

```
*****
*          SCAN PICTURE INPUT          *
*****
CODE 6
FIBK-W
*          Top Left      Top Right      Bottom Left
*          -----
* X-Z WHOLE
* 0.0 10.0 31.0 36.0 10.0 31.0 0.0 10.0 0.0
* X-Z CENTER AREA AROUND PIPE
* 9.0 10.0 21.0 25.0 10.0 21.0 9.0 10.0 3.0
* Y-Z WHOLE
* 17.0 0.0 31.0 17.0 20.0 31.0 17.0 0.0 0.0
END
```

```
*****
*          SCAN PICTURE INPUT          *
*****
SCAN - PICTORIAL CROSS-SECTION OF A MONK SYSTEM
```

THE FOLLOWING SYMBOLS WILL BE USED IN THE PICTURES

MATERIAL NUMBER	SYMBOL
0	F
1	I
2	B
3	K
4	-
5	U
6	

```
*****
*          X-Z WHOLE          *
*****
PICTURE FRAME IS
X= 0.0000, Y= 10.0000, Z= 31.0000 (TOP LEFT)
X= 36.0000, Y= 10.0000, Z= 31.0000 (TOP RIGHT)
X= 0.0000, Y= 10.0000, Z= 0.0000 (BOTTOM LEFT)
HORIZONTAL SCALE ----- 1 CHARACTER = 0.27692E+00
VERTICAL SCALE ----- 1 LINE = 0.46269E+00
```


[illegible]

PICTURE FRAME IS

X= 17.0000, Y= 0.0000, Z= 31.0000 (TOP LEFT)
X= 17.0000, Y= 20.0000, Z= 31.0000 (TOP RIGHT)
X= 17.0000, Y= 0.0000, Z= 0.0000 (BOTTOM LEFT)

HORIZONTAL	SCALE	----	1 CHARACTER	=	0.15385E+00
VERTICAL	SCALE	----	1 LINE	=	0.25620E+00

[illegible]

Verification Information V2.2

sparc : sun4
SunOS : 4.1.3
monkbb : Jun 7 16:02
dicedat1.dat : Jun 7 16:02
scan6d : Jun 7 16:02
Custodian : EM Miller
User : W93290 (Edward Miller)
Input File : incin26
Print File : incin26.prt
Batch File : incin26.run
Date : 09/14/94
Time : 12:26:13

INPUT DATA

INPUT READ FROM :
incin26

```
* File Name      : incin26
* Description    : PFP 232-Z INCINERATOR
* Author        : Edward Miller
* Date          : September 14, 1994
*
* For Report
* Avogadro's No : 6.022045e23
* Fissile       : 10% (Pu-239) PuO2 of density 4.0 g/cc in the
*               : Primary Combustion Chamber, surrounding pipe to 6.5",
*               : and space under the Primary Combustion Chamber.
*               : 0.0
* %240 Pu       : 50% carbon, 39% slag (20% Al2O3 and 19% SiO2), 1% BeO,
* Moderator     : and H2O for an H/Pu of 20
* Model         : Half tube 4" IR, 1/4" INCOLOY 800 wall and bottom
*               : plate, 20" long, surrounded to 6.5" by Pu-slag then
*               : KASTOLITE. Pu-slag directly under 1/2 tube for 1-1/8"
*               : (Modeling the spaces in the brick supports) and then
*               : 6.325" of Firebrick.
* Reflector     : 1" of water in radial directions; spectral reflection
*               : on each end to make an infinite half cylinder.
*
* Code          : MONK68
* Computer      : SECC Sun SPARC 10 workstation with operating
*               : system SunOS 4.1.3
```

```
FISSION
*****
***** MATERIAL DATA AND MAIN CONTROL DATA *****
***** Symbol *****
***** Material # Material Name *****
1 PuO2 in slag F
2 INCOLOY 800 I
3 Firebrick B
4 KAST-O-LITE K
5 CEROFELT W
6 Water P
7 Polyethylene C
8 Hanford concrete C
9 304 Stainless Steel 4
```

* # Materials	6
# Elements	15

*

*	Pu239	Pu240
*	Oxygen	Nitrogen
*	Calcium	Silicon

*
9161
933C
138E
402C
259A
25E

CONC	0.0008887	0.0
PUO2	0.02175	0.0
PUO2 in carbon and slag	0.0008887	0.0

0.02175	0.0	0.00268
* Half Pipe and Plate: INCONEL		
CONC	0.0	0.0
	0.0	0.0

* Fire Brick	0	0	0.002605
ATOM	2.1	0	
	427		

ATOM	* Castable (KAST-O-LITE)	38
1	1.5	0
127	0	0
127	0	0

* CERAFELT	127	0	0
ATOM	1	0	0
	0.16	0	0
	127	0	0

* Water	0.988	0	0
ATOM			

```
* Slip Lid Container - assu
*ATOM 0.92 0 0 0
```

* * *	0
* * *	0
* * *	0
*CONC	0.0
	0.0
	0.0

*	0.04608	0.0
*	0.00152	0.01663
*	304 stainless steel	
*CONC	0.0	0.0

* 0.0 0.0
* 0.0 0.0
*
* Input units are centimeter

* INCHES *

* PART 1
CLUSTER 3
*

*Body 1 - Radial Primary Com	x	0.0	0
*1 BOX ORIGIN			
*			*

*Body 2 - Cuboid Materials B
*
2 BOX

```

*Body 3 - Outside Boundary of Primary Combustion Model
  Mat.  X  Y  Z
  0      36.0 20.0 31.0
3 BOX  ALBEDO 0 1.0 0 0 1.0 0

*
* PART 2
* CLUSTER 6
*
*Body 1 - Pu-Slag Inside Primary Combustion Camber
  Mat.  Radius  Height
  1      4.0    20.0
  Body #1's  Dominance #
  2 3 4 5 6  5
OVERLAP 5

*
*Body 2 - INCOLOY 800 Primary Combustion Camber Pipe
  Mat.  Radius  Height
  2      4.25   20.0
  Body #1's  Dominance #
  1 3 4 5 6  4
OVERLAP 5

*Body 3 - Pu-Slag around Primary Combustion Camber
  Mat.  Radius  Height
  1      6.5    20.0
  Body #1's  Dominance #
  1 2 4 5 6  3
OVERLAP 5

*Body 4 - CASTABLE (KAST-O-LITE)
  Mat.  Radius  Height
  4      17.0   20.0
  Body #1's  Dominance #
  1 2 3 5 6  2
OVERLAP 5

*Body 5 - Nominal 1" Water Reflector
  Mat.  Radius  Height
  6      18.0   20.0
  Body #1's  Dominance #
  1 2 3 4 6  1
OVERLAP 5

*Body 6 - Boundary Box for Radial Model
  Mat.  Radius  Height
  0      18.0   20.0
  Body #1's  Dominance #
  X      Y      Z
  -X      -Y      -Z
  -18.0  0.0  0.0
  Body #1's  Dominance #
  1 2 3 4 5  6
OVERLAP 5

*
* PART 3
* NEST 5
* Body 1 - INCOLOY 800 Bottom Plate of Primary Combustion Camber
  Mat.  X  Y  Z
  1 BOX ORIGIN 13.75 0.0 12.75 2 8.5 20.0 0.25

*
* Body 2 - Pu-Slag in Space below Primary Combustion Camber
  Mat.  X  Y  Z
  2 BOX ORIGIN 13.75 0.0 11.625 1 8.5 20.0 1.375

*
* Body 3 - Brick below Primary Combustion Camber
  Mat.  X  Y  Z
  3 BOX ORIGIN 13.75 0.0 5.25 3 8.5 20.0 7.75

*
* Body 4 - Castable (KAST-O-LITE)
  Mat.  X  Y  Z
  4 BOX ORIGIN 1.0 0.0 1.0 4 34.0 20.0 12.0

*
* Body 5 - 1" Nominal Water Reflector
  Mat.  X  Y  Z
  5 BOX ORIGIN 1.0 0.0 1.0 6 36.0 20.0 13.0
*****
***** CONTROL DATA *****
*****
* Override Default # Generations/ Multiplying Factor
  SUPERHIST 10 1.20

```

```

* First Stage Last Stage Number/Stage Time SD Limit Pu Source
-2 40 500 0 STDV 0.0030 -1
*****
SOURCE
*****
MULTIFISS STD
REGION 1 PART 2 /
REGION 3 PART 2 /
REGION 2 PART 3 /
END
*****
SCAN PICTURE INPUT
*****
CODE 6
FIBK-W
* Top Left Top Right Bottom Left
* X-Z WHOLE 0.0 10.0 36.0 10.0 31.0 0.0 10.0 0.0
* X-Z CENTER AREA AROUND PIPE 10.0 10.0 21.0 10.0 21.0 9.0 10.0 3.0
* Y-Z WHOLE 18.0 0.0 31.0 18.0 20.0 31.0 18.0 0.0 0.0
END

```

```

*****
* SCAN PICTURE INPUT
*****
SCAN - PICTORIAL CROSS-SECTION OF A MONK SYSTEM
-----

```

THE FOLLOWING SYMBOLS WILL BE USED IN THE PICTURES

MATERIAL NUMBER	SYMBOL
0	F
1	I
2	B
3	K
4	-
5	W
6	

```

*
*
* X-Z WHOLE
-----

```

```

-----
PICTURE FRAME IS X= 0.0000, Y= 10.0000, Z= 31.0000 (TOP LEFT)
X= 36.0000, Y= 10.0000, Z= 31.0000 (TOP RIGHT)
X= 0.0000, Y= 10.0000, Z= 0.0000 (BOTTOM LEFT)
-----

```

```

HORIZONTAL SCALE ----- 1 CHARACTER = 0.27692E+00
VERTICAL SCALE ----- 1 LINE = 0.46269E+00

```

XXXXXXXXXXXXXXXXXXXX

[illegible]

--- Verification Information V2.2 ---

sparc : sun2
SunOS : 4.1.3
monk6b : Jun 7 16:02
dicedat1.dat : Jun 7 16:02
scan6d : Jun 7 16:02
Custodian : EM Miller
User : W93290 (Edward Miller)
Input File : incin52
Print File : incin52.prt
Batch File : incin52.run
Date : 09/28/94
Time : 09:31:53

INPUT DATA

INPUT READ FROM :
incin52

* File Name : incin52
* Description : PFP 232-Z INCINERATOR
* Author : Edward Miller
* Date : September 28, 1991
*
* For Report :
* Avogadro's No : 6.022045e23
* Fissile : Pu (Pu-239)
* %240 Pu : 0.0
* Moderator : C/Pu = 400
* Model : Incinerator interior, 76" long, 20" high, and 16" wide,
* : void filled with Pu-C mixture, surrounded by 1.5 g/cc
* : refractory insulation symmetrically to 96" long, 38"
* : wide, 20" down, and 14.75" up. At 14.75" above the
* : center line of the block is a spectral reflection plane
* : to model the effect of the space around the upper
* : combustion chamber conservatively as the upper void is
* : not as large or as well insulated as the lower void space.
* Reflector : 1" of water surrounds incinerator to 98" long, 38" wide,
* : and 34.75" up the sides which with spectral reflection at
* : the top surface surrounds the entire two chamber void
* : space model.

* Code : MONK6B
* Computer : SECC Sun SPARC 10 workstation with operating
* : system SunOS 4.1.3

FISSION

MATERIAL DATA AND MAIN CONTROL DATA

*

* Material # Material Name Symbol
* 1 Pu in carbon F
* 2 KAST-O-LITE I
* 3 Water W
* Hanford concrete C
* 304 Stainless Steel 4

* # Materials 3
* # Elements 15
*

```

* Pu239 Pu240 Iron Chromium HINH20
* Oxygen Nitrogen Nickel Manganese Aluminum
* Calcium Silicon Sodium Carbon Beryllium
* 9161 402C 908A 446C 923A
* 933C 259A 907A 88A 935A
* 138E 182E 182E 902B 967A

* Pu and carbon
* ATOM 1.79 1 0 0 0 0 0
* 0 0 0 400 0
* 0 0 0 0 0
* Castable (KAST-O-LITE)
* ATOM 1.5 0 0 0 0 0
* 127 0 0 1 0 32
* 1 38 0 0 0 0
* Water
* ATOM 0.988 0 0 0 0 2
* 1 0 0 0 0 0
* 0 0 0 0 0
* Hanford Concrete
* *CONC 0.0 0.0 0.00035 0.0 0.01375
* 0.0 0.0 0.0 0.0 0.00175
* 0.00152 0.01663 0.00175 0.0 0
* 304 Stainless Steel
* *CONC 0.0 0.0 0.05986 0.01745 0.0
* 0.0 0.0 0.008135 0.00869 0.0
* 0.0 0.0 0.0 0.0 0.0
* * Input units are inches.

INCHES
*****
***** GEOMETRY DATA *****
*****
* PART 1
* NEST 3
* Body 1 - Plutonium/carbon block
* 1 BOX ORIGIN 11 11 10 MAT x y z 20
*
* Body 2 - Castable (KAST-O-LITE) filled incinerator around block
* x y z MAT x y z
* 2 BOX ORIGIN 1 1 1 2 96 36 33.75
*
* Body 3 - 1" Nominal Water Reflector
* x y x MAT x y z
* 3 BOX ALBEDO 0 0 1 0 0 0 3 98 38 34.75
*****
***** CONTROL DATA *****
*****
* Override Default # Generations/ Multiplying Factor
* SUPERHIST 10 1.40
*
* First Stage Last Stage Number/Stage Time SD Limit Pu Source
* -2 40 500 0 STDV 0.0030 -1
*****
***** SOURCE *****
*****
FISSILE
REGION 1 /
END

```

[illegible]

[illegible]

APPENDIX H VALIDATION OF MONK6B CRITICALITY COMPUTER CODE

I. Validation Procedure

The validation of the methods used in the analysis consists of testing the ability of the code and neutron cross-sections in calculations of known critical configurations, which are various benchmark experiments with the fissile material in question. Such analyses determine a calculational bias (the deviations of calculated k_{eff} values from unity for the benchmark cases) and the uncertainties culminating from the experimental and calculational errors.

The safety criteria for future calculations on undetermined systems requires that the bias-adjusted k_{eff} does not exceed 0.95 at the 95% confidence level. This is expressed by the following formula;

$$k_{eff} = k_{calc} - \text{bias} + (U_b^2 + U_c^2)^{1/2} \leq 0.95$$

where k_{calc} = k value given by calculation for system in question,
bias = mean difference ($k_{calc} - 1.0$) for benchmark criticals
 U_b = 95% confidence level uncertainty in the bias determination,
and U_c = 95% confidence level uncertainty in new calculation.

Thus, the bias-adjusted k_{eff} includes the statistical uncertainties.

II. Generic Validation for Plutonium Systems

A report by L.L. Macklin and E. M. Miller, "MONK6A Pu Validation" [REFERENCE 28], presents the results of calculations to determine a generic bias for plutonium configurations, as encountered in the Plutonium Finishing Plant. Seventy benchmark experiments were calculated, ranging from simple metal spheres to highly dilute (9 g Pu per liter) plutonium nitrate solution spheres, and also compacts of PuO_2 blended with polystyrene. A mean k_{eff} value of 1.0047 was determined over the full experimental range, with an overall standard deviation of 0.0097.

The direct calculational bias is thus +0.0047 (average k_{eff} greater than unity). Accounting for the uncertainties using a tolerance limit analysis, the report then concludes that

At least 95% of all critical experiments of this type computed by the MONK6A code will produce calculated k_{eff} values greater than 0.9857 with 95 % confidence.

For a standard deviation (σ) of 0.01 or less for the convergence of a future calculation (U_c), the 0.9857 value is lowered to 0.9855. Rounded conservatively, a value of +0.015 can be used for $[-\text{bias} + (U_b^2 + U_c^2)^{1/2}]$. On this basis, it

is determined that the true k_{eff} of an analyzed configuration with plutonium will not exceed 0.95 with a 95% confidence level if the calculated value (k_{calc} , $\sigma \leq 0.01$) is limited to a maximum value of 0.935.

The 95% confidence level on 99.9% of the data is 0.9699. So a subcritical margin of 5% is 3.5% larger than the uncertainties between the 95.0% and 99.9% coverage of the benchmark data.

III Validation of MONK6B

The validation of the MONK6B code on the SUN microcomputers was documented in the Computer Code Validation Report CCVR-94-001 [REFERENCE 29]. The essence of the validation was cross-correlation of calculational results obtained with this code version and computer with results for identical input models done on the CRAY machine with MONK6A, as reported in the previous subsection. Also, the equivalence of MONK6B to MONK6A was well documented by the code vendors, the UK Atomic Energy Authority, in the verification package supplied with the software.

The abstract from CCVR 94-001 summarizes the validation study as follows;

The MONK6B validation for bare plutonium and plutonium water systems on the SUN computer and operating system is established in this report. Because the calculational method and nuclear cross-sections have not changed from the MONK6A code to the MONK6B code, the bias determination done for MONK6A is valid for MONK6B.

Appendix I PNL CRITICALITY ANALYSIS OF PFP WASTE INCINERATOR

ITEMS	DESCRIPTION	PAGE
I.1	AW Prichard Cover Letter to LH Rodgers	80
I.2	Criticality Analysis Report by SL Harms	81
I.3	Input File for Computer Run Case 7	88

ITEM I.1 AW Prichard Cover Letter to LH Rodgers

372-4137
30 September 1994

Dr. L. H. Rodgers
Westinghouse Hanford Corporation
Engineering Technology Center 2
Room 211
Richland, Washington 99352

Dear Dr. Rodgers:

The independent criticality calculation of the 232-Z waste incinerator box has been completed. Based on an initial estimate of 10 kilograms of plutonium in the incinerator, the box is safe to approach and make new measurements. Provided that the new measurements show that the box contains less than 10 kilograms of plutonium, the box is safe to dismantle.

The analysis assumed that all of the plutonium in the incinerator is in the combustion chamber, the flues, and an upper gas handling flue. The assumption was based on the fact that the new incinerator was designed to prevent cracks in the combustion chamber. Should measurements indicate that the plutonium is outside of the incinerator apparatus and in the firebrick, additional analysis will be required to determine criticality safety.

For this analysis, the material in the incinerator was assumed to hydrate with water from the air. In the analysis the plutonium was modeled as a uniform mix of plutonium and water, with no upper bound on the amount of water that is with the plutonium. This is a conservative assumption. If the amount of water inside the box is limited, as expected, the result of this analysis will be conservative.

In order for the incinerator box to achieve a critical configuration, it would require a incredible set of conditions. The conditions for criticality include the following: the box interior contains at least 10 kilograms of plutonium; the fire bricks are rearranged to form a tight fitting mass of bricks around the combustion chambers and flues; and the plutonium is significantly hydrated inside of the incinerator. This arrangement is not credible.

I have attached a copy of the analysis prepared for this problem. The analysis follows the Pacific Northwest Laboratories (PNL) format for criticality analysis. This analysis was performed as if it would be used for setting limits in a PNL facility.

If you have any questions, please call me on 372-4137 or Sandra Harms at 372-4149.

Sincerely,


A. W. Prichard
AWP:dlt
Attachment

ITEM I.2 Criticality Analysis Report by SL Harms

September 27, 1994

EC Hawkes
SW Heaberlin
File/LB

AW Prichard

SL Harms *Sandi Harms*

PFP Waste Incinerator Criticality Analysis

- Reference 1 Drawing, "Insulation Sections-Details Incinerator Repair," H-2-24718 Sheets 1-3, 1963.
- Reference 2 Drawing, "Incinerator Heating Element Plug Assembly and Details," H-2-26147 Sheets 1 and 2, June 1966.
- Reference 3 Drawing, "Incinerator Hood Frame Assembly and Details", H-2-24680.
- Reference 4 Fax, AP Green Industries, Inc. to John Gonsky, August 26, 1994.
- Reference 5 Fax, Schuller International, Inc. to John Gonsky, August 26, 1994.
- Reference 6 Fax, FD Fisher to AW Prichard, September 13, 1994.
- Reference 7 SR Bierman, BM Durst and ED Clayton, "Critical Experiments with Subcritical Clusters of 2.35 wt% and 4.31 wt% ²³⁵U Enriched UO₂ Rods in Water with Uranium or Lead Reflecting Walls," NUREG/CR-0796, 1979.
- Reference 8 BM Durst, SR Bierman and ED Clayton, "Handbook of Critical Experiments Benchmarks," PNL-2700, March 1978.
- Reference 9 RC Lloyd, CR Richey, ED Clayton and DR Skeen, "Criticality Studies with Plutonium Solutions," Nuclear Science and Engineering, 25, 165-173, 1966.
- Reference 10 W Marshall, et al., "Criticality Safety Criteria," ANS Transactions, 35, 278-279, 1980.
- Reference 11 ED Clayton, "Anomalies of Nuclear Criticality," PNL-SA-4868 Rev. 5, June 1979.

Introduction

The waste incinerator is located in Building 232-Z of the Plutonium Finishing Plant. During operation, the waste was run through a hemicylindrical or D shaped pipe which was heated by radiant elements to burn the waste. Four flues run between this pipe and an upper pipe to carry the off gases for later

purification. Also, the upper pipe was heated to ensure complete combustion of the waste. The pipes and flues are surrounded by an array of brick, Kast-O-Lite, and filler materials such as insulating block, Marinite, Superex, Cerafelt and MIN-K 2000. The first model of the incinerator operated until 1965/66 when it was replaced by the present version. Examination of the original incinerator found many cracks along the main pipe; the design of the new model was updated to prevent this phenomena.

Currently, 10 kg of Pu is estimated to be inside the incinerator with the specific location and concentration unknown. A criticality analysis was performed to determine the reactivity of Pu inside the incinerator for various amounts, concentrations and geometries. Because the incinerator has not operated for a long time, dry and wet simulations were studied. Reference 6 indicates that calcined materials (materials heated in air) quickly pick up water from the humidity in the air.

Validation of the Technical Bases per ANSI/ANS-8.1-1983 [1988] Requirements

An analysis was conducted of the original technical bases per the requirements of ANSI-ANS-8.1-1983 [Reaffirmed 1988]. The results are as follows:

- (1) Describe the method with sufficient detail, clarity, and lack of ambiguity to allow independent duplication of results.

The waste incinerator as shown in References 1, 2 and 3 was modeled explicitly in KENO-Va. The cerafelt around the pipes was ignored; the instructions for installation called for light packing between the pipes. Thus, the density of cerafelt is unknown but expected to be very low and its existence is not verifiable. The material compositions and densities were taken from References 4 and 5. When the references listed a range of values for the composition, the least neutron absorbing composition was chosen to produce the optimum value of k_{eff} . The plutonium was modeled as 100% Pu²³⁹ in the form of PuO₂ at various densities to determine the optimum. Reflection outside the incinerator was ignored except in case 16.

A number of cases were modeled as shown in Table I in an effort to determine the most reactive PuO₂ concentration and physical scenario. In the first case, a dry layer of PuO₂ at a density of 2 g/cc lined the inside of the D shaped, hemicylindrical pipe (10 cm inner radius) along the entire length (242 cm) of the pipe. This location is the most probable for the Pu because the material to be burned was placed in this pipe during operation. A PuO₂ thickness of 0.47 cm on the inside of the pipe provided for 10 kg of Pu in the pipe for Case 1. Case 2 modeled a similar wet solution of PuO₂ and H₂O on the inside of the pipe. In case 3, the thickness of the wet solution was increased to 0.98 cm and thus the total Pu content increased to 20 kg.

The geometry was changed in case 4. A cylinder of 10 kg Pu in the form of PuO₂ and H₂O was modeled down the center of the entire length of the hemicylindrical pipe.

Table I PFP Waste Incinerator Criticality Analysis Results

Case	Geometry	H/Pu	kg Pu	Density PuO ₂ g/cc	Pu form	KENO keff	KENO Uncertainty	K95/95
1	Line hemicylindrical pipe with 0.47 cm material	0	10.0	2.00	PuO ₂	0.064	0.001	0.109
2	Line hemicylindrical pipe with 0.47 cm material	12	10.0	2.00	PuO ₂ + H ₂ O	0.108	0.002	0.153
3	Line hemicylindrical pipe with 0.98 cm material	12	20.0	2.00	"	0.260	0.003	0.306
4	Cylinder in middle of hemicylinder	12	10.0	2.00	"	0.251	0.003	0.296
5	Line hemicylindrical pipe with 2.16 cm material	58	10.0	0.50	"	0.296	0.003	0.342
6	Fill hemicylindrical pipe	58	16.8	0.50	"	0.837	0.005	0.882
7	Line all pipes and flues with 2.16 cm material	58	18.1	0.50	"	0.586	0.005	0.631
8	Fill hemicylindrical pipe	98	10.0	0.30	"	0.810	0.006	0.855
9	Fill all pipes and flues	182	10.0	0.16	"	0.889	0.005	0.934
10	Fill all pipes and flues	298	6.2	0.10	"	0.849	0.006	0.894
11	Fill all pipes and flues	599	3.1	0.05	"	0.757	0.005	0.802
12	Case 11 + replace Inconel with void	599	3.1	0.05	"	0.695	0.005	0.740
13	Case 9 + replace void regions with Kast-0-Lite	182	10.0	0.16	"	0.978	0.006	1.023
14	Case 13 + replace Inconel with void	182	10.0	0.16	"	0.949	0.006	0.994
15	Case 9 + 5 wt% Pu240	182	10.0	0.16	"	0.824	0.005	0.870
16	Case 9 + external water reflector	182	10.0	0.16	"	0.935	0.005	0.980

Bias = -0.0056

Standard Deviation = 0.019

Variance = 0.00036

The density of the PuO_2 was decreased in case 5 to 0.5 g/cc and 10 kg lined the inside of the pipe. The resulting PuO_2 thickness was 2.16 cm. Case 6 filled the pipe with the same material increasing the total Pu weight to 16.8 kg.

Next the wet material was placed in the 4 flues and the upper pipe in addition to the hemicylindrical pipe. Case 7 modeled 10 kg Pu lining the hemicylindrical pipe, 0.24 kg lining each flue, and 7.2 kg lining the upper pipe for a total of 18.1 kg Pu. The same material thickness of 2.16 cm was used in each pipe.

Cases 8 through 11 bound the optimum concentration for a maximum of 10 kg Pu. Wet PuO_2 with a density of 0.3 g/cc completely filled the hemicylinder with 10 kg Pu in Case 8. All of the pipes and flues were completely filled in Cases 9 through 11 with wet solutions containing PuO_2 densities of 0.16, 0.1, and 0.05 g/cc. The total weight of Pu in the incinerator for these densities was 10, 6.2 and 3.1 kg respectively. Case 9 was the most reactive.

In case 12, the Inconel 800 piping material was replaced by void because the iron in inconel is a neutron absorber. However, the reduction in k_{eff} compared to the previous case indicates that the reflective characteristics of the inconel are dominant over the absorptive characteristics.

Next, the geometry of the incinerator was changed to include Kast-O-Lite immediately surrounding all the pipes and flues. This region is filled with Cerafelt in the as built drawings and modeled as void in the as built KENO model of the incinerator. However, a shifting of the materials over time could have occurred. Case 13 models the pipes as Inconel while case 14 models the pipes as void.

In case 15, the PuO_2 mixture filling all pipes and flues included 5 wt% Pu^{240} . A maximum concentration of 6 wt% Pu^{240} (weapons grade) was used throughout the finishing plant. The addition of Pu^{240} reduces the reactivity as expected indicating the other calculations represent the worst case in respect to Pu composition.

Case 16 models a 60 cm water reflector on all 6 surfaces of the incinerator containing 10 kg wet Pu^{239} filling all pipes and flues to model a person working in the area around the box. The addition of external moderation does not result in criticality.

(2) State computer programs used, the options, recipes for choosing mesh points where applicable, the cross sections sets, and any numerical parameters necessary to describe the input.

Calculations were performed on several experimental benchmarks in order to validate subcritical margins for the worst case scenarios. NITAWL was used to generate standard SCALE 27 group cross section sets for input into KENO-Va. KENO-Va was used to calculate all reported values of k_{eff} . Individual input files for all cases given in Table I are included in Appendix A.

- (3) Identify experimental data and list parameters derived therefore for use in the validation of the model.

The experimental benchmarks used are shown in Table II. All parameters required to model these experiments are adequately described in the input files in Appendix B and the indicated references.

- (4) State the area(s) of applicability.

This analysis is applicable to the waste incinerator in Building 232-Z of the Plutonium Finishing Plant in the 200 area of Hanford.

- (5) State the bias and the prescribed margin of subcriticality over the area(s) of applicability. State the basis for the margin.

Computational results indicate that the overall code bias based on benchmark calculations is -6 mk. The mean of all benchmarks is 1.006 ± 0.019 . Consequently, the standard deviation is 19 mk. If these values are applied to the scenarios in a methodology similar to that employed by Marshall (Reference 6), k_{eff} will never exceed 0.98 for 10 kg wet Pu^{239} in the as built incinerator with full water reflection including experimental error and biases. Therefore, the margin of subcriticality is greater than 20 mk under optimum conditions.

Discussion of Results

The proposed scenario of the as manufactured waste incinerator containing 10 kg Pu does not pose a criticality threat. Table I shows that all cases containing 10 kg are subcritical even under optimum conditions of 100% Pu^{239} with water moderation and full water reflection assuming the as built geometry is maintained and the Pu is located within the pipes and flues. Cases 13 and 14 show that the increased reflection of material in the hemicylindrical pipe is sufficient to cause criticality; however, the combination of a high density collapsed reflector around the pipe filled with 100 wt% Pu^{239} in $\text{PuO}_2 + \text{H}_2\text{O}$ is incredible.

The value of k_{eff} increases as the density of the PuO_2 decreases and the amount of water moderation increases. However, at low densities, the geometry of the problem limits k_{eff} as enough Pu is not allowed to accumulate in the pipes and flues to create a critical assembly.

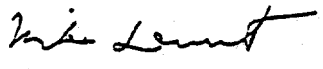
Therefore, the incinerator will remain subcritical if the current Pu estimate of 10 kg in the incinerator is accurate and the original geometry has been maintained over the years. Also, dry PuO_2 in the same configuration has a much larger margin of subcriticality. As shown in Reference 11, the critical mass per unit length of an infinite cylinder is inversely proportional to the density. Thus, a less dense system of 10 kg Pu than modeled would be even more subcritical.

Table II Experimental Benchmarks				
Case	Reference Number	KENO keff	KENO Uncertainty	K95/95
Pu239 minimum critical mass full water reflected	8	1.015	0.005	1.06055
Pu239 thin steel spherical shell full water reflected	8	1.004	0.004	1.04907
Pu239 thin steel spherical shell no water reflection	8	0.991	0.005	1.03589
Pu239 thin steel + 4" concrete spherical shell	8	1.031	0.005	1.07636
Pu239 4" concrete spherical shell	9	1.031	0.005	1.07626
Pu239 10" concrete spherical shell	9	1.022	0.005	1.06749
U02 rods with lead wall @ 0 cm	7	1.009	0.003	1.05499
U02 rods with lead wall @ 2 cm	7	1.006	0.003	1.05197
U02 rods with lead wall @ 3 cm	7	0.995	0.004	1.03964
U02 rods with lead wall @ 5 cm	7	0.978	0.003	1.02394
U02 rods without lead wall	7	0.977	0.003	1.02302
Bias = -0.0056				
Standard Deviation = 0.019				
Variance = 0.00036				

Conclusions

The waste incinerator at PFP is subcritical provided the estimate of 10 kg Pu inside the incinerator is accurate and the original geometry has been maintained with the Pu mixture remaining inside the pipes. Operations around the box have no criticality impact. To achieve criticality requires an incredible set of occurrences that include the box containing 10 kg Pu with no Pu^{240} , all pipes and flues filled with hydrated plutonium oxide, and degraded internal box geometry.

Concurrence:



Senior Specialist
Criticality Safety Analysis

ITEM I.3 Input File for keno Computer Run CASE 7:

Line all pipes and flues with 2.16 cm wet PuO₂

PPF INCINERATOR-18 KG PUO2+H2O 0.5 G/CC LINE D PIPE + LINE FLUES AND GAS PIPE

READ PARAM
RUN=YES TME=300.0 LIB=41 GEN=120 NSK=20
END PARAM

READ START

NST=0
XSM=36.0 XSP=57.0
YSM=0.0 YSP=241.935
ZSM=25.0 ZSP=36.0

END START

READ GEOM

UNIT 5

COM="D" PIPE"

CUBOID

YHEMICYL+Z

YHEMICYL+Z

YHEMICYL+Z

UNIT 6

COM="D" PIPE"

CUBOID

YHEMICYL+Z

YHEMICYL+Z

YHEMICYL+Z

UNIT 7

COM="D" PIPE"

CUBOID

YHEMICYL+Z

YHEMICYL+Z

YHEMICYL+Z

UNIT 8

COM="D" PIPE"

CUBOID

YHEMICYL+Z

YHEMICYL+Z

YHEMICYL+Z

UNIT 9

COM="D" PIPE"

CUBOID

YHEMICYL+Z

YHEMICYL+Z

YHEMICYL+Z

UNIT 10

COM="FLUE FOR LOWER"

ZCYLINDER

ZCYLINDER

ZCYLINDER

UNIT 11

COM="FLUE FOR UPPER"

ZCYLINDER	0	1	4.67	27.93999 0.00001
ZCYLINDER	8	1	6.83	27.93999 0.00001
ZCYLINDER	7	1	7.70	27.93999 0.00001
UNIT 12				
COM="FLUE 1A GAS PIPE"				
ZCYLINDER	0	1	4.67	8.57249 0.00001
ZCYLINDER	8	1	6.83	8.57249 0.00001
ZCYLINDER	7	1	7.70	8.57249 0.00001
UNIT 13				
COM="FLUE 1B GAS PIPE"				
ZHEMICYL+Y	7	1	7.70	8.57249 0.00001
UNIT 14				
COM="FLUE 2 & 3 GAS PIPE"				
ZCYLINDER	0	1	4.67	8.57249 0.00001
ZCYLINDER	8	1	6.83	8.57249 0.00001
ZCYLINDER	7	1	7.70	8.57249 0.00001
UNIT 15				
COM="FLUE 4A GAS PIPE"				
ZHEMICYL-Y	7	1	7.70	8.57249 0.00001
UNIT 16				
COM="FLUE 4B GAS PIPE"				
ZCYLINDER	0	1	4.67	8.57249 0.00001
ZCYLINDER	8	1	6.83	8.57249 0.00001
ZHEMICYL+Y	7	1	7.70	8.57249 0.00001
UNIT 17				
COM="FLUE 1A				
ZHEMICYL-Y	0	1	4.67	15.08489 0.00001
ZHEMICYL-Y	8	1	6.83	15.08489 0.00001
ZHEMICYL-Y	7	1	7.70	15.08489 0.00001
UNIT 18				
COM="FLUE 1B				
ZHEMICYL+Y	0	1	4.67	15.08489 0.00001
ZHEMICYL+Y	8	1	6.83	15.08489 0.00001
ZHEMICYL+Y	7	1	7.70	15.08489 0.00001
UNIT 19				
COM="FLUE 2A				
ZHEMICYL-Y	0	1	4.67	15.08489 0.00001
ZHEMICYL-Y	8	1	6.83	15.08489 0.00001
ZHEMICYL-Y	7	1	7.70	15.08489 0.00001
UNIT 20				
COM="FLUE 2B				
ZHEMICYL+Y	0	1	4.67	15.08489 0.00001
ZHEMICYL+Y	8	1	6.83	15.08489 0.00001
ZHEMICYL+Y	7	1	7.70	15.08489 0.00001
UNIT 21				
COM="FLUE 3A				
ZHEMICYL-Y	0	1	4.67	15.08489 0.00001
ZHEMICYL-Y	8	1	6.83	15.08489 0.00001
ZHEMICYL-Y	7	1	7.70	15.08489 0.00001
UNIT 22				
COM="FLUE 3B				
ZCYLINDER	0	1	4.67	15.08489 0.00001
ZHEMICYL+Y	8	1	6.83	15.08489 0.00001
ZHEMICYL+Y	7	1	7.70	15.08489 0.00001
UNIT 23				
COM="FLUE 4A				
ZHEMICYL-Y	0	1	4.67	15.08489 0.00001
ZHEMICYL-Y	8	1	6.83	15.08489 0.00001
ZHEMICYL-Y	7	1	7.70	15.08489 0.00001

ZHEMICYL-Y	8	1	6.83	15.08489	0.00001	CHORD	-0.635	COM="D" PIPE	VIEW JJ & HH"	1	13.97	0	20.320	0	31.115	0
ZHEMICYL-Y	7	1	7.70	15.08489	0.00001	CHORD	-0.635	CUBOID								
UNIT 24								UNIT 40								
COM="FLUE 4B	0	1	4.67	15.08489	0.00001	CHORD	0.635	COM="D" PIPE	VIEW JJ & HH"	5	21.59	0	20.320	0	31.115	0
ZHEMICYL-Y	8	1	6.83	15.08489	0.00001	CHORD	0.635	CUBOID								
ZHEMICYL-Y	7	1	7.70	15.08489	0.00001	CHORD	0.635	UNIT 41								
UNIT 25								COM="D" PIPE	SEP BLOCK"	5	6.35	0	11.430	0	31.115	0
COM="INSULATION FULL LENGTH"	4	1	93.98	0	241.935	0	10.160	UNIT 42								
CUBOID								COM="D" PIPE	SEP BLOCK"	6	7.62	0	11.430	0	31.115	0
UNIT 26								CUBOID								
COM="BELOW	4	1	24.13	0	12.700	0	5.080	UNIT 43								
CUBOID								COM="D" PIPE	SEP BLOCK"	1	19.69	0	11.430	0	31.115	0
CUBOID	3	1	24.13	0	12.700	0	10.160	CUBOID								
UNIT 27								UNIT 44								
COM="BELOW	1	1	11.43	0	12.700	0	10.160	COM="D" PIPE	SEP BLOCK"	2	11.43	-11.43	11.430	0	5.080	0
CUBOID								CUBOID								
UNIT 28								CUBOID								
COM="BELOW	1	1	22.86	0	12.700	0	10.160	CUBOID								
CUBOID								HOLE								
UNIT 29								HOLE								
COM="BELOW	1	1	11.43	0	12.700	0	10.160	UNIT 45								
CUBOID								COM="D" PIPE	SEP BLOCK"	1	19.69	0	11.430	0	31.115	0
UNIT 30								CUBOID								
COM="BELOW	4	1	24.13	0	12.700	0	5.080	UNIT 46								
CUBOID								COM="D" PIPE	SEP BLOCK"	6	7.62	0	11.430	0	31.115	0
CUBOID	3	1	24.13	0	12.700	0	10.160	CUBOID								
UNIT 31								UNIT 47								
COM="BELOW	4	1	24.13	0	229.235	0	5.080	COM="D" PIPE	SEP BLOCK"	5	6.35	0	11.430	0	31.115	0
CUBOID								CUBOID								
UNIT 32								UNIT 48								
COM="BELOW	3	1	24.13	0	229.235	0	10.160	COM="D" PIPE	OPEN 1"	1	28.42	0	46.990	0	31.115	0
CUBOID								CUBOID								
UNIT 33								UNIT 49								
COM="BELOW	1	1	11.43	0	229.235	0	10.160	COM="D" PIPE	OPEN 1"	2	11.43	-11.43	46.990	0	5.080	0
CUBOID								CUBOID								
UNIT 34								CUBOID								
COM="BELOW	2	1	22.86	0	229.235	0	10.160	CUBOID								
CUBOID								HOLE								
UNIT 35								HOLE								
COM="BELOW	1	1	11.43	0	229.235	0	10.160	UNIT 50								
CUBOID								COM="D" PIPE	OPEN 1"	1	28.42	0	46.990	0	31.115	0
UNIT 36								CUBOID								
COM="BELOW	4	1	24.13	0	229.235	0	5.080	UNIT 51								
CUBOID								COM="D" PIPE	SEP BLOCK"	5	6.35	0	11.430	0	31.115	0
CUBOID	3	1	24.13	0	229.235	0	10.160	CUBOID								
UNIT 37								UNIT 52								
COM="D" PIPE	5	1	21.59	0	20.320	0	31.115	COM="D" PIPE	SEP BLOCK"	6	7.62	0	11.430	0	31.115	0
CUBOID								CUBOID								
UNIT 38								UNIT 53								
COM="D" PIPE	1	1	13.97	0	20.320	0	31.115	COM="D" PIPE	SEP BLOCK"	1	19.69	0	11.430	0	31.115	0
CUBOID								CUBOID								
UNIT 39								UNIT 54								
COM="D" PIPE	2	1	22.86	0	20.320	0	5.080	COM="D" PIPE	SEP BLOCK"	2	11.43	-11.43	11.430	0	5.080	0
CUBOID								CUBOID								
CUBOID	1	1	22.86	0	20.320	0	31.115	CUBOID								
HOLE	5		11.43	0.000	5.080			HOLE								
UNIT 39								HOLE								

