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COMBUSTIBLE RADIOACTIVE WASTE TREATMENT BY INCINERATION AND CHEMICAL DIGESTION

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American Institute of Chemical Engineers

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ABSTRACT

A review is given of present and planned combustible radioactive waste treatment systems in the U.S. Advantages and disadvantages of various systems are considered. Design waste streams are discussed in relation to waste composition, radioactive contaminants by amount and type, and special operating problems caused by the waste.

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COMBUSTIBLE RADIOACTIVE WASTE TREATMENT BY INCINERATION AND CHEMICAL DIGESTION

I. INTRODUCTION

Increasing difficulty in establishing commercial sites for shallow land burial of low-level waste (LLW) and retrievable storage of transuranic waste (TRU) has resulted in pressure to reduce the volume of radioactive waste being generated.

Estimated annual generation(1) of LLW and TRU from 1980 to 1983 are $\sim$90,000 m^3/yr and $\sim$8600 m^3/yr, respectively. Of the LLW generated, $\sim$45% comes from commercial power reactors, $\sim$8% from government activities, and the remainder, nearly equally from industrial uses and institutional generation from facilities conducting educational and medical activities. About 80% of the TRU generation is government-sponsored. If fuel reprocessing should become a viable option again, the generation of TRU waste could double in less than five years.

The waste generated can be separated by physical forms into four basic types: liquid, solid absorbed liquids, dry combustible or compactible solids, and dry noncombustible or noncompactible solids, with the combustible fraction of the LLW and TRU waste averaging $\sim$50%. Organic materials in stored or buried waste may produce hazards including fire, explosion, release of corrosive compounds, and gas generation. Effective treatment of combustible wastes by either incineration or chemical digestion can eliminate the combustible fraction completely, and thus eliminate organic hazards associated with the wastes. Such treatment results in an inert waste form suitable for recovery of radioactive compounds and/or immobilization and disposal.

Initial efforts to develop processes for the treatment of radioactive wastes(2,3) met with equipment problems in feed preparation, corrosion, offgas treatment, combustion effectiveness, and radioactive material containment. Development efforts continued under the Atomic Energy Commission (AEC), the Energy Research and Development Administration (ERDA) and current US Department of Energy (DOE) sponsorships. Several industrial concerns are also developing incineration systems designed to meet specific radioactive waste process requirements. A review of the major waste treatment systems under development in the U.S. follows that includes a brief discussion of the advantages and disadvantages of each system.

II. CHEMICAL DIGESTION

A. ACID DIGESTION (HEDL)

The acid digestion process(4) under development at the Hanford Engineering Development Laboratory (HEDL) in Richland, Washington, involves chemical treatment of combustible wastes for volume reduction, resource recovery and waste stabilization. The process uses sulfuric and nitric acids at 250°C temperatures to decompose waste to carbon dioxide gas, water vapor, and a small amount of residue. The offgas is treated to recover sulfuric acid and nitric acid (which is recycled to the process). The process, successfully demonstrated on all types of common solid combustible waste, is currently being tested for its applicability to sludges, process residues, and other waste forms. During six months in 1978-1979, >2100 kg of low-level TRU waste were processed in a demonstration scale unit, the Radioactive Acid Digestion Test Unit (RADTU) at a 2.7 kg/h average overall rate. The RADTU was then shut down for installation of a high-rate digester and associated equipment that more than doubled its capacity. After shakedown testing, RADTU began processing Hanford's TRU waste in June 1980.

1. Process Description

In the acid digestion process (Figure 1), virtually all solid combustible wastes are readily decomposed. Shredded combustible wastes are continuously added to hot sulfuric acid (250°C) in an annular reactor

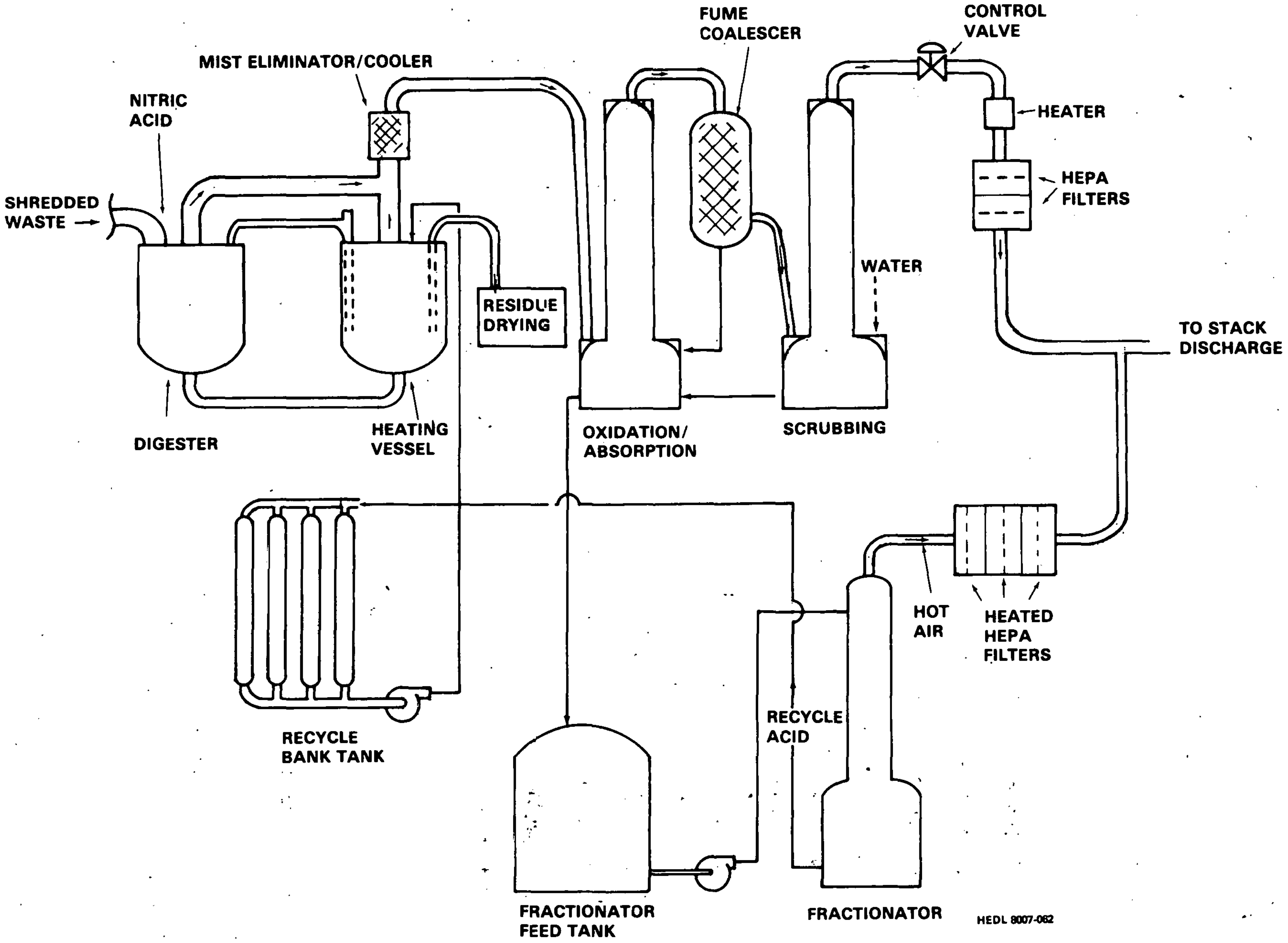

FIGURE 1. HEDL Acid Digestion System.

by a ram feeder. The hot acid attacks the waste, converting it to a charred, carbon-like material. Nitric acid, continuously added at the same time, oxidizes carbon to carbon dioxide, leaving a small amount of solid residue (about 4% of the initial waste volume). The process is readily controlled by regulating the nitric acid or waste addition rates. Criticality control is attained by use of geometrically favorable equipment and administrative control.

The solid residue that accumulates in the acid is periodically removed by transferring the acid slurry to evaporator pots from which sulfuric acid is evaporated at $400^{o}C$ and returned to the digester for reuse. The resulting dry residue, composed primarily of inorganic sulfates and oxides, is thermally stable when heated in air. Plutonium remains with the residue in a soluble, recoverable form.

Off-gases leaving the digester are primarily H_2O, CO_2, CO, SO_2, NO_x and HCl. Air (O_2) is added to this offgas stream to oxidize NO to NO_2, which in turn oxidizes SO_2 and SO_3. The resulting gases are recovered in an oxidation absorption column as nitric and sulfuric acids for recycle to the process. They are first concentrated in an acid fractionator; it separates water and a small amount of NO_x as vapors that are filtered and released to the offgas stream. Nitrogen converted from the reaction of nitric acid with the waste (about 30% of the input HNO_3) also exits via the offgas system as does chlorine (in the form of nitrosylchloride) if present in the incoming waste. No liquid effluents result from the process and virtually no sulfuric acid makeup is required, due to the presence of small quantities of sulfur in rubber and plastic waste materials. The net nitric acid consumption is 1.5 kg to 2 kg per kilogram of waste.

2. Advantages and Disadvantages

The acid digestion process has the following advantages:

- It accepts a wide variety of liquid and solid wastes, including leaded gloves.
- It is a low-temperature (250°C) process that converts refractory actinides to a readily soluble, easily recoverable form.
- It produces no liquid waste streams requiring further treatment.
- Glass and metal components in the digester system are not subject to plutonium uptake.
- The offgas stream does not contain tar, soot, and flyash that can carry radionuclides into the offgas system.
- The process is very stable and readily controlled.

The acid digestion process does have the following disadvantages, however:

- The digester must be fabricated of expensive tantalum or glass-lined steel that requires some care during maintenance and operation. Both materials have a low tolerance for fluoride.
- The presence of a neutron-moderating liquid limits design options and processing rates when waste with high fissile material content is processed.
- The system requires sorting and shredding of incoming waste.

3. Operating Experience

Engineering feasibility of the acid digestion process was demonstrated during a six-month test period in which low-level waste from Hanford's Z-Plant was successfully processed in RADTU. During that period, RADTU was operated 16 hours per day, five days per week. Waste addition was conducted during 12-hour periods that were followed by completion of digestion and eight hours of standing time while the temperature was maintained.

The waste contained a high fraction of cellulosic material, about 15% (estimated) plastic materials, some rubber and a wide variety of intermixed metal and glass components. Bulky, noncombustible items were separated by hand sorting prior to digestion. The 2100 kg of waste processed yielded 325 kg of dried residue product with a 800-kg/m^3 bulk density.

System operation with low-level waste showed that the acid digestion process can be operated on a sustained, reliable basis and is very stable and easy to control. Sustained digestion rates of 3 kg/hour of predominantly cellulosic wastes were achieved with instantaneous rates as high as 4 kg/hour. More details on the experiment are available in Reference 4.

4. Status and Goals

The acid digestion process was demonstrated on a pilot scale of 10 kg of waste per hour using an annular-shaped digester. The annular digester has since been installed in RADTU with other rate-increase components more than doubling the previous 3 kg/h capacity while simultaneously accommodating a higher allowable fissile mass in the system. Shakedown testing of the higher-capacity RADTU unit was completed during the first quarter of 1980 and RADTU processing of Z-Plant TRU waste began during the second quarter.

The higher-rate digestion facility will demonstrate system reliability by processing both low-activity TRU and high plutonium-activity wastes from production and decommissioning. In addition, processing of special waste and scrap forms such as ion exchange resins, liquids, and sludges will be evaluated. Testing of other special waste forms will also be performed as needed.

Application of this process to waste streams other than TRU (i.e., beta gamma waste, reactor waste, etc) is being investigated internationally; HEDL is cooperating with a number of foreign countries in an effort to foster coordinated cooperative development and to minimize costs. An OECD-sponsored international workshop on acid digestion development will be held during October 1980 in Richland with participants attending from the United Kingdom, Germany, France, Switzerland, the Netherlands, and Japan.

III. INCINERATION

Incineration of radioactive wastes for volume reduction, mass reduction, resource recovery, or waste stabilization is recognized as an effective waste treatment method. Several incineration systems are currently in various stages of development, testing, or operation. The following review discusses the major incineration systems currently under development or in operation.

A. CONTROLLED-AIR INCINERATION (LASL)(1,5,6)

In 1973, the Los Alamos Scientific Laboratory was directed to evaluate current incineration and offgas treatment technology for application to the combustion of TRU waste. System selection criteria were established that included flexibility to accept a wide range of feed compositions, ease of combustion rate control with high combustion efficiency, low particulate emissions, and ability to tolerate relatively high levels of noncombustible components in the wastes. A controlled-air incinerator coupled with a high-energy aqueous offgas cleanup system was selected for development and engineering demonstration.

1. Process Description

The controlled-air incinerator (CAI) process is shown as a simplified line drawing in Figure 2. The overall process can be divided into four

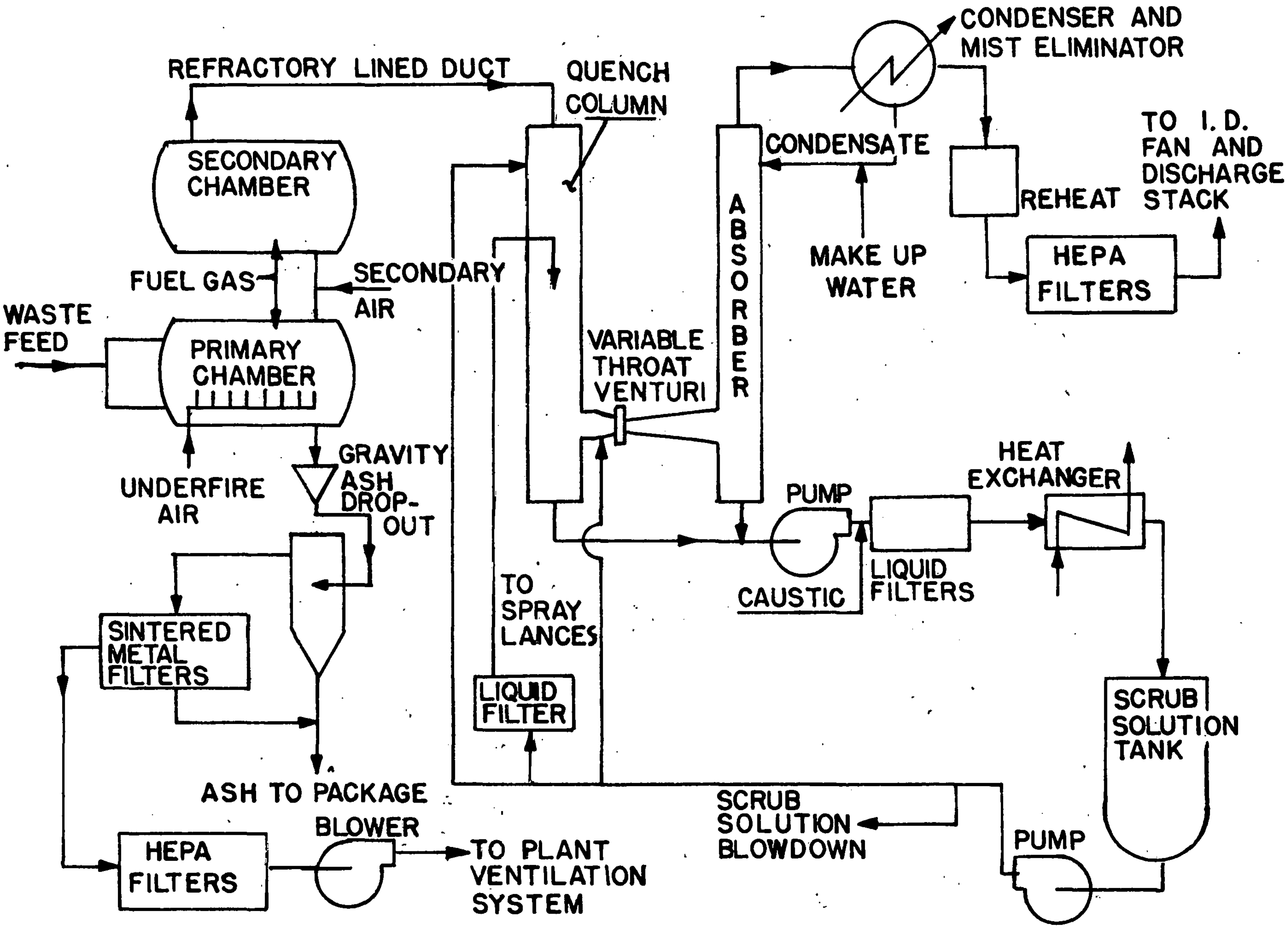

FIGURE 2. LASL Controlled-Air Incinerator.

subsystems, which are a) the feed preparation and introduction subsystem, b) the incinerator subsystem, c) the offgas cleanup subsystem, and d) the scrub solution recycle subsystem. The incinerator consists of a two-stage, refractory-lined, natural gas-fired incinerator. The overall system is constructed in an induced draft configuration to aid in containment of radioisotopes.

TRU wastes are received in 0.06-m^3 cardboard boxes. These packages are assayed for TRU content and passed through a microdose x-ray system to detect noncompatible items such as large noncombustibles and bottles of liquids which would present a potential explosion hazard. After this inspection and sorting, the wastes are charged one box at a time through a ram feeder to the lower incineration chamber. Normal operating temperatures in the lower or primary combustion chamber are from 800°C to 1000°C. Underfire air is admitted to the primary chamber to maintain combustion at slight excess oxygen conditions. Unburned volatile compounds and some particulate matter from the primary chamber are burned to completion under high excess air in the secondary chamber. Secondary air is introduced in the duct connecting the two chambers and a nominal combustion temperature of 1100°C is maintained in the secondary chamber by an auxiliary fuel gas burner.

Offgas from the CAI contains a small amount of particulates and inorganic acids. The offgas is treated by passing sequentially through a quench column, venturi scrubber, a packed column, and HEPA filter elements before releasing to the atmosphere. A direct spray contact with recycle scrub solution in the quench column cools the offgas from 1100°C to $\sim$95°C. The cool gas then passes through a variable-throat venturi where high turbulence and liquid droplet contact remove most remaining particulates. Residual inorganic acids not removed in the quench and venturi system are removed from the gases by counter-current contact with recycled scrub solution or fresh water in a packed absorber column. The offgas then passes through a condenser and reheater to remove the bulk of the water vapor and to assure that the offgas is above the saturation temperature before passing into the filter housing. The filter housing contains a roughing filter followed by two sets of HEPA filters in series to provide final removal of particulates.

A scrub solution recycle system is utilized to minimize the generation of secondary liquid wastes. Cartridge filters are used to remove particulates from the solution and pH is controlled by automatic caustic addition. The scrub solution is then cooled to approximately 50°C and returned to a surge tank for recycle through the quench column, packed column, and venturi scrubber.

Ash is removed from the primary chamber of the incinerator through a gravity ash dropout system into a dropout hopper. A pneumatic transport system transfers ash from the dropout hopper to an ash packaging station. This ash removal system allows continuous incinerator operation. A vacuum ash removal system is also provided to permit thorough cleaning of both incinerator chambers during shutdown conditions.

2. Design Waste Stream

Design basis feed for the LASL CAI process consists of TRU contaminated solids made up of 35% cellulosics, 23% polyethelene, 12% polyvinyl chloride, and 30% rubber. The high plastics and rubber content of the design basis feed result in high heat release during combustion and added difficulty in ensuring efficient conversion of all of the waste. The high content of polyvinyl chloride also results in generation of hydrochloric acid that must be cleaned up in the offgas system.

3. Advantages and Disadvantages

The basic concept of controlled air incineration is a commercially proven incinerator process. The process provides great flexibility in handling varied types and compositions of waste. Controlled-air incinerators are capable of large processing capacities. The limited air input to the primary chamber results in combustion in a quiescent atmosphere and low particulate carryover to the secondary chamber.

System disadvantages include the fact that ash removal is not positive in most CAI systems. The LASL CAI system has successfully utilized a gravity ash dropout system that overcomes this disadvantage effectively. A second potential disadvantage is a possible buildup of plutonium in the refractory lining due to migration into the refractory. Also, a contaminated liquid slurry is generated during offgas treatment requiring low-level liquid waste treatment facilities at the site where the process is applied.

4. Status and Goals

The LASL CAI process has been operated at the design feed rate of 45 kg/h and has achieved mass and volume reduction ratios of 10:1 and 40:1, respectively, while burning design basis feed.

Development with nonradioactive waste was completed during September of 1979. In December of 1979, ~230 kg of TRU-contaminated waste generated at the LASL Plutonium Facility were processed through the CAI system. Operation with contaminated waste was very satisfactory and all combustion secondary waste such as the spent liquid filter cartridges from the scrub liquid recycle system were charged to the incinerator at the conclusion of the run. The realized primary volume reduction ratio significantly exceeded the 40:1 predicted by nonradioactive experiments.

In more than 800 h of operation the CAI system shows no adverse signs of corrosion, erosion, or wear in any of the primary components. The offgas cleanup subsystem has functioned adequately even under abnormal operating conditions. The maximum chloride and sulfate ion concentrations measured at the HEPA filter plenum were on the order of 10 parts per million. HEPA filter life has been demonstrated to be in excess of 230 h operating time.

A final demonstration run with TRU waste will complete the CAI demonstration program for as-generated Defense solid TRU wastes. Experimental results, design specifications, and recommended operating procedures are being compiled for publication in late FY 1980. Transfer of results, design specifications, and recommended operating CAI technology to other DOE sites and to the commercial nuclear industry is a continuing objective.

Commercialization of the CAI process for treatment of low-level wastes generated by the nuclear industry is a near term goal. Extension of the CAI process demonstration to treatment of combustible liquids and spent ion exchange resins is being pursued.

B. CONTROLLED-AIR INCINERATION FOR TRU WASTES (SRL)(7)

A 5 kg/h throughput electric-controlled air incinerator is being developed for combustion treatment of Savannah River Plant solid TRU wastes. The unit is designed to incinerate small quantities of solid waste contaminated up to 10^5 times the minimum of 10 nCi/g alpha activity TRU waste.

1. Process Description

The incinerator proper consists of a ceramic two-stage, electrically-heated controlled-air incinerator. The offgas subsystem consists of a three-stage wet treatment system prior to HEPA filtration. A simplified line drawing of the process is shown in Figure 3. Waste is packaged in

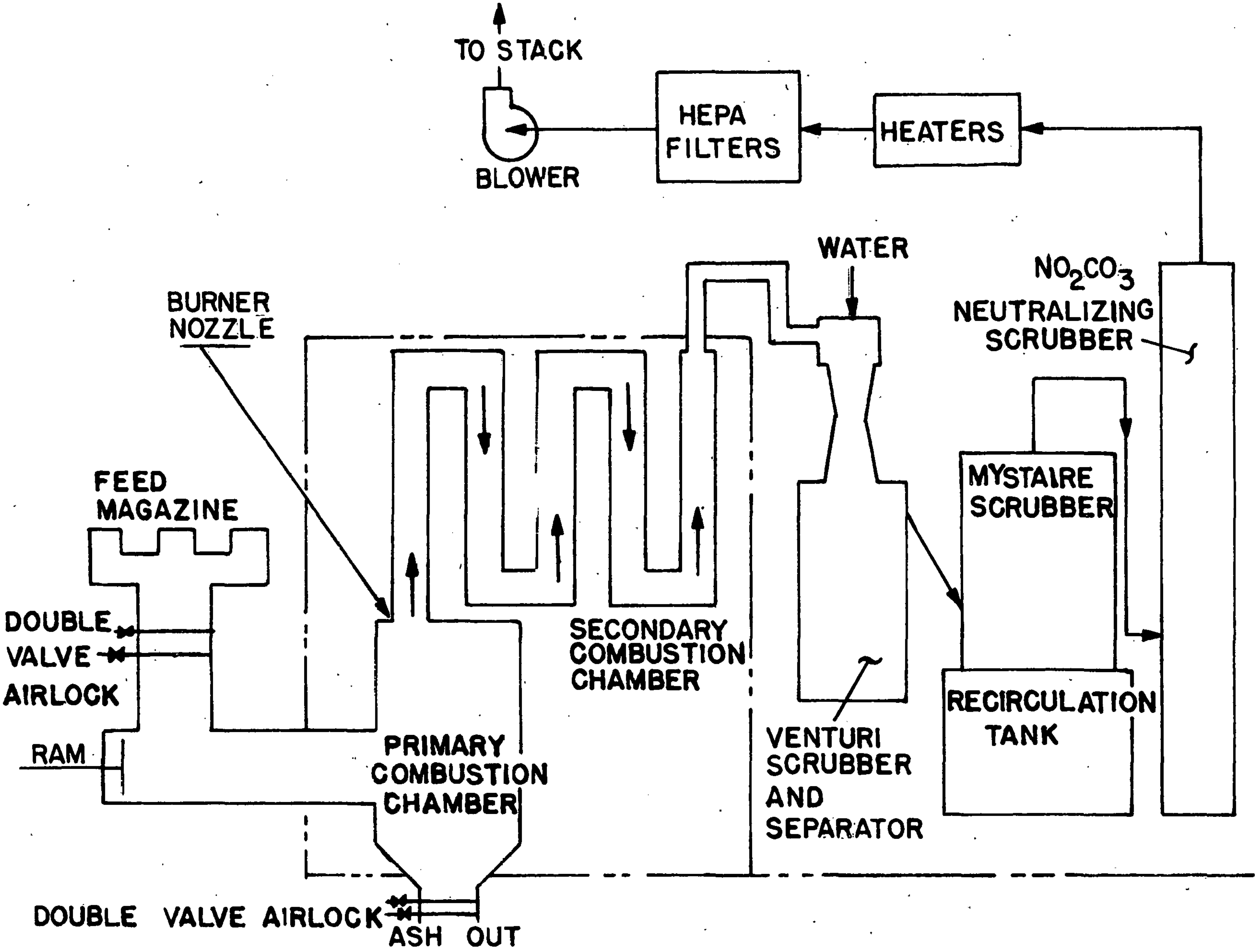

FIGURE 3. Electric CAI at SRP.

400-g lots in paper bags prior to incineration. These packages are fed through a double-valve airlock and rammed into a silicon carbide, horizontal, primary-combustion chamber. The waste is treated at 700°C to 900°C with substoichimetric purge air. At the exit of the primary chamber, 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 a 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 labyrinth is to provide a minimum of 4 seconds offgas residence time at 1000°C to ensure complete combustion.

Offgas treatment consists of a venturi quench, a fibrous bed scrubber, and a packed-bed contactor to neutralize HCl formed from the burning of polyvinyl chloride. The first two scrub systems use continuously recycled water that becomes saturated with inorganic acids but retains the offgas particulates. In-line filters are used to remove the entrained particulates and tars from the filter solutions in the first two scrubber loops. The third scrubber loop is primarily used to remove and neutralize HCl while most TRU contaminants are held in the first two scrubber loops. This results in a sharply reduced generation of TRU-contaminated salt as secondary waste.

HEPA filters provide a final filtration step before the offgas is released. To prevent blinding of the HEPA filters by condensate, the saturated effluent from the scrubber system is superheated to pass through the filters in a dry state.

2. Design Basis Waste

The design waste stream consists of highly TRU-contaminated combustibles made up of 31% cellulosics, 27% polyvinyl chloride, 21% polyethylene, and 21% rubber. The waste is shredded and packaged in paper bags weighing 400 g each, prior to feed to the incinerator.

3. Advantages and Disadvantages

General advantages and disadvantages of the Savannah River Plant alpha waste controlled-air incinerator are similar in nature to those discussed with the LASL CAI system. Although the use of manually prepackaged feed is labor-intensive, it does provide a positive control to prevent fissile material accumulation in the feed system. Similarly, electric heat is costly but the furnace is independent of the waste characteristics, to control temperature.

4. Status and Goals

Nonradioactive testing with wastes characteristic of plutonium finishing operations have been routinely incinerated at throughputs exceeding 5 kg/h for period up to 6 hours. A total of over 1000 kg of such wastes have been incinerated to date. Upon completion of an experimental phase to determine process sensitivity and flexibility, the facility will be used to develop bases for a production unit, a safety analysis report, technical standards, and operating procedures. Operational processing of actual TRU waste is scheduled in 1985.

C. LOW-LEVEL WASTE CAI (SRL)(8)

An incineration process is being developed at the Savannah River Laboratory to reduce the stored volume of combustible processed wastes contaminated with low levels of beta-gamma emitters. More than 5000 m^3 of this waste is disposed of annually in burial ground trenches. Anticipated volume reduction from incineration of these wastes is approximately 20:1. The incinerator will also be used to dispose of an inventory of 600,000ℓ of degraded solvent from chemical separations at a current generation volume of 19,000 ℓ/year.

1. Process Description

The planned process, shown in Figure 4, incorporates a two-stage, 185 kg/h controlled-air incinerator similar in design to the LASL CAI demonstration unit. A portion of the degraded solvents to be incinerated in this unit contain tributylphosphate. In this case, powdered lime is to be added to react with the phosphorus and prevent formation of highly corrosive

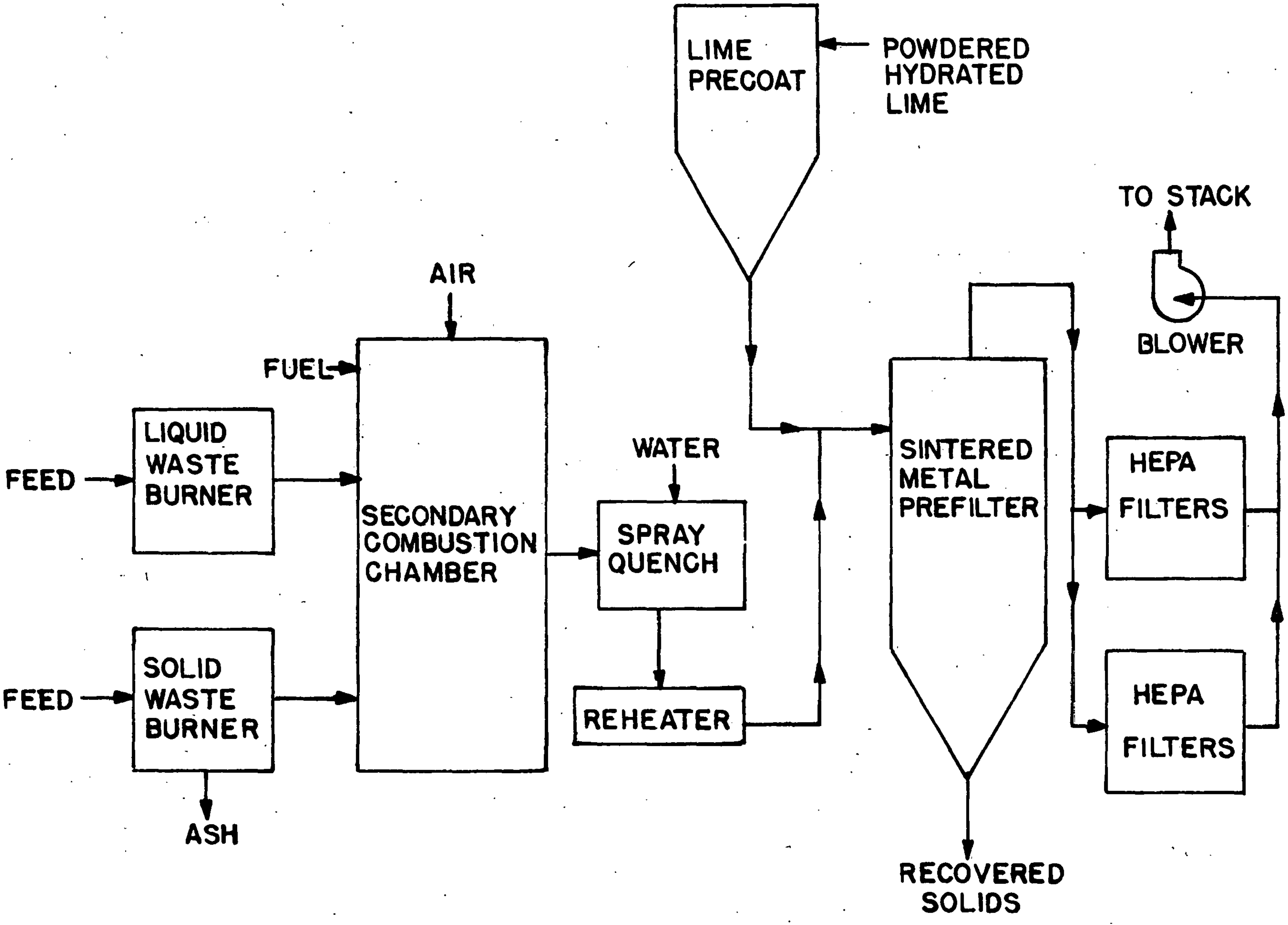

FIGURE 4. SRP Low-Level Waste Incinerator.

P_2O_5. Solvents not containing phosphorus are to be spray injected directly into the primary chamber while the secondary chamber provides for complete combustion.

Equipment is to be provided for cooling, neutralizing, and filtering the incinerator offgas. A spray quench to reduce the gas phase temperature to 150°C prior to prefiltration will ensure the deposition of volatiles and also prevent absorption of moisture by hygroscopic salts on the sintered metal prefilters. Inorganic acids in the offgas are to be neutralized by the lime coating on the prefilters. Residue buildup on the prefilters is controlled by (reversed) flow purging and gravity discharge into drums. Prior to HEPA filtration the gases are further cooled and removed from the saturation point by air dilution to 90°C.

2. Status and Goals

A full scale nonradioactive demonstration unit of this design is proposed for construction and testing during 1980. Proposals for a production low-level waste incinerator facility are being prepared for 1982 funding.

D. FLUIDIZED BED INCINERATION (RFP)(9,10)

Fluidized bed incineration is being developed at the Rocky Flats Plant (RFP) with the primary objective of demonstrating a production scale treatment process for TRU wastes. Extensive development work has also been done in relation to other nuclear fuel cycle waste. Development of the fluidized bed combustion technology was completed with a small scale pilot unit and demonstration runs are being conducted in a 82 kg/h production-scale plant.

1. Process Description

Figure 5 is a line schematic of the fluidized bed incineration demonstration plant at the Rocky Flats facility. Containment for the system is provided by enclosing the entire system in a hot cell and utilizing glovebox enclosures. Waste passes through an air lock into a feed preparation glovebox where it is hand sorted for large pieces of noncombustible materials. The combustible fraction is then shredded through a coarse shredder and air-classified for additional removal of noncombustible tramp metal. A second shredding step is used for final preparation and sizing of the waste prior to incineration. Waste is fed to the incinerator through a tapered screw conveyor into the primary reaction chamber. The fluidized bed consists of heated sodium carbonate granules that are fluidized by compressed air and nitrogen. The waste is decomposed by partial combustion and pyrolysis within the fluidized bed, producing sufficient heat to maintain a bed temperature of approximately 550°C. Combustion control in the process is achieved by varying the ratio of air to nitrogen in the fluidizing gas.

Inorganic acid gases generated by combustion of waste materials such as polyvinyl chloride are neutralized _in situ_ by the sodium carbonate in the fluidized bed. Offgas from the primary reactor then passes through a

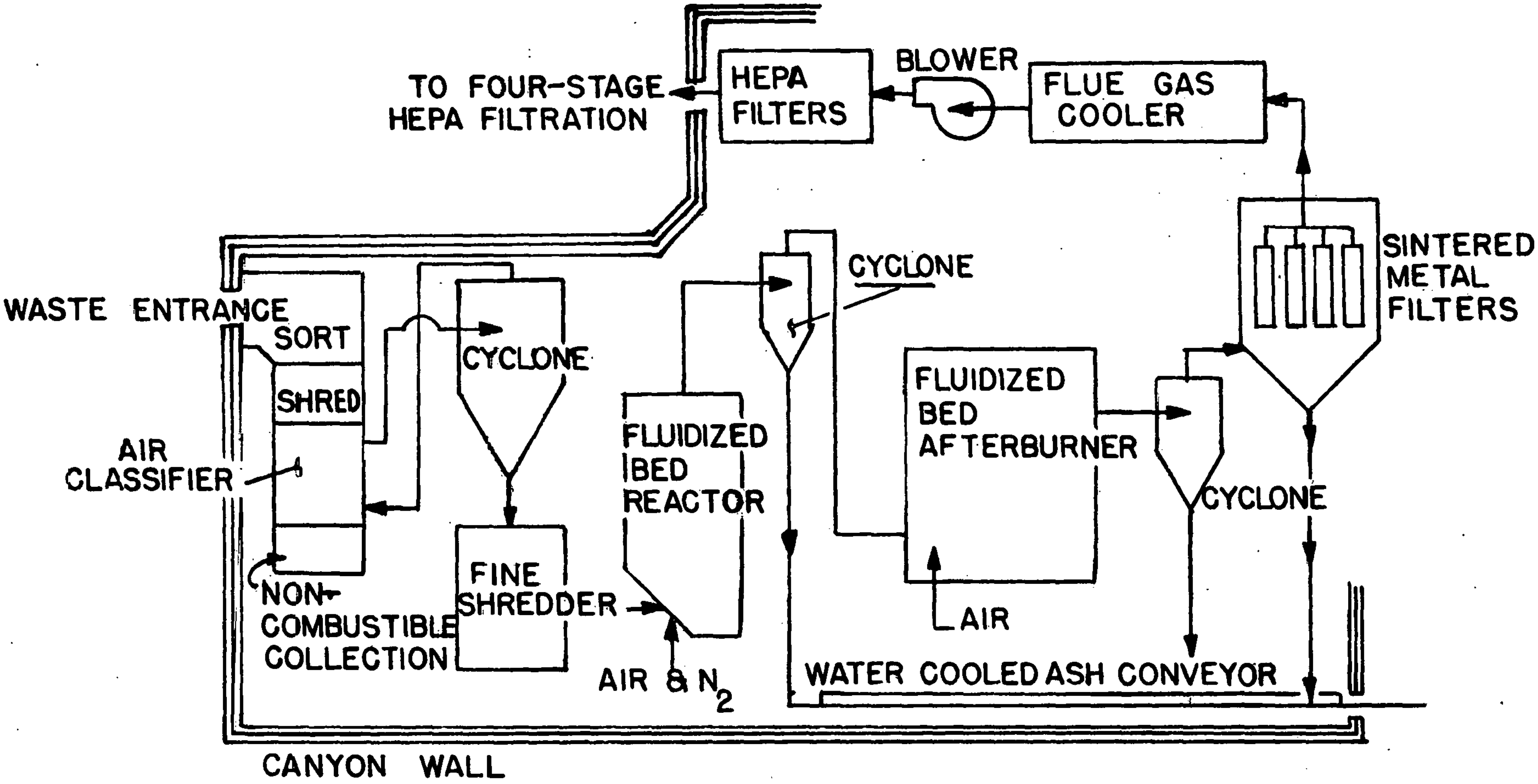

FIGURE 5. Rocky Flats Fluidized Bed Incinerator.

cyclone separator to remove entrained sodium carbonate, sodium chloride, and flyash before the gas enters the catalytic afterburner, consisting of a fluidized bed of oxidation catalyst.

Offgas leaving the catalytic afterburner must be additionally treated to remove flyash, catalyst dust, and small amounts of sodium carbonate and sodium chloride fines not removed by the primary reactor cyclone separation. This additional offgas cleanup is achieved by passing the gas stream through a second cyclone separator and then through a bank of sintered metal filters prior to cooling to 50°C in a water-cooled heat exchanger. The cooled flue gas is then pulled through high speed blowers which maintain a slightly negative draft throughout the system. The offgas then passes through a bank of HEPA filters prior to exiting through the building plenum system, a four-stage HEPA filtration.

2. Design Basis Feed

Feed to the fluidized bed incinerator consists of TRU-contaminated materials containing approximately 50% paper, 22% polyethylene, 9% cloth, 5% wood, 4% polyvinyl chloride, 4% latex rubber, and lesser amounts of leather and other plastics. The waste is presorted and shredded in feed preparation equipment.

3. Status and Goals

Nonradioactive testing of the fluidized bed incineration plant began in November 1978. More than 13,000 kg of solid wastes have been charged through the system during four 100-h runs. Of the total waste charged, approximately 30% was TRU suspect waste. The system has been successfully operated at charging rates exceeding the design rate of 82 kg/hour. Problems were encountered with the sintered metal filters and with the high speed blowers that provided the negative draft to the system. Reduction of the filter face velocity to permit cake disengagement during blowback solved the problems with the sintered metal filters. Air ejectors were used to replace the high-speed blowers.

Modifications to the system to permit liquid waste such as compressor oils and chlorinated solvents to be injected to the system are in progress. Demonstration runs and compilation of design documents are scheduled for completion in FY-1980. Demonstration goals include determination of system reliability, maintenance requirements, and volume reduction capability.

Following completion of demonstration activities with the fluidized bed incinerator, plans include the routine use of the incinerator system for treatment of Rocky Flats Plant low-activity TRU waste. At present, there is no proposal for commercial demonstration of the fluidized bed incinerator.

4. Advantages and Disadvantages

One principal advantage of fluidized bed incineration system utilizing a sodium carbonate bed material is the *in situ* neutralization of HCl and other corrosive gases generated during combustion of the wastes. This makes a dry offgas system possible, thereby eliminating aqueous offgas scrubbing and eventual processing of scrub solutions. Low-temperature (550°C) operation eliminates the need for refractories and the system is more compact than more conventional incinerators. Fluidized bed incineration also claims improved combustion efficiencies.

Disadvantages of the fluidized bed incineration system include the preliminary sorting and shredding of the waste material. For optimum operation, feed material should be relatively free of metals and other noncombustibles to eliminate unnecessary loading up of the fluidized bed. The fluidized bed can tolerate a certain amount of metal and other foreign materials and will still perform satisfactorily if a portion of the bed material is drawn off to provide removal of the foreign material.

E. FLUIDIZED BED INCINERATOR (NEWPORT NEWS)(11,12)

A fluidized bed calciner/incinerator has been developed jointly by Newport News Industrial Corporation and by Energy Incorporated. This system has been designated RWR-1 for Radwaste Volume Reduction. The system claims to have the capability of reducing both liquid and solid radioactive waste to an inert granular solid.

1. Process Description

Shredded solid wastes, dewatered sludges and spent resins, and liquid wastes are fed to a single chamber process vessel that contains a fluidized bed. The fluidized bed design utilizes an alumina/silicate seed bed that results in uniform particle size control and particle distribution. A variety of supplemental fuels can be used to provide heat as required to maintain the system operating temperature. The system is designed to operate at various temperatures up to 1000°C, depending on the particular waste being processed. The products of the calcination and incineration processes are carried out of the vessel in the offgas stream and removed by cyclone separation. Additional offgas treatments include a quench tank, a venturi scrubber, a wet cyclone, a condenser and mist eliminator, followed by HEPA filtration and provision for iodine adsorbtion. A simplified process diagram of the Newport News volume reduction system is shown in Figure 6.

2. Design Basis Feed

The system is designed to accept a wide variety of feed materials and has the capability of adjusting processing conditions to meet the specific feed being processed. Combustible solids can be handled at rates of 90 kg/h and can have a polyvinyl chloride content up to 5 weight percent.

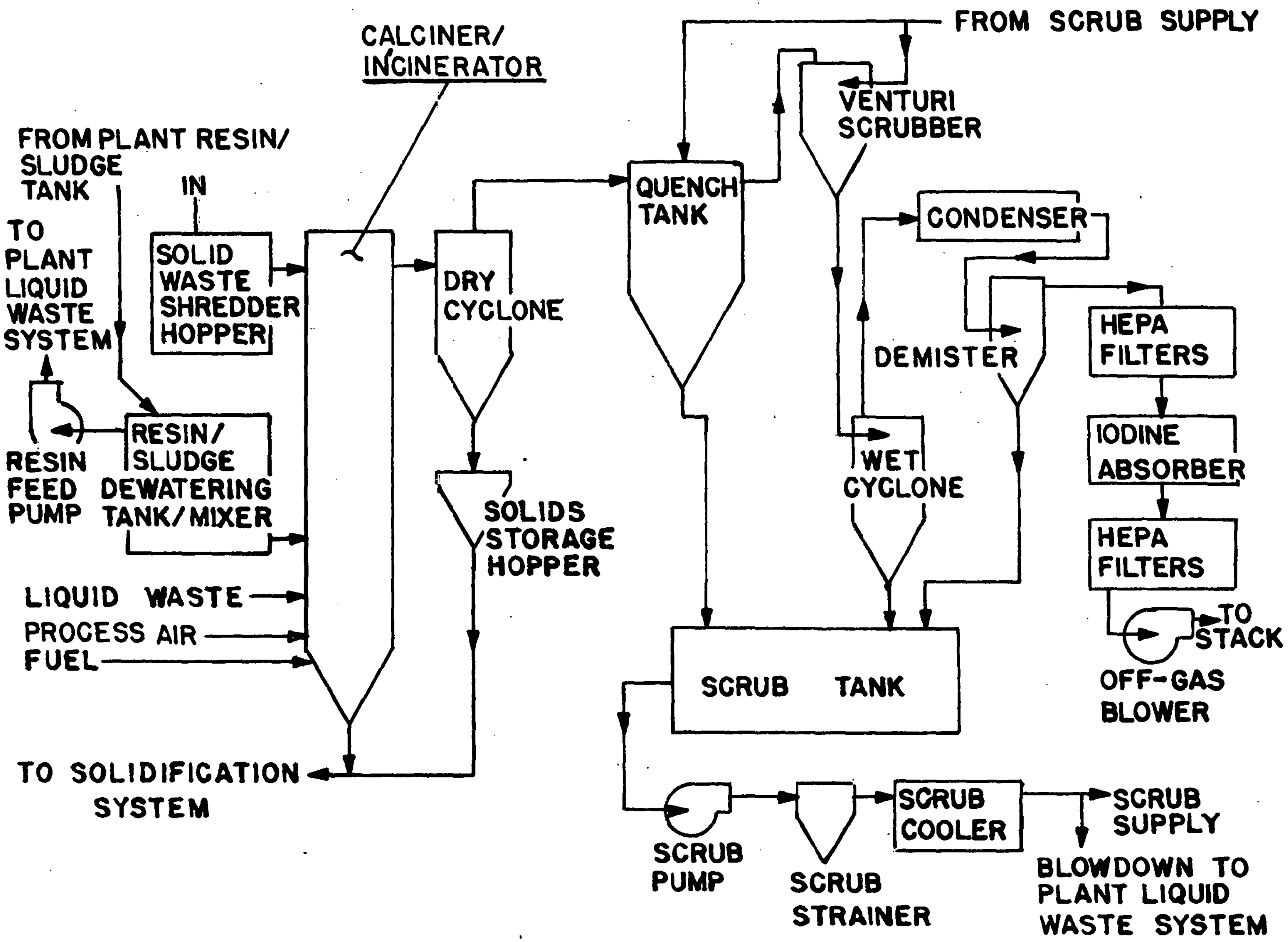

FIGURE 6. Newport News Industrial Calciner/Incinerator System.

3. Advantages and Disadvantages

A major advantage of the Newport News system is that it is a commercial unit designed specifically to handle radwaste. It has the ability to process and reduce the volumes of almost all types of radioactive waste from the operation of a nuclear reactor. The volume reduction factor claimed for combustible solids is 80:1 with an overall average volume reduction factor anticipated to be in the area of 10:1.

The RWR-1 system requires that solid waste be shredded prior to feeding to the fluidized bed and noncombustible materials can build up in the fluidized bed requiring subsequent removal or bed cleaning.

4. Status

A full-scale pilot plant has been in operation at Idaho Falls since mid-1977. A topical safety analysis report for the system has been undergoing review by the US Nuclear Regulatory Commission (NRC) since June of 1977. A commercial unit is being installed at the Nine-Mile Point nuclear station with startup anticipated in early 1980s. The capacity of this commercial unit is approximately 91 kg/h for solid wastes, 45 kg/h for spent resin and filter sludges, and 132 ℓ/h for radioactive liquid wastes.

F. FLUIDIZED BED INCINERATOR (AEROJET)(12,13)

The Aerojet Energy Conversion Company has developed a fluidized bed technology for volume reduction of liquid and solid wastes. This system, like with the Newport News Industrial system, produces an anhydrous product suitable for immobilization.

1. Process Description

The basic system offered by Aerojet is a fluidized bed dryer followed by an offgas system. Handling of solid waste is provided by an additional fluidized bed for that purpose. The solid waste fluidized bed is preheated by heating the fluidizing air with an electrical system. Shredded solid waste is fed to the preheated bed where combustion occurs. Offgas from the fluidized bed dryer and fluidized bed incinerator share a common offgas cleanup system. The offgas passes through a gas-solid separator, a wet scrub system, a condenser, and an absolute-filter charcoal-adsorber unit. A simplified flow diagram of the Aerojet process is shown in Figure 7.

2. Design Basis Feed

The system is designed to handle a wide variety of solid wastes. However, the polyvinyl chloride content of the solid waste is to be kept below 0.5 weight percent. The system is not currently designed to handle ion exchange resins and liquid wastes are handled in a separate fluidized bed unit.

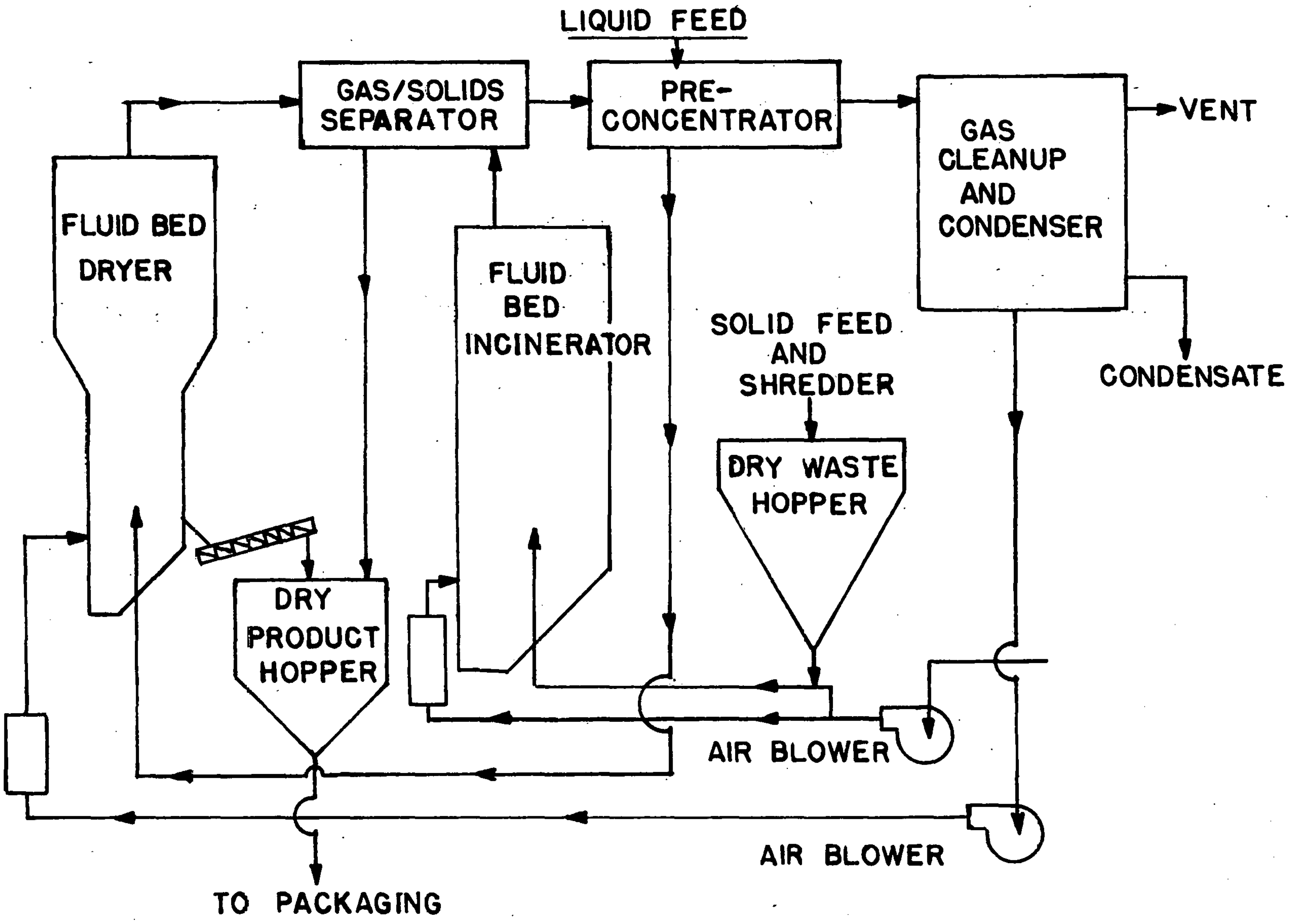

FIGURE 7. Aerojet International LLW Calcination-and-Incineration System.

3. Advantages and Disadvantages

An advantage claimed for the system is the ability to process both liquid and solid wastes simultaneously with the capability of maintaining two fluidized beds at separate operating conditions. Feed to the fluidized bed dryer is used as a scrub solution in the offgas cleanup system. This solution is then passed through the dryer, leaving no additional liquid feed for treatment.

The system, consisting of two fluidized beds and associated offgas cleanup, results in the necessity of two primary process vessels, adding to the initial capital requirements for the system. Waste to the solid waste incineration unit must be shredded prior to feed and provision must be made for removal of noncombustibles either from the feed or from the fluidized bed.

4. Status

The Aerojet pilot plant has operated for over 1400 hours and a full scale dryer system has operated in excess of 3000 hours. A full-scale incinerator vessel is now being incorporated to the fluidized dryer demonstration plant. No commercial units of the Aerojet system are currently in operation. Orders for the system have been placed with Aerojet by Commonwealth Edison and by Carolina Power and Light Company. These systems will be supplied by 1980 with scheduled operation in approximately 1982 to 1984. Incineration capacity will be approximately 92 kg/hour.

A topical report for the dryer system has been approved by the NRC and an addendum to the topical report for the incinerator portion of the system is currently under review.

G. ROTARY KILN INCINERATOR (RFP)[14]

A production rotary kiln incineration unit is being installed in a new facility under construction at the Rocky Flats Plant. The system is designed to accept high-activity TRU wastes.

1. Process Description

A simplified flow diagram for the rotary kiln incineration system is shown in Figure 8. Solid TRU wastes that have been assayed and designated as high activity wastes will be received at the rotary kiln in 208 ℓ-drums or units transferred by internal conveyor systems. The rotary kiln has a nominal waste throughput of 40 kg/h and is direct fired with the solid waste, supplemental fuel, and combustion air introduced at one end of the unit. The rotary kiln achieves highly efficient combustion because of its ability to attain excellent mixing of the loose unburned waste and oxygen as the kiln revolves. Ash removal is also enhanced by the revolving drum in the rotary kiln system.

Normal operating temperature in the primary combustion chamber of the rotary kiln is 800°C. Gases leaving the rotary kiln pass to an

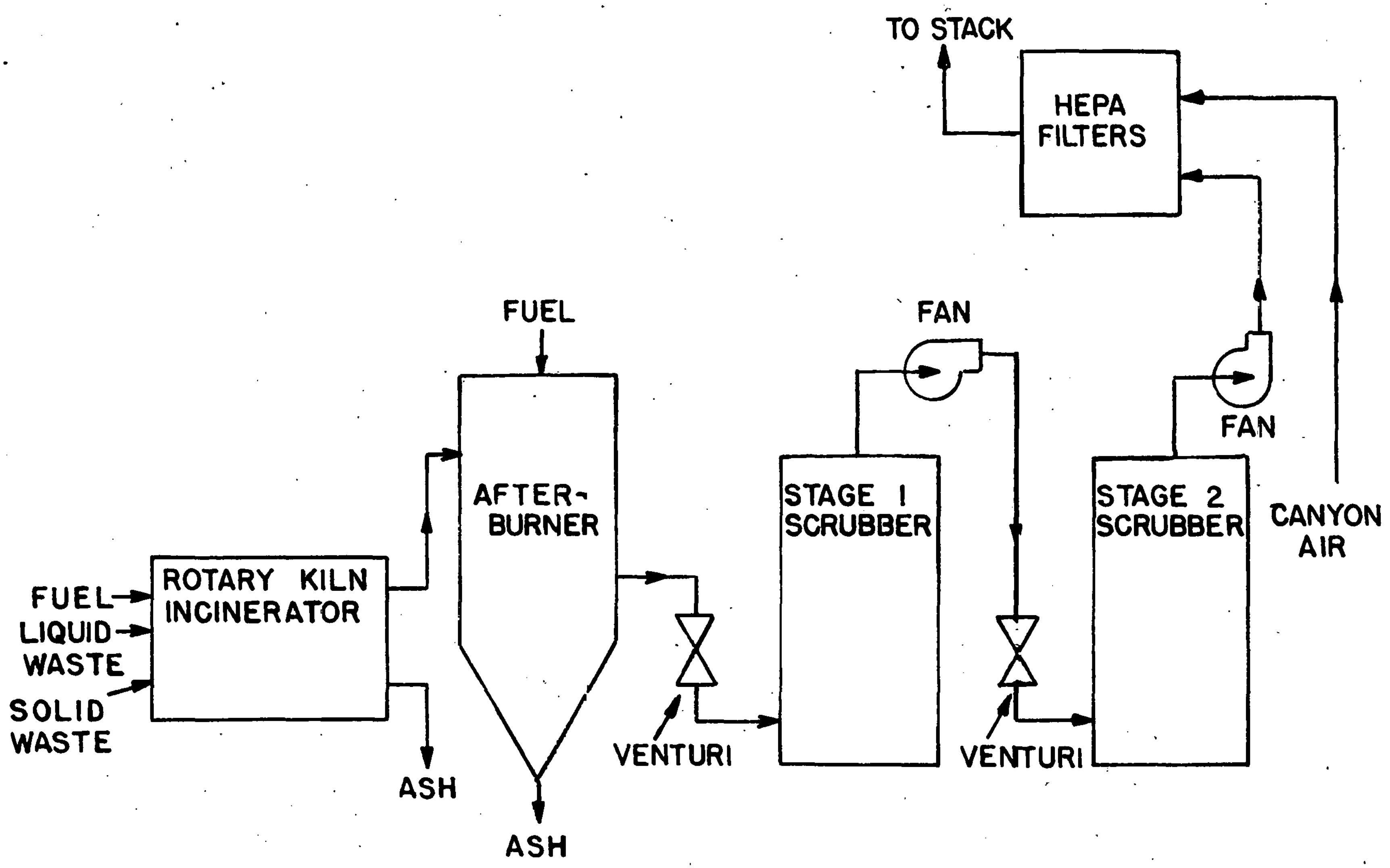

FIGURE 8. Rocky Flats Rotary Kiln Incinerator.

afterburner where supplemental heat is supplied by diesel oil and combustion is completed at a normal operating temperature of 1000°C. The offgas passes through two stages of critically safe, high-energy venturi scrubbing and then enters a filter plenum where it passes through four stages of HEPA filtration. Fans downstream of each scrubber provide induced draft for the incineration and scrubbing system.

2. Design Basis Feed

The rotary kiln system will accept a wide variety of feed materials. The specific feed anticipated for the Rocky Flats Plant rotary kiln consists of highly TRU-contaminated combustibles which are composed of 50% PVC, 12% polyethylene, 12% polypropylene, and 26% paper.

In addition to the solid waste, a liquid waste stream consisting of approximately 36% trichloroethane, 33% carbon tetrachloride, 13% cutting oil, 7% ion exchange resin, and the remainder miscellaneous lab wastes and moisture will also be fed to the rotary kiln.

3. Advantages and Disadvantages

The main advantages of rotary kiln incineration system are its ability to accept a wide variety of waste materials and a high tolerance for noncombustibles in the feed. Little presorting of feed is necessary as long as the ash removal system is capable of handling the large noncombustible items. The tumbling action achieved in the rotary kiln also enhances combustion efficiency and ash removal. Rotary kiln incineration has been widely proven in nonradioactive service and can be manufactured with large throughput capacities.

With refractory lined kilns the possibility of plutonium migration into the lining exists as with other TRU incineration systems. In addition, a rotating direct-fired kiln has a shorter refractory life than other types of incinerators such as controlled-air. It is also difficult to maintain good seals at the end of a rotating kiln, presenting additional difficulty in radioisotope containment. This disadvantage has been handled at the Rocky Flats Plant rotary kiln by enclosing the entire system in a hot cell type structure.

4. Status and Goals

Installation of the rotary kiln system at the Rocky Flats Plant has been completed and the equipment is now in check-out phase. Testing with noncontaminated waste should begin in June of 1980 with charging of contaminated waste scheduled to begin in July of 1981.

H. AGITATED HEARTH INCINERATOR (RFP)(14)

The agitated hearth incinerator system being installed in a new facility at the Rocky Flats Plant is designed to incinerate trace activity TRU wastes.

1. Process Description

An agitated hearth unit was selected for low-activity waste a application at the Rocky Flats Plant primarily for its automatic ash removal system and potential for extended refractory life. Operation of the agitated hearth incinerator is a cyclic procedure consisting of a feed cycle in which waste is charged at a rate of approximately 2.5 kg every two minutes for a period of about 5 hours, a burnout cycle during which feeding is stopped and and the unit held at operating temperature by combustion of supplemental fuel for about 1 h to allow complete burnout of solid waste, and an ash discharge cycle in which the ash discharge door is opened and ash raked out by the rotation of a rabble arm over a half hour period. Following the ash discharge cycle the unit can be returned to the feed cycle. Normal operating temperature of the primary chamber is $800^{o}C$ and offgas is additionally treated in an afterburner operating at $1000^{o}C$ with supplemental heat provided by combustion of diesel oil. Flue gas system on the agitated hearth incinerator is similar to that described in the RFP rotary kiln system. A simplified line drawing of the system is shown in Figure 9.

2. Design Basis Feed

The agitated hearth system is designed to accept a feed with trace contamination of TRU materials with a composition of 25% rubber, 46% paper, 5% polyethylene, 6% cloth, 7% wood, 5% moisture, and 5% tramp metal.

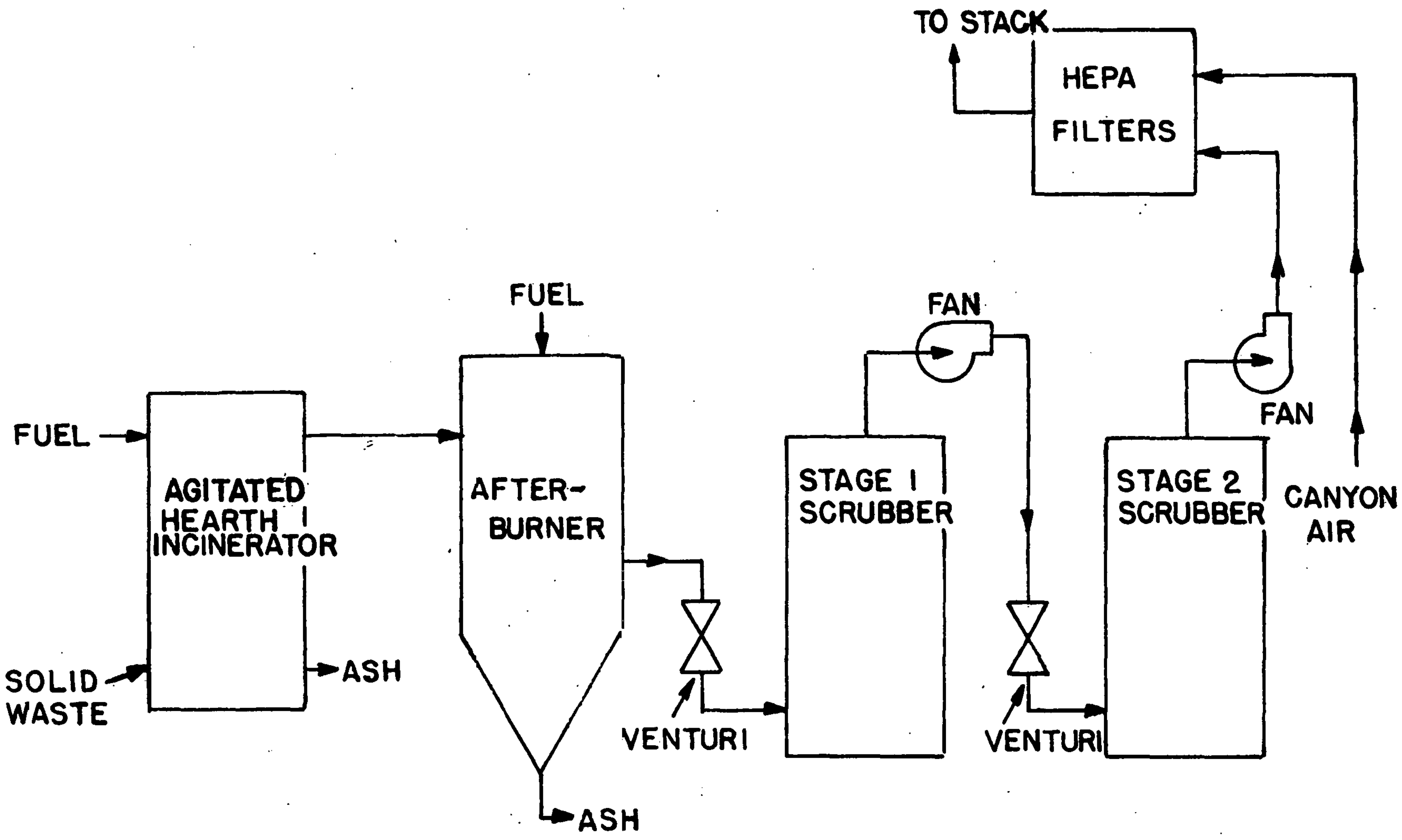

FIGURE 9. Rocky Flats Agitated Hearth Incinerator.

3. Advantages and Disadvantages

When compared with the rotary kiln incineration system, a greater refractory life may be expected from the stationary shell of the agitated hearth incinerator.

As with other TRU incinerator systems, the refractory lining of the agitated heart incinerator may be subject to plutonium uptake. An additional disadvantage is introduced by moving components such as the rabble arm used to mix the burning material and remove ash from the system. This type of equipment can be expected to require periodic maintenance. The low-level liquids generated in offgas cleanup will require a liquid waste treatment facility on site.

4. Status and Goals

Status of the agitated hearth production incinerator at the Rocky Flats Plant is identical with that of the rotary kiln system. Equipment check-out is now in progress with cold waste feeding and testing to begin in June 1980. Charging of trace activity TRU-contaminated waste is scheduled to begin in July 1981.

I. CYCLONE INCINERATION (MOUND)(15)

A cyclone incinerator has been developed at the Mound Facility for treatment of radioactive solid waste. The cyclone incineration system provides the option of burning the waste directly in a typical steel waste drum as a primary combustion container. Provision is also made for substituting a more permanent vessel as the primary combustion chamber. Features of the system include design simplicity and low capital cost.

1. Process Description

Figure 10 shows a process flow diagram including major components of the overall cyclone incineration process. The system is maintained at negative pressure throughout the process by induced draft fans. The combustion unit consists of two chambers: the lower consists of the removable section that is usually the steel waste container and the upper chamber consists of a fixed section that includes air inlet piping and baffling. During operation the two sections are fixed together and surrounded by cooling panels to prevent high shell temperatures in the head and steel drum.

Combustion air is introduced to the system through tangential nozzles in the cover, resulting in a downward spiral of combustion air. The waste is ignited by a small quantity of supplemental liquid fuel and burned uniformly downward in the spiral while combustion gases move upward inside the spiral. The hot combustion gases that reach temperatures up to 1320°C

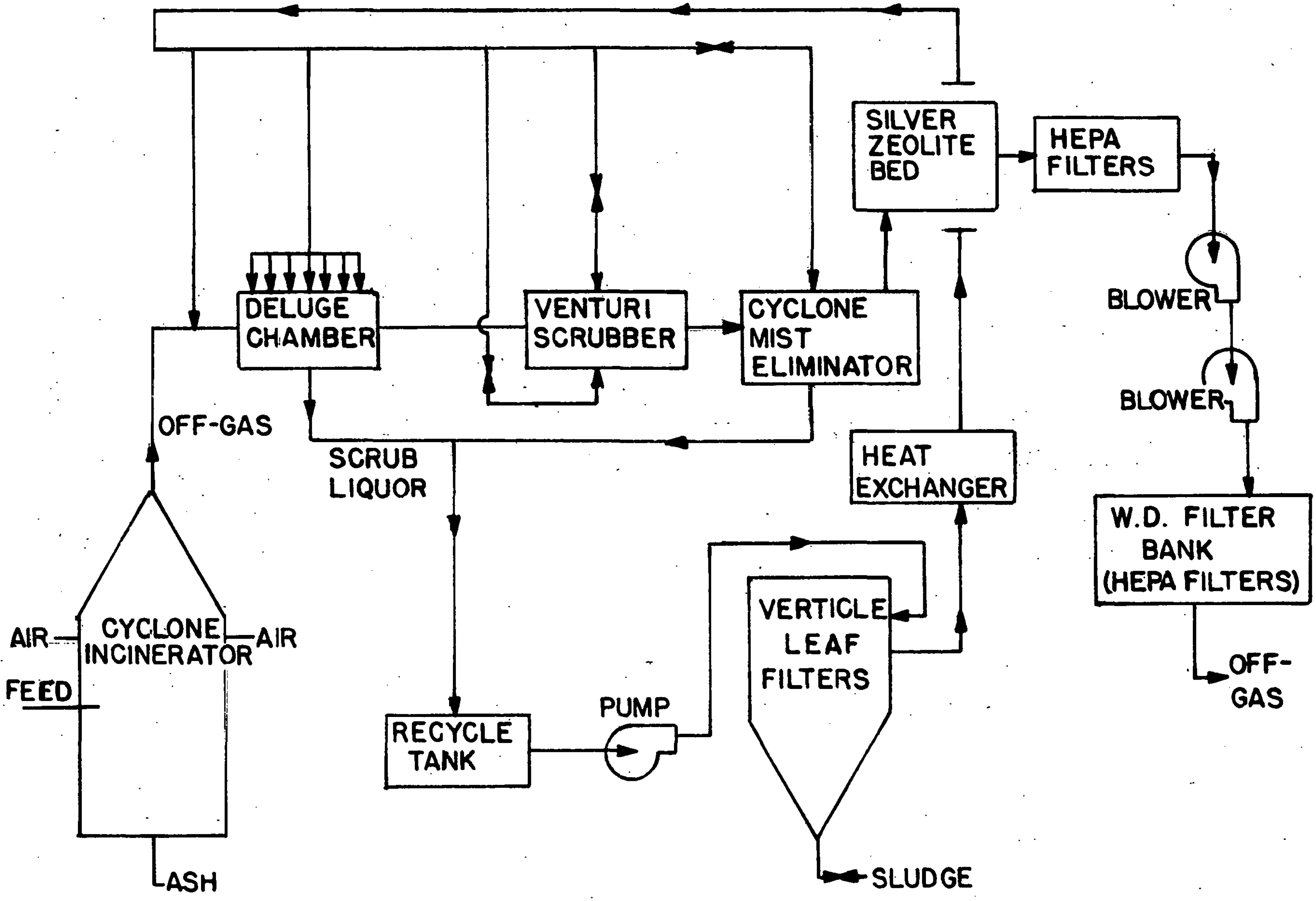

FIGURE 10. Mound Cyclone Incinerator.

pass through the baffles in the upper chamber, which reduce particulate carryover, and enter the deluge tank where they are cooled and scrubbed of acid gases and particulates. The gases then pass through an additional venturi scrubber, demister, HEPA filter, and finally through the induced draft fan prior to discharge to the atmosphere.

Scrub liquid is continuously recirculated through the deluge and recycle tanks, cooled in a heat exchanger, and passed through a vertical leaf filter for removal of particulates. The solution pH is continuously monitored and adjusted as required.

The process is basically a batch operation in which a drum of waste is moved in position either remotely or manually, depending on the level of radioactivity. The drum is then fitted to the air induction cover, the ignition system turned on to ignite the waste, and the blowers turned on to establish the cyclone within the drum. The blowers continue to operate until combustion has been completed and the drum cooled to a manageable temperature.

2. Design Basis Feed

The cyclone was designed primarily to handle contaminated waste from the small generator. The waste feed consists of approximately 32% paper, 9% polyvinyl chloride, 29% polyethylene, 8% polypropylene, 13% rubber, 3% cloth, and 6% metal. Average combustion rate for noncompacted materials was shown to be 27 kg/hour.

3. Advantages and Disadvantages

Principal advantages cited for the cyclone incineration system are low initial capital requirement and design simplicity. Combustion of the waste in the steel drum in which it is delivered reduces need to handle the waste in feed preparation. However, rigid administrative packaging control or inspection is required to assure that no bottled liquids or other potentially explosive materials are in the drums prior to incineration.

The high-velocity cyclone generated in the steel drum during incineration results in the disadvantage of high particulate suspension. However, recent modifications to the offgas configuration above the drum have greatly reduced ash carryover to the offgas deluge chamber. Separation of the steel drum or primary combustion vessel in the head after each burn essentially consists of breaking the containment. Thus, containment must be provided by enclosing the entire system in a hot cell or other such structure. This process also requires that facilities be available to dispose of secondary liquid waste and sludge.

4. Status and Goals

More than 6000 kg of low level plutonium wastes have been burned at the Mound Facility since December 1976. Realized mass and volume reduction ratios are claimed to be 10:1 and 43:1, respectively. Preliminary design criteria have been published.

Present development efforts are focused on adapting the cyclone incinerator for use with low-level wastes as well as TRU wastes. Studies are being conducted to determine fission product distribution and to define off-gas systems requirements. Effort is also being expended to facilitate commercialization of the cyclone incineration concept. Demonstration tests are proposed for radioactive operation at a nuclear utility site by 1984.

J. ELECTROMELT INCINERATION (PENBERTHY ELECTROMELT INTERNATIONAL)(1)

The adaptation of electric glass melting furnaces for the incineration of radioactive waste and simultaneous fixation of the resulting residues is a recent concept proposed for waste treatment. Conventional technology for producing high quality glasses using the conductive properties of glass at elevated temperatures is well established. The Penberthy Company, located in Seattle, Washington, has an Electromelt incinerator capable of treating up to 112 kg/h of toluene, or up to 400 kg/h of cellulosic wastes.

A conceptual flowsheet of an electromelt incineration system is shown in Figure 11. The furnace is a tunnel in a shape 3 ft^2 x 20 ft long and the bottom of the tunnel is a pool of molten glass. Because of its long length, the second half of the furnace corresponds to the afterburner section of other incinerators. Solid waste is ram-fed into the molten glass; liquids and slurry wastes are piped at controlled rates onto the surface of the glass pool. Immersed electrodes are used to heat the glass with the glass temperature being maintained above 1260°C. High residence time in

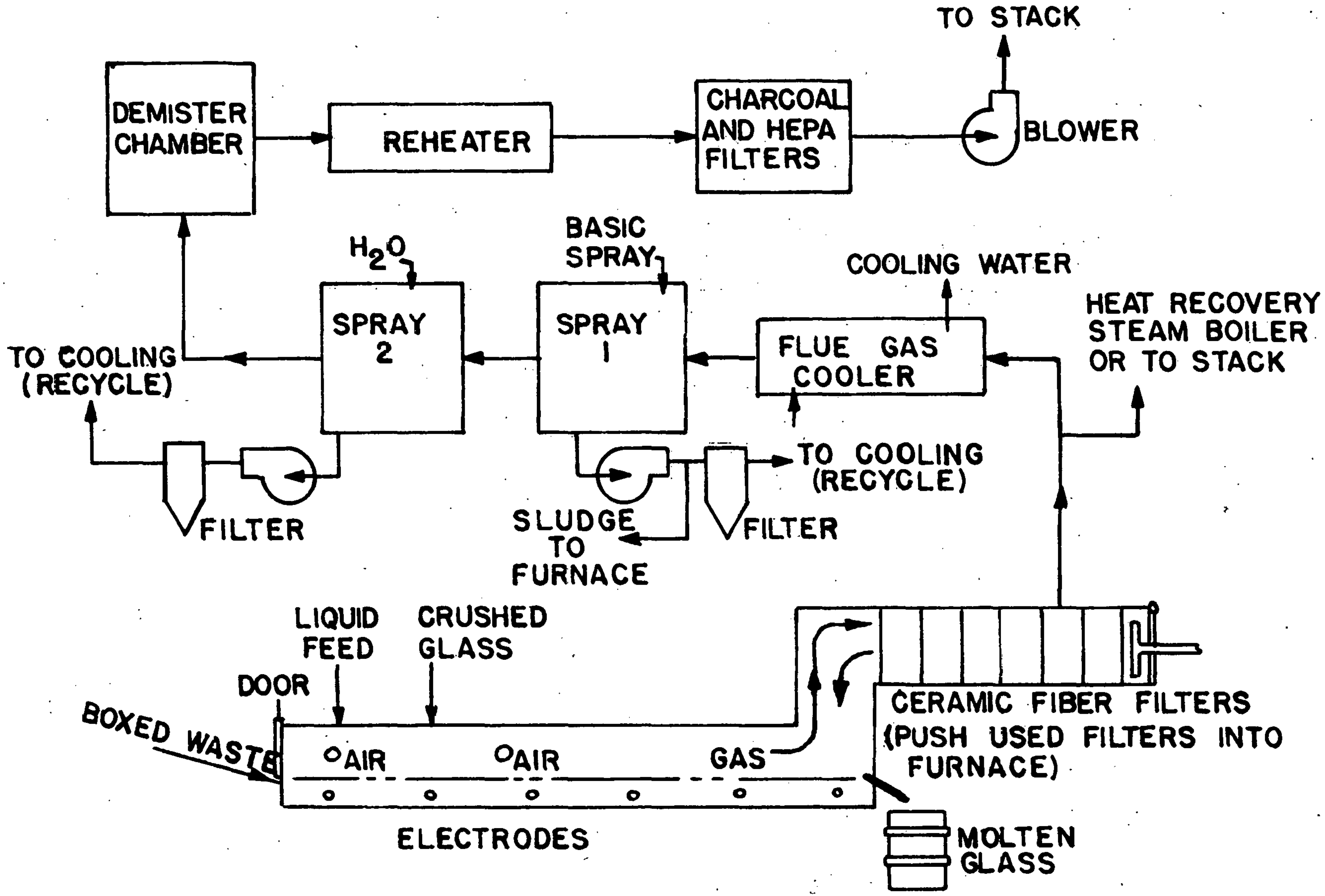

FIGURE 11. Penberthy Electromelt Incinerator.

the glass is provided to assure complete combustion of the materials. Ash residues and melted noncombustible materials combine with the glass, which is drained off periodically as excesses are generated. Various additive compounds, depending on the waste composition, are fed to the glass bath to assure that the resulting glass-waste matrix is a chemically durable material. The glass can be drained from the furnace directly into cannisters suitable for shipping and disposal.

Offgas treatment consists of ceramic fiber prefilters followed by a low-energy aqueous scrub system for cooling and neutralization prior to charcoal and HEPA filtration. Sludges and filter elements generated in the offgas cleanup operation can be charged to the furnace to minimize secondary waste generation.

1. Design Basis Feed

The electromelt furnace has been tested using a wide variety of waste types and composition. Limiting requirements of waste composition are coupled with the required addition of complimentary materials to assure durable glass formation.

2. Advantages and Disadvantages

A main advantage of the electromelt system is the use of the joule effect to provide supplemental process heat, resulting in a substantially reduced offgas volume as compared with the offgas volume from a conventional fossile-fuel fired incinerator. The incorporation of combustion ash into a glass matrix in the process will result in eliminating the need for further immobilization treatment. The company believes that the cost of electric power required is comparable to the cost of fossile fuel required for a conventional incineration system. Offgas treatment requirements and problems are not yet defined.

The glass temperature is always high throughout, well above smoke ignition temperatures, thus providing additional protection from explosions.

Development studies are presently under way to provide information concerning afterburner requirements, offgas cleanup needs, capacity to tolerate noncombustible materials, and system reliability. Immediate interests in this process lie in the area of low-level waste treatment and in the immobilization of some TRU residues. Radioactive testing has not been done to date.

K. SLAGGING PYROLYSIS INCINERATION (INEL)(16,17)

Slagging Pyrolysis Incineration (SPI) has been proposed as the core process for the treatment for buried and stored TRU wastes at the Idaho National Engineering Laboratory (INEL). Conceptual design and development efforts in support of processing alternatives were initiated in May 1979. The process has been selected because of its capability of accepting high volumes of unsegregated wastes including metals, soil, rocks, and significant quantities of nonradioactive hazardous materials, as well as combustible radioactive waste.

1. Process Description

The basic process shown in Figure 12 is a proprietary system of ANDCO, Inc., of Buffalo, NY. The process is similar to that used in steel production technology and currently being used for municipal waste disposal in Europe. Conceptual design capacity is in the neighborhood of 9.4×10^4 kg/day including supplemental wood and coal fuel.

Stored TRU waste will be unpackaged, sorted, and blended with coal and wood chips for supplemental fuel. The resulting mixture will be fed to a vertical, cylindrical gasifier. The fuel and waste mixture is dried in the upper portion of the gasifier while incineration and slagging take place in the lower, refractory-lined section. Preheated air is injected near the base of the gasifier to support oxidation of the wood, coal, and combustible waste fraction. The gaseous material from the gasifier section then passes to a secondary combustion chamber where combustion is completed. Offgas from the secondary combustion chamber is then treated in an offgas cleanup system consisting of heat recovery boiler, a neutralizing spray dryer, sintered metal filter banks, a catalytic reduction system for removal of NO_x and, finally, through HEPA filters. Particulates from the offgas treatment system are recombined with molten slag from the gasifier in an electromelt furnace.

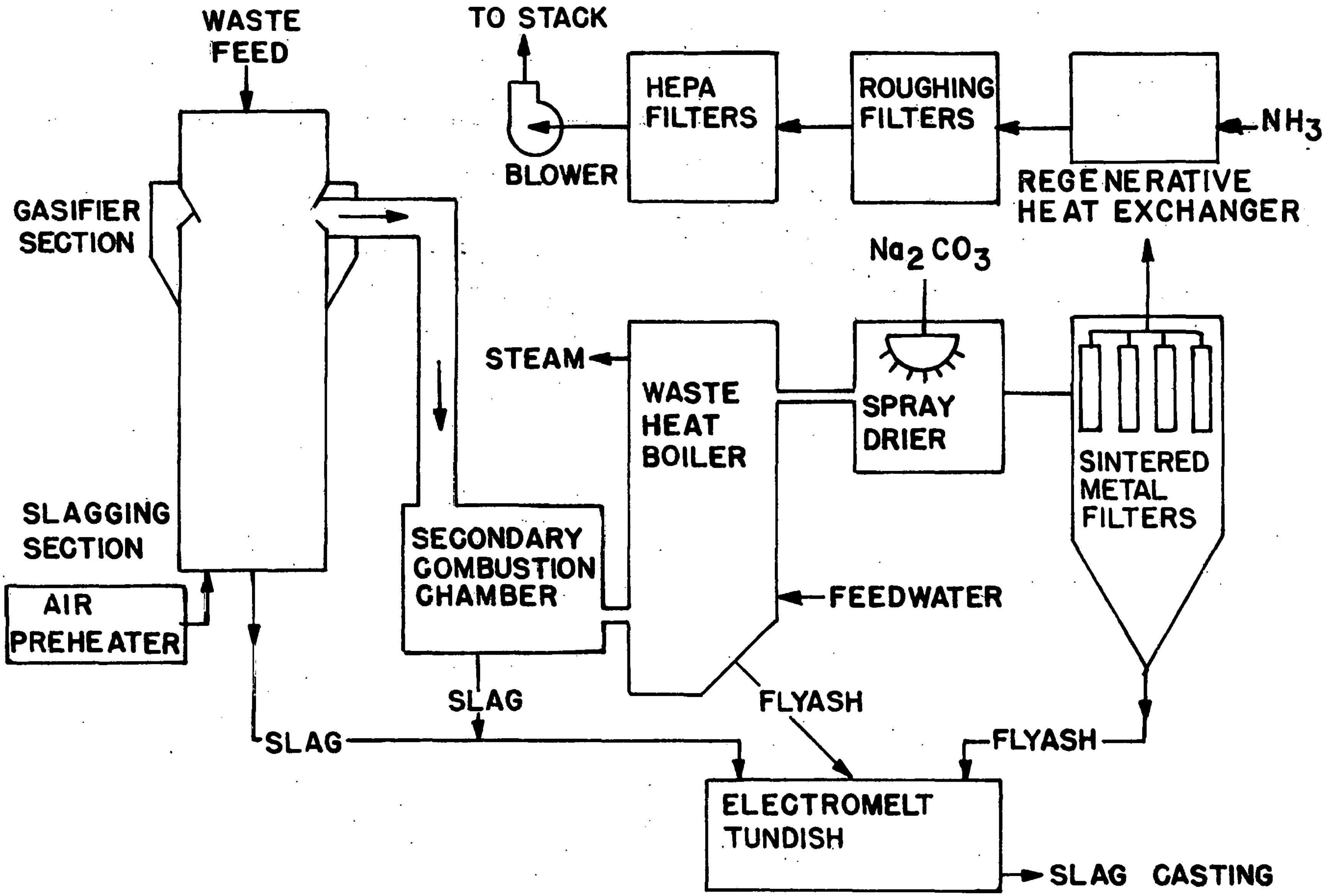

FIGURE 12. Slagging Pyrolysis Incinerator.

2. Design Basis Feed

The conceptual design of the slagging pyrolysis incinerator is to handle exhumed waste including noncombustible fractions of metal, soil, and other unsorted items.

3. Advantages and Disadvantages

The only waste pretreatment requirement is that the size be acceptable to pass the chamber throat of the gasifier (approximately 1 m dia). There is no need for segregation of combustible or noncombustible wastes, metal, glass, soil, or other constituents. The slag residue from the SPI system is both inert and immobile.

Disadvantages include the large volume of waste material which can be held up in the primary chamber. Additional fuel is required to maintain the incinerator at correct operating temperatures and the fuel requirment varies depending on the amount of noncombustible materials in the feed. The system is not designed for liquids.

4. Status and Goals

A 9 x 10^4 kg/day pilot demonstration plant utilizing the ANDCO process is being designed to obtain operating data for the incineration and offgas treatment components. Current scheduling anticipates conceptual design publication in 1980, followed by completion of R&D efforts in 1983. Depending on funding levels, construction could begin as early as 1984 with completion of the system in 1988, cold testing during 1988 and 1989, and hot operation beginning in 1989.

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IV. SUMMARY

Several of the incinerators in this review are commercially available now for radwaste applications. Primary emphasis to date in radioactive waste research and development efforts in the United States has been geared toward the management of TRU wastes and plutonium recovery concerns. Several of these projects are approaching final demonstration phases and redirection to other waste management concerns is being considered. Adaptation of current waste incineration technology for handling low level waste followed by commercialization of the technology is to be expected in the near future. To meet LLW incineration requirements, several development and cooperative-venture demonstration projects have been proposed to define remote handling and offgas systems requirements.

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