DP-MS-80-123
CONF-810606--35

DESIGN AND OPERATION OF A PROTOTYPE INCINERATOR FOR BETA-GAMMA WASTE

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Proposed for presentation at the
American Nuclear Society 1981 Annual Meeting
Miami Beach, Florida
June 7-12, 1981

ABSTRACT

A full-scale test incinerator has been built at the Savannah River Laboratory to provide a design basis for a radioactive facility that will burn low-level beta-gamma contaminated waste. The processing steps include waste feed loading, incineration, ash residue packaging, and off-gas cleanup. Both solid and liquid waste will be incinerated during the test program. The components of the solid waste are cellulose, latex, polyethylene, and PVC; the solvent is composed of n-paraffin and TBP. A research program will confirm the feasibility of the design and determine the operating parameters.

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INTRODUCTION

A program is in progress at the Savannah River Laboratory (SRL) to develop the design of an incineration facility for radioactive waste contaminated with low-level beta-gamma emitters. Low-level solid radioactive waste generated in operations at the Savannah River Plant (SRP) is currently sent to a burial ground for disposal in shallow trenches. Degraded solvent composed of tributyl phosphate (TBP) and an organic carrier is stored in underground tanks at the burial ground. A test facility has been built to burn nonradioactive, simulated waste. The facility is called the Solid/Solvent Waste Incinerator Facility for Testing (SWIFT). This report summarizes the design and research goals for the SWIFT program.

* The information contained in this article was developed during the course of work under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

SUMMARY

The prototype incinerator for β-γ contaminated waste is a full-scale test unit, designed to incinerate 180 kg/hr of solids or 110 kg/hr of liquid. The key objectives of the test facility are to demonstrate the feasibility of full-scale operation, characterize the waste forms generated, and provide a design basis for a radioactive β-γ incinerator. A controlled-air, two-stage incinerator was chosen after a survey of current literature and visits to other nuclear facilities. In this method of incineration, waste is pyrolyzed and the nonvolatile residue chars to low carbon ash in an air-starved primary combustion chamber, and the evolved gases are burned in excess air in a secondary combustion chamber. The advantage of this method in radioactive waste application is that minimum solids and radioactivity are entrained in the off-gas. Equipment is provided for cooling, neutralizing, and filtering the off-gas to meet federal and state air emission standards.

DISCUSSION

Process Description

Processing steps in the test facility are waste feed packaging and loading, incineration, ash residue packaging, and off-gas cleanup. Figure 1 shows the general flowsheet for the radioactive process with the test facility outlined with a dotted line. The elevation arrangement of SWIFT is shown in Figure 2.

The radioactive facility proposed for SRP will include X-ray and assay of the incoming waste and assay of the ash. Waste will not be shredded or sorted at the incinerator facility. Packed cartons of waste containing large noncombustibles will be detected with the X-ray scan and rejected. Boxes with high β-γ activity levels (above the limits in Table 2) will be rejected by the assay system. The low specific activity of 98% of the waste generated at SRP (Table 3) is within the indicated nuclide limits. Rejected waste will be sent directly to the burial ground.

Incinerator Waste Feed

Waste packages are fed directly into the primary combustion chamber by a horizontal ram. The ram assembly is separated from the incinerator by a refractory-lined sliding door. Underfire airflow is reduced automatically in conjunction with the loading cycle to minimize fly ash entrainment during movement of the ash bed. The solid waste feed rate is maintained at 180 kg/hr.

Two different methods are being tested for transferring liquid waste into the incinerator. In the reference method, a solid fixative is mixed with the liquid waste. The slurry is then injected into the incinerator primary chamber through a steam-cooled lance at a rate of 0.04 L/sec. An alternative method that will be studied entails mixing the solvent with enough lime to form a thick slurry that is packaged in plastic-lined cardboard cartons. The cartons are fed into the incinerator in the same manner as solid waste.

Incinerator

The incinerator is a two-stage, commercially available unit with controlled air. The term "controlled air" denotes the incinerator design feature that permits control of the quantity and location of combustion air. In two-stage combustion, waste is semipyrolyzed in the fuel-rich primary chamber. The pyrogenic gases are oxidized to combustion products in the excess air environment of the secondary chamber. Air enters the primary chamber through several underfire air ports on the side of the hearth as shown schematically in Figure 3. The air flow is sufficient to char the waste by slowly oxidizing the carbon, but is low enough to avoid excessive ash entrainment. Combustion air (100-200% excess) is supplied at the entrance to the secondary chamber in order to oxidize the partial combustion products to H_2O and CO_2. The oxygen concentration in each combustion chamber is continuously measured with online analyzers.

Normal operating temperatures are 650° to 800°C in the primary chamber and 850° to 1000°C in the secondary chamber. The control system maintains these temperatures by modulating two diesel-fired burners and combustion air flow. At full fire, the two low-intensity burners consume 90 L/hr of fuel oil. During campaign burning, the burners modulate down to low fire, which uses ~30 L/hr of fuel oil.

The combustion chambers are constructed from 0.63 cm carbon steel. The shell is coated with a protective mastic layer to reduce HCl corrosion of the metal and lined with 5 cm of mineral wool and 12 cm of silica-alumina (52% Al_2O_3, 40% SiO_2) ceramic. The internal dimensions of the chambers are 1.6 m in diameter and 4.3 m long, for a volume of 8.9 m^3 in each chamber. The plug flow residence time in the incinerator is 6 to 8 sec at maximum flow rates.

Ash Packaging

After the waste has charred in the hearth for 8 hours, the remaining ash is pushed along the length of the hearth by an internal ram. At the end of the hearth, the ash falls through an opening in the primary chamber floor, into a retention chamber below the incinerator. The ash cools in this area for 8 hours and is pushed by another ram into a storage drum located below grade level in a 2 m deep pit. This configuration is shown in Figure 4.

The drum fills with ash during one 8-hour shift of operation. The ash is sprayed with water to prevent the top layer of particulates from spreading when the drum is lowered from the incinerator. A gate valve at the exit to the ash hopper is closed, the drum is lowered away from the hopper, and the lid is fastened. The operator manipulates a hoist from the surface to remove the drum from the ash pit.

Off-Gas Treatment

The incinerator off-gas treatment system reduces the temperature of the gas from 1000°C to 150°C, neutralizes acidic components in the gas, and removes entrained solids.

The combustion exhaust is cooled from 1000°C to 150°C in the quench chamber with an air-atomized water spray. The large volume of the quench chamber (56.6 m^3) provides a 12-sec residence time to accomplish complete water evaporation and neutralization. The flow rate of the water spray is controlled by the temperature of the quench chamber outlet. The exit temperature is maintained at 150°C to ensure that the exhaust gas is unsaturated (above the dew point) and below the maximum operating temperature of the baghouse (200°C). When hydrogen chloride and sulfur dioxide are present in the gas, an aqueous neutralizing solution of Na_2CO_3 is sprayed into the chamber. This reduces corrosion problems from the HCl generated during incineration of chlorinated polymers and SO_2 formed from the sulfur in latex and fuel oil. The heavier particulates and salts formed during neutralization settle at the bottom of the quench chamber and are removed by gravity discharge.

The cooled off-gas from the spray quench is drawn through a fabric filter baghouse, which removes particulates and dried salts. The structure contains 96 envelope-shaped Nomex filter bags that have a total surface area of 190 m^2. Envelope-type bag filters are being tested because of their suitability in "bagging out" techniques used in radiation zones. The inlet flow rate is 116 m^3/min (actual), which maintains the facial velocity at 0.61 m/min. The removal efficiency of the filters is 98% for particulates with a diameter of 1 μm. Particulate cake on the filter surface is removed with intermittent reverse air pulsing. The caked particulates fall into a hopper for later gravity discharge into a steel collection drum.

In a radioactive facility, the baghouse will serve as a prefilter to a bank of high efficiency particulate air (HEPA) filters. HEPA filters were deleted from the test facility design since their performance is already well defined.

Two induced draft (I.D.) blowers pull the off-gas through the system and maintain a constant negative pressure. Each blower has a capacity of 2360 L/sec at 10 kPa. A 0.61 m butterfly valve throttles the draft pressure pulled on the system. A 0.30 m valve located behind the larger valve between the blowers and the atmosphere regulates the amount of dilution air added to the stack gas to reduce the exit temperature from 150 to 90°C.

The stack vents the gas to the atmosphere 10.1 m above the process area. The sampling probe for a stack monitor is located in the stack 8 m above the ground. Samples from the stack are monitored for CO_2, CO, SO_2, HCl, and particulates.

Construction

The incinerator, spray quench, and baghouse were purchased from commercial vendors. The items were either "off-the-shelf" units or standard modifications that the manufacturer could supply. Concrete foundations, steel supports, and interconnecting piping were designed and fabricated at SRP. Figure 5 shows the installation of the completed facility.

Instrumentation and Safety Interlocks

Thermocouples, pressure sensors, and online oxygen analyzers were installed in the incinerator and off-gas train. Measurements of temperature, pressure, and O_2 concentration will be used for operation control and performance monitoring. The incinerator is protected from overpressurization with a 0.84 m relief valve in the exhaust stack immediately above the secondary chamber. When the pressure in the secondary increases to +0.25 kPa, the valve opens and the I.D. blowers are deactivated. Most of the safety features are interlocked with the waste feed system. The ram is locked out when the exit temperature from the secondary chamber increases above 1200°C or when the O_2 content decreases below 5%. In the case of a power loss, the incinerator is automatically purged with nitrogen, the pressure relief valve is opened, and an emergency water line to the spray dryer is opened.

Startup

A field engineer from the incinerator manufacturer will perform the checkout and initial startup of the incinerator. The castable ceramic in the combustion chambers and stack will be slowly heated initially to cure the material. The water will be evaporated from the ceramic at 120°C for 8 hours. Then the temperature will be increased at a rate of 50°C/hr to 900°C.

The spray quench, baghouse, and I.D. blower will be checked out individually and run for a trial period to ensure correct operation. After the checkout and startup period is complete, the research tests will begin.

Research Program

The experimental schedule is shown in Figure 6. Solid and solvent burning tests will be performed and, concurrently, off-gas equipment performance will be monitored. The purpose of the test is to confirm the fluid dynamics of the system, soot and ash entrainment, thermal cycling behavior, corrosion rates, and off-gas cleanup performance.

Solid Waste Studies

The combustible solid waste generated at SRP is composed of plastics, rubber, and cellulosics. The main components of the waste are paper, cardboard, polyethylene, PVC, and latex, but small amounts of neoprene, Teflon® (Du Pont Trademark), and cotton fiber are present. Table 3 shows the composition of the β-γ contaminated waste currently generated at SRP. Uncontaminated samples of the materials will be burned in the test facility.

The solid waste incineration program begins with the parametric testing of waste composition, box size, and packing density. Most of the radioactive waste at SRP is packed in 0.38 m or 0.61 m cubic cartons before being sent to the burial ground. The average packing density is 90 kg/m^3, but varies from 30 to 130 kg/m^3. Several box sizes and packing densities will be tested with each waste component and a standard mixture. The weight of waste cartons will range from 5.5 to 38.6 kg during the parametric testing.

Ash and particulate samples from the parametric testing will be weighed and analyzed for carbon content. This will indicate the efficiency of the incinerator. The amount of particulates entrained in the gas stream will be measured before and after filtration. The decontamination factors for the system will be determined from these data. An EPA-approved stack sampler will be used to isokinetically sample the stack gas. In addition to particulate quantity and size distribution, the O_2, CO_2, CO, HCl, and SO_2 concentrations will be measured. Table 4 shows the expected concentration of pollutants in the off-gas.

The solid waste studies will be concluded with a 3 to 5-day burn campaign designed to simulate production operation. The incinerator will be operated 24 hours a day at a constant feed rate of 180 kg/hr. The extended burn will test demonstrate the controllability of the system during constant operation. Temperature and pressure fluctuations and off-gas equipment performance will be studied.

Solvent Burning Studies

Exhausted solvent from plutonium and uranium extraction is currently stored in underground tanks at SRP. The inventory of solvent in these tanks is 570,000 L and is increasing at a rate of 19,000 L yearly. The exhausted solvent contains fragmented alkanes and di- and mono-butyl phosphate, which are formed by radioactive and thermal degradation of TBP and n-paraffin. The scope of the β-γ incinerator program at SRP includes burning the solvent to combustion gases that are to be released to the atmosphere.

Experimental support for solvent burning includes developing a reference and alternative backup method of transferring the solvent into the incinerator and determining the effectiveness of lime fixation of the phosphorous in TBP. In the reference method tested, the solvent will be mixed with lime and pumped through an atomizing spray lance into the primary chamber. Phosphorous fixation is desired since P_4O_{10} or H_3PO_4 released in the system attacks the ceramics and metals. Initial solvent tests will use only n-paraffin solvent and will not require phosphorous fixation. The concentration of TBP will be increased to 50% by weight during subsequent tests.

Burning the solvent in a lime and ash matrix will be tested as an alternative to spray burning. The solvent will be mixed with enough lime and recycled ash to form a slurry that is packaged in plastic-lined cardboard boxes. The cartons will then be fed to the incinerator through the solid waste feed system.

After the more effective method of solvent incineration has been determined, a 24 to 48-hr continuous burn will be attempted. Campaign burning is comparable to the method proposed for solvent incineration in a radioactive β-γ facility. The ability of the solvent to maintain a flame and burn completely (not just vaporized) will be demonstrated during the burn campaign. Transfer and handling of solvent mixed with slurry will be practiced by the operators so that procedures for a radioactive facility can be developed.

Tracer Studies

At the conclusion of these solid and solvent tests, waste feed will be spiked with small amounts of a low-level beta emitter with a short half-life, such as ^{42}K. The location of preferential nuclide migration will be determined during these tests.

Table 1

β-γ Incinerator Feed Radionuclide Signatures and Limits

Isotope	Energy, keV	Limit, μCi/kg Waste[a]
^{90}Y	202	1.76
^{91}Y	1200	0.53
^{95}Zr	724, 756	0.53
^{95}Nb	766	1.76
^{103}Ru	537	1.41
^{134}Cs	600, 800	0.17
^{137}Ba	661	0.17
^{140}Ba	44, 537	0.70
^{144}Ce	133	0.11
^{144}Pr	622,1490,2189	0.44
^{51}Cr	320	35.3
^{58}Co	810, 1680	0.88
^{60}Co	1170, 1330	0.15

a. Assumes
1) no decontamination factor for incineration and off-gas scrubbing and filtration.
2) no dilution of incineration gases with building ventilation air.
3) based on ERDA Appendix 0524 Controlled Area Inhaled Limits.

Table 2

Activity of β-γ Waste at SRP

Activity Range Curies	Volume, m^3	% Volume	Curies	% Curies
0	13,700	56	0	0
0.01 - 1	10,080	42	144	6
1 - 10	326	1.3	250	10
10 - 100	96	0.4	289	11
100 - 1000	2	0.01	670	26
>1000	74	0.3	1,200	47
Totals for FY-72-76	24,278		2,553	

Table 3

Solid Waste Components

Rubbers	- Latex, Neoprene	
Plastics	- Polyethylene, PVC	
Cellulosics	- Paper, Cardboard, Cotton Fiber	
Special Polymers	- Teflon	
Standard Waste Mix	- Latex	19%
	PVC	8%
	Polyethylene	23%
	Cellulosics	40%
	Moisture	5%
	Non-combustibles	5%

Table 4

Effluent Gas Composition (at 1 km from process stack)

Pollutant	Calculated Air Quality, μg/m^3	State Standard, μg/m^3
SO_2	14	1,300
NO_x	2	100
CO	0.001	25,000
Non-methane hydrocarbons	None	130
HCl	7.5	Not Specified
Particulates	0.40	60

Note:

The data are obtained by using a thermodynamic equilibrium computer code to calculate the production rate of each component in the off-gas on a per hour basis. The production rate is then adjusted for the spray quench neutralization effect (~75%) and the baghouse filtration efficiency (~98%). The adjusted generation rate of each component is time-averaged according to the standard measuring interval specified by South Carolina guidelines. Using a decontamination factor derived from meteorological data recorded at SRP, the air quality is calculated for a distance of 1 km from the stack.

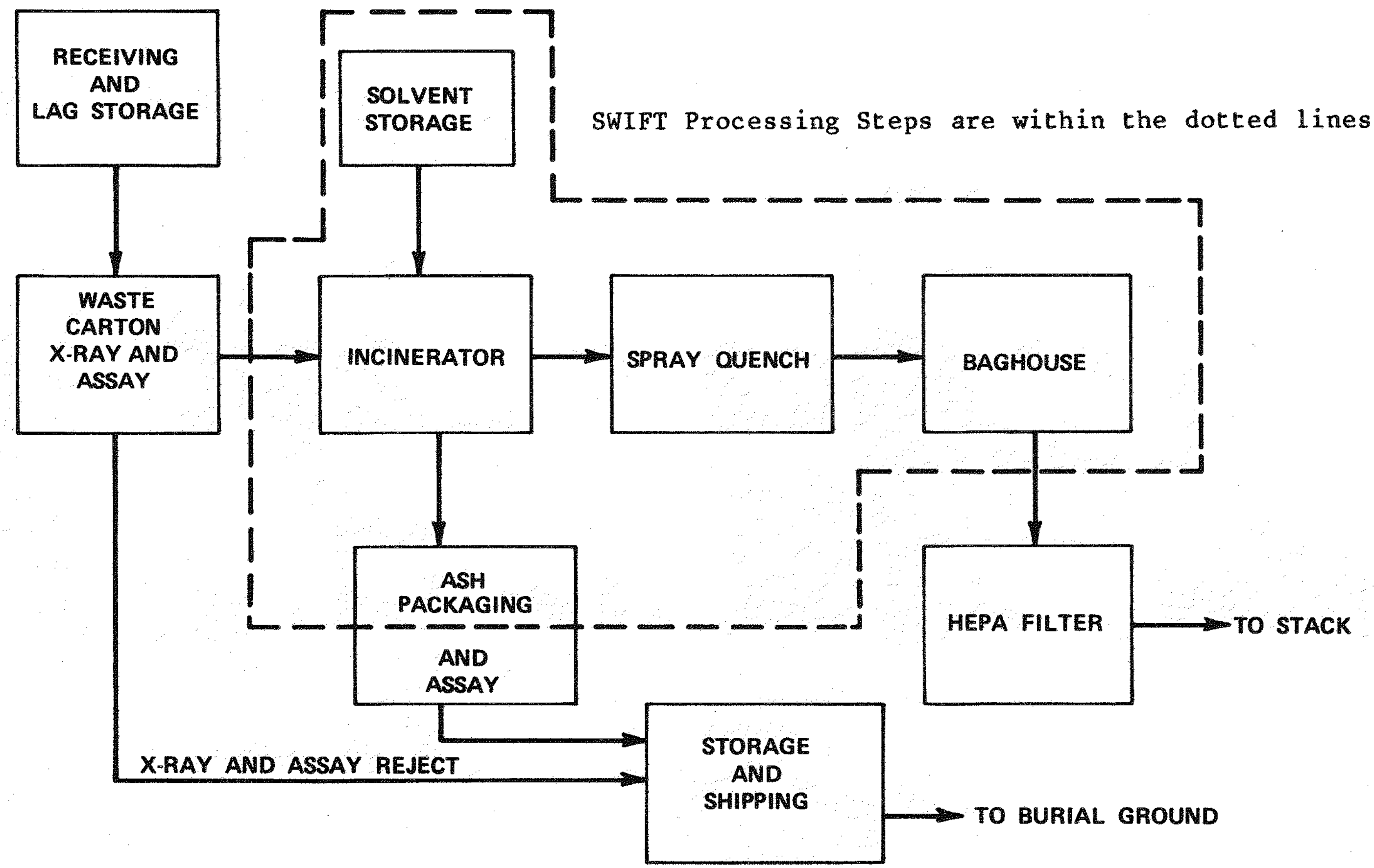


Figure 1. Low-Level Waste Incineration Facility Flow Diagram

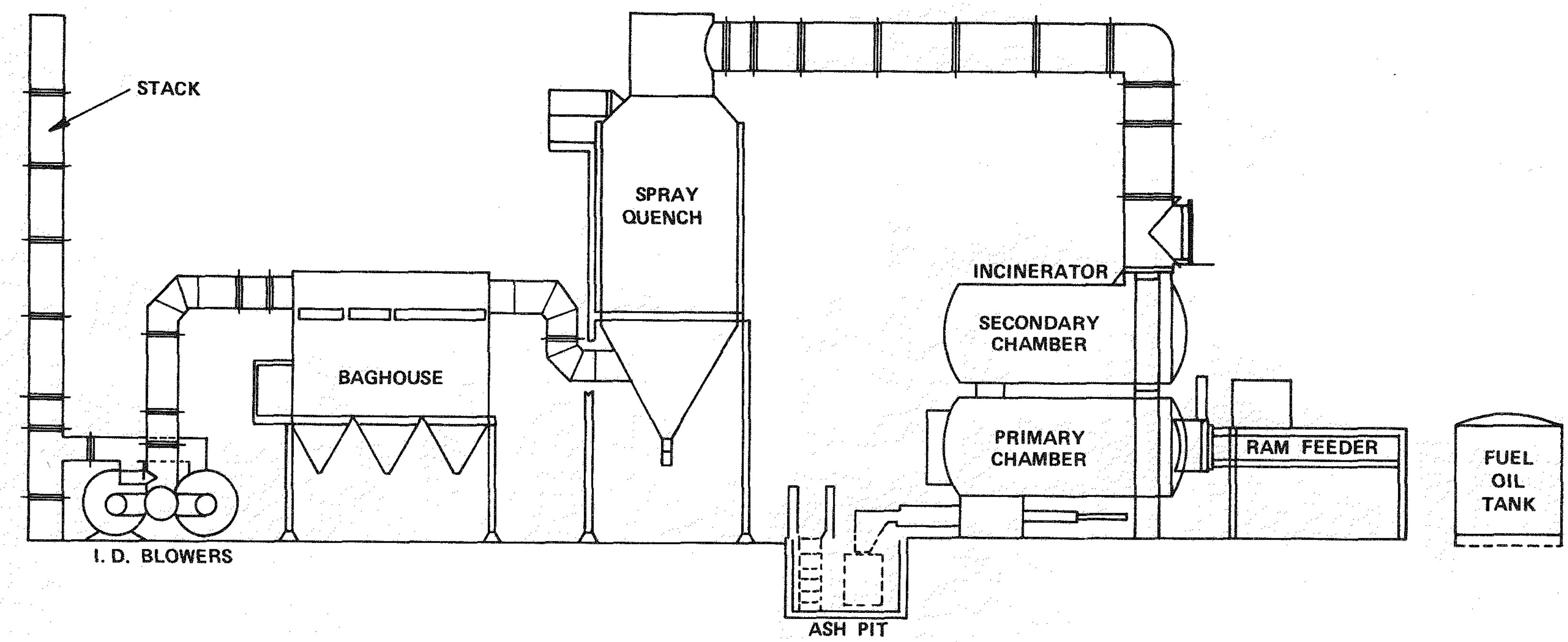


Figure 2. SWIFT Elevation Drawing

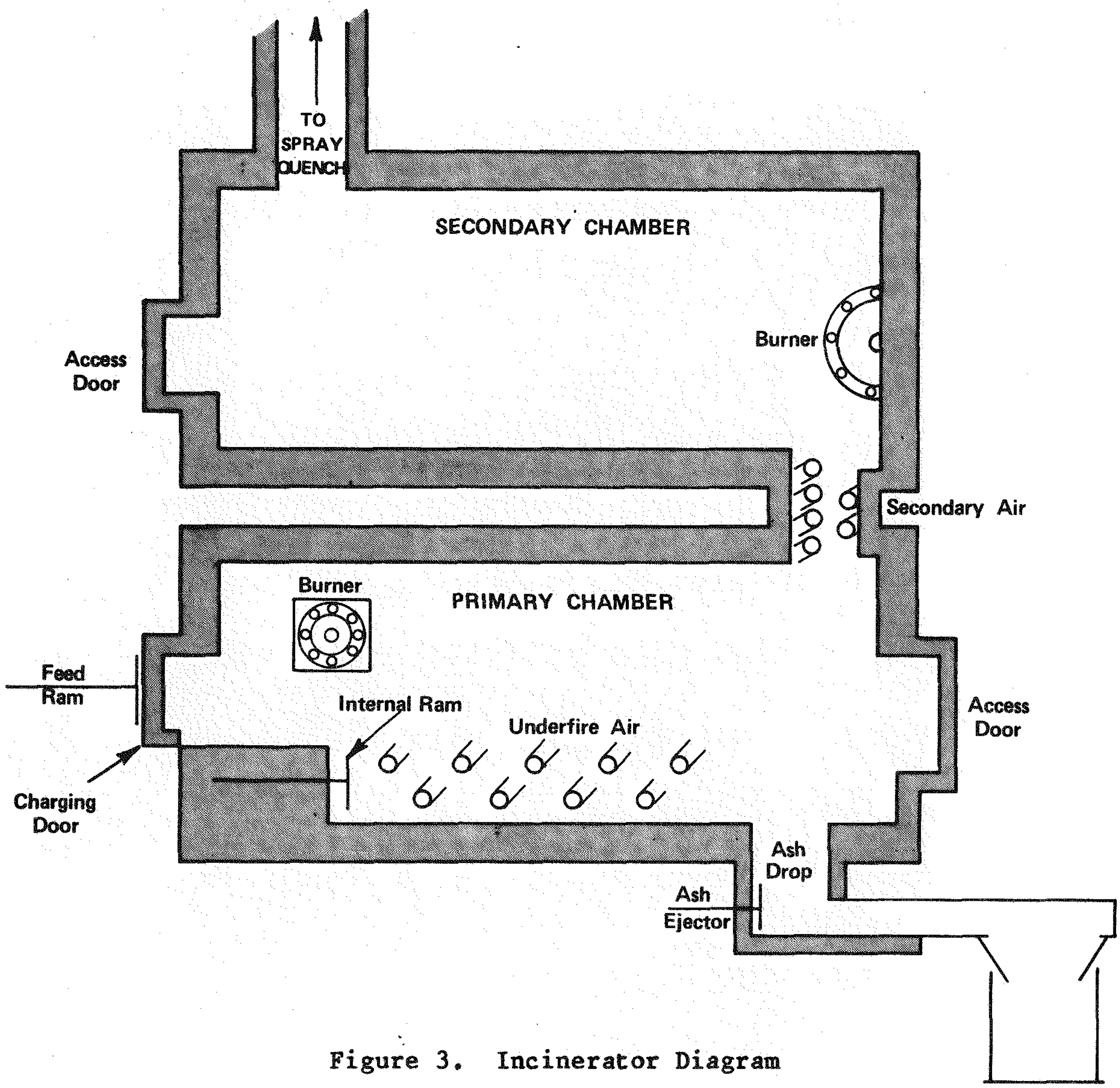


Figure 3. Incinerator Diagram

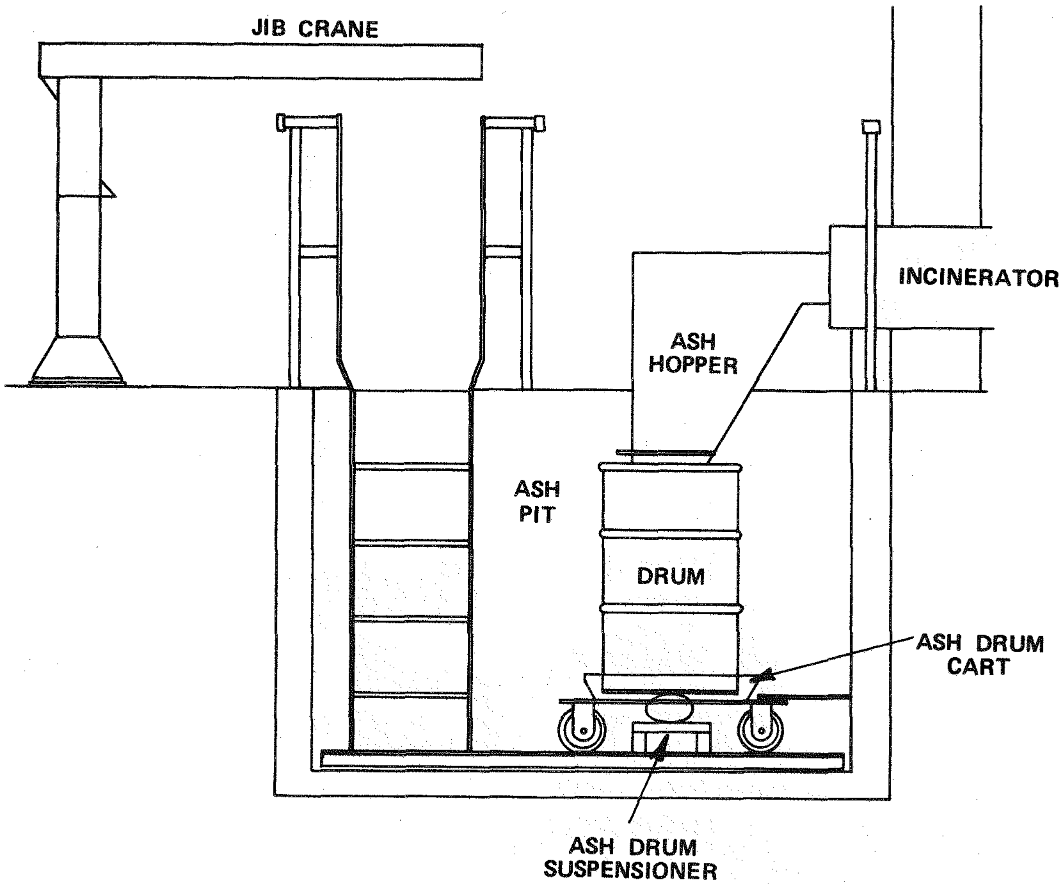


Figure 4. Ash Drum Removal System

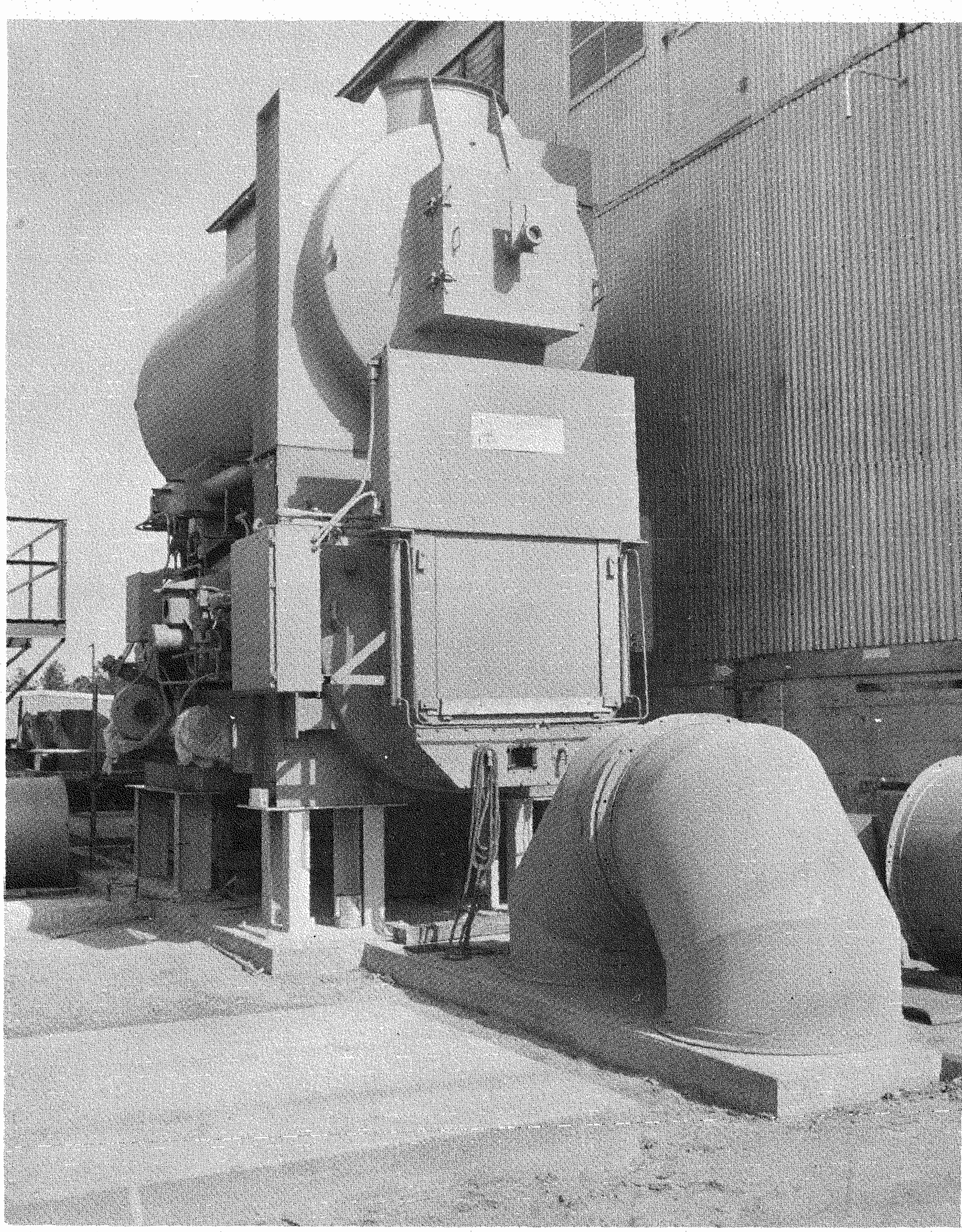
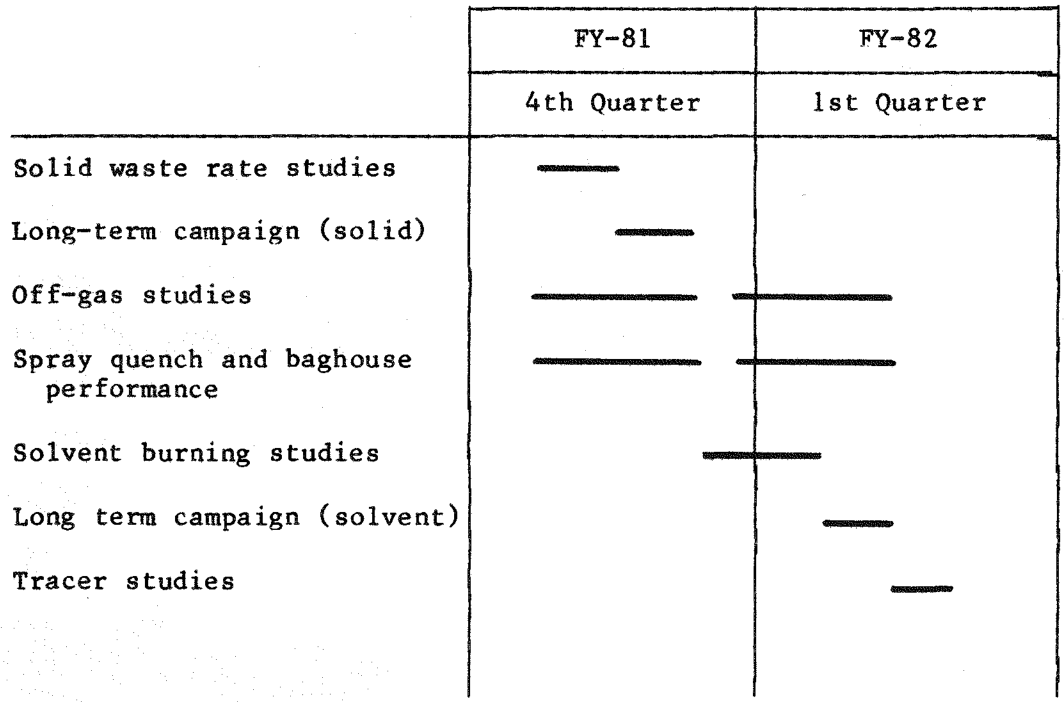


Figure 5. Assembled Incinerator

Figure 6. Experimentation Schedule



FY - Fiscal Year goes from October 1 to September 30