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ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

BASIC OPERATIONAL REPORT OF
THE ARGONNE ACTIVE WASTE INCINERATOR

by

Donald C. Hampson, Edwin H. Hykan, and Walton A. Rodger

CHEMICAL ENGINEERING DIVISION

Work Performed by:

D. C. Hampson	O. E. Lovison
E. H. Hykan	W. A. Pehl
H. L. Brown, Jr.	D. J. Hulet

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	4
FOREWORD	5
I. INTRODUCTION	5
II. PROCESS DESCRIPTION	6
A. General Description	6
B. Equipment Description	10
1. Combustion System	10
a. Furnace Body	10
b. Furnace Grates	10
c. Ash Collection and Removal	12
d. Charging Mechanism	12
e. Steam Jacket	13
f. Gas Burners	13
g. Combustion Air Supply	13
h. View Ports and Manholes	14
i. Steam Quench	14
j. Rupture Disk	14
2. Gas Cleaning Equipment	14
a. Schreier-Bartolucci Scrubber (T-1)	14
b. Pease-Anthony Venturi Scrubber (V-1)	15
c. Peabody Gas Scrubber (T-2)	15
d. A.E.C. Filter (F-1 and 2)	16
e. Reheaters (E-1)	16
f. Gas Blower (G-5)	16
g. Liquid Circulation	16
h. Duct Work and Piping	17
3. Instrumentation	17
C. Operational Difficulties and Equipment Modifications	19
1. Furnace Body Deformation	19
2. Corrosion	22
3. Plugging of Liquid Lines	23
4. Venturi Throat Velocity	23
5. Filter Deformation	24
6. Combustion Rate	24
7. Foaming	24
8. Furnace Cone Plugging	25
9. Charging Chute	25
10. Grate Inoperability	25
11. A.E.C. Filters	25

TABLE OF CONTENTS

	<u>Page</u>
III. EXPERIMENTAL PROGRAM	26
A. History	26
B. Operating Procedure	26
C. Sampling Procedure.	27
1. Theory of Sampling for Particulate Matter	27
2. Sampling Methods	28
3. Sampling Equipment	29
4. Filter Media	33
D. Program Objectives.	33
E. Program	34
1. Furnace Efficiency	35
2. Operating Variables for Gas Scrubbing Components . .	35
a. Venturi Liquid-to-Gas Ratio.	35
b. Venturi Scrub Solution Temperature	39
c. Steam Injection Prior to the Venturi Scrubber	39
d. Peabody Scrub Solution Rate.	42
e. Peabody Scrub Solution Temperature	42
f. Number of Wet Plates in the Peabody Scrubber . . .	44
g. Schreier-Bartolucci Gas Scrubber Efficiency	46
h. A.E.C. Filter Efficiency	47
3. Over-all Decontamination Factor.	47
4. Comparison of Efficiency Evaluation by Particle Weight and Radioactivity Counting	51
5. Activity Build-up	53
6. Operating Variables for Combustion Chamber	53
a. Volume and Weight Reduction	53
b. Charging Rate	53
c. Primary-to-Secondary Air Rates	55
7. Exhaust Duct Corrosion	56
8. Continuous Operation.	58
9. Liquid Fuel Burning	58
IV. ECONOMICS OF THE SYSTEM.	58
V. FUTURE WORK.	59
VI. SUMMARY	62
VII. ACKNOWLEDGMENTS	63
VIII. APPENDIX	64

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Incinerator Installation	7
2	Schematic Flowsheet, Argonne Active Waste Incinerator.	11
3	Incinerator Control Panel	20
4	Furnace Body Deformation.	21
5	Gas Sample Filter Assembly, Drawing	30
6	Gas Sample Filter Assembly, Photograph	31
7	Filter Paper Samples	32
8	Furnace Effluent Gas Activity Versus Run Time	36
9	Effect of Water-to-Gas Ratio in the Pease-Anthony Venturi on Radioactive Removal Efficiency.	38
10	The Effect of Steam Injection on Radio- active Removal Efficiency by Pease- Anthony Venturi.	41
11	Effect of Number of Wet Scrub Plates on Efficiency of Peabody Scrubber.	45
12	Effect of Activity Level in Charge on Over-all Incinerator Decontamination Factor	49

ABSTRACT

The active waste incinerator at Argonne National Laboratory has been successfully operated for 20 months on a combined routine production and experimental basis. Sixteen thousand cubic feet of wastes have been incinerated with a volume reduction from feed material to ash of 95 per cent. The normal burning rate is approximately 17 cu.ft./hr.

An experimental program to evaluate equipment performance and to obtain optimum operating conditions has been carried out. The immediate measured activity of the exhaust gas from the gas scrubbing train has been consistently lower than that of the normal outside air. A plot of decontamination factor versus the activity level of the feed indicates that 3×10^7 is the limiting over-all decontamination value for the present operating conditions of the incinerator. This value is confirmed by cumulative decontamination factors for the individual pieces of equipment.

The cost of incinerating the active wastes (based on a 40-hour week) is approximately \$2.68 per cubic foot. This represents a savings of about \$1.32 per cubic foot over direct storage of the waste at Argonne, the method previously used to handle combustible wastes.

FOREWORD

This report is primarily an operational report and covers the basic design, construction, operating principles, and the data that were necessary to insure reasonably successful operation of the Argonne active waste incinerator. The experimental data contained herein are intended to be used as operational guides and should be used to indicate trends rather than absolute values.

I. INTRODUCTION

The problem of waste treatment or disposal is present in the field of atomic energy, as in all modern industries of today. The waste products of any industry present a dual problem in that the wastes in addition to presenting a bulk or volume to be disposed of may also be hazardous to the surrounding communities. These hazards can be of a poisonous nature to man, animals, or plants, of a chemical nature such as acids, of a combustible nature such as oils, or of a nuisance nature such as smoke and soot.

In addition, the atomic energy installations have the problem of radioactivity. This single problem, because of its newness and uniqueness, can overshadow all of the other considerations. If radioactive wastes are buried in the soil or emptied into a river or lake, they may possibly harm animal, plant, or marine life or upset some sensitive ecological cycle. Many of the radioactive products are water soluble and therefore can be leached out of buried wastes and find their way into rivers, streams, and lakes. Here they can be concentrated in plants which have an affinity for the particular compound or element. These plants are in turn consumed by marine life and after further concentration render their hosts unsafe for human consumption.

The buried wastes, in addition to the leaching problem, would present another hazard in that they would be the subject of scavenging by rodents and other predatory animals. They, being the victims of other animals, could pass on the hazards to man or his domesticated animals. In order to prevent these methods of community contamination, it has been deemed necessary at some of the sites located in more populous areas to store solid active wastes in steel "coffins" and/or concrete burial vaults.

It was apparent that some method of reducing the volume of the active wastes would be desirable. This was necessitated by the high storage cost of these wastes and by permanent deprivation of the use of the land where active wastes are stored.

It has been determined that the dry active wastes collected at Argonne National Laboratory are about 80 per cent (by volume) combustible. This represents a sizable volume and a portion of the problem vulnerable to attack.

This problem had been recognized at Argonne, but because the trained personnel were not available to be released for this work, the Arthur D. Little Company of Cambridge, Massachusetts,¹ was contracted to design an economically feasible system of reducing the volume of solid active wastes.

Several methods were considered by the A. D. Little Company. These include the following:

1. Chemical Digestion;
2. Mechanical Compression;
3. Bacterial Digestion;
4. Selective Extraction;
5. Thermo-decomposition;
6. Combustion.

Economic considerations, feasibility of the process (hindered by the heterogeneity of the waste), degree of volume reduction, and method of storage of the reduced volume dictated the choice of an active waste incinerator. This choice was further confirmed by the added advantage of industrial experience with combustion equipment. The additional problems of gas cleaning and ash handling were obvious, if not simple. The straightforward nature of this process lends itself to simplicity of operation, control, and maintenance of an intermittent cycle, while producing a minimum of volume of waste. The volume of combustible waste is reduced by incineration from 100 cubic feet per day of waste to about 5 cubic feet per day of ash. Figure 1 is a picture of the incinerator based on the A. D. Little design as installed at Argonne National Laboratory.

II. PROCESS DESCRIPTION

A. General Description

The incinerator equipment consists of a type 330 stainless steel incinerator body in which the material is burned in the presence of excess air; a Schreier-Bartolucci vane plate washer, in which large particles of

¹A. D. Little, Inc., Report on Design for Volume Reduction of Combustible Radioactive Wastes by Incineration to Argonne National Laboratory, ALI-C-57867, June 30, 1950.

Figure 1
Incinerator

fly ash are removed; and a secondary scrubbing unit consisting of a Pease-Anthony Venturi and a Peabody scrubber in which the gas-borne radioactivity is normally reduced to within tolerance. Final clean-up is accomplished by an A.E.C. filter. The ash resulting from combustion falls through a grate system and settles through water located in the cone in the base of the furnace into a canvas bag filter inside of a stainless steel drum. The bag and its contents are removed from the system, dewatered, and then stored.

The segregated combustible radioactive waste which is below 50 mr/hr is routinely brought to the incinerator area in 1-cu.ft. fiber drums, loaded onto stainless steel pallets, and hoisted by a crane to the loading platform. The drums are charged into the furnace through electrically-interlocked double doors on the charging chute which prevent blow-back of radioactive ash or fumes from the furnace. The drums build up on the grates of the furnace and are ignited by gas burners located around the circumference of the incinerator. Air is supplied both below and above the grates in order to insure complete combustion. The air supply is drawn from outside the building to eliminate the possibility of radioactive smoke being dissipated through the building in the event of a puff resulting from momentarily accelerated combustion.

As combustion proceeds, the ashes drop through the grates into the cone-shaped bottom of the furnace where they are collected in water. The ashes settle through the water and through a plug valve into a water-filled drum containing a bag filter located beneath the furnace. When a drum is filled with ash, the valve is closed and the drum and bag filter are replaced.

The products of combustion pass upward through the furnace and out through a horizontal gas duct located near the top of the combustion chamber. Most of the heat of combustion is dissipated by generation of steam in a water jacket surrounding the upper part of the combustion chamber. This heat is carried to the fan loft where it is transferred to the atmosphere in standard forced-draft unit heaters. Gases leaving the furnace pass first through a Schreier-Bartolucci vane plate tower. Here the larger pieces of fly ash are scrubbed out from the gases with a water stream which also serves to cool the gases. Water for this scrubbing operation is pumped from the bottom of the ash barrel to the top of the Schreier-Bartolucci tower and returned from the bottom of this tower to the lower portion of the combustion chamber. This scrubbing solution is maintained alkaline through the addition of sodium hydroxide.

The gases, now freed of the larger particles of fly ash, are passed to a Pease-Anthony Venturi scrubber where the high velocity gas stream is used to disintegrate a water stream which is admitted at the throat of the Venturi. This intimate mixture of air and water is admitted tangentially to the bottom of the Peabody scrubber. In this disengaging section, the gas and the droplets of water containing a large fraction of the

smaller particles of dust are separated. The gas flows upward through the Peabody tower passing through fine holes in scrubbing plates where the gas is brought into further intimate contact with the scrubbing solution. In the upper portion of the Peabody tower the gas and water are separated by a mechanical baffle system. The gases then flow past electrical heaters located above the scrubbing tower. Sufficient heat is added by these heaters to vaporize any fine mist particles which are still present in the gas and to raise the gas temperature several degrees above the dew point, thus preventing condensation in the remainder of the system. Like the scrubbing solutions in the Schreier-Bartolucci tower, the liquid in the Peabody scrubber is also recirculated. This scrubbing liquid, which is maintained basic with sodium hydroxide, is pumped from the bottom of the Peabody tower and returned to the top of the same tower or through a heat exchanger to the Pease-Anthony Venturi.

The general flow of solution in the scrubbing train is from the end of the gas scrubbing train toward the furnace. In the furnace and the Schreier-Bartolucci tower, water is evaporated from the scrubbing solution. This water is condensed in the succeeding cooler portions of the system. The heat of condensation is removed in a water-cooled heat exchanger. The result is that water tends to accumulate in the cooler portions of the system and is evaporated from the furnace and primary scrubber (Schreier-Bartolucci), but automatic controls maintain constant liquid levels throughout the system.

The preceding treatment may be enough in most cases of operation to reduce the radioactivity to a permissible discharge level. However, as a final safeguard, the gases are passed through a filter of the A.E.C. type. This filter is capable of removing radioactive particles to well within the minimum tolerance levels specified by this Laboratory's Radiological Physics Division (2×10^3 beta disint./ (min.) (cu.m.) and 70 alpha disint./ (min.) (cu.m.)). When replacement is necessary, the loaded filter is burned in the furnace. From the filter, the gases are drawn through a positive displacement blower which moves the gas stream on to the discharge stack on the roof.

A by-pass is provided in the gas duct system at a point just preceding the Schreier-Bartolucci tower. This line provides a pressure relief system in the event a surge within the furnace occurs from an unusually rapid period of combustion. Such a surge of gases can be vented directly to the roof, preventing disruption of operation of the equipment.

The degree of instrumentation used was dictated by the proposed uses of the unit. Since this unit served as a pilot plant for experimentation in addition to being used as a production unit, its instrumentation is fairly extensive.

Temperatures within the furnace itself, in the gas stream at the exit of the furnace and at the entrance and exit of each gas cleaning unit, are recorded. In addition, the temperatures of the cooling and gas scrubbing liquids are recorded.

The pressure differential around each piece of gas cleaning equipment is recorded. Pressures of the air entering the furnace, gas in the furnace, and the gas leaving the furnace are also recorded. All liquid pressures are locally indicated.

A flow meter records the volume of air entering the furnace. The liquid flow is indicated by rotameters, with the exception of the water to the Venturi heat exchanger which uses a recording rotameter.

Liquid level controllers or indicators are installed on all necessary pieces of equipment.

Figure 2 is a schematic flowsheet of this equipment.

B. Equipment Description

1. Combustion System

a. Furnace Body

The furnace body (H-1) consists of a vertical cylinder on a conical bottom. The vertical section is the combustion chamber, and is separated internally from the cone by grates. The cylindrical furnace body is constructed of type 330 stainless steel and is of all-welded construction. The cylindrical section is 5 feet in diameter and 9 feet 11-1/2 inches high. The cone, fabricated of type 304 stainless steel, tapers at an angle of 60 degrees from the 5-foot diameter to an 8-inch diameter in a vertical distance of 4 feet. A 1.5-inch mesh screen made from 1/8-inch type 330 stainless steel rod is tack-welded at an angle of 15 degrees across the top of the combustion chamber from a point above the charging chute to a point below the effluent gas duct. The purpose of this screen is to hold back any large pieces of material that have been entrained in the gas stream and to allow their complete combustion to occur before the gas enters the scrubbing train.

b. Furnace Grates

The combustible material is supported within the furnace by a series of 7 interlocking cast iron grate bars. Each grate bar consists of 10 octagonal plates at right angles to the grate bar shaft and is cast in one piece. Two sets of three grate bars, and one center independent grate bar, are interlocked with gears inside the combustion chamber. The even-numbered grate bars extend through the combustion body and are interlocked

with gears outside of the combustion chamber. This arrangement allows the grates to be shaken in a manner which produces a grinding action. The grates are manually shaken by means of the external portion of the grate bars. Contamination of the area around the furnace by means of gas and dust escaping through the grate bar openings is prevented by stuffing boxes. The grate assembly can be removed, cleaned, or inspected by means of removable plates on either side of the combustion chamber at grate level.

c. Ash Collection and Removal

The ash resulting from the combustion drops through the grates and into the water which fills the conical bottom section of the furnace and the ash barrel. The ash, upon becoming water-saturated or due to its original density, passes downward through the water and into the ash-collection barrel (B-1). The ash barrel and furnace cone are connected by an 8-inch plug valve (N-6) constructed of type 347 stainless steel. The outer shell and bottom of the ash barrel are fabricated of 1/8-inch type 347 stainless steel. It contains an inner basket made of 1/8-inch mesh type 347 stainless steel screen. This basket is supported by stainless steel bars from the bottom of the barrel and is used to support a cotton flannel filter bag. When the filter bag becomes full, the plug valve is closed and the free water is drained through a valve in the bottom of the ash barrel. The barrel assembly is then removed to a drainage area and another assembly is attached to the furnace. After draining, the filter bag is simultaneously closed and removed by means of a draw rope located in the top of the bag.

This system allows the ashes to be removed in a wet or dampened state and thereby eliminates the hazard of dusting. The original plan was to remove the water and ashes in a 55-gallon drum and store in that condition. This proposal was not feasible due to the freezing temperatures encountered in this locality. The bag filter system, in addition to eliminating this problem, also is less expensive and presents a smaller volume of waste to be handled.

d. Charging Mechanism

The charging chute, constructed of type 330 stainless steel, is inclined at a 45-degree angle and is connected by means of a bolted flange plate to the top portion of the combustion chamber. The chute has a rectangular cross section of 21 inches by 27 inches and is 7 feet 9 inches long. The chute has two interlocked hinged doors. One is located at the top end of the charging chute, and the other is about halfway down the chute. The doors are push-button operated by motorized gear reducers. These doors are electrically interlocked so that during normal operations it is impossible to open either door unless the other door is completely closed. This interlock feature safeguards the operator from dust and blow-back during the charging procedure. An emergency override of the interlock

is provided whereby both doors can be opened at the same time if necessary. An additional safeguard is provided by a hinged cover plate which fits over the top of the charging chute and is bolted on when the chute is not being used. During charging operations, this cover plate folds back and is used as a loading shelf.

e. Steam Jacket

The upper portion and top of the combustion chamber is surrounded by a jacket of carbon steel. This jacket serves as a boiler and is used to remove the heat generated in the combustion chamber. It is equipped with a steam pressure gauge, a pressure relief valve, a sight glass, and a thermocouple point. The steam generated in the jacket is transmitted in pipe to a bank of three forced-convection unit heaters (E3-4-5) located in the fan loft about 10 feet above the top of the steam jacket. Here the steam is condensed, and the condensate is returned by gravity to the steam jacket.

f. Gas Burners

The furnace is equipped with three gas burners spaced equidistantly on the periphery of the combustion chamber and located about 2 feet above the grates. They are so located that the flames from the burners impinge on the grates. The burners are supplied with a mixture of natural gas and air and are ignited by means of a high voltage spark. The ignition system contains safety provisions for gas cut-off in the event of flame, gas pressure, or power failure.

The purpose of these burners is threefold: (1) to ignite the initial charge; (2) to dry out any charges that are damp or wet and will not readily support combustion; and (3) to cremate any residue that remains on the grates after the normal combustion period has been completed.

g. Combustion Air Supply

The air necessary to support combustion is supplied in two locations. The primary air enters the combustion chamber in four 4-inch ducts located about 6 inches below the grate line. The secondary air enters the combustion chamber tangentially through four 1-inch pipes spaced equidistantly around the circumference of the combustion chamber about 16 inches above the grate line. Air is fed to these two systems by two bustle ducts located around the lower portion of the combustion chamber. The flow of air to these two systems is regulated by means of a butterfly blast gate (N-2) on the primary air line and by means of individual gate valves on the secondary air pipes. Air for the combustion system is drawn through a duct from outside the building. A check valve (C-1) is located in the inlet air duct.

The primary air duct supplies the majority of the air necessary for combustion, while the secondary system supplies air which imparts turbulence and promotes better mixing by means of its tangential entry.

h. View Ports and Manholes

Both visual and physical accessibility to the interior of the combustion chamber is provided by means of three pyrex glass view ports, one manhole, and two removable plates, in addition to the charging chute. One of the pyrex glass ports is located on each side at the base of the charging chute, and one is located on a manhole just below the charging chute. These view ports allow visual observation of the grates, combustion conditions, gas burners, and the general interior of the combustion chamber. Compressed air is blown across the face of the glass in the view ports in order to reduce the build-up of soot. In addition to the two aforementioned removable cover plates at the grate line, physical entrance to the combustion chamber may be made through the charging chute or through the manhole located below the charging chute.

i. Steam Quench

A steam line (35 p.s.i.g.) enters the furnace below the grate line through one of the primary air inlet ducts. This steam serves the dual purpose of quenching the combustion in case of power failure or other emergencies and as a method of prolonging the normal combustion period each day by reducing the shutdown or burn-off time. At the end of a burn period, the steam quench is turned on long enough to smother the combustion completely. The unburned residue left on the grates is consumed during the next combustion period.

j. Rupture Disk

A 10-inch pipe extends from the top of the combustion chamber through the water jacket. A rupture disk, made of Monel metal and rated at 37 p.s.i.g. at 850°F., fits on top of this pipe. A duct leads from the rupture disk to the outside of the building. It was necessary to make this duct telescopic in order to allow passage of an overhead crane. This rupture disk will prevent the rupture of the furnace walls or connecting ductwork in event of a minor explosion.

2. Gas Cleaning Equipment

a. Schreier-Bartolucci Scrubber (T-1)

The Schreier-Bartolucci centrifugal gas washer consists of 10 plates in a vertical tower. Nine of these plates operate wet and the tenth, the top plate, operates dry as an entrainment separator. Each

plate is 17 inches in diameter and consists of about 20 radial, inclined vanes. Between each plate is located a flat horizontal ring about 10 inches internal diameter and 17 inches outside diameter. As the flowing-upward gases and the flowing-downward scrub solution come into contact on a vane plate, they are thoroughly mixed and thrown outward. The purpose of the intermediate rings is to redirect the gas-water mixture to the center again so as to promote more efficient contacting on the following vane plate. The scrubbing solution enters on the ninth plate and is withdrawn from the cone-shaped bottom of the scrub tower. The gases flow countercurrent to the scrub solution, entering below the bottom plate and leaving above the top plate. The entire tower is fabricated of type 316 stainless steel and is about 9 feet high and 17 inches in diameter. The scrubbing action of this tower provides a large surface area of contact between the gas and the scrubbing solution by means of the vane plates. Its purpose is to carry the bulk of the scrubbing load, in terms of weight, by removing the large (greater than 10 micron) pieces of fly ash and soot. In addition, this tower serves to cool the gases leaving the furnace.

b. Pease-Anthony Venturi Scrubber (V-1)

The Venturi scrubber consists of a converging section, a throat section, and a diverging section. The scrub solution enters the Venturi at four points around the circumference of the throat section. The Venturi is constructed of type 316 stainless steel and is 6 feet 2 inches long, 6 inches in diameter at either end, and 2-11/16 inches in diameter at the throat.

The Venturi serves to wet, and thereby enlarge, the particulate material that passes through the throat. This is accomplished by the impingement of the particles on the mist and liquid droplets formed by the scrubbing solution and by condensation of moisture on the particles. Once the particle size, and hence its mass, has been increased, it can be removed from the gas stream by centrifugal force. This is done by introducing the gases tangentially and at high velocity into the base of the Peabody tower.

c. Peabody Gas Scrubber (T-2)

The Peabody scrub tower is divided into two sections; the lower section is used to separate the particles which were collected in the Venturi scrubber, and the upper section contains four scrub plates. The tower is 2 feet in diameter, and about 17 feet tall, and is fabricated from type 316 stainless steel. An entrainment separator is located above the top plate.

Each scrub plate contains several hundred small holes about 3/64 inch in diameter. An individual baffle or impingement plate is located about 1/4 inch above each hole. The liquid level is maintained on each

plate by a standpipe. The scrub liquid line is manifolded so that the scrub solution can be introduced on any of the four scrub plates. The liquid flows downward from plate to plate, countercurrent to gas flow, by means of the overflow pipes and downcomers.

d. A.E.C. Filter (F-1 and 2)

The final piece of equipment in the gas cleaning train is a standard 24 x 24 x 12-inch A.E.C. filter. This filter, in addition to removing sub-micron particles, serves as a safeguard in case of failure of any of the preceding pieces of scrubbing equipment. Two filters are placed in parallel in the gas train, which is so valved so that either one of them can be used. This arrangement allows the filter to be replaced during continuous operation.

e. Reheaters (E-1)

Three electrical heaters are located in the duct between the top of the Peabody tower and the A.E.C. filter. The purpose of these heaters is to reheat the gas stream leaving the Peabody scrubber to vaporize any entrained moisture and to bring the temperature of the gas stream well above its dew point. This is necessary because the contraction and expansion of the filter fibers caused by condensation and evaporation of moisture on the fibers shortens the life of the filter.

f. Gas Blower (G-5)

A 10-horsepower, variable speed, Roots-Connersville positive-displacement blower is used as the prime mover of the gas stream and follows the A.E.C. filter in the gas train. By locating the blower in this position, a negative pressure 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.

g. Liquid Circulation

The main collection point for activity and particulate materials is the ash barrel below the combustion chamber, hence all scrubbing solution flow is directed to this locality. The gases with particles are borne outward from the furnace through the scrubbing train. Conversely, the liquids flow in a generally countercurrent manner from the scrubbing train toward the furnace.

The liquid for the Schreier-Bartolucci tower is drawn from the bottom of the furnace cone through the bag filter. The effluent scrub solution from this tower is returned to the furnace cone above the bag filter.

The Venturi and Peabody scrubbers obtain their scrub solutions from a 50-gallon hold-up section in the conical base of the Peabody scrubber. In the process of scrubbing, both liquid streams are returned to this hold-up cone. The Venturi scrub stream is directed through a shell and tube heat exchanger (E-2) to control the temperature of the final scrub solution.

Water is evaporated in the cone of the furnace and in the Schreier-Bartolucci tower. This moisture is borne in the gas stream to the Venturi and Peabody scrubbers where it is condensed. A liquid-level controller (LLC-1) in the cone of the furnace directs some of the liquid from the Peabody cone to the furnace cone when the liquid level in the furnace becomes low. The liquid level is maintained in the Peabody cone by means of a liquid-level controller (LLC-2) from an additional holding tank containing weak caustic.

h. Duct Work and Piping

All of the present duct work is fabricated from welded type 304 or 316 stainless steel. The piping is type 304 stainless steel.

3. Instrumentation

The instrumentation was designed for pilot plant operation to permit study of the process occurring. However, operation of the incinerator on a production schedule has shown that the instrumentation included is very beneficial for normal operation. As with any complex process, proper interpretation of the data produced by the instruments is the criterion for smooth and safe operation.

There are nine recording, indicating, or control instruments incorporated in the incinerator design. They are:

(1) Gas Burner, Ignition, Regulator, and Safety Control System

This system provides for proper purging of the gas burners prior to ignition, insures the proper sequence of burner ignition, and provides positive shutdown of the burners in case of power failure, gas pressure failure, or failure of any one of the three gas burners.

(2) Pressure Recorders

Two instruments are used to record the negative pressures within the entire system. Pressures are recorded in the furnace itself and in the gas ducts prior to and following each piece of equipment in the scrubbing train.

(3) Pressure Indicators

Locally-indicating pressure gauges are placed on liquid lines.

(4) Temperature Recorders

Two temperature recording instruments are used. The first records the temperatures in the thermally hot part of the system (above 250°F.); that is, in the furnace, on the furnace wall, and in the gas duct leading to the Schreier-Bartolucci scrubber. The other instrument records the temperatures in the liquid lines and in the gas duct prior to and following the other piece of gas-cleaning equipment.

(5) Fluid Flow Recorders

The volume of combustion air drawn to the furnace is measured by a gas rotameter (FI-3) and recorded. The amount of cooling water used in the heat exchanger in conjunction with the Venturi scrub solution is measured by a rotameter (R-4) and recorded.

(6) Liquid Flow Indicators

The flow of the three scrub solution streams is measured by rotameters (R1,2,3). Bulls-eye sight glasses are located in effluent scrub stream lines.

(7) Pressure Controllers

Two pressure controllers are employed. One, a Mercoid type (PC-2), controls the butterfly valve on the relief exhaust line and vents the furnace to the atmosphere in case of a major pressure build-up. The other, a recording controller (PC-1), regulates the amount of gas that is recycled to the scrub system. Any minor pressure build-up in the combustion chamber can be overcome by regulating the amount of recycled air. Under present operating conditions, none of the gas is recycled.

(8) Venturi Flow Meter

Pressure taps at appropriate locations on the Venturi scrubber are connected to a manometer (M-1). This is used as a cross check on the intake air rotameter.

(9) Liquid Level Controllers

Two liquid-level controllers are incorporated in the system, one (LLC-1) controlling the liquid level in the cone of the furnace, and the other (LLC-2), controlling the liquid level in the hold-up cone in the base of the Peabody scrubber.

(10) Sight Glasses (Liquid Level)

One sight glass is located on the cone of the Peabody scrubber; another is located on the steam jacket of the furnace.

(11) Liquid Level Electrodes

An electrode is located in the top of the ash receiving barrel. This electrode indicates the pressure or absence of liquid between the barrel and the plug valve and is used during barrel changes.

All of the major instrumentation and electrical switches are located on a central panel board (Figure 3).

C. Operational Difficulties and Equipment Modifications

Some operational difficulties have been encountered in the program to date. The modifications in equipment and procedure that have been made to overcome those difficulties are as follows.

1. Furnace Body Deformation

After approximately one year of operation an inspection of the interior of the combustion chamber revealed that some buckling and weld separation had occurred on the circumference of the non-water jacketed portion of the metal wall as shown in Figure 4. Eight thermocouples were installed at points on the outside of the furnace body shell where maximum buckling had taken place in order to determine the temperature at these points during normal operation. These temperatures varied between 1200°F. and 1400°F.

The blanket insulation was removed from the exterior walls of the combustion chamber and a galvanized iron duct was installed around the entire furnace body about 4 inches from the furnace wall to permit cooling by natural convection. The weld separations were rewelded.

20

Figure 3
Incinerator Control Panel

Figure 4

Furnace Body Deformation

Prior to the installation of the duct, metal templates were made of the buckled areas. After eight months of continued operation, the buckled areas were checked with the templates and no further indication of buckling or weld separation was detected.

In addition to the air duct, a steel baffle was installed inside the combustion chamber to prevent the combustible wastes from piling against the wall opposite the charging chute. Additional supports for the furnace were installed at the bottom of the water jacket.

These two modifications, which resulted in lower furnace wall temperatures, have apparently stopped the buckling in the furnace walls.

2. Corrosion

Extensive corrosion has occurred in the section of the gas scrub train between the top wet plate of the Schreier-Bartolucci scrubber and the point in the throat of the Venturi scrubber where the scrub solution enters. At first, there was doubt whether the pinholes that developed in the duct work in this area were due to erosion caused by high velocity particles or to corrosion. Examination of the duct work in the remainder of the system failed to show any pinholes, even in the section of the duct between the combustion chamber and the Schreier-Bartolucci scrubber where the particle loading would be the highest. This fact overrules the assumption that the pinholes were caused by erosion. A chemical analysis of the deposit taken from the inside walls of the pin-holed duct showed the following results:

Halides	490 p.p.m. by wt.
Nitrates	275 p.p.m. by wt.
Phosphates	530 p.p.m. by wt.
Sulfates	3100 p.p.m. by wt.

It appears that sulfate, probably produced by the high percentage of paper burned, is the primary corrosive agent.

Prior to the Schreier-Bartolucci tower, the gas is hot and dry and therefore does not exhibit a corrosive action; following the throat of the Venturi scrubber, the moist acids present in the gas stream are diluted to such an extent that they do not present as grave a problem. Hence, the main area of corrosion is between the first two scrubbing units where the gas is moist and relatively concentrated.

An attempt to protect the duct from this attack was made by coating the inside of the duct with a plastic paint (Amercoat 44). This did not prove to be a satisfactory solution because the scrub solution line to the Schreier-Bartolucci tower became plugged, and consequently, the

exhaust gas from this tower became hot (above 250°F.) and burned the paint off. Coupons of various alloys have been inserted in this section of the gas train in an attempt to find a suitable material of construction for the duct. Data obtained from these tests (see page 57) indicate that Hastelloy C is the best material of construction for this application.

3. Plugging of Liquid Lines

Considerable trouble was experienced during the initial phase of the program with plugging of the liquid lines with solids. Plugging was also experienced in the rotameters and in the liquid level controllers. In the original flowsheet, the scrub solution for the Schreier-Bartolucci tower came from the cone of the furnace and consequently contained a high percentage of solids. This problem was satisfactorily solved by changing the source of the liquid to the bottom of the ash barrel. In this manner all of the large pieces of particulate are removed in the bag filter. This solution also remedied the problem of plugging rotameters.

The effluent scrub solution line from the Schreier-Bartolucci tower discharges at the liquid interface in the cone of the furnace. During shutdown any solids that were floating on the surface of the liquid had a tendency to plug this discharge opening. This line can now be flushed free with a water purge, should a plug develop. A stainless steel screen baffle has been welded over the outlet of this line to prevent clogging from the inside of the furnace.

At times, the liquid level controllers in the furnace cone and the Peabody tower cone have become jammed with a build-up of solids. This problem was also solved by installing a fresh-water purge in the system.

4. Venturi Throat Velocity

The manufacturer recommends that the throat velocity of the gases in the Venturi scrubber be maintained between 200 and 350 ft./sec. The original installation would produce a velocity of only about 150 ft./sec. The 7.5-horsepower motor on the Roots-Connersville blower was replaced with a 10-horsepower motor. This change allowed the throat velocities recommended by the manufacturer to be reached. However, for the most efficient scrubbing conditions obtained, the pressure drop developed by the Venturi (50 inches w.g.) reduced the throat velocity to about 150 ft./sec. again. When the converging section of the Venturi showed pinholes due to corrosion, it was repaired. A new converging section was also made. This new section has a smaller throat diameter, and when installed, the recommended throat velocities should be obtained at maximum efficiencies. In addition, the new section was modified so that the diameter of the liquid jets in the throat could be varied. This new section has not been installed to date.

5. Filter Deformation

The higher-than-expected pressure drop experienced in the Venturi scrubber resulted in a relatively high pressure differential (90 inches w.g.) between the inside and the outside of the filter. This pressure caused the walls of the filter (3/4-inch white pine) to buckle. This problem was solved by constructing a housing around the outside of the filter and connecting it to the filter plenum chamber in order to equalize the pressure on the filter wall.

6. Combustion Rate

The combustion rate has been governed by the ability of the steam jacket to remove the heat generated within the combustion chamber. Originally, two 360,000-B.t.u./hr unit heaters were used to condense the steam. These units did not have sufficient capacity, so a third similar unit was installed. This additional unit increased the capacity for combustion, and while the unit heaters are still the governing factor during the warm summer months, it appears that they are adequate in the cooler seasons of the year. The combustion rate was also improved by removing the insulation and cooling the furnace walls by natural convection as described on page 19. These modifications have allowed the operation of the incinerator at almost twice design capacity. Data concerning the combustion rates are given on page 53.

Trouble was experienced with air blocks in the unit heaters, but this was overcome by increasing the size of air vents.

7. Foaming

Considerable difficulty was encountered with foaming in the Peabody tower. Several methods of combating this problem were tried. These included use of anti-foams, regulation of the scrub solution pH, and frequent change of the scrub solution in order to reduce the solids concentration. None of these methods reduced the foaming sufficiently. However, by lowering the liquid level in the cone of the Peabody, the foaming was so reduced that it is no longer considered a problem. The entrance of the gas stream from the Venturi was previously about 5 inches above the liquid level and apparently the velocity of the gas stream produced vortexing in the cone resulting in foaming. By changing the location of the liquid level controller to increase the distance between the gas entry point and the liquid level to 16 inches, the foaming problem was solved.

Foaming originally resulted in considerable entrainment of liquid in the effluent gas stream from the Peabody. The entrained liquid was collected on the A.E.C. filter, and reduced the life of the filter by reducing the fiber strength.

8. Furnace Cone Plugging

The cone of the furnace has been plugged with solids many times since the start of operations. The two major causes for this plugging are (1) non-combustibles, and (2) materials that melt, drop through the grates, and resolidify in the water in the cone. The non-combustible problem can only be solved by more stringent segregation of wastes. The main material that caused plugging by melting and resolidification was the asphalt lining used in the original waste collection containers. New containers, similar to bulk ice cream containers, were substituted for the old asphalt-lined bags. This substitution has removed the major source of this problem, but melting and resolidification still occur occasionally when plastic bottles are in the feed charge.

The furnace cone plugs are broken up and removed by air sparging through the ash barrel or by rodding from above through the side access plate holes.

9. Charging Chute

Trouble was experienced during the initial shakedown period when the doors of the charging chute slipped on their axes and when material became lodged in the charging chute. The original design provided for connecting the doors to their axes with set screws. This proved very unsatisfactory, and the round shaft was replaced by a square shaft which could not slip. Lodging of material in the charging chute was prevented by grinding the surface of the chute to remove any protrusions.

10. Grate Inoperability

The bearings for the grate bars are too small, and therefore the grates sometimes bind when they become hot. Since they free themselves when they cool down, and because any modification of the grate supports would be a major project, nothing has been done on this problem.

11. A.E.C. Filters

Two small fires have occurred with A.E.C. filters. In one case, a filter caught fire while in use under normal operating conditions, and the other during experimentation with the gas burners. The incidents were accompanied by excessive pressure drop across the filter, failure of the main blower (G-5), and flame in the filter plenum chamber. The fires were extinguished without incident.

It is conjectured that during actual operation the reheaters were furnishing burning particles to the A.E.C. filter. The flow of gas across the filter face fanned the fire and ultimate destruction of the filter resulted.

The following remedial steps were proposed:

- (1) Install a non-combustible roughing filter to trap burning particles upstream of the A.E.C. filter.
- (2) Increase the heating surface of the electric reheaters to reduce surface temperature and eliminate possible combustion of particulate matter.
- (3) Install a thermal cut-out switch to shut off the Roots-Connersville blower when the blower inlet gas temperature rises 50°F. above normal operating temperature (about 160°F.). When the blower becomes inoperative, combustion air will no longer be supplied to the filter, and the fire will be smothered.

III. EXPERIMENTAL PROGRAM

A. History

Construction and leak testing of the equipment were completed by the middle of May, 1951. Fourteen runs were made using inactive dummy charges for the purpose of testing equipment, determining an operating procedure, and familiarizing the operating personnel with the process. This phase of the program was completed by the end of June, 1951. Four runs were made with charges to which mixed fission product activity was added to test the efficiency of the gas cleaning equipment. On July 12, 1951, the first run was made using normal laboratory wastes as feed material. Since that date, the incinerator has been operated daily, except for shutdowns due to modifications or maintenance, as a combined experimental and production unit. This incinerator is the first full-scale unit to be installed as a production unit for the purpose of handling combustible radioactive wastes.

B. Operating Procedure

A brief outline of operational procedure is given here:

- (1) Check all services, instruments, motors, and liquid levels.
- (2) Adjust liquid and gas flow rates to desired values.
- (3) Start exhaust air monitoring equipment.
- (4) Charge 4 to 6 cubic feet of material to the combustion chamber.
- (5) Ignite gas burners and continue using them until charge is burning well.

- (6) Continue charging at prescribed rate (as determined by temperature in combustion chamber and in steam jacket) for remainder of combustion period.
- (7) Take any samples of the gas stream required during this combustion period.
- (8) After the charging and the main burning have been completed, turn on the steam quench. Leave the steam quench on until the temperature within the combustion chamber is below 300°F. and the temperature in the steam jacket is below the boiling point (212°F.).
- (9) Turn off all scrub streams and allow the air to pass through the ducts for 5 minutes to dry them out.
- (10) Turn off all remaining pumps, exhaust air monitoring equipment, motors, etc.
- (11) Change ash barrel if full (based on ash as being 5 per cent of volume of material charged) and adjust pH of the water in the furnace cone.
- (12) Change A.E.C. filter if the particulate matter has built up a resistance to flow on the filter equal to 6 inches water gauge.

C. Sampling Procedure

1. Theory of Sampling for Particulate Matter

Sampling of particulate matter borne in a fluid stream can be accomplished most accurately by isokinetic means. Isokinetic sampling is based on obtaining the same velocity within the sample probe as exists in the main body of the fluid being sampled. If the velocity of the gas in the sample probe is higher than that of the gas in the duct that is being sampled, the results may be lower than the true gas stream loading; the opposite occurs when the sample stream velocity is higher than the main stream velocity. The greater the difference in velocity and the larger the particles, the larger the error that will be produced. This phenomenon is a result of the momentum of the particle due to its mass and velocity.

At velocities less than isokinetic, the momentum of the particle in the path of the probe carries the particle into the probe, while the gas stream is deflected and flows around the edge of the probe. This, naturally, enriches the sample and yields high results. The converse is true at higher than isokinetic velocities. Here, the gas that would normally flow past the sample probe is drawn into it while the particle, having a

higher inertia, continues in its path around the sample probe, thus yielding a sample of lower than true particle loading. It can be seen that larger or heavier particles are more influenced by this effect than those of similar sizes and weights.

In order to reduce turbulence and to obtain true representation of the stream being sampled, it is necessary to have a long straight section (10 pipe diameters minimum) prior to the sample point or to use straightening vanes or some other device to produce uniform velocity at the sample point. A device known as a Stairmand disc will produce a uniform velocity and a uniform particulate loading across a cross section. This device is a solid disc having a diameter equal to 0.707 of the duct diameter and is located in the duct 4 to 6 diameters prior to the sample point. While this device produces high flow resistance in the duct, it is a convenient means of producing a representative gas flow.

Another essential in sampling is to obtain the sample in a manner which does not disturb the flow pattern at the sample point. This can be done by using a thin or sharp-edged sample probe with an orifice perpendicular to the line of gas flow. If there are any sharp bends in the sample probe, some of the heavier particles may be deposited on the walls of the sample tube. This can be circumvented by placing the sample collection device within the duct so that the sample is collected before any bends in the tube occur.

Another advantage of placing the sample head in the gas duct is the prevention of condensation in the sampler. Condensation can cause two problems; one, moisture weakens the filter paper, and two, condensation formed on the walls of the sample tube tends to collect particles and thereby invalidates the results.

A more basic discussion of this problem can be found in an unclassified Atomic Energy Commission report by the Harvard University School of Public Health.²

2. Sampling Methods

Sampling of the gas stream to determine the efficiency of each piece of equipment was carried out in two ways. The first method was based on the total amount of activity entering and leaving each unit. The second method was based on the total amount of particles (based on weight) entering and leaving a unit. Experimental results, as shown on page 52, have shown that these two methods produce nearly equal results, at least in the less-than- 2μ particle size range.

²M. W. First, L. Silverman, et al., Air Cleaning Studies Annual Report, February 1, 1950, to January 31, 1951, NYO-1581, June 30, 1951.

The gas stream was monitored after it passed through the final unit of the cleaning train (A.E.C. filter). This monitoring, based on radioactive counting of particulate matter, helps to insure safe operation of the incinerator with respect to the total amount of radioactivity discharged to the atmosphere.

With the recirculating scrub solution system employed in this installation, it is not possible to determine the amount of activity or of particles removed by each piece of scrubbing equipment through samples of the scrub solution.

In cases where the gas temperature was too high (above 200°F.) to allow use of cellulose filter paper, a special fiber glass filter was used. The only sample point where this media is necessary is prior to the Schreier-Bartolucci scrubber. Here, in addition to high temperatures, a heavy particle loading is encountered. In order to be on a comparable basis, both influent and effluent gas samples around the Schreier-Bartolucci scrubber were taken with the same media.

Stairmand discs were used prior to the sampling points. The sample probe or head was inserted through a 2-inch pipe coupling welded into the gas duct.

3. Sampling Equipment

Two types of sampling equipment were used, both employing the principle of filtering the gas stream to remove the particles.

The monitoring sampling device, used to determine the amount of particulate radioactivity being discharged to the atmosphere, was a modified Filter Queen vacuum cleaner which draws the gas through a filter paper (Hollingsworth and Vose number H-70).

The gases were sampled by means of the sample head shown in Figures 5 and 6. This device was placed inside the gas duct facing upstream; and by means of the vacuum, the sample was drawn through the filter paper in the sample head. The sample flow rate was measured by a gas rotameter and the volume calculated from the length of time that the sample was taken. Figure 7 is a picture of typical sample papers.

After the sample has been taken, the filter media was removed and the radioactive count determined by use of Bradley Proportional Counters. The low level samples (less than 1×10^4 beta ct./min. per paper) were counted by means of PC-2 counters and the high level samples (greater than 1×10^4 beta ct./min. per paper) were counted in PC-1 counters. The counting time varied from 1 to 10 minutes depending on activity level. Both counters have 62 per cent yield.

Figure 5

Figure 6

Gas Sample Filter Assembly

32

Figure 7
Filter Paper Samples

For weight determinations, the sample medium was dried and weighed prior to and following the sampling. Both weight efficiencies and activity efficiencies can be determined on each sample. Efficiencies are based on the influent and effluent concentrations of the particulate matter in the gas at each unit of the scrubbing train.

4. Filter Media

For gas samples taken at less than 200°F., the filter media used was Whatman No. 44 paper. Gas streams having a temperature greater than 200°F. were sampled with a special fiber glass filter, AAA superfine, manufactured by the Owens-Corning Fiberglass Company. This filter media has an average pore size of 0.6 micron.

D. Program Objectives

The over-all objectives of the incinerator program were three-fold:

- (1) The incinerator was to serve as a production unit to process the daily accumulation of wastes produced by the Laboratory. In addition, it was desired to process the backlog of wastes accumulated in the burial grounds since the formation of the Laboratory in 1942. The purpose of this was to free the vaults for non-combustible wastes and thereby reduce the over-all solid active waste costs for the Laboratory.
- (2) The Argonne incinerator is essentially a prototype unit since it is the first production-sized unit to be operated successfully on a routine basis. Therefore, it was necessary to perform experimental work that would provide sufficient data to be the basis of design for any future incinerators.
- (3) As with any new process, it was necessary to perform sufficient experimentation to insure the most economical operation.

Since the Argonne incinerator was one of the first units to be constructed, it is somewhat overdesigned. A rather extensive experimental program was planned to investigate the operating characteristics and efficiencies of the various pieces of equipment that comprised the unit. The purpose of this program was to obtain the maximum efficiency for each type of gas cleaner and for the incinerator itself. Since this is a prototype unit, it was planned to determine if it were practical to reduce the number of pieces of gas cleaning equipment and thereby reduce both the initial cost and the operational cost of the incinerator.

E. Program

The experimental program has included a study of the following items:

- (1) Furnace efficiency
- (2) Operating variables for gas scrubbing components
 - a. Venturi liquid-to-gas ratio
 - b. Venturi scrub solution temperature
 - c. Steam injection prior to the Venturi scrubber
 - d. Peabody scrub solution rate
 - e. Peabody scrub solution temperature
 - f. Number of wet plates in the Peabody scrubber
 - g. Schreier-Bartolucci scrub solution rate
 - h. A.E.C. filter efficiency
- (3) Over-all decontamination
- (4) Comparison of efficiency evaluation by particulate weight and radioactivity counting
- (5) Activity build-up
- (6) Operating variables for combustion chamber
 - a. Weight and volume reduction
 - b. Charging rates.
 - c. Primary-to-secondary air rates
- (7) Corrosion
- (8) Continuous operation
- (9) Optimum operating conditions

1. Furnace Efficiency

The amount of activity or solids retained by the furnace itself was determined by use of charges with added, known radioactive contamination. This was determined on a radioactivity basis. These data are expressed as a decontamination factor (D.F.) which is the ratio of the total influent feed radioactivity concentration to the total effluent gas radioactivity concentration.

A mixed fission product solution was added to the feed material. This was reasonably evenly distributed throughout the feed material by injecting an equal volume of the solution into each charge by means of a hypodermic needle. In a series of three runs made with added activity, the activity level in the effluent gas from the furnace varied considerably with time, or more accurately with the charging rate, and probably with the nature of the material being charged as shown in Figure 8. A more complete combustion would result in fewer unburned particles in the effluent gas stream. Average decontamination factors of 150 to 310 were obtained, as shown in Table 1.

2. Operating Variables for Gas Scrubbing Components

a. Venturi Liquid-to-Gas Ratio

As it was not feasible to sample the gas stream between the Pease-Anthony Venturi scrubber and the Peabody scrubber, the effect of varying the scrub water-to-gas ratio in the Pease-Anthony Venturi scrubber on radioactivity removal efficiency was determined around the Pease-Anthony Venturi-Peabody scrubber couple at a constant water temperature and flow rate to the Peabody scrubber.

The effect of the water-to-gas ratio can be seen in Figure 9. The water rate was varied between 2.0 and 13.0 gal./min., and the gas flow from the incinerator was varied between 285 and 425 standard cu.ft./min. This resulted in a water-to-gas ratio varying between 4.7 and 45.6 gal./min. per 1000 standard cu.ft./min. The left side of the curve, the area between 4.7 and 20 gal./min. per 1000 standard cu.ft./min., shows that efficiency increased due to the increased water-to-gas ratio from 67 to 93 per cent and reaches a maximum of about 20 gal./1000 standard cu.ft.

At a higher water-to-gas ratio, it is thought that the water "jets" across the throat of the Venturi rather than forming a spray. This "jetting" effect results in a lower efficiency due to the less intimate contact between the scrub water and the flowing gas stream. Visual observations have shown that at a lower water-to-gas ratio the scrub water sprays into the throat of the Venturi and forms a curtain of water through which the gas must pass. Results of these tests are summarized in Table 2.

FIGURE 8.
FURNACE EFFLUENT GAS ACTIVITY vs. RUN TIME.

Table 1

FURNACE DECONTAMINATION FACTORS (D. F.)

Feed Material: laboratory wastes, wood, filters

Run No.	Added Activity, total disint. / (min.)(run)	Charging Time, min.	A Activity Charging Rate, total disint. /(min.)(min.)	Furnace Gas Discharge Rate, cu. ft. /min.	Furnace Gas Discharge Activity, total disint. / (min.)(cu. ft.)	B Activity Discharge Rate, total disint. /(min.)(min.)	Furnace Decontamination Factor, $\frac{A}{B}$
219	5.8×10^{12}	210	2.8×10^{10}	225	7.8×10^5	1.8×10^8	150
220	5.5×10^{12}	260	2.1×10^{10}	225	7.0×10^5	1.6×10^8	130
221	5.1×10^{12}	300	1.7×10^{10}	225	2.4×10^5	5.4×10^7	310

FIGURE 9.

EFFECT OF WATER TO GAS RATIO IN THE PEASE -
ANTHONY VENTURI ON RADIOACTIVE REMOVAL EFFICIENCY.

Gas Flow Rate 285-425 S.C.F.M.

Scrub Solution Flow Rate:

Pease - Anthony Venturi 2-13 gal./min.

Schreier - Bartolucci Scrubber 9.0 gal./min.

Peabody Scrubber 5.5 gal./min.

Table 2

EFFECT OF VARIABLE WATER-GAS RATIO IN PEASE-ANTHONY
VENTURI SCRUBBER ON RADIOACTIVITY REMOVAL EFFICIENCY

Feed material of variable composition (laboratory wastes,
wood, paper, etc.).

Liquid Rate In Peabody Scrubber: 5.5 g./min.
Liquid Rate In Schreier-Bartolucci: 9.0 g./min.

Gas Flow Rate, S.C.F.M.	425	420	380	340	310	285
Water-Gas Ratio, gal./1000 S.C.F.	4.7	11.9	19.7	23.6	32.2	45.6
Liquid Rate In Venturi Scrubber, gal./min.	2.0	5.0	7.5	8.0	10.0	13.0
Number of Runs	3	4	4	4	5	2
Pairs of Samples	29	18	22	28	16	15
Radioactive Removal Efficiency of Peabody-Venturi Couple, per cent	66.7	80.9	93.4	93.3	90.5	87.7

b. Venturi Scrub Solution Temperature

The effect of varying the scrub solution temperature on the radioactivity removal efficiencies in the Pease-Anthony Venturi was investigated over the range 64 to 148°F. in two groups of tests. Scrub solution temperatures between 90 and 148°F. were obtained by recycling the scrub solution through the heat exchanger. Scrub solution temperatures below 90°F. were obtained by the use of tap water. The Peabody tower was not used in the first series of experiments in order to magnify any change in efficiency resulting from changes in Venturi liquid temperature. Up to 108°F., 90 to 94 per cent of the radioactive particles were removed by the Venturi scrubber; while above this temperature, efficiency dropped to 82 per cent at 121°F., as shown in Table 3. In the second series, the scrub solution rate to the Peabody scrubber was constant at 5.5 gal./min. Efficiency of the Pease-Anthony-Peabody couple was over 96 per cent up to 132°F., but again dropped at a higher temperature (to 86 per cent at 148°F.) as indicated in Table 3 and Figure 10.

c. Steam Injection Prior to the Venturi Scrubber

The use of steam injection to enlarge the particles by means of the condensation nuclei principle was also investigated. The particles in the gas stream act as nuclei for the condensing steam and are

Table 3

THE EFFECT OF VENTURI SCRUB SOLUTION TEMPERATURE
AND STEAM INJECTION ON EFFICIENCY

Scrub Solution Flow Rates:

Pease-Anthony: 8.0 gal./min.
 Schreier-Bartolucci: 9.0 gal./min.
 Steam, when used: 190 lb./hr.

Gas Flow Rate: 315 S.C.F.M.

Venturi Solution Temp., °F.	Peabody Scrub Solution Rate, 5.5 gal./min.		Peabody Scrub Solution Rate, 0 gal./min.	
	Removal Efficiency Without Steam	Removal Efficiency With Steam	Removal Efficiency Without Steam	Removal Efficiency With Steam
64-66	-	-	93.9	96.5
76	-	-	93.4	-
88-94	96.8	98.1	92.2	-
97-102	-	-	93.8	94.5
108-116	94.8	97.3	88.2	95.7
121-126	95.2	96.6	81.6	92.9
132-140	93.3	96.5	-	-
148-154	85.7	95.4	-	92.0

FIGURE 10.

THE EFFECT OF STEAM INJECTION ON RADIOACTIVE
REMOVAL EFFICIENCY BY PEASE-ANTHONY VENTURI.

Gas Flow Rate 315 S.C.F.M.

Scrub Solution Flow Rate:

Pease-Antony Venturi 8.0 gal./min.

Schreier-Bartolucci Scrubber 9.0 gal./min.

Peabody Scrubber 0 or 5.5 gal./min.

Steam Injection 0 or 190 lb./hr.

consequently enlarged by it. The larger particles are more easily removed by the gas scrubbing equipment. The use of the condensation nuclei principle for the removal of submicron particulate has been investigated at other A.E.C. sites.³

A series of tests with constant steam injection and varying scrub solution temperatures and flow rates was made as a probing experiment to determine the feasibility of steam injection. Steam at a rate of about 190 lb./hr. (entering at 0 p.s.i.g.) was introduced into the duct leading to the Pease-Anthony scrubber about 12 inches upstream from the Venturi throat.

In general it was found that for a given Venturi scrub solution temperature, particle removal efficiency was about 50 per cent greater with steam injection than without steam up to temperatures at which efficiency fell off rapidly with no steam (about 140 and 110°F., respectively with and without scrub solution in the Peabody scrubber). Above these temperatures, removal efficiency with steam injection decreased only slowly as the scrub temperature was further increased compared to a rapid decrease in efficiency in the absence of steam. These results are shown in Figure 10 and Table 3.

d. Peabody Scrub Solution Rate

The effect of a variable Peabody scrub solution rate on radioactivity removal efficiencies in the Pease-Anthony Venturi-Peabody scrubber couple was determined in an experiment in which the efficiency of the Venturi was purposely kept low so as to accentuate any changes that might occur in the Peabody. The latter was accomplished by reducing the Venturi scrub flow rate to 2.5 gal./min. (water-to-gas ratio of 8 gal./1000 cu.ft.). The particle removal efficiency was 72 per cent at 2.5 and 7.0 gal./min. of solution to the Peabody unit, as shown in Table 4. This compares with 73 per cent efficiency interpolated for the same water-to-gas ratio in Figure 9 and indicates that the flow rate to the Peabody scrubber is not critical as regards efficiency in this range.

e. Peabody Scrub Solution Temperature

Data in Table 5 illustrate the effect of varying the Peabody scrub solution temperature on radioactivity removal efficiencies in the Pease-Anthony Venturi-Peabody scrubber couple. Peabody scrub solution temperature was controlled by means of a heat exchanger.

³P. J. Schauer, Removal of Submicron Aerosol Particles from a Moving Gas Stream by the Condensation Center Effect, Monsanto Chemical Co. Report MLM-490, Sept. 1, 1950.

Table 4

EFFECT OF PEABODY SCRUB SOLUTION RATE ON
PARTICLE REMOVAL BY SCRUBBER COUPLE

Feed Material: laboratory wastes, filter, wood

Scrub Solution Flow Rates:

Pease-Anthony Venturi: 2.5 gal./min.

Schreier-Bartolucci Gas Washer: 9.0 gal./min.

Gas Flow Rate: 315 S.C.F.M.

Ten to nineteen pairs of samples obtained per run.

No. of Runs	Flow Rate to Peabody Scrubber, gal./min.	Radioactivity Removal Efficiency of Pease-Anthony Peabody Scrubber Couple,
		per cent
2	2.5	72.0
4	7.0	71.9

Table 5

EFFECT OF PEABODY SCRUB SOLUTION TEMPERATURE
ON PARTICLE REMOVAL BY SCRUBBER COUPLE

Feed Material: laboratory wastes, filters, wood

Scrub Solution Flow Rates:

Pease-Anthony Venturi: 2.5 gal./min.

Peabody Scrubber: 5.5 gal./min.

Schreier-Bartolucci Gas Washer: 9.0 gal./min.

Gas Flow Rate: 315 S.C.F.M.

Twelve to fourteen pairs of samples obtained per run.

No. of Runs	Temperature of Peabody Scrub Solution, °F.	Radioactivity Removal Efficiency of Pease-Anthony Venturi-Peabody Couple, per cent
4	98	70.4
3	145	68.1

The water temperature appears to have very little effect on the efficiency of the Peabody scrubber. Sixty-eight per cent was obtained at 145°F. and 70 per cent at 100°F.

f. Number of Wet Plates in the Peabody Scrubber

The Peabody scrubber contains four scrub plates and is normally operated with the scrub solution fed to the top plate and descending successively to the plates beneath. The solution feed manifold was so installed, however, that the scrub water can be introduced on any one of the four plates. This permits a determination of the effect of varying the number of wetted plates in the Peabody scrubber tower on radioactivity removal efficiencies. A series of tests was conducted in which 0 to 4 plates were wet, other conditions being constant. As shown in Figure 11 and Table 6, efficiency of the Pease-Anthony Peabody couple was proportional to the number of wet plates ranging from 82 per cent with no scrubbing to 93 per cent with four wet plates. Since essentially the same result (93 per cent efficiency) was obtained with either three or four wetted plates, it is not probable that significantly increased removal could be accomplished with additional plates.

Table 6

EFFECT OF VARIABLE NUMBER OF WETTED PLATES IN PEABODY
SCRUBBER ON PARTICLE REMOVAL BY SCRUBBER COUPLE

Feed Material: laboratory wastes, filters, wood, etc.
 Scrub Solution Flow Rates:
 Pease-Anthony Venturi: 8.0 gal./min.
 Peabody Scrubber: 5.5 gal./min.
 Schreier-Bartolucci Gas Washer: 9.0 gal./min.
 Gas Flow Rate: 305 to 340 S.C.F.M.
 Ten to twenty-eight pairs of samples obtained per run.

<u>No. of Runs</u>	<u>No. of Wetted Plates</u>	<u>Radioactivity Removal Efficiency of Pease-Anthony Venturi-Peabody Couple, per cent</u>
2	0*	81.6
4	1	88.3
2	2	89.6
2	3	92.7
4	4	93.3

*0 = 0 gal./min. with no wet plates

FIGURE II.

EFFECT OF NUMBER OF WET SCRUB PLATES
ON EFFICIENCY OF PEABODY SCRUBBER.

Gas Flow Rate: 305-340 S.C.F.M.

Scrub Solution Flow to

Pease - Anthony Venturi 8.0 gal./min.

Schreier-Bartolucci Gas Washer 9.0 gal./min.

Peabody Scrubber 5.5 gal./min.

(0 gal./min. with no wet plates)

g. Schreier-Bartolucci Gas Scrubber Efficiency

The heterogeneous composition of the feed material makes the determination of particulate or activity removal efficiency of the Schreier-Bartolucci gas scrubber very difficult. From the data amassed to date, it appears that the efficiency of this scrubber is affected by the type of material charged and the combustion rate. Filters and organic solids tend to produce larger particles while burning, and the larger particles are more easily removed by scrubbing.

An attempt was made to correlate the effect of scrub water rate on the efficiency of the scrubber. While the data obtained are not conclusive, the following results were noted:

- (1) Varying the scrub water rates from 4 gal./min. to 15.5 gal./min. had little or no effect on the radioactivity removal efficiency of this scrubber when the feed material was composed of mostly small-particle forming material, i.e., paper and cloth. The resultant efficiency is in the order of 25 per cent.
- (2) When filters and other large-particle forming materials are burned, the efficiency of radioactivity removal is proportional to the scrub solution rates between 4 gal./min. and 15.5 gal./min. The efficiencies obtained with such feed material were as follows:

<u>Scrub Rate, gal./min.</u>	<u>Efficiency, per cent</u>
4	50
9	60
15.5	75

- (3) The normal laboratory wastes are a combination of large and small-particle forming materials, and consequently, the efficiencies fall between the two previously-stated cases. The results obtained were as follows:

<u>Scrub Rate, gal./min.</u>	<u>Efficiency, per cent</u>
4	40
9	55
15.5	60

- (4) Gas samples taken following runs with highly active feeds have shown negative efficiencies. This is attributed to entrainment of the scrub solution in the gas stream.
- (5) In addition to removing 40 to 50 per cent of the activity from the gas stream, the scrubber acts as a classifier of the particulate matter leaving the furnace. All of the large particles are removed by this unit so that the issuing gas contains particles of a relatively narrow size spectrum.

h. A.E.C. Filter Efficiency

Very little experimental work has been done to determine the over-all efficiency of the A.E.C. filter since A. D. Little Company,⁴ who designed the filter, has determined that it is 99.9⁺ per cent efficient on 0.3 to 1 micron sized particulate. This corresponds to a minimum decontamination factor of 1×10^3 .

The efficiency of the filter was checked during one of the high activity level runs, and as shown below, an average decontamination value of 2.6×10^3 was obtained. This value corresponds to an efficiency of 99.96 per cent.

A.E.C. FILTER DECONTAMINATION FACTOR

Influent Gas (average)		Effluent Gas, (average)	Decontamination Factor
disint./ (min.)(cu.ft.)	disint./ (min.)(cu.m.)	disint./ (min.)(cu.m.)	
8.7×10^3	3.1×10^5	1.2×10^2	2.6×10^3

3. Over-all Decontamination Factor

The following are experimental results obtained by the introduction of known quantities of activity into the furnace. Varying quantities of a mixed fission product solution were added to the feed material.

The mixed fission product solution was evenly distributed throughout the feed material by injecting with a hypodermic syringe and needle an equal volume of the solution into each charge.

⁴A. D. Little, Inc., Interim Memorandum Report on Filter Development and Discussion on Availability of Materials, ALI-27-C57896, May 19, 1950.

The radioactivity present in the effluent stack gas in all runs with added activity was less than the natural radioactivity present in the influent air.

As illustrated in Figure 12 and Table 7, the over-all decontamination factor reached a constant value at about 2 to 3×10^7 . This value is substantiated by a cumulative decontamination factor representing the product of the individual equipment decontamination factor values as shown in Table 8.

In order to test the efficiency of the gas scrubbing train on atmospheric dust two experiments were conducted in which air from outside of the building was drawn through the gas train. The conditions were the same as during a normal combustion period except that no material was burned. The results are as follows:

	Air Intake,* disint./ (min.)(cu.m.)	Air Exhaust,* disint./ (min.)(cu.m.)
Run 1	$\alpha = 73$ $\beta = 219$	Background of Counter 40
Run 2	$\alpha = 393$ $\beta = 863$	2.8 14

*Conditions: Air Flow: 315 S.C.F.M.;
Scrub Solution Flow Rates: Schreier-
Bartolucci Scrubber, 9.0 gal./min.; Ven-
turi Scrubber, 8.0 gal./min.; Peabody
Scrubber, 5.5 gal./min.

It should be noted that the decontamination factor for the furnace itself (about 200) is significantly different from that previously reported by KAPL⁵ (about 2000). Private communications indicate that the originally reported figure of 2000 was in error by a factor of 10, and the two sites are in agreement that 200 is a realistic value for the furnace decontamination factor.

It is apparent, since the exhaust stack gas contains less activity than the natural radioactivity present in the surrounding atmosphere, that a higher level of activity could be handled or that considerably

⁵F. N. Schell, A Report on the Development and Operation of a Pilot Incinerator for Contaminated Combustible Solid Wastes, KAPL-610, page 38.

FIGURE 12.

EFFECT OF ACTIVITY LEVEL IN
CHARGE ON OVER-ALL INCINERATOR
DECONTAMINATION FACTOR.

Table 7

DECONTAMINATION ACHIEVED IN CONTAMINATED WASTE INCINERATOR RUNS WITH ADDED ACTIVITY

Run No.	Air In, beta disint. / (min.)(cu. m.)	A	B	Exhaust Air, beta disint. / (min.)(cu. m.)	C	Decontamination Factor, $\frac{A + B}{C}$	Activity, beta ct. /(min.)(ml.) in:			
		Air In, (1)	Feed,		Exhaust Air,		total beta	Furnace	Peabody	Liquid Drained
		total beta disint. / (min.)(run)	total beta disint. / (min.)(run)		total beta disint. / (min.)(cu. m.)		total beta disint. / (min.)(run)	Liquid, ~ 300 gal.	Scrub Solution, ~ 70 gal.	From Ash, ~ 50 gal.
T-15	195	4×10^5	1×10^7	14	2.8×10^4	2.6×10^2	Bkgd. (2)	Bkgd. (2)	Bkgd. (2)	
T-16	116	2.3×10^5	9×10^7	2	4×10^3	2.2×10^4	14	3	Bkgd. (2)	
T-17	185	3.7×10^5	3.7×10^9	2.5	5×10^3	7.4×10^5	1.3×10^3	30	11	
T-18	166	3.3×10^5	1.6×10^{11}	4	8×10^3	2.0×10^7	2.5×10^4	780	52	
219	300	6.0×10^5	5.8×10^{12}	97	1.9×10^5	3.1×10^7	6.3×10^4	8.3×10^4	6.2×10^4	
220	300	7.5×10^5	5.5×10^{12}	105	2.7×10^5	2.1×10^7	2.6×10^5	6.0×10^4	1.9×10^5	
221	300	7.0×10^5	5.1×10^{12}	94	2.2×10^5	2.4×10^7	3.9×10^5	7.0×10^4	2.7×10^5	

(1) Air intake: 180 S.C.F.M. during Runs T-15, 16, 17, and 18 and 225 S.C.F.M. for Runs 219, 220, and 221.

(2) Count not distinguishable from background of counter.

lower efficiency could be tolerated throughout the system. However, on the basis of activity readings encountered during the high level runs, it is apparent that remote charging, ash removal, and additional shielding of the furnace cone and ash barrel would have to be provided to enable this level of activity to be handled routinely. The individual charges read 5 to 15 r./2" H & S, and the ash bag, 2 to 10 r./2" H & S. The cone and ash barrel read 300 to 500 mr./2" H & S during the runs, and the A.E.C. filter face read 60 mr./2" H & S.

Table 8

DECONTAMINATION ACHIEVED BY INCINERATOR COMPONENTS

Component	Decontamination Factor
Furnace	2.2×10^2
Schreier-Bartolucci Scrubber	1.2
Pease-Anthony Venturi Scrubber	50
A.E.C. Filter	2.6×10^3
Over-All	3.4×10^7

The main value of increasing the over-all efficiency is in decreasing the "dust" load to the A.E.C. filter, thereby increasing its operating life. The experimental work on the Venturi-Peabody couple produced data which enabled the filter life to be extended from one 8-hour day to ten 8-hour days. This over-all increase has reduced the cost of filter from \$40.00/day to \$4.00/day.

During a continuous run, one filter was used for 115 hours. This long life can be attributed to a minimum of condensation on the filters since the gas stream was not cooled for start-up and shutdown operations during this run.

4. Comparison of Efficiency Evaluation by Particle Weight and Radioactivity Counting

A comparison was made between gas scrubbing equipment efficiencies determined on weight and radioactivity removal bases. Filter papers resulting from sampling were dried for 3 to 5 hours at 110°C. to constant weight. These sample papers were then counted for radioactivity. As expected, the weight removal efficiencies were a few per cent higher than the activity removal efficiencies as shown by the data in Table 9. This is assumed to be a result of self-absorption of low energy particles on the filter papers.

Table 9

COMPARISON OF ACTIVITY AND PARTICULATE WEIGHT SAMPLING

Feed Material: laboratory wastes, wood, filters

Scrub Solution Flow Rates:

Pease-Anthony: 8.0 gal./min.

Schreier-Bartolucci: 9.0 gal./min.

	<u>Test A</u>	<u>Test B</u>
Peabody Scrub Solution Rate, gal./min.	0	5.5
Gas Flow, S.C.F.M.	305	340
Venturi Scrub Solution Temp., °F.	95	140

Particulate Removal Efficiency, per cent

<u>Test A</u>		<u>Test B</u>	
<u>Radioactivity Basis</u>	<u>Weight Basis</u>	<u>Radioactivity Basis</u>	<u>Weight Basis</u>
91.7	90.0	96.1	97.0
96.4	94.7	94.0	96.7
84.0	91.0	90.7	95.5
92.8	94.6	84.6	94.1
94.2	90.5	92.6	91.7
		96.5	93.0
		95.0	96.2
		97.4	96.7
Ave. = 91.8	Ave. = 92.1	Ave. = 93.3	Ave. = 95.1

5. Activity Build-Up

At no time during the incinerator operations has there been any evidence of radioactivity build-up or concentration in the system other than in the ash barrel. Survey meters were used extensively to check activity levels throughout the system. Combustion chamber effluent gas radioactivity content is normally about 3×10^2 beta disint./ (min.) (cu.ft.). During the high activity level runs this was about 5×10^5 beta disint./ (min.) (cu.ft.). In succeeding runs, burning normal wastes, the activity of the effluent gas returned to its normal level. This indicated that the variation in stack gas activity occurred because of the varying activity levels in the feed material rather than the dislodging and entraining of active residual particulate matter from the system.

During a continuous run (118 hours), the level of activity in the system remained fairly constant since the activity was removed from the system in the ash at the same rate that it was added in the charge.

6. Operating Variables for Combustion Chamber

a. Volume and Weight Reduction

The incinerated feed material is reduced to approximately 5 per cent of its original volume. The bulk density of daily accumulation wastes, 6.4 lb./cu.ft., was determined by weighing 125 1-cu.ft. fiber drums. These were representative of daily collection wastes and can be taken as an average bulk density of the normal wastes for the Laboratory. Special wastes, such as wood and cloth, have a higher bulk density.

A series of three runs in which 238 cu.ft. of waste weighing 1,410 pounds were burned showed a volume reduction of 95 per cent from the charge to the ash and a weight reduction from charge to moist ash of about 70 per cent.

b. Charging Rate

The charging rate has been increased as a result of the following equipment modifications:

- (1) Installation of a third unit heater to raise the nominal heat-dissipating capacity of the system from 720,000 B.t.u./hr. to 1,080,000 B.t.u./hr.
- (2) Removal of furnace body insulation to permit additional cooling by convection and radiation.

Prior to these modifications, an 18-hour run was made to determine capacity and charging rate of the incinerator. During the first part of the run Chemical Warfare Service filters, clothing, and wood were burned; and during the second part of the run, normal laboratory wastes were burned. The combustion rates for these materials were:

1. Chemical Warfare Service filters and wood	8 cu.ft./hr.
2. Clothing	12 cu.ft./hr.
3. Laboratory collection wastes	18 cu.ft./hr.

A total of 7 filters, 1 box of wood, 7 boxes of clothing, and 33 boxes of daily laboratory collection wastes were burned. The average combustion rate for the run (including start-up and shutdown) was 11 cu.ft./hr. A total of 200 cu.ft. was burned.

Design capacity was 16.6 cu.ft./hr. for normal laboratory wastes (excluding start-up and shutdown) based on an average bulk density of 10 lb./cu.ft.

After the installation of an additional unit heater, a run was made to determine maximum capacity with normal laboratory collection wastes packaged in 1-cu.ft. fiber drums. A charging rate of 21 cu.ft./hr. (excluding start-up and shutdown) was obtained. A total of 125 cu.ft. was burned in this 8-hour run.

After removal of the furnace body insulation, an 8-hour run was made using normal laboratory collection wastes packaged in 1-cu.ft. fiber drums. A maximum charging rate of 26 cu.ft./hr. (excluding start-up and shutdown) was obtained. A total of 157 cu.ft. was burned in this run.

The controlling factor for determining the maximum charging rates is the steam condensing capacity of the unit heaters. The water jacket temperature varied from 213°F. to 230°F. Charges were introduced at a rate that kept this temperature approaching the maximum, intermittently fluctuating, thus indicating that more rapid introduction of feed would produce excessive jacket temperatures. The combustion chamber temperatures varied in all runs from 850°F. to 1450°F. with an average of 1150°F.

After the addition of the third unit heater and the replacement of the insulation by the convection cooling ducts, a continuous run of 118 hours duration was made. During this run a total of 1149 cu.ft. of wastes was burned. This consisted of 479 cu.ft. of wood, 104 cu.ft. of filters, and 566 cu.ft. of normal laboratory waste. This is equivalent to 1986 cu.ft. of normal wastes or 16.6 cu.ft. burned per hour of operation. The charging rates for this run (exclusive of start-up, shutdown, and barrel changing) were 9.6 cu.ft./hr. for wood and filters and 23.4 cu.ft./hr. for normal wastes. These figures represent the charging rates that can be maintained under normal operating conditions.

NORMAL CHARGING RATES; CU.FT./HR.

(exclusive of start-up, shutdown,
and barrel changes)

	<u>Normal Collection Wastes</u>	<u>Clothing</u>	<u>C.W.S. or A.E.C. Filters</u>
Prior to Equipment Modifications	18	12	8
After All Equipment Modifications*	23.4	15**	9.6

*Installation of third unit heater rated 360,000 B.t.u./hr. Removal of furnace body insulation and installation convection air cooling duct.

**This extrapolated value is based on data obtained by burning wastes packaged in 1-cu.ft. fiber drums.

c. Primary-to-Secondary Air Rates

Air for combustion of the furnace charge is introduced at two points; primary air beneath the grates and secondary air somewhat above the grates. The volume introduced at each point may be separately controlled. It was of interest to determine the effect of varying primary or secondary combustion air on particulate loading in the off-gas stream as a means of developing the most efficient operating conditions. A comparison was made between supplying all air as primary or as secondary combustion air. Only wood was burned during the sampling period so that particulate size, distribution, and quantity would be approximately the same. All samples were taken between the Schreier-Bartolucci gas washer and the Venturi scrubber.

The use of only secondary air, as opposed to only primary air, reduced the particulate concentration in the gas stream by a factor of 3. The tangential entry of the secondary air imparts turbulence to the gas mixture in the combustion chamber and thus aids in more complete combustion. The results of this test are shown in Table 10.

The existing secondary air ports are not large enough to allow entry of sufficient combustion air to maintain the desired combustion rates so under normal operating conditions they are augmented by use of the primary air ports.

Table 10

EFFECT OF PRIMARY OR SECONDARY COMBUSTION AIR ON
PARTICULATE LOADING OF SCHREIER-BARTOLUCCI EFFLUENT GAS

Feed Material: wood			
Schreier-Bartolucci Scrub			
Solution Rate: 9.0 gal./min.			
<u>Gas Flow Rate</u>	<u>300 S.C.F.M. Primary Combustion Air</u>	<u>155 S.C.F.M. Primary Combustion Air</u>	<u>155 S.C.F.M. Secondary Combustion Air</u>
No. of Samples	12	9	10
Average Particulate Loading, grams/cu.ft.	0.0022	0.0017	0.0006

7. Exhaust Duct Corrosion

The wet gaseous products of combustion and particulate matter leaving the Schreier-Bartolucci gas washer have given the most corrosion difficulties. The existing duct is pitted in many locations. A study was therefore made of several materials of construction which were tested by inserting them into the duct work between the Schreier-Bartolucci gas washer and the Pease-Anthony Venturi scrubber. Metal coupons of Hastelloy B, type 347 stainless steel, Hastelloy C, H.R. carbon steel, 52S aluminum, 61S aluminum, Carpenter 20, and Inconel were inserted in the existing duct. These coupons were measured, weighed, tested, removed, cleaned, and reweighed after 150 to 180 hours of exposure. Table 11 shows that only Hastelloy C was free from corrosion, and that of the other materials, Carpenter 20 alloy corroded less than 0.01 in./yr. but showed evidence of pitting.

There are many nonmetallic materials of construction that would be suitable for this application, i.e., Teflon, Polyethylene, Haveg, etc.; but the possible failure of the Schreier-Bartolucci scrub liquid recirculation system would permit the furnace off-gases to enter this duct at 800 to 1000°F. and possibly result in ultimate failure to any nonmetallic duct. Other metals are being investigated.

It was concluded that of the metals tested, only Hastelloy C would be satisfactory. For fabrication purposes, it is desirable to keep duct work at a maximum thickness of 1/16 inch. Since all corrosion taking place

Table 11

CORROSION OF DUCT MATERIALS

Samples placed in duct between Schreier-
Bartolucci and Pease-Anthony Venturi.
Sample Dimensions: 15 x 2.7 x 0.05 in.

Test A

Total Test Time: 180 hours

Material Tested	Weight Loss		Corrosion Rate,	Remarks
	grams	per cent	in./yr.*	
Carpenter 20	6.4	1.3	0.0083	Pitted.
347 Stainless Steel	31.1	6.5	0.0420	Pitted very badly.
Inconel	24.4	4.6	0.0300	Pitted.
Hastelloy B	49.8	8.7	0.0600	Pitting not evident.

Test B

Total Test Time: 150 hours

Material Tested	Weight Loss		Corrosion Rate,	Remarks
	grams	per cent	in./yr.*	
Carpenter 20	2.7	0.73	0.0049	Pitted.
H. R. Carbon Steel	33.4	10.2	0.062	Pitted and scaled.
52S Aluminum	14.5	11.3	0.078	Pitted very badly.
61S Aluminum	26.1	21.3	0.140	Pitted very badly.
Hastelloy C.	0	0	0	No corrosion evident.

*Based on burning time of 30 hours per week and 48-week work year.

(with the exception of Hastelloy B and C) appears to be pitting, holes would appear very quickly through duct walls. While Hastelloy B does not pit, it had the highest corrosion rate of any samples tested with the exception of aluminum.

Carpenter 20 was used as a basis of comparison between Tests A and B. The difference in corrosion rates obtained can be attributed to different types of material being burned since a lower percentage of paper was burned in Test B, and therefore the resultant gases would contain less sulfates.

8. Continuous Operation

To demonstrate the feasibility of continuous operation, a run of 118 hours duration was made. Except for the failure of one pump seal (G-3), which was easily and quickly replaced, the run was made without incident.

A total of 1149 cu.ft. of wastes was burned. This consisted of 41.7 per cent wood, 9.1 per cent filters, and 49.2 per cent normal laboratory wastes. This is equivalent to 1986 cu.ft. of normal wastes or 400 cu.ft./24-hour day. Ash receivers were changed every 8 hours.

There was no evidence of activity build-up in the system since the activity was removed in the ash at the same rate it was charged to the furnace.

9. Liquid Fuel Burning

A system for burning liquid fuels was incorporated into the combustion chamber for test purposes. The fuel was introduced into the combustion chamber through the nozzle (a modified Huck No. 628) which replaced one of the gas burners on the periphery of the furnace. The unit was tested by burning kerosene at 3.0 gal./hr. and found to operate successfully. However, inspection of the furnace cone and gas scrubber showed the presence of unburned kerosene. This discovery indicated that the possibility of an explosion within the incinerator system was present, and so these tests with the liquid fuel burner were discontinued.

IV. ECONOMICS OF THE SYSTEM

Incineration of moderate level radioactive wastes is a costly process. It is only justified economically when the cost of storage is high, compressibility is low and the collection system precludes unsafe feeds. Rigid control at Argonne National Laboratory of all potentially contaminated wastes has resulted in high costs. The solid wastes are stored in carbon steel boxes and these boxes are then placed in wood-covered, concrete-lined trenches. The

storage costs amount to about \$4.00/cu.ft. This figure of \$4.00/cu.ft. is for a relatively small volume of storage and permits segregation and ultimate removal of the stored waste. It could undoubtedly be reduced for a large volume permanent storage facility. Thus incineration, and the consequent reduction in volume of the combustible active wastes, can result in a saving.

A cost analysis comparing 8-hour and 24-hour day operation of the incinerator is summarized in the following Table 12. The savings per year indicated for 8-hour per day operation is about \$26,000. The total processing cost per cubic foot for the 8-hour per day incineration operation is \$2.68.

V. FUTURE WORK

It is felt that further investigation of operational variables is required to complete the experimental program and yield optimum operating conditions. It is hoped to continue with this investigation during routine operations. The variables of prime interest are listed below.

- (1) Obtain particulate size data at each sample point
- (2) Investigate the following variables in the steam injection system
 - a. Steam pressure
 - b. Steam quantity
 - c. Steam quality
 - d. Location of steam entry point
- (3) Study elimination of entrainment from Peabody scrubber.
- (4) Determine the minimum scrubbing equipment required to obtain the necessary over-all efficiency
- (5) Determine the feasibility of the use of roughing filters to extend the life of the A.E.C. filter
- (6) Test the smaller-throat Venturi section
- (7) Review the experimental program so as to correlate the previously-obtained data in order to insure the maximum over-all efficiency of the unit.

Table 12

ECONOMIC EVALUATION OF INCINERATOR OPERATIONS

	8-hour day	24-hour day
A. Basic Data		
1. Operating Capacity, cu.ft. Basis: 16.6 cu.ft./burning hr.	100	400
2. Nature of Material Burned, per cent		
Wood	30	30
Normal Waste	60	60
Filters	10	10
3. Use Factor, per cent	75	75
4. Annual Burning Rate, cu.ft. Basis: 260 working days/year 8 hours operation = 6 hours burning 24 hours operation = 24 hours burning 75 per cent use factor	19,500	78,000
B. Cost of Operation Per Year, Labor		
1. Operators, man-hours/day (\$2.00/hr.)	16	48
2. Supervisors, man-hours/day (\$2.50/hr.)	2	4
3. Total Salaries and Wages	\$ 9,800	\$ 27,560
4. Overhead, 100 per cent	\$ 9,800	\$ 27,560
Total	\$19,600	\$ 55,120
C. Cost of Operation Per Year, Material and Utilities (cost of waste material containers in collection costs)		
1. A.E.C. Filters, \$40 ea., 1 per 60 operating hours	\$ 1,040	\$ 4,160
2. Ash Containers, \$2.40 ea., 1 per 8-hour shift	\$ 624	\$ 1,872
3. Steam at \$1.00/M lb.	\$ 312	\$ 1,248
4. Gas at \$0.70/M cu.ft.	\$ 105	\$ 21
5. Water at \$0.03/M lb.	\$ 275	\$ 1,100
6. Electricity at \$0.0083/kw.-hr.	\$ 190	\$ 760
	\$ 2,546	\$ 9,161
D. Cost of Operation Per Year, Maintenance		
1. Man Years	0.5	1.5
2. Wages	\$ 2,000	\$ 6,000
3. Overhead (100 per cent)	\$ 2,000	\$ 6,000
4. Materials	\$ 600	\$ 1,800
	\$ 4,600	\$ 13,800

Table 12 (continued)

	8-hour day	24-hour day
E. Cost of Operation Per Year, Waste Water Treatment		
1. Volume, gal./operating day	100	300
2. Total cost/year, \$0.10/gal.	\$ 2,600	\$ 7,800
F. Cost of Operation Per Year, Ash Handling and Storage	\$ 5,410	\$ 21,645
G. Summary of Operating Cost Per Year		
1. Labor	\$ 19,600	\$ 55,120
2. Materials	\$ 2,546	\$ 9,161
3. Maintenance	\$ 4,600	\$ 13,800
4. Waste Water	\$ 2,600	\$ 7,800
5. Ash Handling	\$ 5,410	\$ 21,645
Total	\$ 34,756	\$ 107,526
6. Burning Rate, cu.ft./yr.	\$ 19,500	\$ 78,000
7. Operating Cost Per Cubic Foot	\$ 1.78	\$ 1.38
H. Investment		
1. Building and Services	\$ 70,000	\$ 70,000
2. Equipment and Installation (not including design)	\$ 70,000	\$ 70,000
Total	\$ 140,000	\$ 140,000
I. Depreciation Costs		
1. Building and Services, 5 per cent	\$ 3,500	\$ 3,500
2. Equipment and Installation, 20 per cent	\$ 14,000	\$ 14,000
Total	\$ 17,500	\$ 17,500
3. Depreciation Cost Per Cubic Foot	\$ 0.90	\$ 0.22
J. Annual Costs		
1. Operating	\$ 34,756	\$ 107,526
2. Depreciation	\$ 17,500	\$ 17,500
Total	\$ 52,256	\$ 125,026
K. Cost Per Cubic Foot Burned		
1. Annual Costs	\$ 52,256	\$ 125,026
2. Burning Rate, cu.ft./yr.	\$ 19,500	\$ 78,000
3. Total Cost Per Cubic Foot	\$ 2.68	\$ 1.60
L. Savings		
1. Cost Per Cubic Foot Stored	\$ 4.00	
2. Annual Cost of Storage	\$ 78,000	
3. Savings Per Cubic Foot	\$ 1.32	
4. Annual Savings	\$ 25,744	

VI. SUMMARY

The two primary objectives of the Argonne Incinerator Program have been successfully accomplished. They were:

First, to design and construct an incinerator which would safely and economically reduce the volume of combustible radioactive waste that is produced at Argonne National Laboratory. The incinerator's capacity of 100 cu.ft. of normal wastes per 8-hour day is more than ample to handle the daily accumulation of wastes. The radioactivity of the exhaust gas from the incinerator has, under normal combustion conditions, been consistently below the exhaust gas tolerance specified by Health Physics and has in most cases contained less immediately measured activity than that found in normal surrounding atmosphere. The volume reduction, from feed material to ash, is 95 per cent. A savings of \$1.32/cu.ft. based on an 8-hour day, is realized over storage (non-treatment) of the waste at Argonne, the method previously used to handle combustible wastes.

Second, to determine and make the modifications in the equipment and flowsheet that were necessary to obtain maximum efficiency throughout the system. These modifications were the result of the data obtained in the experimental phase of this program. These modifications have resulted in a 50 per cent increase in combustion rate and in an increase of A.E.C. filter life from 6 hours per filter to more than 60 hours per filter. The maximum over-all decontamination factor from feed to exhaust gas for the present operating conditions is 2 to 3×10^7 .

As shown by the over-all decontamination factors and by the fact that the effluent exhaust gas contains less than the natural activity of the surrounding atmosphere, the incinerator system is able to handle higher levels of activity than used in those runs to which activity was added (maximum of about 10^{11} disint./(min.)(cu.ft.)) since the effluent gas from these high level runs was a factor of 20 lower than tolerance. However, on the basis of the high background activity readings encountered during these runs, it is apparent that remote charging, ash removal, and additional shielding of the furnace cone and ash barrel would have to be provided to enable such levels of activity to be handled routinely.

Since the Argonne Incinerator is the only full-scale active waste incinerator operating on a production basis, it may also serve as a prototype unit for any future incinerator projects.

On the basis of the information obtained from the experiments that have been conducted to date, the following are the operating conditions recommended:

Charging Rate: 23.4 cu.ft./hr. of normal wastes
Combustion Air Rate: 315 S.C.F.M.

Schreier-Bartolucci Scrub Solution Rate: 15 gal./min. at 145°F.
Pease-Anthony Venturi Scrub Solution Rate: 8 gal./min. at 95°F.
Peabody Scrub Solution Rate: 5.5 gal./min. at 145°F.
Steam Rate Prior to Venturi: 190 pounds of 35 p.s.i.g. steam per
hour entering at 0 p.s.i.g.

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VIII. APPENDIX

Equipment Specifications (Equipment Costs Are Based on Year 1950)

B-1	<u>Ash Filter Bags - Burcott Mills, Incorporated</u>	\$2.40
	Canton flannel bag filter, 31 by 33 inches, fitted with brass grommets for insertion of rope to facilitate ash handling. One required per 8-hour operating day.	
C-1	<u>Check Valve - shop fabricated</u>	\$75.00
	A type 316 stainless steel sheet metal orifice fitted with a hinged flapper to act as a check valve and prevent flow of contaminated gases out of air intake when the pressure within the combustion chamber is above atmospheric. Mounted between flanges in horizontal section of main air intake line.	
D-1	<u>Ash Barrel - shop fabricated</u>	\$500.00
	Type 316 stainless steel 70-gallon ash receiver fitted with stainless steel filter bag basket and supports. Receiver is fitted with 3/4-inch drain.	
D-2	<u>Drum - Pressed Steel Tank Company</u>	\$50.00
	Standard type 316 stainless steel, 55-gallon, open head drum fitted with 1/2-inch drain opening.	
D-3	<u>Ash Barrel Sampling Tank - shop fabricated</u>	\$65.00
	Type 304 stainless steel sample vessel fitted with openings for filling, compressed air, vacuum, and drain lines.	
E-1	<u>Reheaters - Edwin L. Wiegand Company</u>	\$140.00
	Six Chromalox 230-volt, 1000-watt stainless steel tubular heating elements made of type 347 stainless steel. Over-all length approximately 16 inches with thermostatic control range 60 to 250°F.	
E-2	<u>Heat Exchanger - Patterson Kelley Company</u>	\$763.00
	Heat exchanger to transfer 25,000 B.t.u./hr. with 12 to 19 gal./min. cooling water temperature differential 20 to 30°F. Solution to be cooled 35°F. at 11 gal./min. All metal in contact with liquid constructed of type 304 stainless steel.	

E-3,4,5	<u>Heat Exchangers (unit heaters) -</u> <u>James B. Clow Company</u>	\$750.00
	Three finned-tube heat exchangers, each to condense 400 pounds of steam per hour. Heat to be removed by forced draft outside air, motor and mounting included. Rated at 2 lb./sq.in. gauge steam.	
F-1,2	<u>Filter Plenum Chambers - shop fabricated</u>	\$2,000.00
	Dual filter plenum chamber, housing, and mounting.	
F-3,4	<u>Filters - Arthur D. Little Company</u>	\$80.00
	A.E.C. combustible, pleated, paper filter in wooden frame 24 by 24 by 12 inches. Two required initially, replacement when necessary.	
FI-1,2,4	<u>Bull's Eye Flow Indicators -</u> <u>Jacoby Tarbox Company</u>	\$80.00
	Three visual sight flow indicators. All metal in contact with liquid of type 304 stainless steel for caustic slurry. One for 2-inch pipe, the other two for 1-inch pipe.	
FI-3	<u>Recording Gas Flow Meter -</u> <u>Fischer Porter Company</u>	\$815.00
	Gas flow meter, two 10 by 10 by 8-inch cast iron flanged tees, brass metering tube, brass float, capacity of 50 to 500 standard cu.ft./min. Operating with inlet pressure at atmospheric 70°F., pressure drop not to exceed 3 inches of water column. Also one recorder for above, electric transmission type, flush mounting case, with necessary accessories.	
G-1,2	<u>Liquid Pumps -</u> <u>Worthington Pump and Machine Corporation</u>	\$645.00
	Open impeller, solid volute casing, mechanically-sealed centrifugal pump to handle 20 gal./min. against a 50-foot head. One-horsepower motor and drive included. All metal in contact with liquid of Worthite metal.	

G-3	<u>Liquid Pump -</u> <u>Worthington Pump and Machine Corporation</u>	\$295.00
	Open impeller, solid volute casing, mechanically-sealed, centrifugal pump to handle 20 gal./min. against a 50-foot head. One-half horsepower motor and drive included. All metal parts in contact with liquid of Worthite metal.	
G-5	<u>Gas Pump -</u> <u>Roots-Connersville Blower Corporation</u>	\$2,011.00
	Positive-displacement blower to handle 2100 lb./hr. dry gas, specific gravity 1.0. Two hundred forty lb./hr. moisture entering at 160°F., 10.7 lb./sq.in. absolute. Blower driven by a 10-horsepower Vari-drive motor.	
H-1	<u>Furnace Body - Alloy Grafts</u>	\$9,200.74
	Gas-tight furnace body of type 330 stainless steel, jacket of mild steel, charging port of type 330 stainless steel, conical bottom of type 304 stainless steel, all piping connections to furnace body are flanged except welded air manifold connections.	
H-1A	<u>Gas Ignition System -</u> <u>Eclipse Fuel Engineering Company</u>	\$1,004.00
	Three 1000-B.t.u./hr. gas burners producing long, semi-luminous flame for natural gas, with igniter and standard safety features.	
LLC-1	<u>Liquid Level Indicator -</u> <u>Moore Products Company</u>	\$135.00
	Float, flexible arm, off-on type for operating valve electrically. Four-inch stainless steel float.	
LLC-2	<u>Liquid Level Indicator -</u> <u>Moore Products Company</u>	\$280.00
	Float type, flexible arm proportioning type for operating valve with air float chamber external to tank with 5-inch stainless steel float. All metal in contact with liquid is type 316 stainless steel.	

LLC-CV1 Control Valve -
Mason-Neilan Regulator Company \$296.00

One-inch, type 316 stainless steel diaphragm valve, solenoid operated, spring return.

LLC-CV2 Control Valve -
Mason-Neilan Regulator Company \$95.00

Air diaphragm-operated proportioning valve, 1-inch size for cooling water service.

LL1-1,2 Sight Glass -
Meter and Controls, Incorporated \$102.00

One safety glass, threaded ends, approximately 21 inches long to withstand 75 lb./sq.in. gauge with all necessary fittings. Also one sight glass with flanges, ends approximately 15 inches long to withstand 15 lb./sq.in. gauge. All metal parts in contact with liquid of type 316 stainless steel.

M-1 Manometer - Meriam Instrument Company \$80.00

Flush mounting, well type, single tube 0 to 20-inch range manometer. All metal parts in contact with liquid or gas are of type 316 stainless steel.

N-1,2 Butterfly Valve -
R and S Products Corporation \$205.00

Two 6-inch flanged butterfly valves, standard steel construction, 150 pounds standard ASA-flanges, one with end wheel control and the other with chain wheel control.

N-4 Butterfly Valve -
Minneapolis-Honeywell Regulator Company \$379.00

One 10-inch, type 304 stainless steel butterfly valve automatically controlled by means of a solenoid trip valve with 150 pound ASA flanges, normally closed.

N-5 Butterfly Valve -
Minneapolis-Honeywell Regulator Company \$247.00

One 4-inch type 304 stainless steel butterfly proportioning valve with 150 pound ASA flanges, normally open, air to close.

N-6	<u>Plug Valve -</u> <u>Rockwell Manufacturing Company</u>	\$1,182.00
	One 200-pound, 8-inch stainless steel tapered plug, gear operated, straightway plug valve with flanged ends.	
PC-1	<u>Pressure Controller - Bristol Company</u>	\$352.00
	One recording pressure control, pneumatically operated with proportional band, 0 to 200 per cent and adjustable reset, range 0 to 20 inches, water vacuum, to include necessary accessories. Decrease in vacuum to output air pressure.	
PC-2	<u>Pressure Controller -</u> <u>Minneapolis-Honeywell Regulator Company</u>	\$42.00
	Bourdon tube type element to measure gas pressure at a temperature about 800°F. and to close electrical contact for actuating trip valve when gas pressure reaches 5 lb./sq.in. gauge, range 0 to 10 lb./sq.in. gauge.	
P1-4	<u>Vacuum Recorder - Foxboro Company</u>	\$289.00
	One 4 pen, 4 color recording vacuum gauge flush mounting case, 24-hour electric chart drive, range 0 to 20 inches, water vacuum, 12-inch circular chart with necessary accessories.	
P4-6A	<u>Vacuum Recorder - Foxboro Company</u>	\$279.00
	One 4 pen, 4 color recording vacuum gauge, flush mounting case, 24-hour electric chart drive, range 0 to 120 inches, water vacuum, 12-inch circular chart with necessary accessories.	
P-7,9	<u>Pressure Gauges - Master Gauge Company</u>	\$36.00
	Three standard liquid pressure gauge 1 to 15 lb./sq.in. bourdon tube type. All metal in contact with liquid of type 316 stainless steel.	
P-10	<u>Pressure Gauge - Master Gauge Company</u>	\$12.00
	Standard liquid pressure gauge, 1 to 30 lb./sq.in. bourdon tube type.	

R-1	<u>Rotameter - Fischer Porter Company</u>	\$172.00
	Flush mounting rotameter for caustic abrasive slurry, range 0 to 20 gal./min. with Teflon gaskets. All metal parts in contact with liquid of type 316 stainless steel. Used with 2-inch pipe.	
R-2	<u>Rotameter - Fischer Porter Company</u>	\$160.00
	Flush mounting rotameter for caustic slurry, range 0 to 20 gal./min. with Teflon gaskets. All metal parts in contact with liquid of type 316 stainless steel. Used with 1-inch pipe.	
R-3	<u>Rotameter - Fischer Porter Company</u>	\$172.00
	Flush mounting rotameter for caustic abrasive slurry, range 0 to 12 gal./min. with Teflon gaskets. All metal parts in contact with liquid of type 316 stainless steel. Used with 1-inch pipe.	
R-4	<u>Recording Rotameter - Fischer Porter Company</u>	\$420.00
	Flush mounting rotameter screwed bronze fittings, Neoprene gaskets, range 2.1 to 21 gal./min. for 1-inch pipe. Also one electric transmitting, flush mounting, pen recorder with necessary accessories for use with above.	
T-1	<u>Gas Scrubber - Austin Machine Company</u>	\$2,830.00
	Schreier-Bartolucci centrifugal gas washer to handle 2100 pounds dry gas, specific gravity 1.0, and 240 lb./hr. moisture entering at 800°F., water temperature 212°F. Constructed of type 316 stainless steel.	
T-2	<u>Gas Scrubber - Peabody Engineering Corp.</u>	\$3,765.00
	Peabody gas scrubber to handle 2100 lb./hr. dry gas, specific gravity 1.0, and 325 lb./hr. moisture at 150°F. Constructed of type 316 stainless steel.	
TI-1-6B	<u>Temperature Recorder - Foxboro Company</u>	\$680.00
	One 6-station multi-record temperature recorder, electronic continuous self-balancing, stepless capacitator, flush mounting case, range 0 to 2000°F., 12-inch 24-hour circular chart electrically driven with standard accessories.	

TI-1-12 Temperature Recorder -
Minneapolis Honeywell Regulator Company \$1,010.00

One 12-station, flush mounting, multi-record temperature recorder, electronic continuous self-balanced capacitator, range 0 to 250°F. with standard accessories.

V-1 Gas Scrubber -
Chemical Construction Corporation \$1,000.00

Standard Pease-Anthony Venturi for scrubbing gas, 6-inch inlet and outlet, flanged connections to handle 2100 lb./hr. dry gas, specific gravity 1.0, and 375 lb./hr. moisture at 210°F. Constructed entirely of type 316 stainless steel.