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OPERATION OF A PILOT ALPHA WASTE INCINERATOR AT THE SAVANNAH RIVER LABORATORY

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INTRODUCTION

A test program is in progress at SRL (Savannah River Laboratory) to confirm and develop incinerator design technology to provide design bases for alpha waste incinerators. Incineration will be employed to convert the transuranic combustible wastes to a chemically inert form and reduce its storage volume. This report summarizes the design, initial operating experience, and the results of combustion tests performed in a 0.5 kg/hr pilot incinerator. These results are to be used as a basis for designing and operating a full-scale 5 kg/hr incinerator.

SUMMARY

The pilot incinerator was built and operated successfully at design throughput with simulated wastes. Operating ranges of stable incinerator performance were defined as a function of air and waste feed rates for different materials and mixtures of materials. The complete range of waste materials can be burned without producing tar or soot. The limiting capacity of this

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incinerator is 0.5 kg/hr if all latex rubber is charged or ∿0.84 kg/hr with a waste mixture. Off-gas particulate sampling prior to scrubbing indicates negligible solid carryover. The only material which may present off-gas cleaning problems is a light white smoke which accompanies the burning of PVC (polyvinyl chloride). This is due to volatile metallic oxides and chlorides from plasticizers and stabilizers in the plastics. Aqueous scrubbing should effectively remove these particulates.

The incinerator was operated continuously at temperatures between 850 and 1000°C from startup on September 6, 1977 until February 2, 1978, when it was shut down for modifications, inspection, and repair. The 3.6-kW electric heater for the primary combustion chamber burned out on January 13; however, adequate burning temperatures were provided by the eight 1.25-kW heaters in the afterburner to maintain sootless burning. As a result, future incinerator operation will be at 900°C rather than 1000°C with no reduction in burning efficiency and probable increased lifetime of incinerator components.

When the incinerator was inspected after 5 months of operation, the condition of the ceramics was very good. No soot or dust accumulated in the afterburner, and no material stuck to or melted into the cast refractory primary hearth. Minor cracks were noted in the primary refractory casting and in several mortar joints, but they were not considered serious structural defects. The metal components of the incinerator showed no deterioration or serious corrosion.

The incinerator was modified by installing a different design gas burner block, and two baffles and a choke in the afterburner to increase turbulence and mixing.

The incinerator was started up again on February 27, 1978, and testing was resumed.

DISCUSSION

Background

An experimental program is currently being conducted at the Savannah River Laboratory to confirm and develop technology for burning solid TRU (transuranic) waste in support of short- and long-term waste management objectives, and alternate (commercial) fuel cycle studies.

A controlled-air two-stage incineration process was chosen after a survey of current literature, visits to other DOE (Department of Energy) sites, and foreign nuclear facilities. In this method of incineration, solid wastes are pyrolyzed in an air-starved primary combustion chamber, and the evolved gases are burned in excess air in an afterburner or secondary combustion chamber. The advantage of this method in TRU solid waste application is that there is a minimum of ash and solids entrainment in the off-gas and a maximum retention of the radioactivity in the ash residue.

Description of the Pilot Incinerator

The pilot incinerator is being tested to determine the fluid dynamics of the system, thermal cycling behavior, soot and dust entrainment, and off-gas cleaning, and to evaluate construction materials. Uncontaminated combustible waste is shredded, packaged, and fed to the pilot two-stage controlled-air incinerator. Distinguishing features of the SRL incinerator are:

- *All-electric.* Auxiliary fuel (gas or oil) is excluded from the design for intrinsic safety. The pyrolysis (primary) chamber is heated through an *Inconel** 601 roof plate. Ceramic-sheathed SiC (silicon carbide) heaters are located in the combustion (secondary) chamber.
- *All-ceramic firebox* except primary roof. The primary chamber hearth is a U-shaped trough of cast refractory. The afterburner (secondary combustion chamber) is refractory with insulating brickwork.
- *Compact design* for space and energy conservation. The primary and the multiple secondary channels are horizontal with several common walls. The primary chamber, where endothermic pyrolysis takes place, is above the first secondary channel, where exothermic combustion takes place. The entire incinerator is contained in a rectangular steel shell, 28 in. wide × 39 in. high × 68 in. long.

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* Trademark of Huntington Alloys, Inc.

Figure 1 shows side and cross-sectional views of the pilot incinerator. The waste is shredded and wrapped in a paper container approximately 2.5 inches in diameter by 6 inches long. The waste is loaded into the incinerator at the top and pushed into and along the U-shaped primary chamber by the ram. The waste package is semipyrolyzed in the cast refractory primary chamber, which is heated by a 3.6-kW electric heater on top of an *Inconel* 601 plate covering the chamber. Ash falls into the ash drawer for intermittent removal. The pyrolysis gas and nitrogen from the air supply will pass through a gas burner block. Excess air enters at the block. Eight 1.25-kW silicon carbide heaters preheat the afterburner to 1000°C and supplement combustion heat to maintain that temperature. The burned gas then exits the afterburner to an off-gas cleanup system before release to the atmosphere.

All of the firebricks in the incinerator that are exposed to pyrolysis gases are made from Babcock and Wilcox SR-90 firebrick. The primary chamber is cast from B&W's *Kao-Tab CS* and coated with *Super* 3000,* a protective layer of $Al_2O_3 + SiO_2$. Both *Kao-Tab CS* and SR-90 have high alumina contents (about 90%) to resist attack by fluoride. The SR-90 and *Kao-Tab CS* are insulated with K-30 insulating brick and high-temperature insulation.

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* Trademark of Combustion Engineering Inc. Refractories.

Safety features provided in the design include the following:

- The refractory structure is enclosed by a 1/8-inch protective steel shell, to guard against unexpected pressurization and provide a more airtight system. Between the refractory and the steel shell is 1.0 inch of *Fiberfrax** insulation which reduces the temperature of the steel shell to ∿100°C. All exhaust pipes exiting the incinerator are also well insulated by standard methods.
- A relief device set at 0.25 psig is installed on the incinerator. Its inlet leads directly from the afterburner to relieve any sudden pressurization in the incinerator.
- The waste loading mechanism was designed so that no direct path between the operator and the pyrolysis chamber exists (Figure 2). At the ash removal end, a sliding door is provided that slides between the operator and the fire before the ash box is removed.
- Nitrogen addition into the afterburner for rapid quenching is provided via a three-way valve prior to the air preheater entering the afterburner. Should temperatures in the incinerator get too high, a manual button switch will turn off the air and turn on the nitrogen, which stops burning and reduces

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* Trademark of Carborundum Company.

the temperature. A diaphragm-actuated valve that will modulate combustion air supply as a function of afterburner temperature is provided as a means of automatic control.

Off-gas processing includes cooling and scrubbing. Acid, mainly HCl from the incineration of chlorinated plastics, is scrubbed with water in a gas-liquid adsorber. The off-gas system consists of an ejector and a plexiglass packed scrubber column mounted on a stainless steel 55-gallon drum as shown in Figure 3. An insulated incinerator exhaust pipe leads from the incinerator to the ejector. A PVC stack goes from the scrubber to the outside of the building. The system scrubs HCl and heavy metal oxides out of the exhaust. The air and water exiting the ejector is ∿15°F warmer than the inlet water temperature. Operating temperatures therefore present no hazard to the plexiglass column or to the PVC stack. A continuous water spray (∿1 gpm) runs through the scrubber at all times. This protects the plexiglass scrubber and PVC stack from hot gases which are drawn by a natural draft through the system even when the ejector is turned off.

Construction and Startup

Photographs taken during construction of the pilot incinerator are shown in Figures 4 and 5. The masonry structure of the afterburner was built upon a steel baseplate. Ceramic tubes which contain the SiC heater rods were cemented into the afterburner walls. The U-shaped primary burner hearth was cast separately of castable refractory and inserted in the channel formed by the masonry walls. The primary casting is removable and designed for easy access and replacement. An angle-iron framework secures the steel shell panels. Insulation blanket installation is shown in Figure 5, which also shows the black mastic coating applied to the inside surfaces of the shell panels. The mastic coating is to protect the steel from HCl fumes during the incineration of PVC.

During startup of the incinerator, the temperature was held at 100°C to drive the excess water out of the primary casting and the mortar joints. After 36 hours, the water was driven off and the temperature was gradually increased to 1000°C over a 3-day period.

Waste Materials Incinerated and Incinerator Performance

Nuclear production processes generate a variable mixture of combustible TRU waste. A typical composition has been estimated to be:

Material Type	*Volume Percent*
Cellulosic	26
PVC	22
Polyethylene	17
Rubber	17
Other	9
Noncombustibles	9

Table 1 lists the materials tested in the incinerator and considered representative of the waste composition and form. Several materials such as PVC shoecovers and *Tygon** tubing have a similar chemical base but differ considerably in form and plasticizers.

Operating limits were initially defined for airflows and waste feed rates that produced burning in the afterburner and a smokeless exhaust (without off-gas scrubbing). Operating regions of airflow and feed package size are shown in Figure 6 for the different waste materials. An operating region is bounded by two straight lines. The lower line is set by the stoichiometric air requirement for the waste package size. The upper line is caused by lean air to fuel ratios or high air velocities causing flame-outs in the afterburner and subsequent reignitions. This re-ignition causes sudden pressurizations up to 15 inches of H_2O (called "Whoofing") and is an unstable operating area. Airflows and waste feed sizes within these two limiting boundaries provide quiet, controlled and consistent burning of the waste with no measurable particulate. For example, 30-gram packages of waste mixtures can be incinerated effectively by 3-6 SCFM of combustion air at the rate of one package every 2-1/2 minutes or 0.72 kg/hr. An all latex feed package is the most restrictive, 20-g packages every 2-1/2 minutes at 6 SCFM for a rate of 0.48 kg/hr (Figure 6).

Figure 7 shows the percentage oxygen in the incinerator exhaust as a function of time for a 20-g latex package burned at

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* Trademark of U. S. Stoneware Co.

700°C. This change in the oxygen demand is used to infer pyrolysis rates of waste packages in the incinerator primary chamber. These data are being used to evaluate calculated pyrolysis rates derived from theoretical and empirical models.

Off-gas composition and particulate samples were taken. Ash samples were analyzed for carbon content, and both ash and particulate samples were spectrographically analyzed (Tables 1 and 2). Table 3 indicates the particle size and density of the sampled ash. Particulate samples were taken in the hot exhaust from the incinerator. Quantities of particulate were found to be insignificant unless the incinerator was fed beyond the stoichiometric air demand. Figure 8 shows the particulate size distribution for a typical TRU waste material mix; 60% of the particulates are greater than one micron. In terms of off-gas cleanup equipment requirements a venturi or a fibrous-bed scrubber would appear to be necessary to remove the small particulates from a production incinerator.

The only material which may present off-gas cleaning problems is a light white smoke which accompanies the burning of PVC. This is due presumably to volatile metallic oxides and chlorides from plasticizers and stabilizers in the plastics. Aqueous scrubbing should effectively remove these particulates.

Residence times for combustion gases in the incinerator were measured and found to be about one-third that calculated for plug flow (Figure 9). This indicates that the addition of chokes and baffles to increase turbulence is desirable to increase utilization of the afterburner volume.

Shutdown Inspection

The condition of the incinerator was very good after five months of continuous operation. There were no dust or soot accumulations in the primary or afterburner. Minor cracks were noted in the primary but they are not considered to be serious structural defects (Figure 10). The largest cracks are high on the left side of the U-shaped primary casting and are attributed to temperature gradients through the casting wall. The flat plate heater was shifted to the left side of the trough in order for the thermocouples to be inserted in the thermowell as shown in Figure 11. The inside surface was cooler due to a constant airflow and in tension compared to the interface of the primary casting with the adjacent firebrick wall which was hotter, and hence in compression. This force couple cracked the left side of the trough. There was an air gap on the right side, between the casting and the firebrick wall. With the heater being shifted to the other side and the air gap which tended to moderate the high temperatures, the relative compression was not severe enough to cause cracking. As a result of this analysis, an air gap will be designed into both sides of any future replacement primary casting and the incinerator firebrick walls. Small cracks in the bottom of the trough were found adjacent to a thermocouple well.

These cracks are attributed to stress risers caused by the thermowell. No materials stuck to or accumulated in the castable refractory primary surface. Figure 12 shows the interior of the afterburner. The heater sheaths are intact and show no visible cracking where they are cemented into the firebrick. The rough surface visible on some of the tubes is due to mortar which dropped on the tubes while laying the course of bricks on top of the afterburner channel. The small cracks observable between the bricks are expected to close at operating temperatures.

A *Vycor** (96% silica) thermocouple well was found broken off in the afterburner. Upon further inspection, it was found that the glass had devitrified from chemical attack by the off-gas (Figure 13a). The 304 stainless steel thermal shield on the exhaust thermocouple was completely corroded and had no structural strength. The *Inconel* 601 metal plate covering the primary chamber was in excellent condition considering the temperatures (up to 1500°C) and corrosive gases present. The plate underside was slightly discolored green over the vertical ash pit section; a light black oxide was on the top of the plate at the heater interface. Figure 13b shows the failed electric heater and blobs of the *Kanthal* A-1** alloy heater which froze to the *Inconel* plate. This heater failed when temperatures in the primary chamber were briefly allowed to exceed the melting point of the *Kanthal* A-1 alloy (1482°C).

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* Trademark of Corning Glass Works.
** Trademark of Kanthal Corporation.

Modifications to the Pilot Incinerator

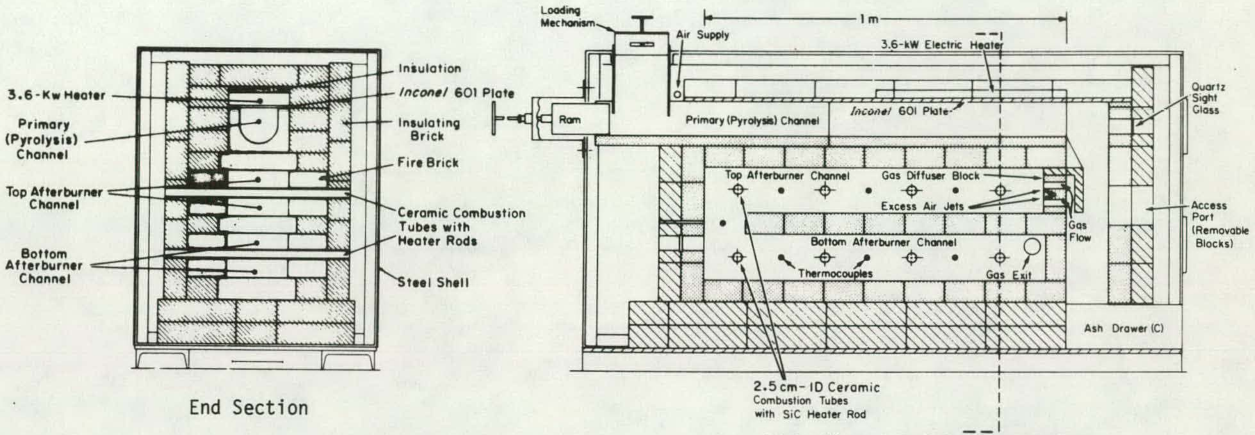
A new design burner block which allows premixing of some of the secondary air with the primary waste gases has been installed. Figure 14 shows the original burner block design and the new design. The purpose of the new design is to provide a flame holder with a rich flame at low fuel (waste gas) to air ratios between waste chargings. Firebrick chokes and baffles have been placed in the afterburner to increase turbulence and mixing of the hot gases.

PROGRAM

A high degree of completeness of combustion is required in nuclear waste application to minimize the off-gas particulate load which will block HEPA (high efficiency particulate air) filter flow. Off-gas liquid scrubbing will reduce the particulates in the gas but create a radioactive sludge problem in the scrub liquor as well as cause HEPA filter moisture problems. The best method of reducing particle loading of the off-gas is efficient incinerator design.

The effect of the incinerator modifications will be determined. An off-gas heater, HEPA filter, and high volume blower are to be added to the present incinerator system. The scrubber will be modified for closed cycle operation to determine acidity and sludge buildup.

Work to develop computer design codes for incinerator scale-up will involve parametric studies of the effects of temperature, air, and waste package geometry and size on waste burning in the primary combustion chamber.



End Section

Side View

FIGURE 1. Pilot-Scale SRL Incinerator

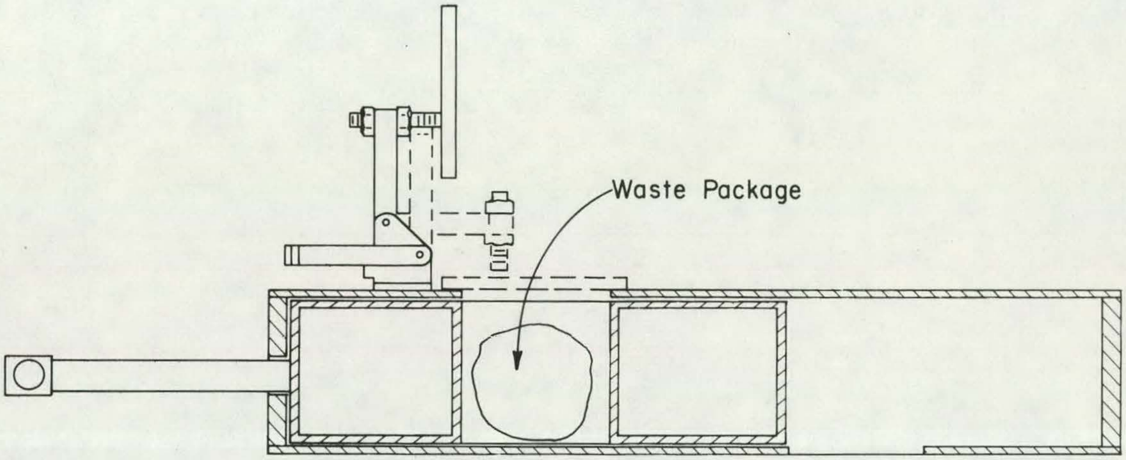


FIGURE 2. Waste Loader

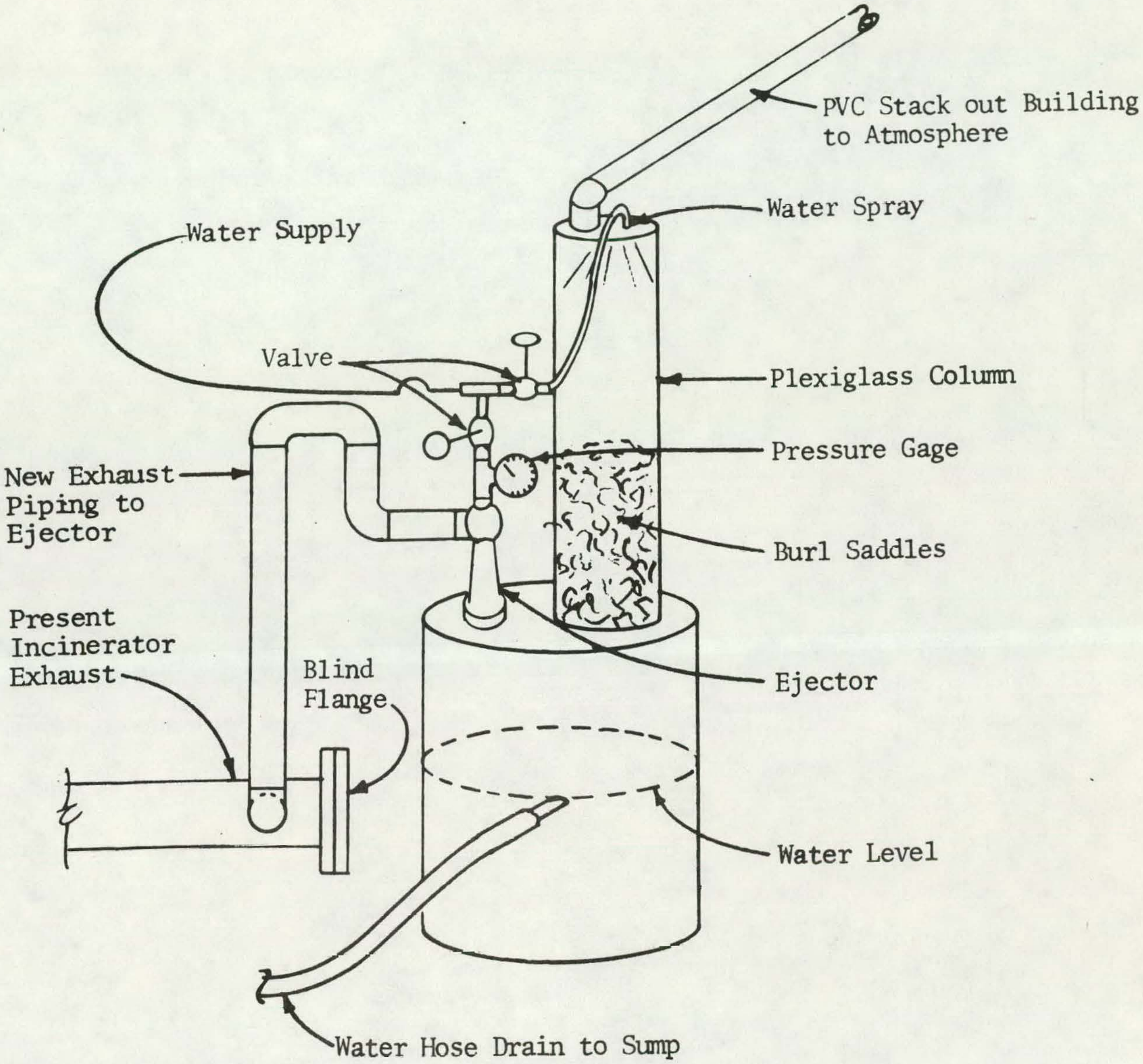
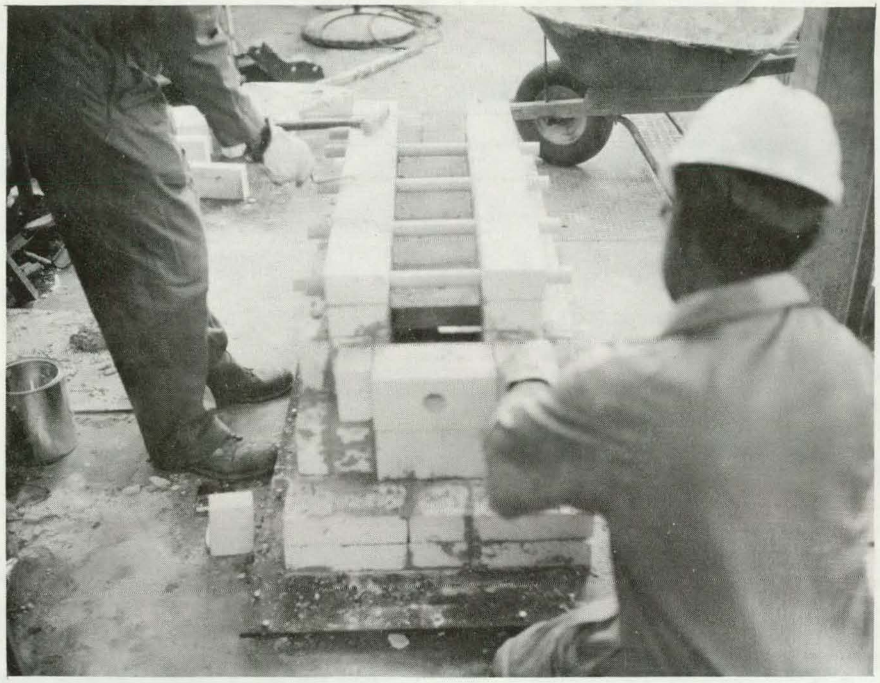


FIGURE 3. Schematic of Incinerator Off-Gas System



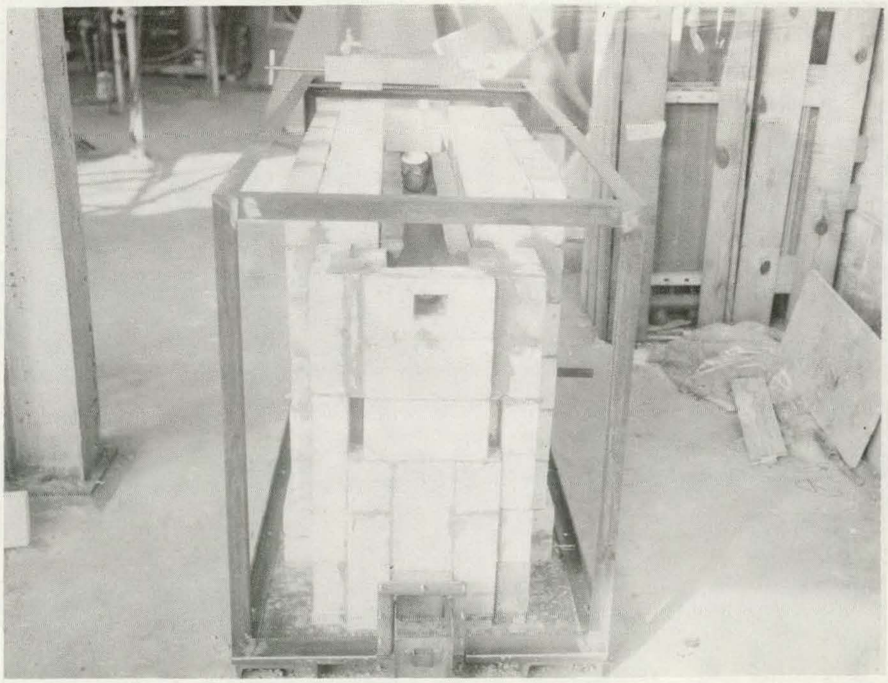
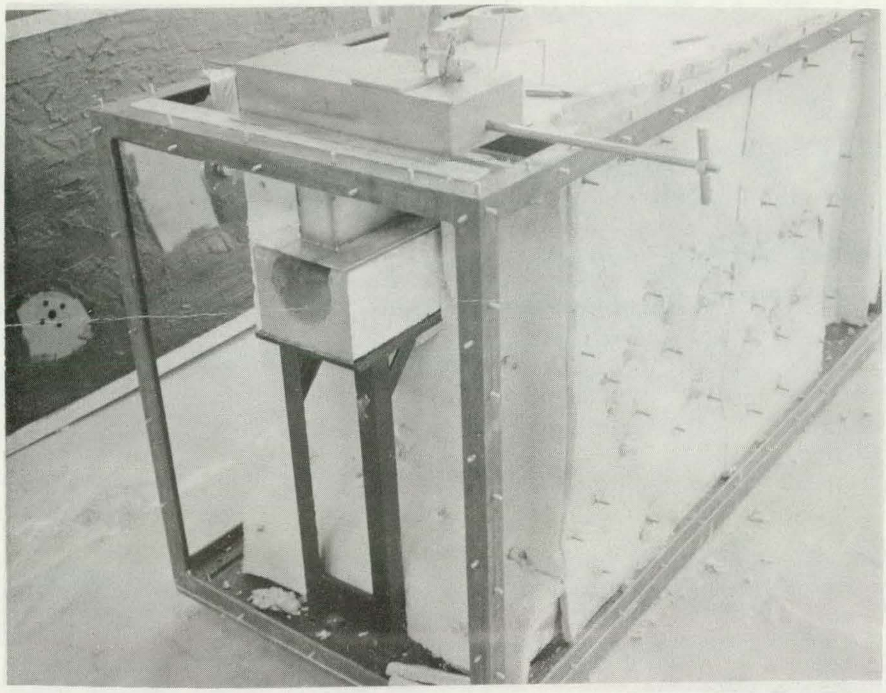


FIGURE 4. Incinerator Construction



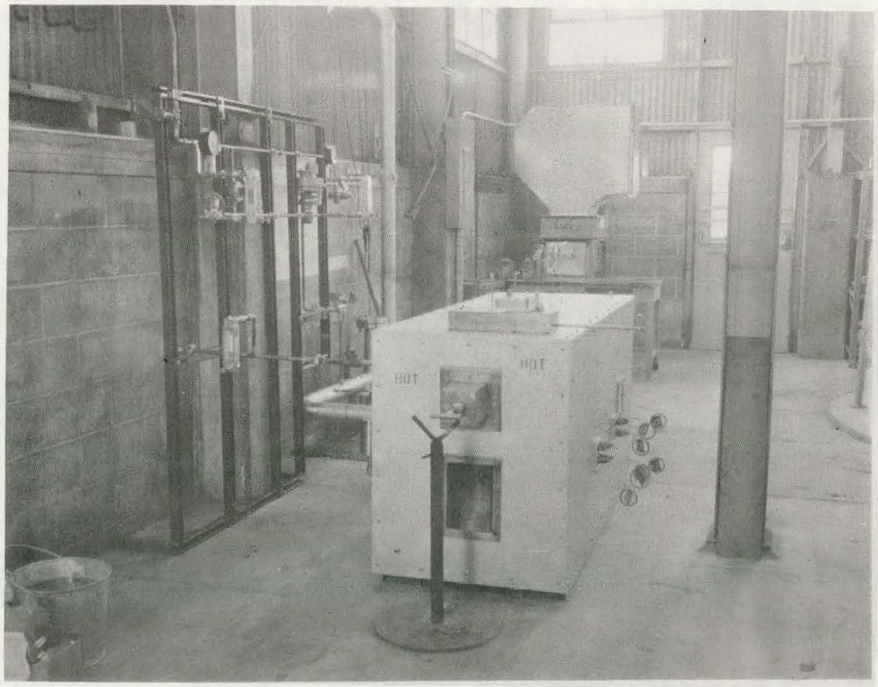


FIGURE 5. Incinerator Construction (Continued)

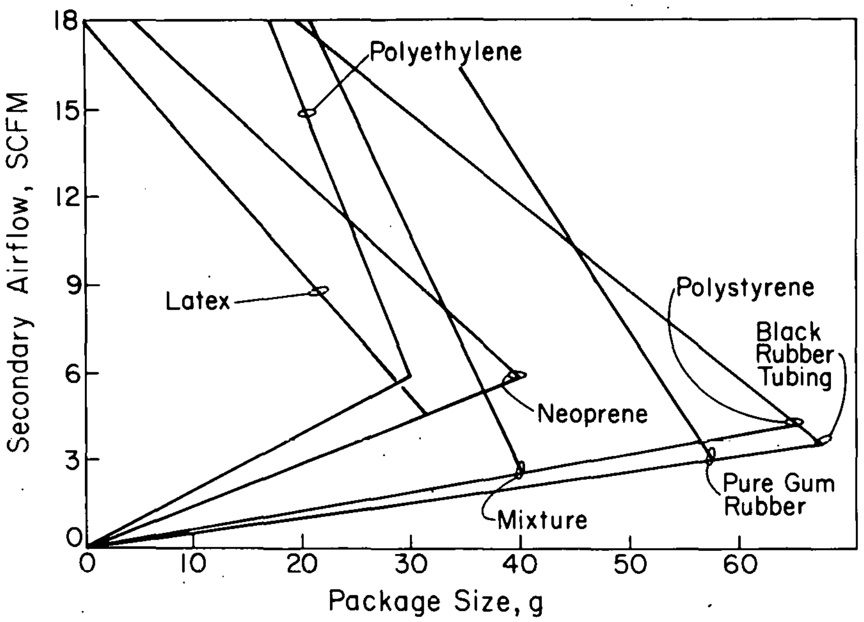


FIGURE 6. Smokeless Burning Conditions for Various Waste Components

Operation is recommended within the indicated triangles for each material.

Cellulose burns well at all observed air/fuel ratios. PVC and *Tygon* give a light white smoke at all air/fuel ratios.

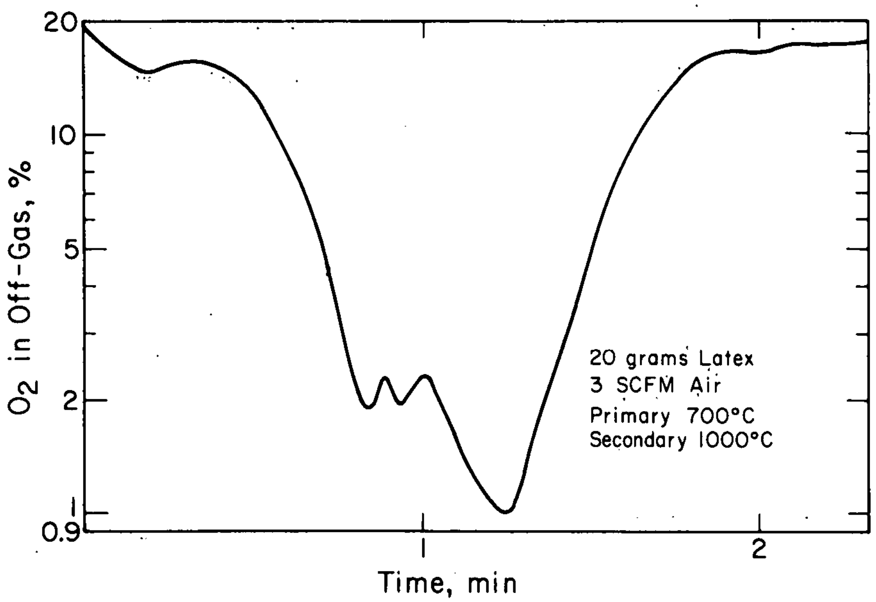


FIGURE 7. Typical Waste Package Burning Cycle as Determined by Oxygen Depletion in the Incinerator Exhaust

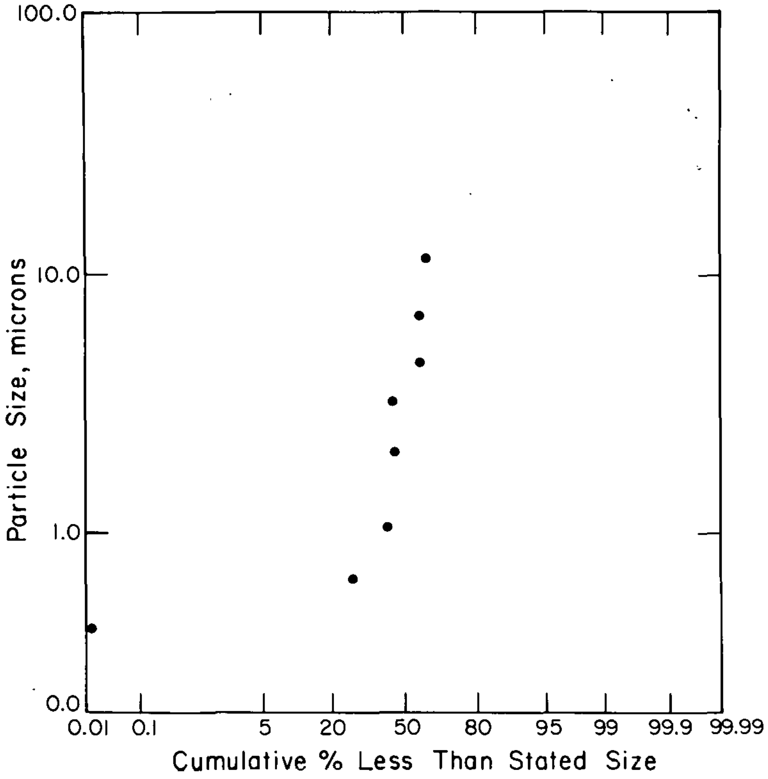


FIGURE 8. Particulate Sizes in Exhaust of Incinerator when Typical Alpha Waste Mix is Burned with Substoichiometric Air

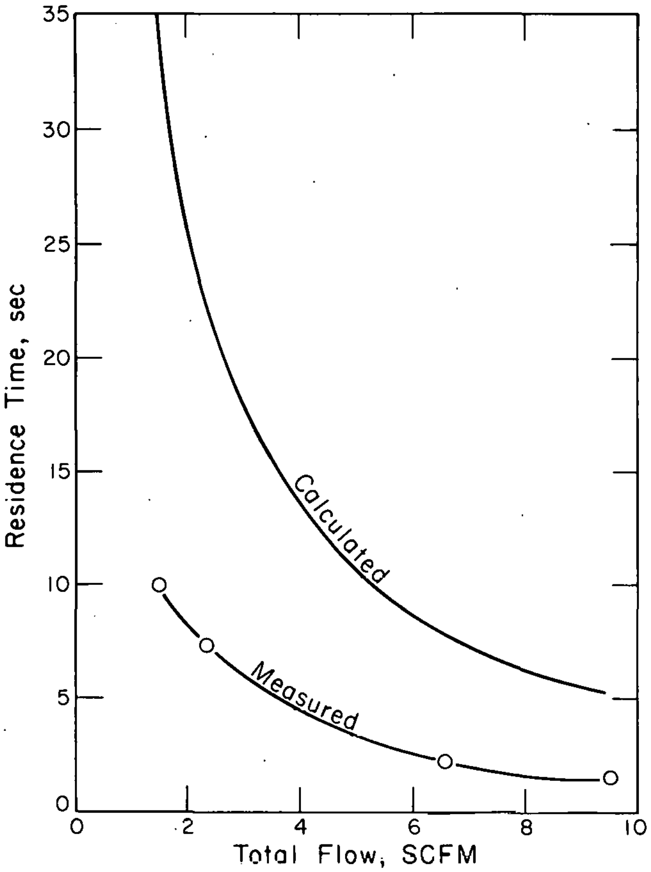


FIGURE 9. Gas Residence Time in Pilot Incinerator Afterburner

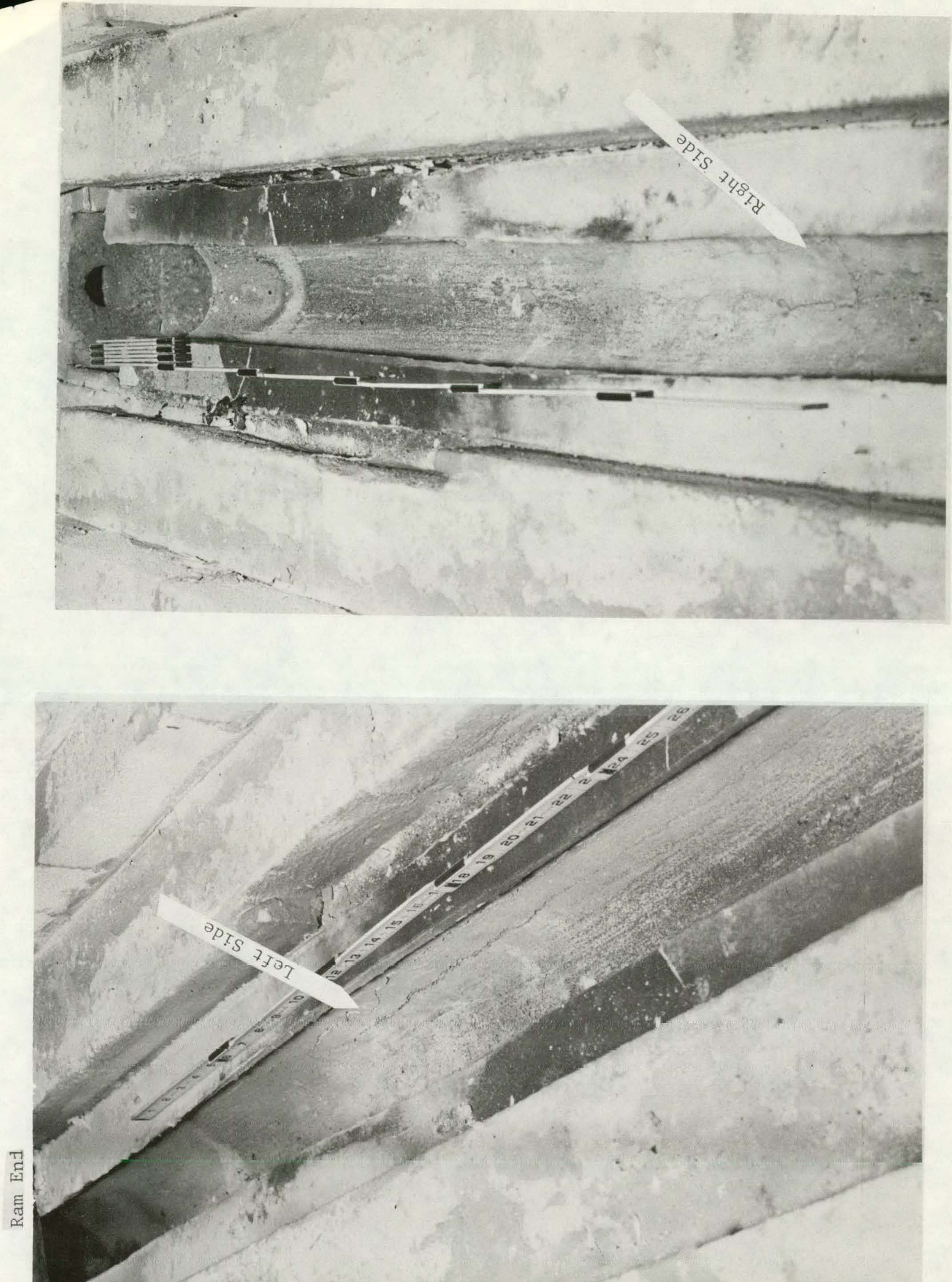
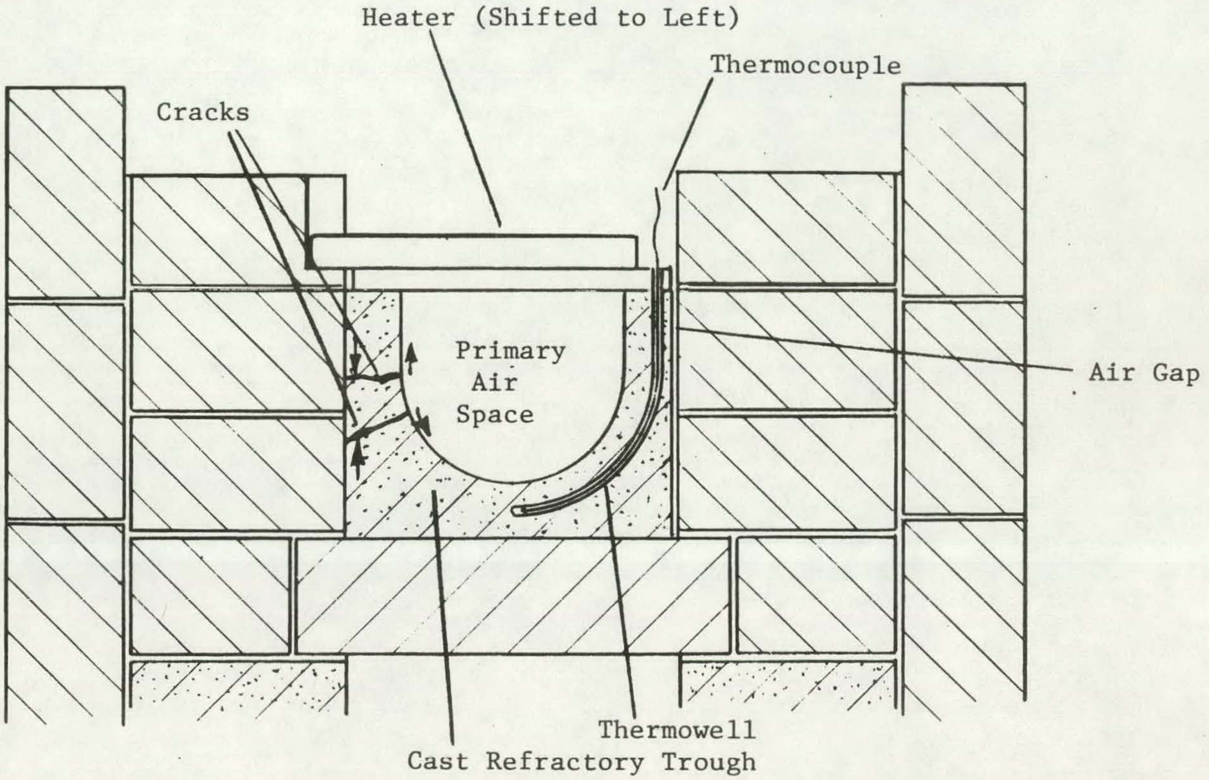


FIGURE 10. Primary Casting After Operation



Note: Section taken from ram end of incinerator

FIGURE 11. Cross Section of Primary Chamber

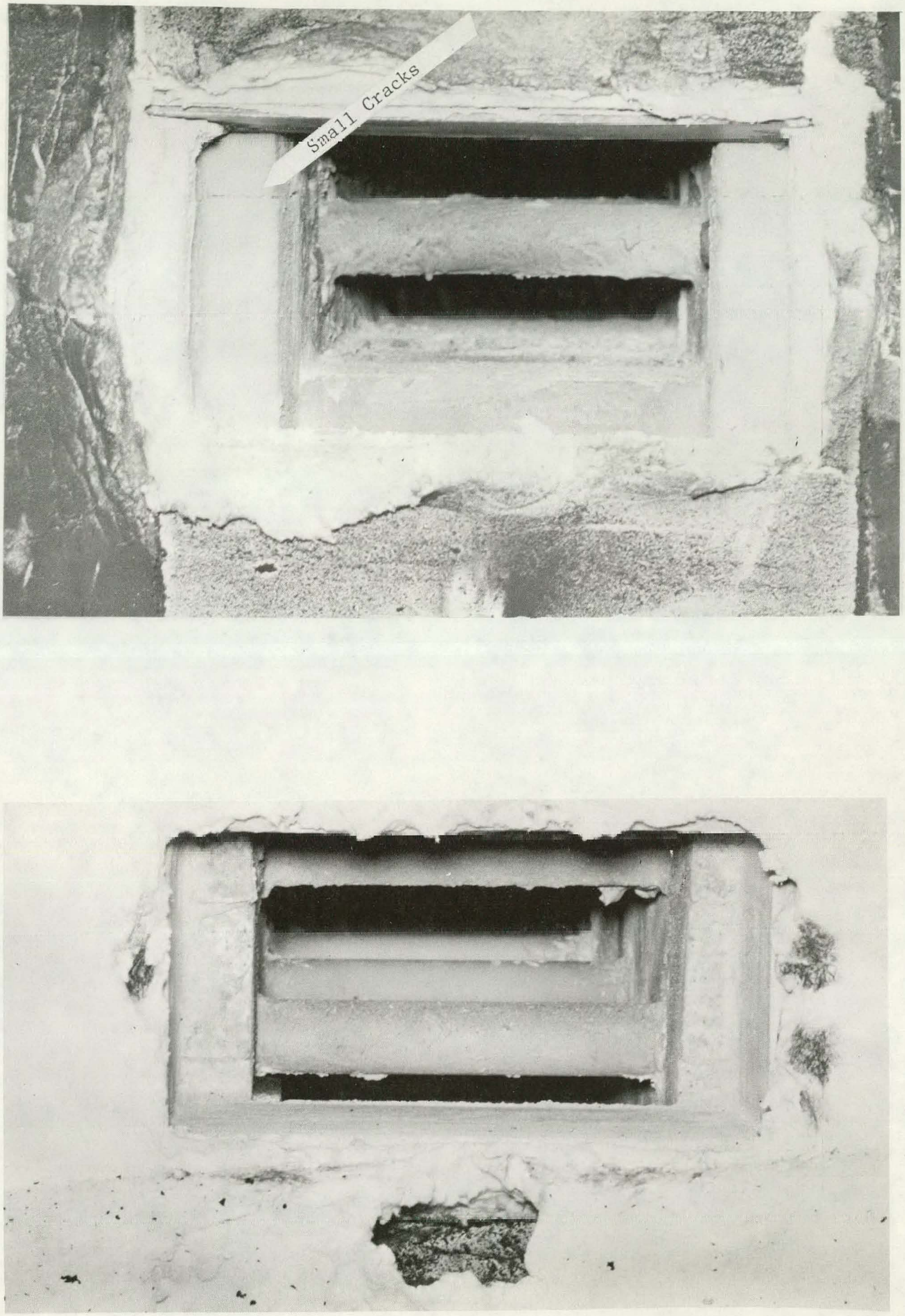


FIGURE 12. Upper and Lower Afterburner

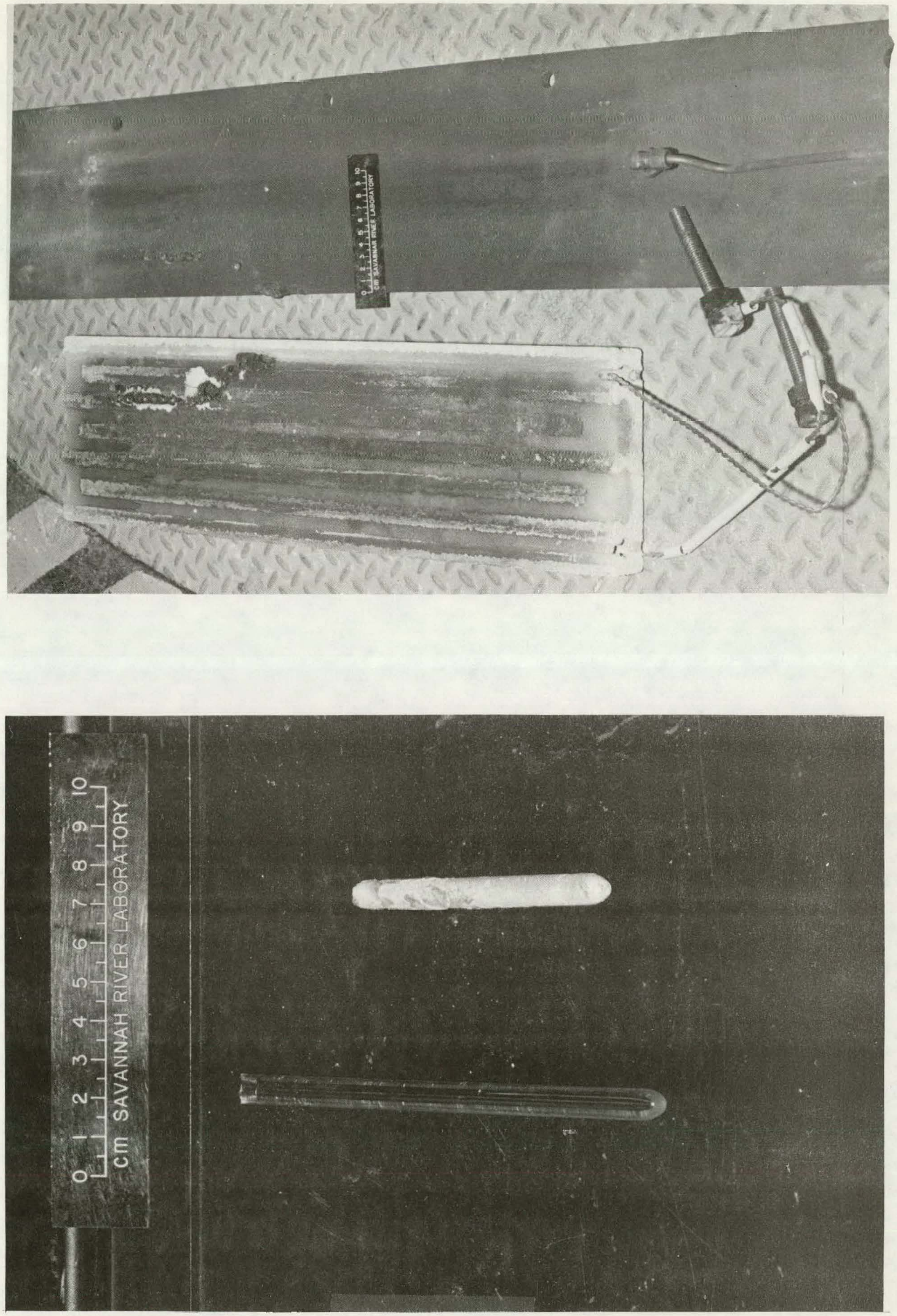


FIGURE 13. Devitrified Thermowell and Primary Heater Failure

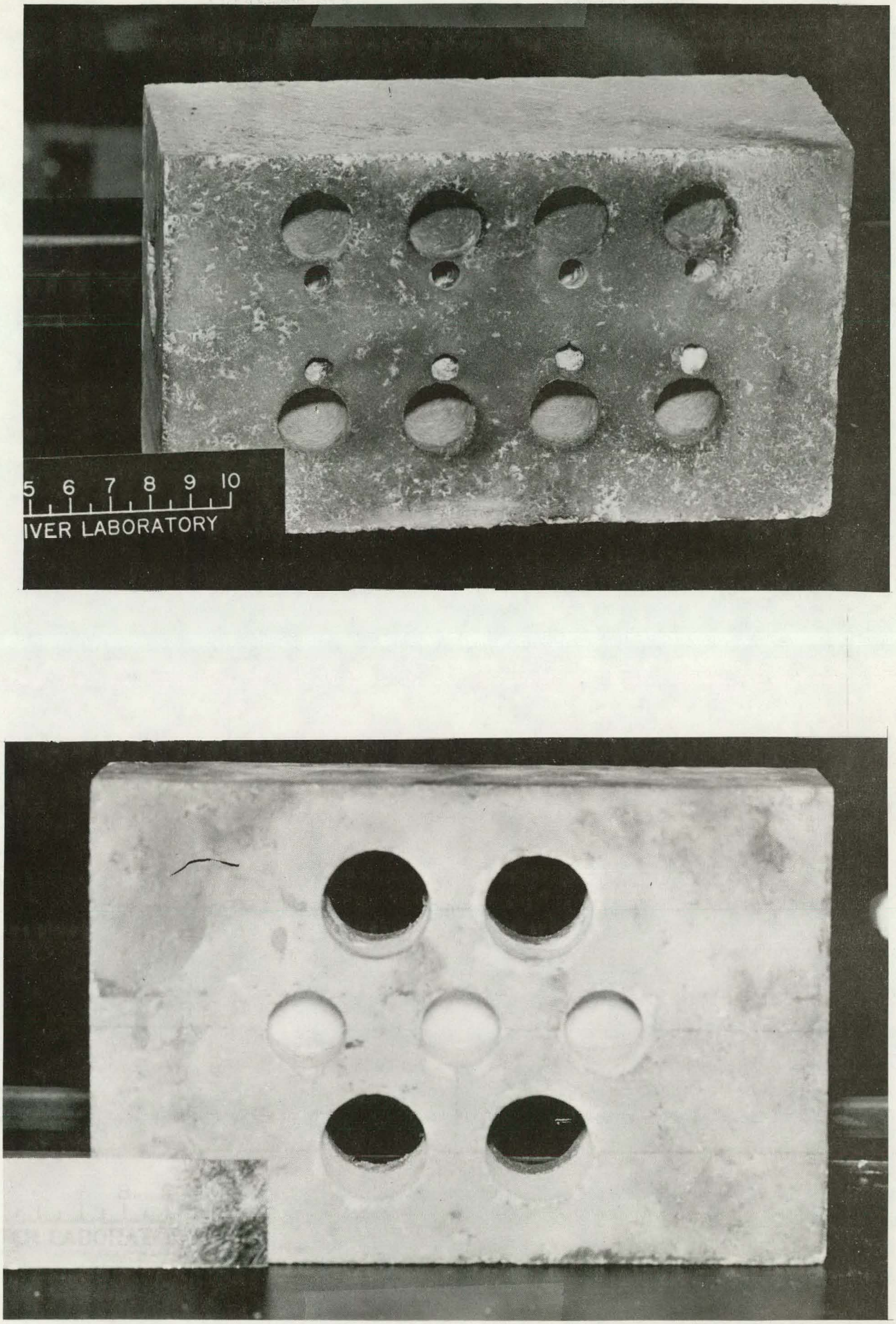


FIGURE 14. Gas Burner Blocks

TABLE 1

Test Results of Incineration of Waste Mixtures

	Material Burned, g													
Run	*Poly-ethylene*	*Latex*	*PVC*	*Tygon*	*Poly-styrene*	*Black Rubber Tubing*	*Pure Gum Rubber*	*Neoprene*	*Cellulose*	*Paper Packaging*	*Total*	*Ash, g*	*Reduction, wt %*	*Carbon, %*
1	1098.3	665								290.9	2054.2	17.5	0.85	
2	520	60								130	720	5.5	0.76	
3	1650	220								365	2235	14.9	0.67	3.5
4	930	200	740							330	2200	64.5	2.9	2.5
5	856	100	1125	30						535	2646	106.3	4.0	0.6
6	220	630	100	1020	540	700	250			570	4030	78.6	2.0	
7	66	520	220	110	180	380	680	290	580	635	3661	106.5	2.9	
8	277.7	690.2	262.7					517.6	154.8	435	2257	47.6	2.1	7.8
9	120.0	292.8	153.8					302.4	91.2	240	1200	50.7	4.2	
10	97.5	237.9	124.8					245.7	74.1	195	975	73.6	7.5	2.5
11	120.0	292.8	153.6					302.4	91.2	240	1200	142.9	11.9	
12	70.0	170.8	89.6					176.4	53.2	140	700	27.4	3.9	
13	180.0	439.2	230.4					453.6	136.8	360	1800	333.9	18.6	

TABLE 2

Incineration Residues

I. Analysis of Incinerator Ash

	Element (Excluding C, N, and O), wt %					
Element Run →	*3*	*4*	*5*	*8*	*10*	*11*
Pb	≤0.001					≤0.001
Ba	0.1	4	1.0	0.6	0.8	0.3
Sb	-	0.03	0.03	0.03	5	1
Zn	15	0.2	0.7	4	6	2
Fe	36	1.0	24	2	3	0.9
Mn	0.7	0.04	0.5	0.1	0.06	0.02
Ti	0.9	38	21	34	11	2
Ca	13	52	26	38	22	14
K	0.8	0.03	0.08	0.4	0.2	0.1
Cl	0.02	0.2	0.05	0.3	0.4	0.9
S	0.2	0.03	-	0.2	0.5	0.3
P	0.2	0.3	0.2	0.5	0.2	0.02
Si	13	3	6	10	18	4
Al	14	0.9	18	4	26	4
Mg	5	0.3	0.7	6	8	0.9
Na	1.0	0.09	0.2	0.2	0.1	0.1

II. Analysis of Off-Gas Particulate (Run 11)

Element →	Zn	Ca	Sb	Pb	Fe	Cd	Na	K	Cl
Wt % → *(Excluding C, N, O)*	62	14	11	1	1	2	2	2	1

TABLE 3

Particulate Size Distribution[a] of Ash Residue

Particle Size μ	*Run* → *4*	*5*	*10*
>420	69.7	78.6	66.2
>250	13.6	8.1	12.0
>149	7.4	6.0	16.6
>74	8.0	4.4	4.6
<74	1.3	2.9	0.6

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[a] These distributions are valid for normal ash transfer and handling. Because of the frangible nature of the ash, it is easily crushed and powdered by handling and ash particle size distribution skews to the smaller sizes. For example:

Ash Density, g/cc	
Free	0.1-0.3
Tap	0.4-0.5