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SUMMARY

A full-scale (5 kg waste/hour) controlled-air incinerator is presently being tested as part of a program to develop technology for incineration of Savannah River Plant solid transuranic wastes. This unit is designed specifically to incinerate relatively small quantities of solid combustible wastes that are contaminated up to 10^5 times the present nominal 10 nCi/g threshold value for such isotopes as ^{238}Pu, ^{239}Pu, ^{242}Cm and ^{252}Cf. Automatic feed preparation and incinerator operation and control have been incorporated into the design to simulate the future plant design which will minimize operator radiation exposure. Over 250 kg of nonradioactive wastes characteristic of plutonium finishing operations have been incinerated at throughputs exceeding 5 kg/hr for periods up to 6 hours. Safety and reliability were major design objectives.

Upon completion of an initial experimental phase to determine process sensitivity and flexibility, the facility will be used to develop bases for the production unit's safety analysis report,

technical standards, and operating procedures. An ultimate use of the experimental unit will be the testing of actual production unit components and the training of Savannah River Plant operating personnel.

PROCESS DESCRIPTION

A ceramic two-stage electrically heated controlled-air incinerator employs a three stage wet off-gas system prior to HEPA (high efficiency particulate air) filtering (Figure 1). The waste feed, typically 31% cellulosic, 27% polyvinylchloride, 21% polyethylene and 21% rubber, is mechanically shredded and packaged in 250 gram, 4-inch by 9-inch long paper bags prior to incineration. These packages are dropped from a rotating feed magazine through a double valve airlock and rammed into a silicon carbide horizontal primary combustion chamber. The waste is semipyrolyzed at 700-900^{o} C with substoichiometric purge air. At the exit of the primary tube, the ashes fall into a lower retention chamber where they can be removed periodically through a double valve airlock. The pyrolysis gases are burned in a mixing nozzle where excess air is added in the first tube of the vertical labyrinth afterburner. Nine cast alumina afterburner tubes are connected in series by cast manifolds to create a continuous tortuous path. The purpose of the long labyrinth is to provide an off-gas residence time of up to 8 seconds at 1000^{o}C to ensure complete combustion. The top manifold blocks contain access plugs for cleanout, instrument probes, sight glasses and exhaust ports. It is possible to vary the useful length of the afterburner and experimentally define the optimum afterburner volume for the future production incinerator.

The off-gas treatment consists of three independent liquid scrubber systems: a venturi quench, a fibrous bed scrubber, and a packed-bed contactor to neutralize HCl formed from the burning of PVC. The purpose of three independent scrubber loops is to minimize the volume of transuranic contaminated salt from the evaporation of the scrubber solutions. Most of the contaminated particulate is captured in the first two scrubbers; hence, the neutralizing scrubber is last in the scrubbing sequence. The first two isolated scrubber loops continuously recycle water which becomes saturated with HCl but retain the off-gas particulate. In-line filters in the two scrubber loops remove these entrained particulates and tars. With infrequent replacement of the water in these loops, generation of TRU contaminated salt is sharply reduced.

The incinerator off-gas undergoes final filtration by passing through high-efficiency particulate air (HEPA) filters series, before release. To prevent blinding of the HEPA filters by condensate, the saturated effluent from the scrubber is then heated from 50 to 65°C to pass through the filters in a dry state. The gas flow is induced through the incineration and off-gas treatment systems by a blower that discharges to the atmosphere. By locating the blower in this position, a vacuum is maintained throughout the system. Thus, any leaks that might develop will be into the system rather than out, and thereby contamination of the surrounding area will be minimized.

EQUIPMENT DESCRIPTION

Incinerator

Figure 2 shows a cutaway view of the incinerator. Distinquishing features are compactness, light weight, and ease of assembly all provided by using prefabricated ceramic components to form two combustion chambers surrounded by packed fiber insulation within a steel case. The vertical tubes and manifolds maintain an airtight seal by use of the compressive load of their own weight.

Thermal expansion is compensated for by the freestanding tubes and independent end manifolds. Thermal cycling of the ceramic components is minimized by maintaining the unit at operating temperature continuously. Because of the low thermal yield of the small amount of waste burned, supplemental heating is required. Electric heating is used for intrinsic safety with high activity transuranic wastes. Process heat is provided by girdle heaters on the outside of the tubes and flat plate heaters on the end manifolds. Power to the primary combustion chamber is 4.8 kW divided into three zones, power to the afterburner is 5 kW per tube and 11.4 watts/in^2 on the flat plate heaters. Total heat input to the incinerator is 125 kW. Replacement of individual tubes, end manifolds and heaters is made relatively easy through access plates in the steel casing. The entire unit is insulated with a minimum of 10 inches of fiber blanket insulation and enclosed in a 1/4-inch thick airtight steel shell.

Supply Gas System

Three feed gases - air, steam and nitrogen - are supplied to the combustion chambers through a metered distribution system. The air supply to support combustion is divided into two streams. The first and smaller quantity, 0-10 scfm, is routed through a rotameter to an inlet located at the end of the primary combustion chamber near the waste feed entry. The second and larger capacity (0-60 scfm) air supply is to the secondary chamber through an air preheater. During normal operation the primary airflow was set at 5 scfm and the secondary airflow was varied depending on the feed package size and composition. The secondary airflow as adjusted to meet the waste combustion air demand by maintaining oxygen in the incinerator exhaust as indicated by an on-line oxygen analyzer.

Steam may be injected into the incinerator primary. The purpose of the steam was twofold. First, the steam reacts with the waste residue by the water shift reaction to convert carbon to CO_2 and second as a temperature reducing quench.

Nitrogen is used as a blanket gas within the case of the incinerator to reduce the possibility of pyrolysis gas accumulation. A second independent nitrogen gas system to manually quench and dilute the combustion gases can purge the entire incinerator and off-gas system within 20 seconds.

Off-Gas Scrubbers

The venturi quench scrubber is the first of three independent scrub systems. It consists of a jet venturi constructed of Inconel 625 and a fiberglass reinforced polyester separation tank of about a 60 gallon capacity. Water is recirculated at 20 gpm continuously in the system so that heat must constantly be removed, and since the scrub solution can get as much as 24 without HCl concentration, its construction materials must also be acid resistant. An in-line 30 psi pump recycles the scrub solution through a filter to remove gross particulate and a heat exchanger to remove 36°C of heat from the quench fluid. A 15-ton chiller is used to provide heat removal capacity from the incinerator off-gas. Appropriate instrumentation is provided to monitor the process. An emergency cooling water source is included to protect the fiberglass reinforced polyester contruction if a power failure occurs.

The fibrous bed scrubber is the second of three independent scrub systems. It consists of two recirculating systems, one with an external recirculation tank of ∿100 gallons. Two pumps recirculate the scrub solution, one low pressure header pump and the other a high pressure spray pump. An in-line filter removes gross particulate. Materials have been selected for acid resistance because the system is expected to equilibriate at up to 24 without HCl.

The neutralizing scrubber is the third of three independent scrub systems. It consists of a single recirculating system of basic solution to neutralize the HCl in the off-gas. A 40 psi pump supplies ~15 gpm of neutralizing scrub solution to an overhead spray which countercurrently washes the off-gas in a packed column. A mist eliminator is incorporated in the top of the column. Provision has been made for batch draw-off of expended solution and mixing and replenishment of fresh basic scrub solution.

Instrumentation

The experimental unit is fully instrumented with online gas analysis equipment for both diagnostic and control purposes. Exhaust gases in the afterburner are characterized by an oxygen analyzer, a CO_2 analyzer and a combustibles (or hydrocarbon) analyzer.

An annunciator panel with 12 different alarm conditions provides the operator with an immediate status of the incinerator if any preconditions for operation are not satisfied (e.g., incinerator shell N_2 pressure below setpoint).

The incinerator feed is made entirely automatic (except for loading the 18-package feed magazine) by a cycle timer which can vary the charge sequence frequency from 90 seconds to 99 minutes but is nominally 3 minutes for 12 lb/hr waste throughput. (Figure 4) Photoelectric cells ensure that the waste packages have dropped out of the charging airlock prior to advancing the rotary feed magazine to minimize jamming. All automatic systems are provided with a manual override.

Waste Feed Bagger

Figure 5 shows the mechanical shredder and feed bagger that is being developed to reduce operator contact with the waste during waste feed pretreatment. Waste contaminated with ^{238}Pu has a dose rate of ∿0.7 mrem/hr per gram of ^{238}Pu (0.3 mrem/hr/gram of ^{239}Pu) at one foot distance and manual packing of the shredded waste into the paper bags presents a serious hazard for containment box glove puncture. Hence, to minimize both operator dose and hand puncture wound occurrence, a mechanical waste feed bagger is being developed. Plastic waste bags are loaded in the hopper above the shredder. Shredded waste falls into the tapered hopper below where an air driven platen compresses the waste transversely into the loading tube shown at the right in Figure 4. Another air driven piston pushes the waste out of the tube into a paper bag placed over the end of the tube. The bag receiver is rotated up 90° closing the mouth of the bag which is taped and removed from the receiver.

In a production operation the bags are weighed and assayed radiometrically before being inserted in the incinerator loading magazine. Incoming plastic bags of waste will also be x-rayed for noncombustibles prior to shredding. Only those non-combustibles that would jam the shredder or the incinerator ram and airlock valves need to be removed, the remainder can pass through the process and end up in the ash.

INCINERATOR PERFORMANCE

Oxygen Requirements

Oxygen depletion in the incinerator exhaust was measured in the off-gas with an online analyzer. Figure 6 compares the oxygen content of exhaust gas as a function of time for single packages of different types of waste and for a typical Savannah River Plant waste mixture. Latex rubber shows the greatest oxygen depletion (i.e., requires the most air) and polyvinyl chloride shows the least oxygen depletion (requires the least air).

Continuous burning of waste was tested by feeding 250-gram packages of waste one after the other at intervals of 3 minutes. Oxygen analyzer readings initially indicate burning cycle variations as each new waste package was fed into the primary chamber. But these variations became less pronounced as the primary filled with burning waste; stable equilibrium is eventually achieved at about 11% O_2. Waste feed rates of up to 5 kg/hr were attained and maintained as long as six hours.

PRODUCT CHARACTERIZATION

Ash Product

The amount of residual ash and its carbon content are a function of residence time in the primary chamber. Typically, after 1/2 hour, the residue was less than 5 wt % of the waste feed and contained about 5 wt % carbon.

The free density of the ash ranged from 0.1 to 0.3 g/cm^3; 95 wt % of the ash had particle diameters larger than 150 microns. Major ash constituents were oxides of Zn, Ti, Sb, Fe, Ca, Mg, and Ba. These metals are commonly used in additives to modify the physical properties of plastics and rubbers. Other major ash components, Al and Si, probably came from cellulosic fillers.

Particulate Carryover

The particulate carryover for the incinerator was less than 0.1% of the feed material. Amounts of particulates from the pilot incinerator increased significantly when the incinerator was fed beyond the stoichiometric air demand.

The particle size distribution for the Savannah River Plant waste mixture indicated that 30% of the particulates was less than one micron in diameter when the incinerator was fed beyond the stoichiometric air demand. (Figure 7)

Particulate acid in the scrubber consisted of carbon and metals such as Fe, Zn, Cu, Ca, Na, Cd, Cr, Ni, and Pb. The metals were transported to the liquid scrubber as volatile oxides and chlorides. Particulate loading of the HEPA filter was negligible.

EVALUATION OF MATERIALS OF CONSTRUCTION

The incinerator ceramics are in very good condition after 6 months of operation. There are no accumulations of dust or soot in the primary or afterburner.

Samples of the metallic construction materials evaluated in the exhaust of the incinerator indicate that high nickel, cobalt, and chromium containing alloys are the best for corrosion resistance.

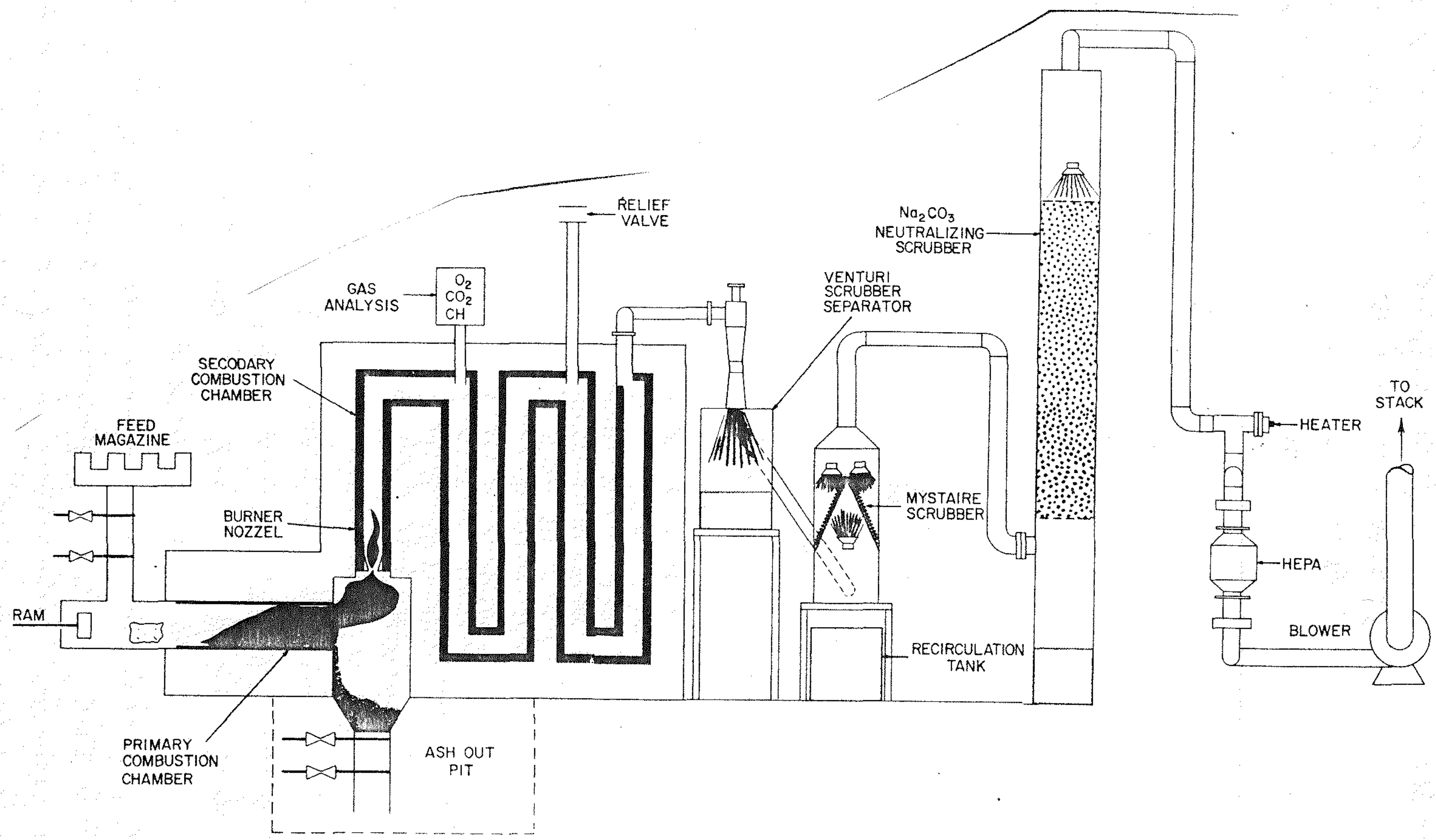

FIGURE 1. TNX Incinerator Facility

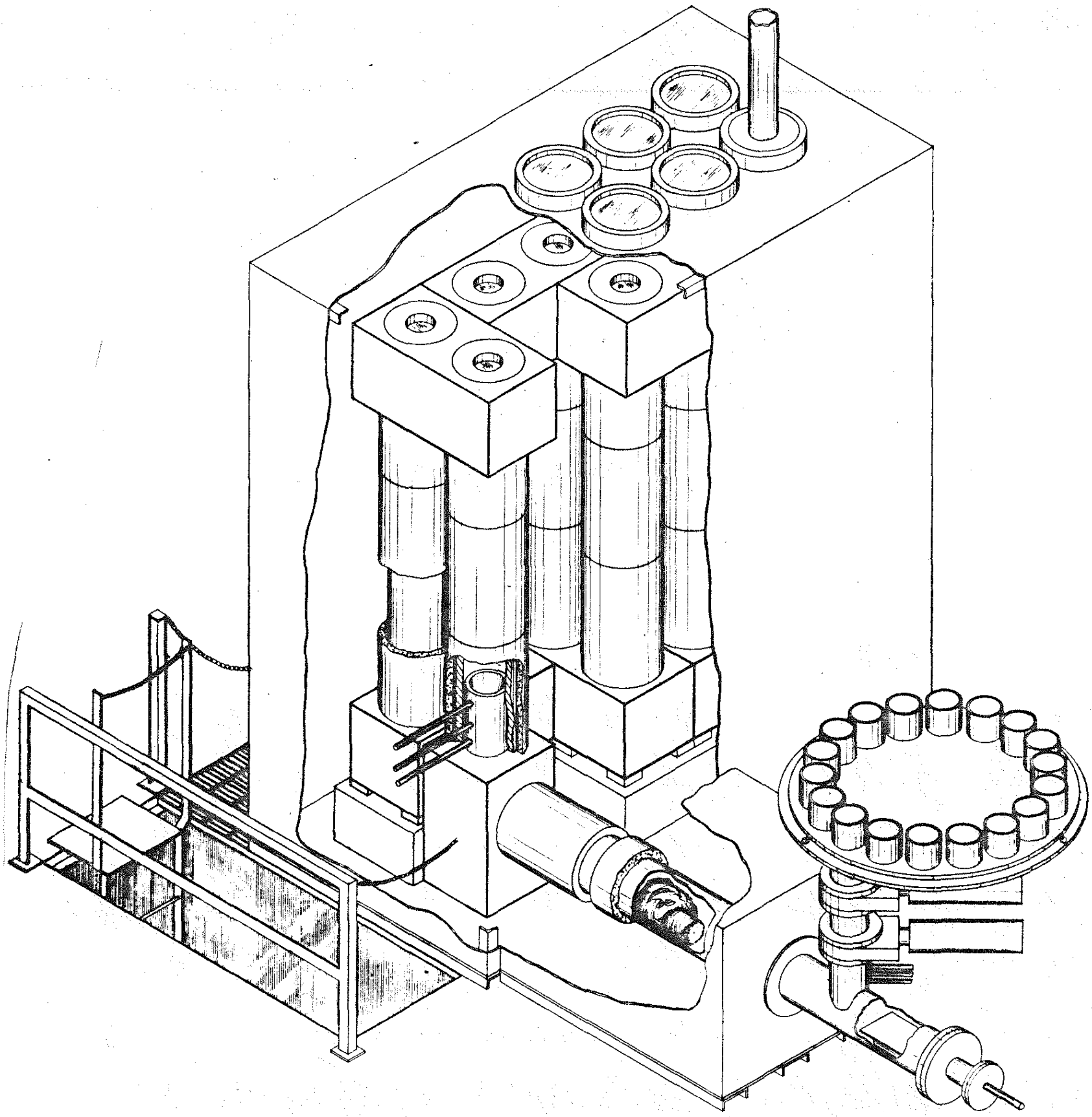

FIGURE 2. Full-Scale Prototype Waste Incinerator for Test with Nonradioactive Waste.

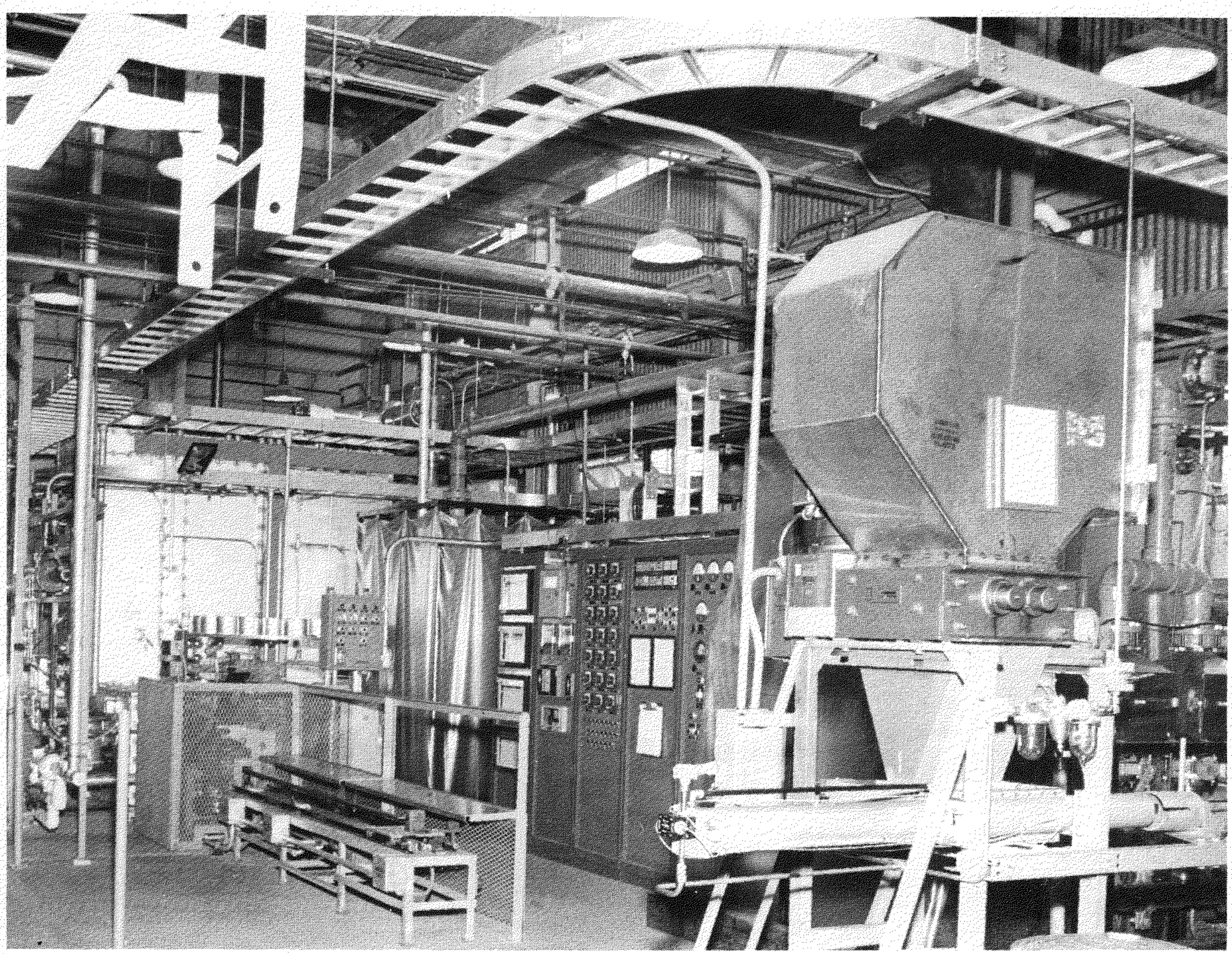

FIGURE 3. View of Incinerator Components Test Facility Operating Area

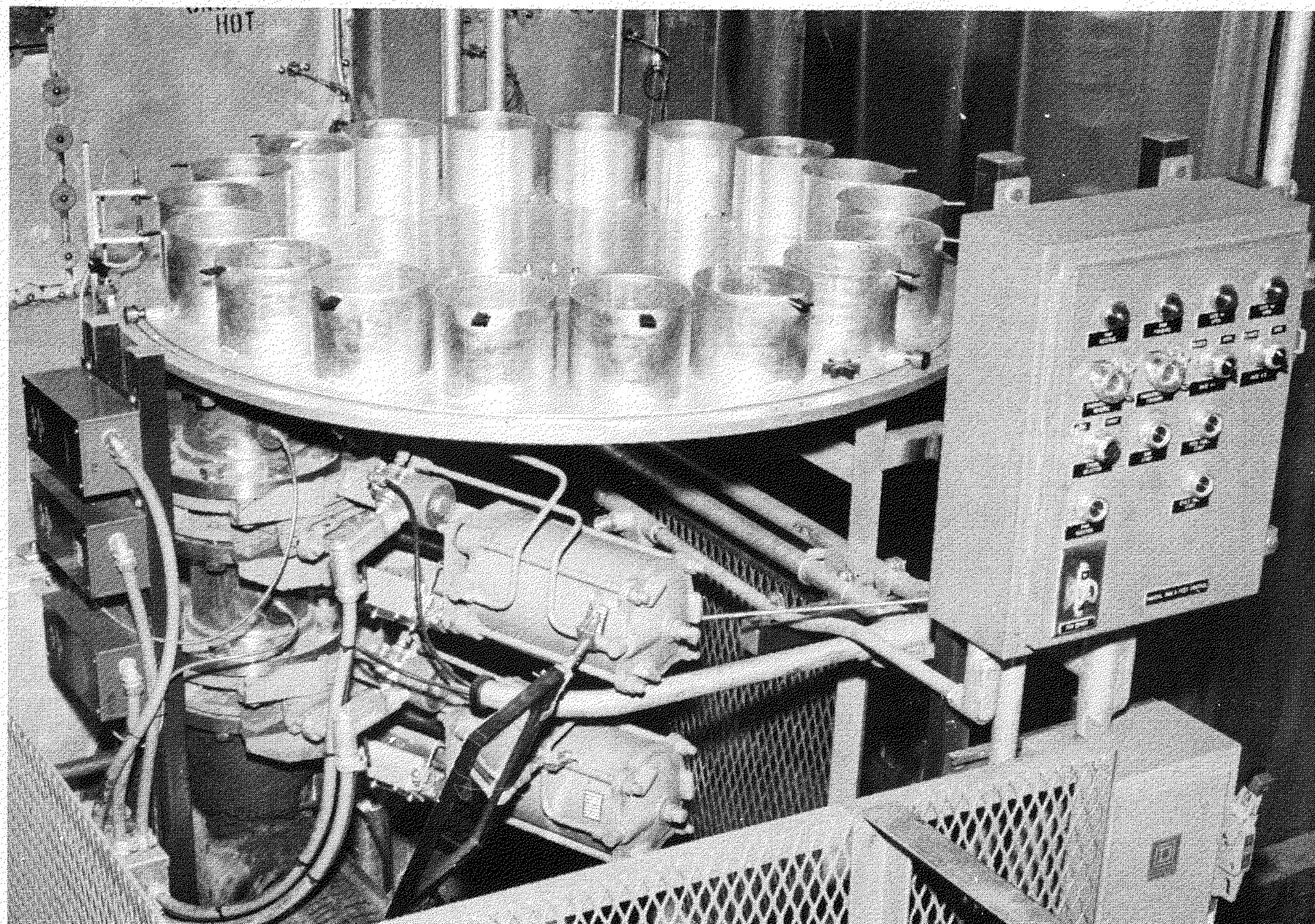

FIGURE 4. Automatic Feed Package Magazine and Charging Airlock

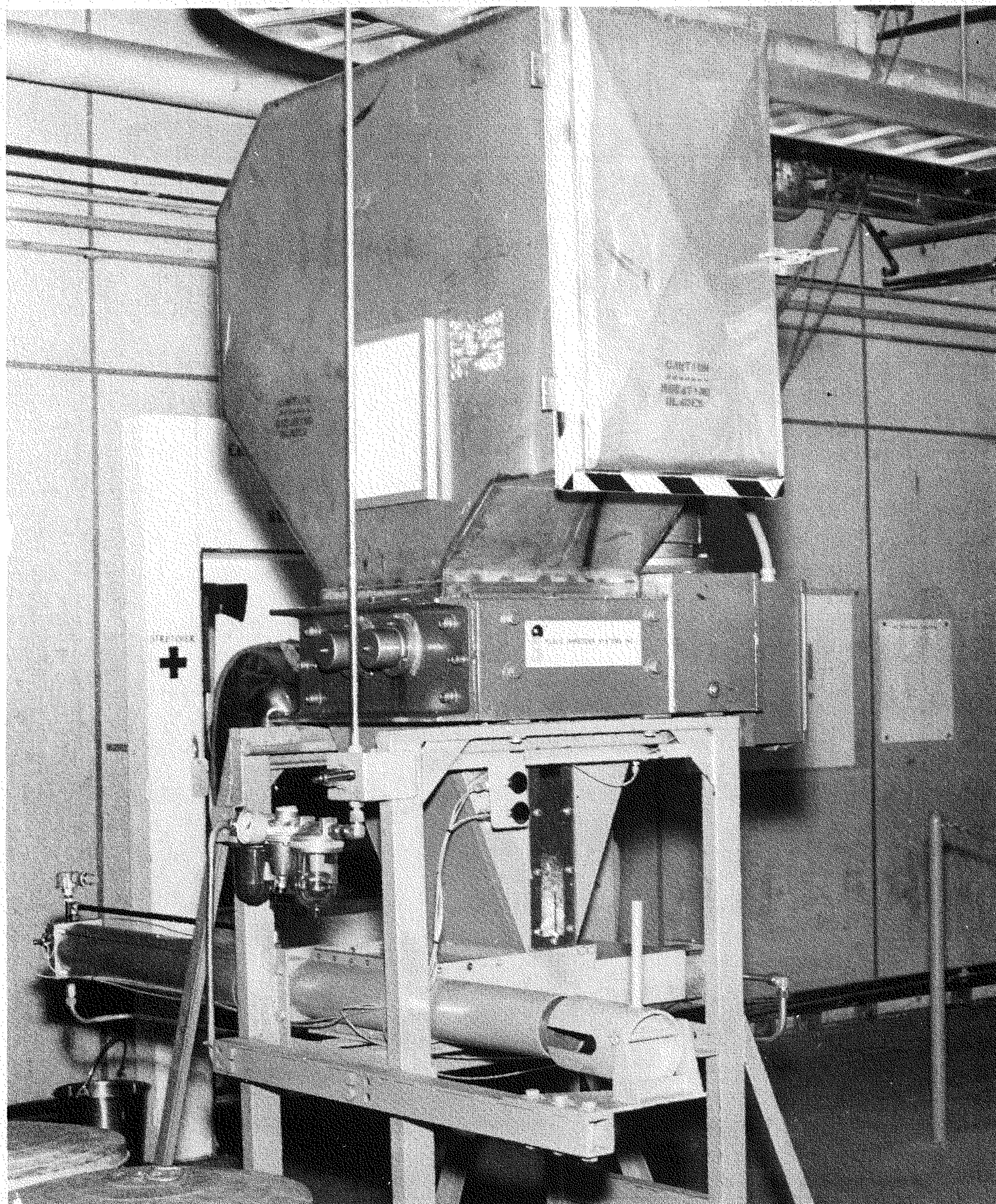

FIGURE 5. Waste Shredder and Bagger

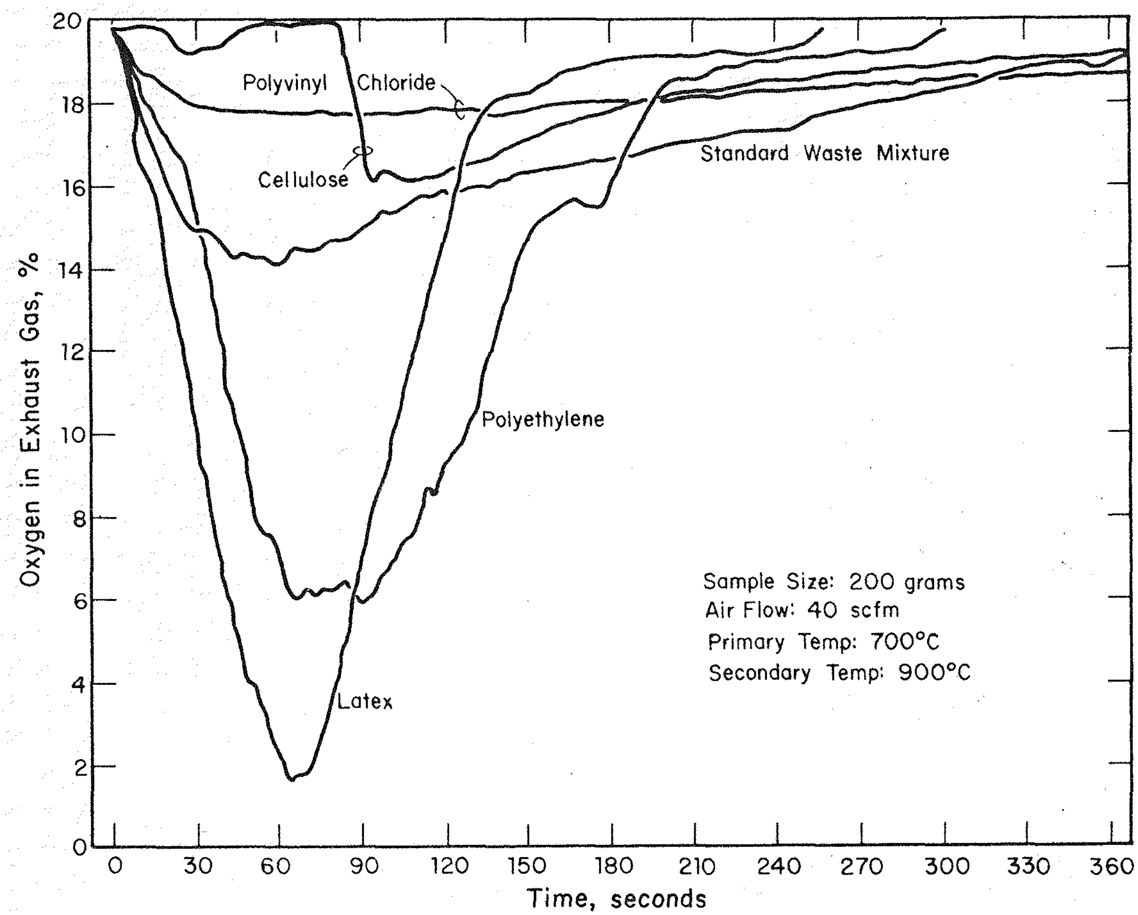

FIGURE 6. Typical Waste Package Burning Cycles

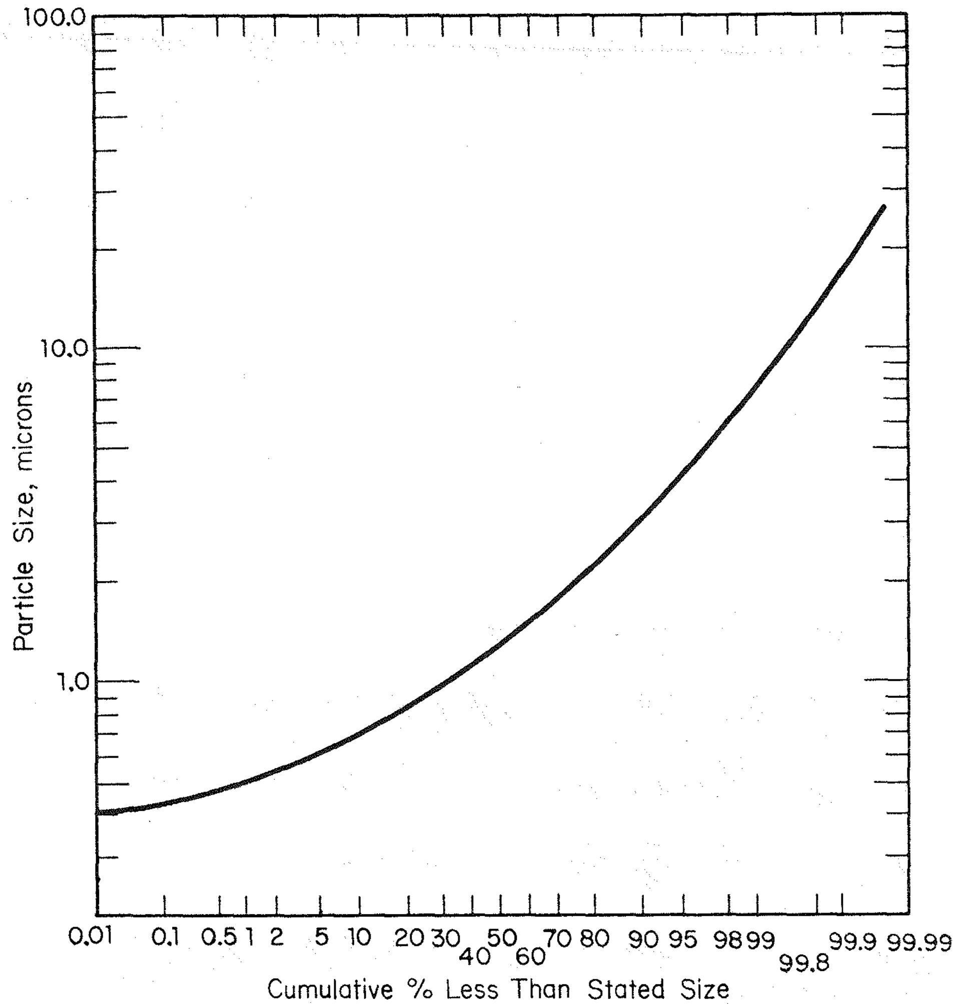

FIGURE 7. Incinerator Exhaust Particle Size Distribution with Substoichiometric Air