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Incineration of a Typical LWR Combustible Waste and Analysis of the Resulting Ash

Prepared by R. L. Treat, R. O. Lokken, M. J. Schliebe

Pacific Northwest Laboratory
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Office of Nuclear Regulatory Research
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ABSTRACT

In this study 4540 kg (10,000 lb) of simulated nuclear power plant combustible wastes were burned in a controlled-air incinerator. The purpose of this work was to generate ashes suitable for solidification, the products of which will be analyzed to determine if they are suitable for disposal. Two different types of waste were burned: resins and simulated crud, and general trash (paper, plastics, wood, rubber, and cloth). Volume-reduction ratios (unburned waste: ash) were 13:1 and 22:1, respectively. Approximately 20% of the ash was lost due to adherence to incinerator walls and entrainment in the off-gas stream. Losses of the volatile species cesium and iodine were 79% and 100%, respectively. The ashes were not hygroscopic, but they exhibited a pH of 4.6 to 5.0 when water was added. Corrosion of mild steel drums would occur within this pH range. The ashes contained a significant quantity of clinkers having lengths as great as 20 cm (8 in.). Most of the clinkers were fully incinerated and easy to crush, suggesting that standard comminuting equipment should be effective in reducing the size of clinkers to allow their solidification with the fine ashes.

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In this study 4540 kg (10,000 lb) of simulated nuclear power plant combustible wastes were burned in a controlled-air incinerator. The purpose of this work was to generate ashes suitable for solidification, the products of which will be analyzed to determine if they are suitable for disposal. Two different types of waste were burned: resin and simulated crud, and general trash (paper, plastics, wood, rubber, and cloth). Volume-reduction ratios (unburned waste: ash) were 13:1 and 22:1, respectively. Approximately 50% of the ash was lost due to adherence to incinerator walls and entrainment in the off-gas stream. Losses of the volatile species cesium and iodine were 7% and 100%, respectively. The ashes were not hygroscopic, but they exhibited a pH of 4.6 to 5.0 when water was added. Corrosion of mild steel drums would occur within this pH range. The ashes contained a significant quantity of clinkers having lengths as great as 20 cm (8 in.). Most of the clinkers were fully incinerated and easy to crush, suggesting that standard comminuting equipment should be effective in reducing the size of clinkers to allow their solidification with the fine ashes.

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EXECUTIVE SUMMARY

This report contains information on the operation of a controlled-air incinerator (CAI) which burned wastes that are similar to those generated by a light-water reactor. Ashes that were produced during the operation of the CAI are also described.

Incineration of low-level radioactive waste (LLW) is being viewed with increasing interest for several reasons. First, rising disposal costs for LLW have provided an incentive for reducing the volume of combustible wastes through incineration. Further, incineration enhances the safety of handling and disposal of combustible waste by rendering it more chemically inert. Moreover, incinerator ashes that are solidified ensure the stability of the waste burial site. This is an important consideration of the U.S. Nuclear Regulatory Commission (10 CFR 61).

Several sources were consulted to develop a reference, light-water-reactor (LWR), combustible-waste composition. A total of 4540 kg (10,000 lb) of the various reference waste components was procured. None of the wastes was radioactive. The wastes were packaged in 0.063 m³ (2.2 ft³) cardboard boxes to facilitate charging them to a CAI similar to a type developed with the support of the U.S. Department of Energy (DOE). The wastes were incinerated in two runs: the first involved resins and simulated crud, and the second involved general trash (plastics, paper, wood, rubber and cloth). Results are tabulated below:

Run	Charging Rate	Average Charging Temperature		Ash Recovered	Ash Bulk Density	Volume Reduction Ratio
		Lower	Upper			
1	58 kg/h	800°C	970°C	148 kg	0.9 g/cm ³	13:1
2	52 kg/h	870°C	820°C	122 kg	0.3 g/cm ³	22:1

Incineration rates did not seem to be affected by the type of wastes burned. The burning rate of the general trash wastes was lower than expected, especially since the burning waste was frequently stoked to encourage combustion. Low burning rates may have been caused by 1) somewhat lower than desired burning temperatures, 2) high package masses that may have prevented combustion air and heat from efficiently reaching the center of the package, and 3) high waste densities that may have produced the same effect. These factors may also be related to the high content of volatile chemicals in the ash (40 wt%). It appears that high burning temperatures, low package weights, and low waste densities may all be important in assuring high burning rates, low volatile contents, and high volume-reduction ratios.

Analyses of non-volatile tracer chemicals in the ash indicated that approximately 20 wt% of the resin ash was lost due to entrainment in the off gas and adherence to the incinerator walls. Losses of the volatile cesium and iodine tracers in the blended ash were 79% and 100%, respectively. Assessment of off-gas characteristics and efficiency of removing volatiles and particles from the off-gas stream was not within the scope of this study. The ashes were not hygroscopic. Therefore little risk of ash agglomeration or free-standing

water exists. However, the pH of the combined ash ranged between 4.6 and 5.0, a level sufficient to cause corrosion of mild steel if water were inadvertently added during storage. The exposure of combustible materials to hygroscopic salts during normal plant operations could result in producing a wet, acidic ash that could also be quite corrosive to mild steel.

A significant fraction of ash produced in Run 2 consisted of clinkers. Over 5 wt% was in clinkers greater than 8 cm (3 in.) diameter. Clinkers present a concern since they could jam ash conveyors and ash solidifying systems. Except for some wood-charcoal cinders, the ash clinkers were well-burned and did not disintegrate when reheated. Thus, more efficient combustion may not prevent the formation of some clinkers. The clinkers were fairly easy to crush, however, which suggests that standard comminuting equipment would be effective in pulverizing the clinkers to enable processing the product in the ash solidification system. Some method of separating tramp metal must be employed, however. Clinkers may also be suitable for direct disposal in 210 L (55 gal) drums with a capacity of 114 kg (250 lb) per drum. Soot which adhered to the surfaces of clinkers was easily washed away with water. If necessary, washing would significantly reduce the potential for dust dispersion from clinkers.

INTRODUCTION

The current inventory of low-level radioactive waste (LLW) from defense and commercial industries in the U.S. is $\sim 2 \times 10^6 \text{ m}^3$ and is increasing at a rate of $\sim 10^5 \text{ m}^3/\text{yr}$ at the current level of operations (Borduin and Taboas 1981). All the commercial waste is disposed of at commercial burial sites. Since 1975 the number of such sites has been reduced from six to three (DiSibio 1980). Furthermore, the states which contain the three remaining sites have taken actions that have limited the sites' capacities to dispose of low-level wastes (DiSibio 1980). At the same time, disposal costs have risen substantially. These factors provide an incentive to reduce the volume of LLW for disposal.

Most LLW can be classified as combustibles, liquids and sludges, or noncombustible solids. The combustible fraction, comprising about 40% of the volume of newly generated waste (Borduin and Taboas 1981), has the greatest potential for volume reduction. Most combustible wastes are currently compacted, which reduces their volumes by about 75%. Volume-reduction ratios of 40:1 have been reported when incinerating uncompacted wastes (Borduin and Taboas 1981). Proper incineration also results in a more chemically inert waste which enhances the safety of waste handling, packaging, and storage. Further, at least one study (Osmeyer 1980) indicates that incineration is economically attractive.

In 1973 Los Alamos National Laboratory (LANL) was directed by DOE to evaluate current incineration technology for combustion of transuranic (TRU) wastes. A controlled-air incinerator (CAI) was selected for development and demonstration. Advantages of the CAI include 1) flexibility to accept a wide range of feed compositions, 2) ease of combustion rate control, 3) low particulate emissions, 4) high combustion efficiency, and 5) the ability to tolerate relatively high levels of noncombustibles.

In 1981 the U.S. Nuclear Regulatory Commission (NRC) commissioned Pacific Northwest Laboratory (PNL) to characterize volume-reduced LLW forms to provide a basis for policy and licensing decisions. Initial work focused on the combustion of simulated LLW materials using a CAI. Ashes resulting from the incineration were characterized. This report discusses the performance of the CAI and the properties of the ash produced. Subsequent reports will deal with the properties of solidified ashes and their suitabilities for disposal.

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SELECTION OF REFERENCE COMBUSTIBLE WASTE

A number of sources were consulted to define a combustible waste typical of that generated by a commercial light water reactor (LWR). Combustible waste components and their concentrations from four sources are itemized in Table 1. The first source (USDOE 1979) provided data obtained from a survey of several LWRs. The second source (TROJAN Nuclear Power Plant, Rainier, Oregon) provided data that was reasonably consistent with the first. It represented only the TROJAN Nuclear Power Plant, however. The third source (Combustion Engineering, Inc., Windsor, Connecticut) did not include resins and indicated that paper was the major type of combustible waste. The fourth source (Osmeyer 1980) divided the waste into only two categories: trash and resin waste.

TABLE 1. Components of Combustible LLW, wt%

Component	Sources			
	USDOE	TROJAN	Combustion Engineering	Osmeyer
<u>TRASH</u>	<u>56</u>	<u>60</u>	<u>100</u>	<u>82</u>
(Plastics)	(36)	(42)	(12.2)	
[PVC]		[4]		
[Polyethylene]		[38]		
(Paper)	(12)	(9)	(67.7)	
[Sulfite]		[3]		
[Kraft]		[6]		
(Wood)	(4)	(4.8)	(1.4)	
(Rubber)	(3)	(1.2)	(10.8)	
(Cloth)	(1)	(3)	(7.9)	
<u>RESINS (low activity)</u>	<u>44</u>	<u>40</u>		<u>18</u>
(Cation Resin)		(29)		
(Anion Resin)		(9)		
(Crud)		(2)		
<u>TOTALS (Trash + Resins)</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>

Although the TROJAN source provided the most definitive breakdown, the DOE source was selected because it was more representative. The definition of DOE source wastes was broadened, however, by dividing the plastic category into polyvinyl chloride (PVC) and polyethylene subcategories, and the paper category into sulfite and Kraft paper subcategories, in proportion to the TROJAN levels. Also, the resin category was divided into cation exchange resins, anion exchange resins and "crud," again in proportion to the TROJAN levels. "Crud" is a mixture of metallic oxides resulting from the corrosion of process pipes and vessels. The reference combustible waste is shown in Table 2. Note that wood is defined as fir, rubber as latex, and cloth as cotton. (TROJAN was again the source of this information).

Plastics were obtained as shredded scrap (<1 cm or 0.4 in.) from Talco Plastics, El Monte, California. Scrap computer paper served as the source of sulfite paper. Paper towels were used for Kraft paper. Douglas fir chips (3 cm x 3 cm x 0.3 cm, or 1 in. x 1 in. x 1/8 in.) were donated by the Boise Cascade Corporation, Wallula, Washington. Cotton rags represented the cloth category. Slightly off-specification, beaded resins were purchased from Diamond Shamrock Corporation, Cleveland, Ohio. The cation exchange resin was a hydrogen form, sulfonated polystyrene cross-linked with divinylbenzene. The

TABLE 2. Reference LWR Combustible LLW, wt%

Component	wt%
PVC Plastic	3
Polyethylene Plastic	33
Sulfite Paper	4
Kraft Paper	8
Wood (fir)	4
Rubber (latex)	3
Cloth (cotton)	1
Cation Exchange Resin	31
Anion Exchange Resin	11
Crud ^(a)	2
<u>TOTAL</u>	<u>100</u>

(a)Crud: 80% Fe₂O₃, 20% CuO.

anion exchange resin was a hydroxide form, strong base (quaternary ammonium functional group) polystyrene cross-linked with divinylbenzene. A blend of powdered, technical grade Fe₂O₃ and CuO served as crud. A total of 4540 kg (10,000 lb) of these simulated wastes was procured.

WASTE PACKAGING

Discussions with operators of controlled-air incinerators at Los Alamos National Laboratory (LANL) and Environmental Control Products, Inc., Charlotte, North Carolina revealed that wastes typical of those in this study are usually packaged before charging in the incinerator. Cardboard boxes serve as suitable containers because they are themselves combustible. A 40 cm x 40 cm x 38 cm (16 in. x 16 in. x 15 in.) cardboard box was chosen as the standard packaging container as it was deemed large and strong enough to minimize handling but small enough that the contents should burn relatively well.

Wastes were divided into two categories: resins and trash. In actual practice these wastes may be generated and incinerated separately rather than as blends. The trash wastes (plastics, paper, rubber, cloth, and wood) were loaded into plastic bags which lined each box, blending some of the various trashes together as might be expected in the actual application. Trash weights in each box ranged between 11 and 27 kg (25 and 60 lb). Generally each box of trash was filled nearly to capacity, but wastes were not compressed. Resins containing about 50% water were also loaded into plastic-lined boxes. However, the moisture content and activity level of resins may be too high to practically charge resins in boxes. A continuous charging method may be more suitable. Crud, which represented about 5 wt% of the resin weight in each box, was blended by hand with the resin. About 34 to 36 kg (75 to 80 lb) of the resin and crud blend were contained in each package. These packages were not filled to capacity because of the possibility that due to the high density (0.8 g/cc or 50 lb/ft³), the boxes might rupture.

Before each package was sealed, approximately 300 cc of a simulated radioactive spiking solution were added to each box. These spiking chemicals serve as tracers for performing leaching studies on consolidated ash waste forms.

Two different spiking solutions were prepared as shown in Table 3. The selection of spiking chemicals was based on the radioactive spiking elements used in studies at Brookhaven National Laboratory (Colombo and Neilson 1979). The use of similar spiking chemicals will facilitate the comparison of data. Batch A was added to trash packages, while Batch B was added to resin packages. The higher chemical concentration of Batch B is attributed to the higher fission product level of the resins (USDOE 1979). The overall quantity of spiking chemicals added was based on the amount necessary to observe leaching by the inductively-coupled plasma emission spectrometry and atomic absorption methods. We estimated that 160 kg (350 lb) of ash would be recovered and then we added chemicals so that 1/2 wt% each of cesium and strontium and 1 wt% each of cobalt and iodine would exist in the ash. This was assuming, of course, that none of the chemicals would vaporize, although it was doubtful that much iodine would be retained.

TABLE 3. Combustible Waste Spiking Solutions

Compounds	Batch A	Batch B
CsNO ₃	126 g	710 g
Sr(NO ₃) ₂	204 g	1150 g
Co(NO ₃) ₂	852 g	4824 g
CaI ₂	200 g	1123 g
H ₂ O	41 L	21 L

INCINERATION

The combustible waste was incinerated in a Model 500-T CAI manufactured by Environmental Control Products, Inc. (ECP), a company instrumental in the early development of the CAI at LANL. The incinerator is located at Battelle Columbus Laboratories, Columbus, Ohio. The unit features a 940 kW (3.2 million BTU/h) thermal capacity, which corresponds to an incineration feed rate of approximately 182 kg/h (400 lb/h) of normal, dry combustible waste.

A schematic of the incinerator is shown in Figure 1. The unit consists of two drum-shaped burning chambers, one positioned on top of the other. Wastes were charged batchwise in the lower incinerator chamber. Air was added under the fire at nearly the stoichiometric oxygen requirement for complete combustion, thus controlling the burning rate of the waste. Unburned volatile compounds and combustible particles were then burned completely in the upper chamber, where additional air for combustion was added. Temperatures of approximately 850 and 900°C were maintained in the lower and upper chambers, respectively, by the introduction of natural gas. Flow rates of natural gas and combustion air were manually regulated. Exhaust gases from the upper chamber were vented directly to a stack.

FIGURE 1. Controlled-Air Incinerator

The resin wastes and the trash wastes were incinerated separately in two runs. Prior to each run the incinerator was thoroughly swept and vacuumed to minimize the potential for contamination of the ashes. Before charging packaged waste, the incinerator was brought to operating temperatures by firing only with natural gas. Once the desired temperatures were achieved, waste packages were charged individually to the incinerator via an electrically-operated access door. A safety interlock prevented the operation of the natural gas burners while the access door was open. With the door open, a damper in the off-gas line automatically closed, which reduced the draft through the furnace and minimized the temperature drop. Approximately 30 seconds after the door was closed, natural gas injection was resumed, which quickly raised temperatures to normal operating levels.

During the burns different waste charging rates were explored until a suitable rate was found. At the end of each burn, the incinerator was left operating for approximately 8 hours. The incinerator was then shut down and the ash was permitted to cool for approximately 24 hours, at which point it was removed from the incinerator and stored in steel 210 L (55 gal) drums.

BURN NO. 1, RESIN WASTE

Details of the charging rates and combustion temperatures are shown in Appendix A. The average lower and upper chamber temperatures were 800 and 970°C, respectively. It was found that a charging rate of 45 to 73 kg/h (100 to 160 lb/h) was optimum as long as the burning resin was frequently stoked with a long-handled metal hoe. The average charging rate was 58 kg/h (127 lb/h) with stoking every 8 to 10 minutes. This charging rate was expected because the resin contained a high amount of water (~50%). A total of 148 kg (325 lb) of ash was recovered from this burn.

BURN NO. 2, TRASH WASTE

Details of charging rates and combustion temperatures are shown in Appendix B. The average lower and upper chamber temperatures were 870 and 820°C, respectively. A charging rate of 136 kg/h (300 lb/h) was tried initially for a period of 1 hour until it was apparent that this rate was exceeding the capacity of the unit to combust the waste. Charging rates were reduced to an average charging rate of 52 kg/h (115 lb/h) with stoking required every 10 minutes to achieve this rate. The low burning rate was unexpected since the waste was essentially dry and contained a high heat value.

The three kinds of packages (plastics; wood and Kraft paper; and rubber, sulfite paper, and cloth), were alternately charged to the incinerator. Smoke was produced by the burning of the plastic wastes. This smoky condition normally lasted about 5 minutes after charging. A total of 122 kg (268 lb) of ash was recovered. Approximately 5% of the mass was composed of clinkers greater than 8 cm (3 in.) diameter.

DISCUSSION OF INCINERATION RESULTS

Burning rates did not seem to be significantly affected by the type of wastes being burned. BCL operators estimated that burning rates would have

been reduced by more than half had stoking not been used. Apparently the burned crust that covered each burning package inhibited the flow of air into the package and thereby reduced the burning rate. This suggests that a smaller, less dense charge size may be critical in maximizing burning rates. Our use of shredded wastes having high bulk densities (0.2 to 0.9 g/cc, or 11 to 55 lb/ft³) undoubtedly restricted oxygen availability at the center of the burning package. At LANL, TRU contaminated wastes were burned in packages of similar volume that contained 4 kg (9 lb) (Borduin and Taboas 1981), as compared to the 12 to 36 kg (26 to 80 lb) charges in this study. Moreover, LANL reports combustion temperatures of 800 to 1000°C in the lower chamber and 1100°C in the upper chamber. These higher temperatures may also account, in part, for the relative ease of combustion. Also, less smoke might have been produced when burning the plastics had the upper chamber been operated at 1100°C.

Even though the bulk density of the waste was relatively high before incineration, volume-reduction ratios of 13:1 and 22:1 were achieved with the resin waste and trash waste, respectively.

Ralph Koenig of LANL subsequently reported that the LANL incinerator experience generally agreed with the results of this study. Highlights of the LANL experiences are provided below:

- Low burning rates and clinker formation occurred when burning compacted material such as stacks of computer print-out paper and stacks of polyethylene film. Burning rates increased dramatically when this type of material was shredded and repackaged.
- Higher temperatures in the upper chamber helped to reduce smoke, but other changes were required to completely eliminate it, including redesigning the upper chamber air injector, better controlling oxygen levels in the exhaust, and injecting steam.

ASH CHARACTERIZATION

Approximately 2 months after the ash was produced, samples were collected at the top, middle, and bottom of each drum of ash. For several weeks prior to removing the samples, the drums were loosely lidded to permit air to enter the drums. We were concerned that these ashes might have exhibited a hygroscopic nature that could have resulted in the presence of free-standing liquids and container corrosion. However, a moisture analysis of the samples revealed no relationship between water content and position in the drum, which suggests that these ashes are not highly hygroscopic. The average moisture contents of the resin and trash ashes were 0.39 and 0.37 wt%, respectively. Moisture content was determined by drying the samples at 110°C for 16 hours and measuring weight loss. Densities of the bulk resin and trash ashes were 0.9 and 0.3 g/cm³ respectively.

To prepare the ashes for further analyses and solidification, large (>2.5 cm, or 1 in.) clinkers were separated from the resin and trash ashes. Most of the remaining ash was blended in the same weight proportion as the ash was produced (325 parts of resin ash to 268 parts of trash ash). The blended ash was then screened through a 0.6 cm (1/4 in.) mesh screen. The coarse fraction, when combined with the large clinkers, comprised 12 wt% of the ash produced. The separation step was necessary to ensure that the ashes, when combined with solidifying agents and cast in small molds, would not be dominated in some samples by the presence of large particles which may not have chemical and physical properties typical of the fine ashes. The bulk density of the blended ash was 0.9 g/cm³.

Both the fine ashes (before and after blending) and the clinkers were characterized as follows.

FINE ASHES

X-Ray Diffraction

Although both ashes were primarily amorphous, three distinct crystalline phases were found in the resin ash. The main phase was essentially Fe₂O₃ (hematite). The second phase was a solid/solution between Fe₃O₄ and CuFe₂O₄ with a spinel structure, while the third phase was probably a Fe-Cu sulfide. The trash ash analysis revealed a distinct amorphous "hump" that can be attributed to the presence of carbon. Two or three crystalline phases appear to be present, but they were not identified.

Brunauer-Emmett-Teller (BET) Surface Area

BET surface area measurements, based on N₂ adsorption at liquid nitrogen temperatures, resulted in values of 3.68 m²/g and 33.27 m²/g for the trash and resin ash, respectively. The large surface area in the resin ash was due to extensive microporosity and rough surfaces present in the particles. The higher surface area of the resin ash was not surprising since it is a characteristic of unburned resins. Evidence of this is seen in the scanning electron microscope (SEM) micrographs discussed later.

Thermogravimetric Analysis-Differential Thermal Analysis (TGA-DTA)

Simultaneous TGA-DTA was conducted on samples of trash, resin, and blended ashes. The samples were heated in air at 300°C/h to 800°C, and held there for 4 hours. The total weight losses of the three samples at the end of the analysis were 40.6, 50.9, and 41.8 wt% for the trash, resin, and blended ashes, respectively. Figure 2 illustrates the weight loss of the trash and resin ashes as a function of temperature and time. After a slight (and perhaps anomalous) weight gain between 200 and 400°C, both ashes lost weight rapidly with increasing temperature. The trash ash continued to lose weight at 800°C for about 40 minutes, after which the weight loss stabilized, reaching a total loss of 40.6 wt% after 4 hours. The weight loss of the resin ash progressed at a slower rate than the trash ash and continued until about 2 1/2 hours at 800°C, reaching a total loss of 50.9 wt% after 4 hours. Exothermic peaks were observed at 750 and 800°C for resin ash and trash ash, respectively, perhaps signifying ignition of residual carbon.

Quadrupole Mass Spectrometry (QMS)

Gases evolved from samples of ash heated in air were analyzed by QMS. Samples of trash, resin, and blended ashes were heated at 300°C/h to 800°C and held there for 4 hours, as in the TGA-DTA analyses. Gas analyses showed the only gases detected were CO₂ and SO₂. There was no detectable NO_x, H₂O, or CH₄. The bulk of the gas was CO₂, which comprised >99% of the total quantity of gas released. Evolution of SO₂ was the highest from the resin and blended ash samples. This was expected because of the high sulfur content of resins. Since heating of the samples was terminated at 800°C, little decomposition of carbonates should have occurred. Thus, it is concluded that essentially all of the weight loss can be attributed to oxidation of carbon. The absence of H₂O and CH₄ in the gas suggests that the carbon was essentially elemental in form. QMS data are shown in Appendix C.

Scanning Electron Microscopy/Energy Dispersive Analysis by X-Ray (SEM/EDAX)

The SEM revealed that the trash ash consisted of three basic particle types, as seen in the micrographs in Figure 3. The most abundant particle type (Photo A) is believed to contain substantial carbon because of its extremely low EDAX peaks and its particular morphology. Photo B shows another particle which has a grainy surface texture. This particle is composed primarily of Al, Si, Ca, K, and Ti, with traces of Fe and S, as seen in the EDAX trace in Figure 4. The third type of particle, seen in Photo C, is characterized by a rough surface containing numerous craters. The EDAX spectra of this particle (Figure 4) is similar to that of the previously discussed particle in the major elements; however, S, Cl, and Na are present in substantial amounts.

Nearly all the particles in the resin ash sample were spherical in shape, but they had widely different morphologies. The two particles seen in Figure 5 have spherical shapes with large pore structures, which may account for the large BET surface area measured for this ash. Figure 6 illustrates two more resin ash particles, one nearly spherical and the other irregularly shaped. The spherical particle has a relatively smooth-textured surface, while the irregularly-shaped particle has a very rough surface. Some of the spheres

examined had numerous small particles adhering to their surfaces, as seen in Figure 7. EDAX analysis of the resin ash particles showed nearly the same overall composition for all particles. An EDAX trace of a typical particle is shown in Figure 8.

Chemical Analysis by Inductively Coupled Plasma (ICP) Emission Spectrometry

As-received and calcined samples of dry trash and resin ashes and a ball-milled sample of blended ash were analyzed by ICP. Calcining was conducted at 800°C for 16 hours in static air. The blended ash sample was ball-milled in alcohol for 12 hours using stabilized zirconia grinding media. The oxide composition of the three materials is shown in Table 4.

The major constituents of trash ash, assumed to be oxides, are SiO_2 , Al_2O_3 , CaO , and TiO_2 , with lesser amounts of Fe_2O_3 , K_2O , MgO , Na_2O , and P_2O_5 . The total oxide weight in the as-received trash ash was 56.6 wt%, suggesting substantial residual carbon or other non-decomposed compounds. From the TGA data (Figure 2) a 60% oxide weight can be inferred which closely agrees with the ICP data. Some particles examined by SEM/EDAX contained substantial amounts of Cl, probably originating from PVC plastic. Residual carbon is also suggested by weak EDAX peaks and by the substantial increase in relative weight percent oxides (56.6 to 92.5 wt%) after calcination.

The resin ash consisted largely of Fe, Cu, and S as seen in the EDAX trace (Figure 8). Fe_2O_3 and CuO were added in substantial amounts to the resin before burning to simulate crud. The Fe content in the ash (listed in the table as Fe_2O_3) is believed to exist in part as Fe_3O_4 because of the magnetic properties of the ash particles. Calcination did not increase the relative oxide content of the resin ash (53.2 to 69.8 wt%) as much as it did the trash ash. The difference is most likely due to the presence of more refractory sulfur compounds. ICP and TGA oxide values (53 and 50%, respectively) agree closely.

Table 5 gives the percents of spiking chemicals added to combustible wastes that were recovered in the ashes.

From these data we conclude that virtually all of the iodine vaporized and that the retention of cesium was only about one-quarter that of strontium and cobalt. The impossibly high retention of strontium and cobalt in the dry trash ash may be attributed to 1) sampling bias, 2) their innate presence in the combustible waste, 3) cross-contamination from materials left in the incinerator, and/or 4) analytical inaccuracy.

FIGURE 2. TGA Weight Loss of Resin Ash and Trash Ash Heated at 300°C/h in Air

FIGURE 3. SEM Micrographs of Typical Trash Ash Particles

FIGURE 4. EDAX Spectra of Trash Ash Particles Seen in Photos B and C of Figure 3

FIGURE 5. SEM Micrographs of Resin Ash Particles A and B

FIGURE 6 SEM Micrographs of Resin Ash Particles C and D

FIGURE 7 SEM Micrographs of a Resin Ash Particle Showing Adhered Crystals

FIGURE 8. EDAX Spectra of Typical Resin Ash Particle

TABLE 4. Oxide Composition of As-Received and Calcined Trash Ash, Resin Ash, and Ball-Milled Blended Ash Determined by ICP and AA Analysis

Oxide(a)	Trash Ash		Resin Ash		Blended Ash(b)	
	As-Received	Calcined	As-Received	Calcined	As-Received	Calcined
Al ₂ O ₃	20.3	32.3	0.18	0.27	8.73	15.8
B ₂ O ₃	--	0.05	0.04	0.04	0.05	0.06
BaO	0.02	0.03	0.01	0.01	0.01	0.03
CaO	5.45	8.98	0.36	0.51	2.25	4.22
Co ₂ O ₃	0.21	0.36	0.69	0.94	0.49	0.90
Cr ₂ O ₃	0.04	0.05	0.04	0.05	0.03	0.06
CuO	0.13	0.31	10.3	12.5	5.81	10.4
Fe ₂ O ₃	0.94	1.32	40.1	53.4	20.6	35.9
K ₂ O	0.8	1.71	--	--	0.5	0.7
MgO	0.57	1.08	0.08	0.13	0.24	0.51
Na ₂ O	0.7	1.1	0.28	0.3	0.6	0.6
P ₂ O ₅	0.5	1.0	--	--	0.2	0.4
SiO ₂	25.1	41.0	0.72	1.0	11.3	20.7
SrO	0.11	0.17	0.24	0.39	0.19	0.37
TiO ₂	1.58	2.55	0.05	0.04	0.68	1.24
ZnO	0.08	0.40	0.07	0.1	0.08	0.13
ZrO ₂	--	--	0.01	0.03	0.21(c)	0.24(c)
Cs ₂ O	0.021	0.036	0.071	0.12	0.047	0.10
TOTAL	56.55	92.45	53.24	69.83	52.02	91.73

(a) Oxidation state is assumed.

(b) Resin and trash ash were mixed in a 325:268 weight ratio, in accordance with the mass of each type of ash collected.

(c) Values are high due to contamination from the zirconia grinding media.

TABLE 5. Percent of Spiking Chemicals Recovered

Chemical	Waste Ash Type		
	Trash	Resin	Blended
Cs	28	20	21
Sr	132	62	76
Co	107	75	83
I	0(a)	0(a)	0(a)

(a) Iodine was below detection limit in all samples.

As previously stated, Fe_2O_3 and CuO were added to the resin waste to simulate crud. The amounts of each of those compounds retained in the resin ash were 81 and 84%, respectively. These data are similar to the strontium and cobalt retentions in resin ash, which suggests that approximately 20% of the resin ash was lost due to factors such as entrainment in the off gas and adherence to the incinerator walls.

ASH CLINKERS

The clinkers, which were separated from the bulk ash by sieving through a 0.6 cm (1/4 in.) screen, comprised 12 wt% of the ash produced. Clinkers up to 20 cm (8 in.) long and 5 cm (2 in.) thick were recovered. To ensure that jamming of the cement and bitumen mixing systems would not occur when producing waste forms and to ensure that small representative waste forms would be made, clinkers were removed from the bulk ash. The same precaution would be necessary when operating an actual waste solidification system. Hence, a method of treating clinkers for disposal would be required. Possible methods include:

- directly disposing in drums
- washing to remove dust, drying, and then disposal
- grinding and solidifying, as with fine ash
- casting cement or bitumen around clinkers.

Analyses conducted to evaluate the suitability of clinkers for disposal are discussed below.

Appearance

Clinkers were very "sooty" because fine particles adhered to their surfaces. By rinsing the clinkers on a 20 mesh screen, we collected 4 wt% as "fines" in the rinse solution. This high fines content presents a dust dispersion concern.

Photos of two typical, large (~8 cm or 3 in. dia.) clinkers are shown in Figure 9. The clinker on the right originated from the combustion of trash (paper, plastic, rubber, cloth, and wood). Its surface is shiny blue and very porous. The clinker on the left originated from the combustion of ion exchange resins. It is grey-to-black and its surface is grainy.

Density

The densities and open porosities of three clinkers were determined (see Figure 10). Clinker A was produced during the incineration of resin waste, and clinkers B and C were produced during the incineration of trash. The clinkers were cleaned in water with ultrasonic agitation to remove fines and then dried. After weighing, the materials were immersed in water under a vacuum to saturate the open pores with water. The saturated samples were weighed, and then reweighed suspended in water. The calculated apparent density and open

FIGURE 9. Typical, Large Ash Clinkers

FIGURE 10. Types of Clinkers Used for Density Measurements

porosity of clinkers A, B, and C were 1.53 g/cm³ and 42%, 1.34 g/cm³ and 29%, and 2.44 g/cm³ and 18%, respectively.

The bulk density of grab samples of clinkers ranged from 0.5 to 0.6 g/cm³ or 240 to 290 lb per 210 L (55 gal) drum.

Calcination

Clinkers were separated into sample categories as follows:

- wood chip charcoal
- cinders
- small magnetic particles (probably originating from iron in resins to simulate crud)
- -20 mesh fines.

The four samples were calcined in air at 800°C for 18 hours and weighed, and then were recalcined at 1100°C for 18 hours and reweighed. Results are tabulated below:

TABLE 6. Clinker Weight Loss After Calcination

<u>Clinker Category</u>	<u>Wt% Loss at 800°C</u>	<u>Wt% Loss at 1100°C</u>
Wood chip charcoal	98.6	ND(a)
Cinders	1.1	1.1
Magnetic particles	2.2	2.8
-20 mesh fines	31.0	33.1

(a) not determined

For comparison, the bulk ash (after screening to remove clinkers) lost 41.8% of its weight when calcined at 800°C. It appears from these results that the clinkers, except wood chip charcoal, are essentially fully incinerated and require no further thermal treatment.

Friability

Approximately 100 g of representative smaller clinkers were ball-milled in alcohol for 6 hours to determine their "crushability." After ball-milling, 56 wt% of the original mass passed through a 20 mesh screen. A large fraction (~40 vol%) of material greater than about 2 mm was wood chips that failed to be reduced because the wood clinkers floated above the balls. Dry, mechanical comminution techniques, however, would easily reduce the wood chips, since they are totally charred and thus crush quite easily. The remaining clinkers, greater than 5 mm, appear to be of the same type and are very tough. However, they did break up when ground using a mortar and pestle. It appears, therefore, that mechanical crushing by a roller mill or disc mill would reduce

the size of clinkers sufficiently to allow their incorporation into either cement or bitumen. Provision must still be made for separating out metals and other tough materials which would jam the solidification process.

Leaching

Leaching tests were conducted on the clinker samples listed below to provide data for assessing the potential of direct disposal of washed and unwashed clinkers:

- grab sample (200 g)
- grab sample washed with water and dried before leaching
- 6 individual clinkers (3 washed and 3 as received; see Figure 11)
- -20 mesh fines removed from surfaces of clinkers.

We could not measure the sample surface areas because of their highly irregular geometries. Therefore leaching was conducted at a constant sample-mass-to-leachant-volume ratio of 100 g/L. Samples were leached at 90°C under static conditions for 14 days. Deionized water served as the leachant. Following leaching, the leachates were filtered through a 0.22 μm membrane and the pH was measured as shown in Table 7. The pH values of the fines leachate and unwashed clinker leachates are considerably lower than those of the washed samples. The leachate pH values of the fines and the as-received composite clinkers are the same (pH = 4.6), suggesting that the fines are the main factor in controlling solution pH.

Following leaching the various leachates and clinker samples were analyzed by Inductively Coupled Plasma Emission Spectrometry (ICP). Results are shown in Tables 8 and 9.

FIGURE 11. Individual Clinkers Subjected to Static, 90°C Leach Tests
A = as received,
W = washed

TABLE 7. Leachate pH Values After Leaching Various Ash Clinkers for 14 Days at 90°C

Sample	pH	
	As Received	Washed
200 g grab sample	4.60	5.73
Individual 1	5.75	7.73
Individual 2	6.74	9.80
Individual 3	5.25	7.64
Fines	4.60	--

The extent of dissolution of the nine samples tested appears to be dependent on the amount of small particles present which possess a high composite surface area. This is evidenced by comparing the washed and as-received clinkers. For example, the total ion content in solution from leaching the washed grab sample is 68% less than from leaching the as-received grab sample. However, pH also appears to have a pronounced effect on dissolution. The two samples that had the highest concentrations of ions in solution (fines and the as-received grab sample) also had the lowest leachate pH (4.6). The low pH of these solutions resulted in relatively high Fe concentrations in solution (>6 mg/L), whereas solutions with a pH of greater than 5.75 had less than the detection limit (0.005 mg/L). These low pH values may be of concern when considering direct placement of unwashed clinkers and even bulk ash in steel drums because of the possibilities of enhanced container corrosion rates and overall dissolution of the clinkers.

DISCUSSION OF ASH CHARACTERIZATION RESULTS

The presence of clinkers and the high carbon content in the ashes indicate that this study's incineration was not typical of that expected of an ideally-controlled CAI system. The ashes produced probably represent those that would be generated when the bulk density of the combustible wastes is too high, when the incinerator is charged at too high a rate, or when the incinerator is operated at too low an oxygen content or temperature. In spite of the best efforts to control a process, periods of poor operation periodically occur. Hence, the ash produced in this study is probably representative of ash that will occasionally be produced. Certainly the chemical composition of the ash (except for carbon) is typical of the expected average composition. However, because the applied incinerator will be charged with a wide variety of materials that will not always be well-blended, the ashes produced will vary considerably in chemical composition, including carbon content. Solidifying agents, such as concrete and bitumen, must be able to accommodate these expected variations in chemical composition. The results of the characterization of solidified ashes will be presented in a subsequent report. However, preliminary results indicate that the high-carbon ash produced in this study can be satisfactorily solidified in portland cement and bitumen.

TABLE 8. Concentration of Ions in Solution After Leaching
14 Days at 90°C in D.I. Water

Ion	Concentration in Solution								Fines (a)
	GS-A(a)	GS-W(a)	A-1(a)	W-1(a)	A-2(a)	W-2(a)	A-3(a)	W-3(a)	
Al	0.72	--(b)	0.03	0.03	0.05	1.47	0.34	0.05	0.31
B	1.11	0.74	0.08	0.07	0.04	0.01	0.48	0.07	2.30
Ba	0.04	0.14	0.15	0.01	0.08	--	0.06	0.07	0.05
Ca	127	49.6	24.3	3.98	14.6	17.9	228	5.31	508
Co	5.27	0.18	4.13	0.06	0.64	--	18.6	0.05	60.1
Cu	0.69	0.23	5.76	--	0.11	--	57.1	--	3.21
Fe	7.10	0.17	--	--	--	--	--	--	6.15
K	88.0	20.8	2.37	1.43	2.26	2.75	72.9	8.74	56.0
Li	0.21	0.08	0.03	0.02	0.03	0.09	0.66	0.06	0.46
Mg	13.1	3.51	3.23	0.66	1.80	0.03	26.0	0.78	92.4
Mn	2.98	0.45	0.11	0.01	0.05	--	1.31	--	5.45
Na	69.6	9.02	2.29	1.07	2.46	2.40	96.7	3.74	63.7
Ni	0.09	0.04	0.04	--	0.03	--	0.24	--	0.10
Si	88.7	33.7	19.6	9.07	12.2	0.17	57.1	16.7	110
Sr	11.3	15.0	3.94	0.55	1.90	0.12	9.02	0.83	12.2
Zn	1.38	0.04	0.43	--	0.08	--	3.15	--	4.36
Cs	6.30	1.80	1.10	0.28	0.56	0.22	4.50	0.43	22.5
pH	4.60	5.73	5.75	7.73	6.74	9.80	5.25	7.64	4.60

(a) GS = grab sample, A = as received, W = washed (see Table 7).

(b) Below the detection limit (typical).

TABLE 9. Oxide Composition of Individual Clinkers and Fines After Leaching

Oxide	Composition, wt%(a)						FINES(b)
	A-1(b)	W-1(b)	A-2(b)	W-2(b)	A-3(b)	W-3(b)	
Al ₂ O ₃	32.25	33.25	30.25	43.10	30.30	26.15	15.60
B ₂ O ₃	0.09	0.12	0.07	0.11	0.11	0.19	0.15
BaO	0.03	0.03	0.03	0.03	0.04	0.21	0.02
CaO	8.17	9.11	5.78	5.81	9.43	14.35	2.76
Co ₂ O ₃	0.39	0.17	0.03	--	0.15	1.78	0.39
Cr ₂ O ₃	0.04	0.04	--	--	0.06	--	--
CuO	0.27	0.24	0.23	0.24	0.99	0.39	5.13
Fe ₂ O ₃	1.00	0.81	1.96	1.13	2.18	0.98	15.65
K ₂ O	0.64	1.30	0.92	--	2.00	2.10	--
LiO ₂	0.03	0.02	--	--	0.02	0.03	--
MgO	0.60	0.46	0.33	0.24	0.86	1.25	0.27
MnO ₂	0.02	0.02	0.05	0.03	0.03	0.04	0.02
Na ₂ O	--	0.04	--	--	0.69	0.25	--
P ₂ O ₅	--	0.49	1.37	--	0.77	7.30	--
SiO ₂	38.65	39.25	23.10	30.10	35.00	31.40	18.30
SrO	0.22	0.11	0.04	0.02	0.10	0.85	0.14
TiO ₂	2.25	2.01	0.80	0.96	2.58	2.29	1.00
ZnO	--	--	0.08	--	0.09	0.06	0.11
ZrO ₂	0.38	0.03	0.01	0.08	0.05	--	0.04
Cs ₂ O	0.06	0.03	0.02	0.02	0.03	0.06	0.02
TOTALS	85.09	87.53	65.37	81.87	85.48	89.68	59.60

(a) Determined by average from KOH/Ni and Na₂O₂/Zr fusion and ICP analysis.

(b) A = as received, W = washed (see Table 7).

Although the ashes were not hygroscopic, they exhibited an acidic pH when water was added. This may signal a corrosion concern if hygroscopic materials are allowed to come into contact with the combustible materials during plant operations or if water is inadvertently added to stored ashes.

Analyses of "crud" and spiking materials in the ashes yielded somewhat confusing results. However, it can be confidently concluded that most of the cesium vaporized from the burning waste and virtually all of the iodine escaped. It is assumed that these waste components would be captured in the incinerator off-gas system and processed in the ash solidification system.

Clinkers generally were well-incinerated (i.e., they contained a low content of volatile chemicals). This suggests that further incineration will not reduce their quantity appreciably. Clinkers heated to 1100°C did not become a powder. Therefore, pneumatic methods of removing ash from an incinerator may not be successful, as clinkers would not be easily transported. Mechanical crushing of clinkers to allow them to be fed to the ash solidification process appears feasible. However, before this is done, tramp metals and other tough materials that might jam the process must be removed. Washing clinkers removes most of the dust that would be dispersible in a handling accident. However, the leach resistance of washed clinkers does not appear to be much greater than that of the fine ash. Because they are somewhat leachable and easy to crush, clinkers may not be well-suited to shallow land burial. Better methods of treatment include crushing and solidifying them with fine ash and directly incorporating them into a solidifying matrix.

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APPENDIX A

INCINERATOR OPERATING CONDITIONS FOR RESIN WASTE

TABLE A.1. Incinerator Operating Conditions for Run 1 (Sheet 1 of 4)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	1747	0	81.4		1000	1500	Rising
2	1824	30 min	78.2	159.6	1175	1600	Rising
3	1855	1 hr 8 min	79.2	238.8	1350	1675	Rising
4		2 hr 0 min	78.6	317.4	1550	1800	Rising
5	2038	2 hr 50 min	78.2	395.6	1550	1800	Rising
6	2106	3 hr 20 min	78.8	474.4	1450	1750	Rising
7	2133	3 hr 45 min	80.2	554.6	1500	1800	Rising
8	2202	4 hr 15 min	79.6	634.2	1500	1800	Rising
9	2250	5 hr 3 min	86.0	714.2	1450	1750	Rising
10	2310	5 hr 23 min	78.8	793.0	1450	1775	Rising
11	2335	5 hr 47 min	79.0	872.0	1450	1750	Rising
12		6 hr 13 min	79.6	951.6	1450	1800	Rising
13	0033	6 hr 40 min	79.4	1031.0	1500	1750	Rising
14	0112	7 hr 24 min	79.8	1110.8	1550	1800	Rising
15	0150	8 hr 3 min	79.2	1190.0	1500	1800	Rising

WASTE TYPE Resin

AVERAGE CHARGING RATE 148

AVERAGE UPPER CHAMBER TEMP 1743.3

AVERAGE LOWER CHAMBER TEMP 1428.3

ENGINEER - name Bruce Rising ; signature _____

TECHNICIAN - name John Faught ; signature _____

DATE 10/9/81

TABLE A.1. Incinerator Operating Conditions for Run 1 (Sheet 2 of 4)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	0225	8 hr 38 min	80.2	1270.2	1500	1800	Murin
2	0250	9 hr 3 min	80.4	1350.6	1500	1800	Murin
3	0320	9 hr 33 min	79.0	1429.6	1500	1800	Murin
4	0410	10 hr 23 min	80.4	1510.0	1500	1800	Murin
5	0450	11 hr 3 min	80.6	1590.6	1500	1800	Murin
6	0530	11 hr 43 min	75.4	1666.0	1500	1800	Murin
7	0610	12 hr 23 min	80.6	1746.6	1500	1800	Murin
8	0650	13 hr 3 min	80.2	1826.8	1500	1800	Murin
9	0730	13 hr 43 min	78.8	1905.6	1500	1800	Murin
10	0810	14 hr 23 min	77.6	1983.2	1500	1800	Murin
11	0850	15 hr 3 min	78.2	2071.4	1500	1800	Murin
12	0930	15 hr 43 min	78.8	2150.2	1500	1800	Murin
13	1010	16 hr 23 min	80.4	2230.6	1500	1800	Murin
14	1050	17 hr 3 min	87.4	2313.0	"	"	Webb
15	1130	17 hr 43 min	79.0	2392.0	"	"	Webb

WASTE TYPE Resin

ENGINEER - name Jeannette Murin ; signature _____

AVERAGE CHARGING RATE 125 lbs/hr

TECHNICIAN - name Earl Cox ; signature _____

AVERAGE UPPER CHAMBER TEMP 1800

DATE 10/10/81

AVERAGE LOWER CHAMBER TEMP 1500

TABLE A.1. Incinerator Operating Conditions for Run 1 (Sheet 3 of 4)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	1210	18 hr 23 min	80.4	2472.4	1500	1800	Webb
2	1250	19 hr 3 min	78.8	2551.2	1500	1800	Hupp
3	1330	19 hr 43 min	80.8	2632.0	1500	1800	Webb
4	1410	20 hr 23 min	78.6	2710.6	1500	1800	Webb
5	1450	21 hr 3 min	79.4	2790.0	1500	1800	Hupp
6	1530	21 hr 23 min	79.4	2869.4	1500	1800	Webb
7	1610	22 hr 23 min	79.8	2949.2	1500	1800	Webb
8	1650	23 hr 3 min	80.2	3029.4	1500	1800	Webb
9	1730	23 hr 43 min	79.8	3109.2	1500	1800	Rising
10	1800	24 hr 15 min	79.8	3189.0	1500	1800	Rising
11	1830	24 hr 45 min	79.6	3268.6	1500	1800	Rising
12	1900	25 hr 15 min	81.4	3350.0	1500	1800	Rising
13	1930	25 hr 45 min	76.8	3426.8	1500	1800	Rising
14	2010	26 hr 25 min	158.2	3585.0	1500	1800	Rising
15	2120	27 hr 35 min	80.2	3665.2	1450	1800	Rising

WASTE TYPE Resin

ENGINEER - name P. Webb ; signature _____

AVERAGE CHARGING RATE 129.8 lbs/hr

TECHNICIAN - name D. Hupp ; signature _____

AVERAGE UPPER CHAMBER TEMP 1800 F

DATE 10/10/81

AVERAGE LOWER CHAMBER TEMP 1496.7

TABLE A.1. Incinerator Operating Conditions for Run 1 (Sheet 4 of 4)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	2150	28 hr 5 min	80.6	3745.8	1500	1800	Murin
2	2220	28 hr 35 min	80.0	3825.8	1500	1800	Murin
3	2250	29 hr 5 min	80.2	3906.0	1500	1800	Murin
4	2320	29 hr 35 min	79.6	3985.6	1500	1800	Murin
5	2350	30 hr 5 min	81.4	4067.0	1500	1800	Murin
6	0150	32 hr 5 min	0	4067.0	1500	1800	Rising
7							
8							
9							
10							
11							
12							
13							
14							
15							

WASTE TYPE Resin

ENGINEER - name Jeannette Murin ; signature _____

AVERAGE CHARGING RATE 127.09 lb/hr

TECHNICIAN - name John Faught ; signature _____

AVERAGE UPPER CHAMBER TEMP 1800 F

DATE 10/10/81

AVERAGE LOWER CHAMBER TEMP 1500 F

APPENDIX B

INCINERATOR OPERATING CONDITIONS FOR GENERAL TRASH WASTE

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 1 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	1751		no. 1 58.4	58.4	1100	1450	MURIN
2	1800	9 mins	2 47.6	106.0	1300	1600	"
3	1808	17 mins	3 37.2	143.2	1250	2000	"
4	1815	24 mins	1 45.4	188.6	1500	1750	"
5	1825	34 mins	2 28.4	217.0	1500	1750	"
6	1830	39 mins	3 39.2	256.2	1500	1750	"
7	1850	59 mins	1 46.4	302.6	1400 ^{±*}	1700 ^{±*}	"
8	1900	1 hr 9 min	2 31.2	333.8	1650	1750	"
9	1925	1 hr 34 min	3 54.4	388.2	1450	1550	"
10	1945	1 hr 54 min	1 48.6	436.8	1420	1750	"
11	2025	2 hr 34 min	1 55.8	492.6	1500	1700	"
12	2050	2 hr 59 min	1 45.0	537.6	1530	1700	"
13	2110	3 hr 19 min	1 43.0	580.6	1660	1780	Faught
14	2130	3 hr 39 min	1 46.8	627.4	1900	2200	"
15	2150	3 hr 59 min	2 26.0	653.4	1775	1825	"

WASTE TYPE _____ ENGINEER - name Jeanette Murin ; signature _____
 AVERAGE CHARGING RATE 164.0 lb/hr ($\frac{653.4}{3 \text{ hr } 59 \text{ min}}$) TECHNICIAN - name John Faught ; signature _____
 AVERAGE UPPER CHAMBER TEMP 1750.3
 AVERAGE LOWER CHAMBER TEMP 1497 DATE 10/23/81

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 2 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	2210	4 hr 19 min	22.8	676.2	1820	1860	Faught
2	2220	4 hr 29 min	28.6	704.8	1780	1700	"
3	2230	4 hr 39 min	51.6	756.4	1740	2300	"
4	2300	5 hr 9 min	52.6	809.0	1800	2300	"
5	2330	5 hr 39 min	30.4	839.4	1840	1890	"
6	2350	5 hr 59 min	27.6	867.0	1700	1810	"
7	10	6 hr 19 min	42.0	709.0	1820	2030	"
8	30	6 hr 39 min	43.6	952.6	1750	2000	"
9	100	7 hr 9 min	30.2	982.8	1700	1800	"
10	115	7 hr 24 min	43.6	1026.4	1710	1880	"
11	125	7 hr 34 min	27.4	1053.8	1980	1980	"
12	145	1 hr 54 min	48.0	1101.8	1780	2080	"
13	2:05	8 hr 14 min	30.2	1132.0	1800	1820	"
14	2:30	8 hr 39 min	49.6	1181.6	1860	1680	"
15	2:45	8 hr 54 min	31.2	1212.8	1840	2380	"

WASTE TYPE

AVERAGE CHARGING RATE $117.1 \frac{\text{lb}}{\text{hr}} \left(\frac{536.6}{4 \text{ hr } 35 \text{ min}} \right)$

AVERAGE UPPER CHAMBER TEMP 1963.4

AVERAGE LOWER CHAMBER TEMP 1794.7

ENGINEER - name: signature

TECHNICIAN - name John Faught; signature Terry Sullivan

DATE 10/23, 24/81

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 3 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)*	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	3:30	9 hr 39 min	1 47.0	1259.8	1680	2500+	Faught
2	3:55	10 hr 4 min	2 30.2	1290.0	1650	T.C. Burnout	"
3	4:30	10 hr 39 min	1 47.0	1337.0	1570	1500	"
4	4:42	10 hr 51 min	2 32.2	1369.2	1480	2100	"
5	5:00	11 hr 9 min	1 48.6	1417.8	1500	2100	"
6	5:10	11 hr 19 min	3 31.6	1449.4	1800	2100	"
7	5:45	11 hr 54 min	1 43.8	1493.2	1000	1100	"
8	5:55	12 hr 4 min	2 31.2	1524.4	1800	2100	"
9	6:15	12 hr 24 min	1 49.8	1574.2	1450	1150	"
10	6:39	12 hr 48 min	2 29.6	1603.8	1920	1650	Murin
11	7:00	13 hr 9 min	1 51.6	1655.4	1450	1100	"
12	7:20	13 hr 29 min	2 32.2	1687.6	1850	1450	"
13	7:40	13 hr 49 min	1 50.4	1738.0	1600	1250	"
14	7:55	14 hr 4 min	2 30.2	1768.2	1800	1650	"
15	8:15	14 hr 24 min	1 52.0	1820.2	1500	1250	"

WASTE TYPE _____

AVERAGE CHARGING RATE $118.0 \frac{lb}{hr} \left(\frac{560.4}{4.75 hr} \right)$

AVERAGE UPPER CHAMBER TEMP 1642.9

AVERAGE LOWER CHAMBER TEMP 1596.7

ENGINEER - name Jeannette Murin ; signature _____

TECHNICIAN - name John Faught / Terry Sullivan ; signature _____

DATE 10/24/81

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 4 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	8:35	14 hr 44 min	² 30.8	1851.0	1800	1600	MURIN
2	8:45	14 hr 54 min	¹ 44.4	1895.4	1600	1300	"
3	9:10	15 hr 19 min	² 32.4	1927.8	1750	1400	"
4	9:30	15 hr 39 min	¹ 48.0	1975.8	1650	1200	"
5	9:50	15 hr 59 min	² 30.8	2006.6	2000	1500	SULLIVAN
6	10:10	16 hr 19 min	¹ 49.8	2056.4	1600	1250	"
7	10:35	16 hr 44 min	² 29.8	2086.2	1550	1450	MURIN
8	11:02	17 hr 11 min	¹ 53.0	2139.2	1400	1100	"
9	11:20	17 hr 29 min	² 30.0	2169.2	1700	1600	"
10	11:30	17 hr 39 min	¹ 54.0	2223.2	1650	1350	" #
11	12:10	18 hr 19 min	² 23.2	2246.4	1600	1250	"
12	12:30	18 hr 39 min	¹ 49.8	2296.2	1450	1100	"
13	12:55	19 hr 4 min	³ 43.6	2339.8	1650	1400	"
14	13:15	19 hr 24 min	¹ 55.2	2395.0	1500	1250	"
15	13:50	19 hr 59 min	¹ 43.6	2438.6	1600	1400	"

WASTE TYPE _____

AVERAGE CHARGING RATE $111.9 \frac{\text{lb}}{\text{hr}} \left(\frac{587.6}{5.25 \text{ hr}} \right)$

AVERAGE UPPER CHAMBER TEMP 1343.3

AVERAGE LOWER CHAMBER TEMP 1633.3

ENGINEER - name Jeannette Murin ; signature _____TECHNICIAN - name Terry Sullivan ; signature _____DATE 10/24/81

John Faught *

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 5 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	14:10	20 hr 19 min	² 29.4	2468.0	1650	1500	MURIN
2	14:35	20 hr 44 min	¹ 54.4	2522.4	1450	1100	"
3	15:00	21 hr 9 min	² 31.4	2553.8	1550	1450	"
4	15:22	21 hr 31 min	¹ 45.8	2599.6	1400	1100	"
5	15:45	21 hr 54 min	³ 54.6	2654.2	1750	1550	"
6	16:05	22 hr 14 min	¹ 48.4	2702.6	1600	1250	"
7	16:28	22 hr 37 min	² 29.0	2731.6	1700	1500	"
8	16:50	22 hr 59 min	¹ 48.4	2780.0	1500	1100	"
9	17:10	23 hr 19 min	² 29.6	2809.6	1900	1550	"
10	17:35	23 hr 44 min	¹ 45.6	2855.2	1500	1250	"
11	18:00	24 hr 9 min	³ 29.4	2884.6	1650	1550	"
12	18:30	24 hr 39 min	¹ 51.2	2935.8	1400	1800	"
13	18:50	24 hr 59 min	² 30.0	2965.8	1600	1400	"
14	19:10	25 hr 19 min	¹ 46.8	3012.6	1450	1100	"
15	19:22	25 hr 31 min	² 30.2	3042.8	1740	1700	"

WASTE TYPE _____ ENGINEER - name Jeannette Murin ; signature _____
 AVERAGE CHARGING RATE 110.5 ^{lb} (574.8) (5.2 hr) TECHNICIAN - name JOHN FAUENT signature _____
 AVERAGE UPPER CHAMBER TEMP 1393.3 DATE 10/24/81
 AVERAGE LOWER CHAMBER TEMP 1589.3

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 6 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	19:45	25 hr 54 min	37.6	3080.4	1600	1300	MURIN
2	20:00	26 hr 9 min	60.8	3141.2	1800	1700	"
3	20:20	26 hr 29 min	41.4	3182.6	1550	1250	"
4	20:45	26 hr 54 min	30.4	3213.0	1600	1450	"
5	21:08	27 hr 17 min	47.2	3260.2	1450	1100	"
6	21:30	27 hr 39 min	32.4	3292.6	1600	1450	"
7	21:55	28 hr 4 min	45.6	3338.2	1400	1100	"
8	22:15	28 hr 2 min	29.4	3367.6	1650	1450	"
9	22:40	28 hr 49 min	48.4	3416.0	1450	1150	"
10	23:00	29 hr 9 min	56.0	3472.0	1800	1450	"
11	23:20	29 hr 29 min	42.8	3514.8	1500	1200	"
12	23:45	29 hr 54 min	25.2	3540.0	1650	1450	"
13	0:08	30 hr 17 min	52.6	3592.6	1400	1200	"
14	0:30	30 hr 39 min	29.8	3622.4	1800	1750	SULLIVAN*
15	0:50	30 hr 59 min	47.6	3670.0	1500	1300	"

WASTE TYPE _____

AVERAGE CHARGING RATE 116.0 lb/hr ($\frac{589.6}{5.0833 \text{ hr}}$)

AVERAGE UPPER CHAMBER TEMP 1353.3

AVERAGE LOWER CHAMBER TEMP 1583.3

ENGINEER - name J. Murin / J. Faught; signature _____

TECHNICIAN - name T. Sullivan / E. Cox; signature _____

DATE 10/24, 25/81

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 7 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	1:22	31 hr 31 min	³ 31.4	3701.4	1500	1350	SULLIVAN
2	1:52	32 hr 1 min	¹ 51.0	3752.4	1300	1100	"
3	2:10	32 hr 19 min	² 30.2	3782.6	1800	1600	"
4	2:30	32 hr 39 min	¹ 47.8	3830.4	1550	1200	"
5	2:49	32 hr 58 min	² 29.8	3860.2	1750	1600	"
6	3:09	33 hr 18 min	¹ 42.8	3903.0	1600	1200	"
7	3:25	33 hr 34 min	² 32.8	3935.8	1700	1700	"
8	3:40	33 hr 49 min	¹ 47.6	3983.4	1550	1250	"
9	4:03	34 hr 12 min	³ 54.8	4038.2	1600	1600	"
10	4:20	34 hr 29 min	¹ 47.0	4085.2	1700	1400	"
11	4:44	34 hr 53 min	² 29.0	4114.2	1650	1500	"
12	5:00	35 hr 9 min	¹ 43.4	4157.6	1500	1300	"
13	5:15	35 hr 24 min	³ 46.4	4204.0	1800	1700	"
14	5:33	35 hr 42 min	¹ 45.6	4249.6	1600	1300	"
15	5:51	36 hr	² 28.6	4278.2	1800	1700	"

WASTE TYPE _____
 AVERAGE CHARGING RATE 128.7 ^{lb} hr (576.8 / 4.4833)
 AVERAGE UPPER CHAMBER TEMP 1433.3
 AVERAGE LOWER CHAMBER TEMP 1626.7

ENGINEER - name _____; signature _____
 TECHNICIAN - name E. Cox, T. Sullivan; signature 7
 DATE 10/25/91

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 8 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	6:03	36 hr 12 min	44.6	4322.8	1700	1400	SULLIVAN
2	6:52	37 hr 1 min	45.5	4368.3	1300	900	"
3	7:06	37 hr 15 min	45.8	4414.1	1400	1100	"
4	7:25	37 hr 34 min	30.4	4411.5	1700	1650	"
5	7:37	37 hr 46 min	54.0	4498.5	1600	1300	"
6	8:20	38 hr 29 min	56.8	4555.3	1300	1000	"
7	8:45	38 hr 54 min	50.0	4605.3	1400	1100	"
8	9:15	39 hr 24 min	29.6	4634.9	1400	1300	"
9	9:35	39 hr 44 min	49.8	4684.7	1300	1100	MURIN *
10	10:00	40 hr 9 min	29.0	4713.7	1500	1500	"
11	10:25	40 hr 34 min	39.8	4753.5	1300	1100	"
12	10:45	40 hr 54 min	36.6	4790.1	1550	1400	"
13	11:10	41 hr 19 min	50.8	4840.9	1450	1150	"
14	11:30	41 hr 39 min	61.2	4902.1	1650	1550	"
15	12:00	42 hr 9 min	37.8	4939.9	1450	1150	"

TC
Burnout

B.8

WASTE TYPE _____

AVERAGE CHARGING RATE 103.7 ^{lb} (67.1) / hr (5.95)AVERAGE UPPER CHAMBER TEMP 1246.7AVERAGE LOWER CHAMBER TEMP 1466.7ENGINEER - name J. Murin * ; signature _____TECHNICIAN - name T. Sullivan / E. Cox ; signature _____DATE 10/25/81

TABLE B.1. Incinerator Operating Conditions for Run 2 (Sheet 9 of 9)

INCINERATOR OPERATING CONDITIONS							
No.	Time (100's hrs)	Length of Operation (hrs)	Wt. of Charge (lbs)	Total Wt Fired (lbs)	Lower Chamber Temp (F)	Upper Chamber Temp (F)	Entered by
1	12:30	42 hr 39 min	² 29.0	4968.9	1650	1250	Murin
2	12:50	42 hr 59 min	¹ 49.0	5017.9	1450	1100	"
3	13:10	43 hr 19 min	² 29.0	5046.9	1700	1500	"
4	13:30	43 hr 39 min	¹ 45.4	5092.3	1550	1200	"
5	13:55	44 hr 4 min	¹ 48.4	5140.7	1500	1350	"
6	14:35	44 hr 44 min	¹ 45.0	5185.7	1650	1250	"
7	15:05	45 hr 14 min	¹ 44.8	5230.5	1600	1350	"
8	15:30	45 hr 39 min	¹ 41.8	5272.3	1700	1450	"
9	15:55	46 hr 4 min	¹ 42.0	5314.3	1800	1400	"
10	16:15	46 hr 24 min	¹ 39.4	5353.7	1650	1550	"
11	16:35	46 hr 44 min	¹ 44.6	5398.3	1600	1550	"
12	17:00	47 hr 9 min	¹ 46.4	5444.7	1500	1500	"
13	17:25	47 hr 34 min	¹ 44.8	5489.5	1600	1400	"
14	17:50	47 hr 59 min	¹ 36.4	5525.9	1550	1500	"
15	18:15	48 hr 24 min	¹ 46.2	5572.1	1650	1450	"
16	18:35	48 hr 44 min	¹ 45.6	5617.7	1550	1600	"

WASTE TYPE _____
 AVERAGE CHARGING RATE 106.7 hr (648.8 / 6.0833)
 AVERAGE UPPER CHAMBER TEMP 1400
 AVERAGE LOWER CHAMBER TEMP 1606.3

ENGINEER - name J. Murin ; signature _____
 TECHNICIAN - name J. Faught ; signature _____
 DATE 10/25/81

APPENDIX C

MASS SPECTROMETRY OF GAS COMPONENTS OF ASHES

FIGURE C.1. Trash Ash Mass Spectrometry for CO₂(44), H₂O(18), N₂(29) and NO(30)

C.2
THO PK. HEIGHT

FIGURE C.2. Trash Ash Mass Spectrometry for CO₂(45), SO₂(64), and SO₂(48)

TRASH ASH

FIGURE C.3. Trash Ash Mass Spectrometry for H₂S(34), and CH₄(15)

C.4.0

PK. HEIGHT

FIGURE C.4. Trash Ash Mass Spectrometry for CO₂(46)

FIGURE C.5. Trash Ash Mass Spectrometry for CO₂(12)

FIGURE C.6. Trash Ash Weight Loss Versus Temperature

PK. HEIGHT

FIGURE C.7. Resin Ash Mass Spectrometry for N₂(29), CO₂(44), H₂O(18) and NO(30)

FIGURE C.8. Resin Ash Mass Spectrometry for CO₂(45), SO₂(48), and SO₂(64)

RESIN ASH

FIGURE C.9. Resin Ash Mass Spectrometry for CH₄(15), and H₂S(34)

FIGURE C.10. Resin Ash Mass Spectrometry for CO₂(46)

FIGURE C.11. Resin Ash Mass Spectrometry for $\text{CO}_2(12)$

FIGURE C.12. Resin Ash Weight Loss Versus Temperature

FIGURE C.13. Blended Ash Spectrometry for $N_2(29)$, $CO_2(44)$, $H_2O(18)$ and $NO(30)$

BLENDING ASH, AS RECEIVED

FIGURE C.14. Blended Ash Mass Spectrometry for $\text{CO}_2(46)$, $\text{SO}_2(48)$, and $\text{SO}_2(64)$

C.15

BLENDING ASH, AS RECEIVED

FIGURE C.15. Blended Ash Mass Spectrometry for H_2S (34) and CH_4 (15)

FIGURE C.16. Blended Ash Mass Spectrometry for NO(30), N₂(29), CO₂(44), and H₂O(18)

BLENDING ASH, AS RECEIVED

FIGURE C.17. Blended Ash Weight Loss Versus Temperature

FIGURE C.11. BLENDING WITH WEIGHT LOSS AGAINST TEMPERATURE

BLENDING WITH WEIGHT LOSS AGAINST TEMPERATURE

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