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MLM-567

Subject Category: CHEMISTRY

X-18022

UNITED STATES ATOMIC ENERGY COMMISSION

DEVELOPMENT OF THE FLOW SHEET
FOR INCINERATING CONTAMINATED
COMBUSTIBLE WASTE

Engineering Research Final Report

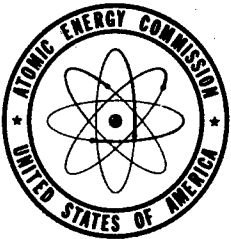
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May 15, 1951

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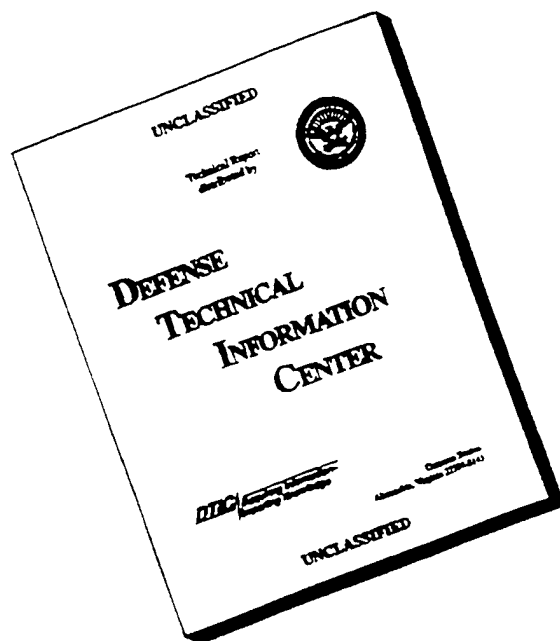
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MOUND LABORATORY
Operated By
MONSANTO CHEMICAL COMPANY
MIAMISBURG, OHIO

**DEVELOPMENT OF THE FLOW SHEET FOR INCINERATING
CONTAMINATED COMBUSTIBLE WASTE**

(Engineering Research Final Report)

Date: May 15, 1951

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INTRODUCTION

One of the major problems inherent in any work associated with radioactivity is the disposal of material contaminated with activity by such work. Biological investigations have shown that this material, unless contaminated to an insignificant degree, cannot be indiscriminately discharged to the plant environment without some hazard to humans, either directly or indirectly. These materials may be in the liquid, solid, or gas form.

No radioactive material of gaseous nature has been encountered at Mound Laboratory. In regard to liquid wastes, a process has been in service here for several years which satisfactorily decontaminated these wastes at this laboratory and concentrates the activity originally contained therein to a very small percentage of the original volume. Solid wastes, however, accumulate daily in large amounts throughout this site, and these, along with the liquid waste concentrates (in solid form), are packaged and shipped several hundred miles to a national burial ground for burial.

Because the amounts of solid waste sent to burial represent large volumes (thousands of cubic feet annually), research was initiated to determine methods for concentrating this material to reduce the quantity requiring burial. The largest percentage of this material by far is combustible, and for this reason an incineration process was fully investigated in this connection. This process involves the incineration of the waste, the decontamination of the flue gas by a wet process, and the transfer of the contaminated incinerator ash, fly-ash, and soot particles in water, to the liquid waste process for further concentration. This investigation and its outcome is covered by this report: the small percentage of noncombustible solid waste presents a separate problem and is not discussed here.

This report serves as a recommendation that a full-scale incineration process be installed at Mound Laboratory and provides a complete flow sheet for this process and recommended designs for the critical parts of the processing equipment. It contains a justification for the process, a history of the investigation including early work and pilot plant results, an explanation of the values and information given in the flow sheet, and the reasons for the recommended design features.

DETAILED REPORT

A. Recommendation and Justification of Process

It is recommended that a full-scale incineration system be constructed and placed in operation at Mound Laboratory as per the attached flow sheet. This flow sheet includes a material balance, a heat balance, and is sufficiently complete to allow a preliminary cost estimate. It does not presume that a site has been selected for the installation, but it does fix the general requirement in regard to area, services, ventilation, etc.

The justification of the process revolves around the results obtained in the preliminary and pilot-plant work and the inadequacies of the present cumbersome method of handling these wastes. The following section of this report is offered as justification for the process and includes: the process premises, a description of the preliminary work and results, a description of the pilot plant work and results, a description of present method of handling these wastes, and a comparison of this method and the recommended incinerator method.

1. Process Premises

It is assumed that only two methods exist for disposing of combustible waste; either direct packaging and burial or volume reduction by incineration, and packaging and burial of the concentrates. For the latter scheme certain basic premises can be listed.

a. Decontamination of the flue gas must be virtually complete. The degree of completeness depends upon the type of activity in the combustible waste and the tolerance levels established for that activity.

b. Dilution cannot be considered as a satisfactory overall method for reducing the specific activity concentration in the process off-gases.

c. Decontamination must be obtained by a practical and feasible method.

d. A wet ash-collecting system and a wet flue-gas-scrubbing method can be used because of the availability of the local liquid waste disposal process. In this case all the activity in the original combustible waste would be sent to the Liquid Waste Disposal Building as a slurry containing ash, fly-ash, and soot and would be further concentrated there.

e. The flue gases do not contain radioactive gases, but the radioactivity is associated with particulate matter. The size of these particles vary over a wide range; the loading of submicron particles must be assumed to be high.

f. The flue-gas volume would be small and consequently the power requirements per cubic foot could be relatively high when compared with standard air cleaning methods.

2. Process Development

a. Early Work

(1). Method Survey

A literature survey showed that the removal of submicron particles from moving gas streams has been effected with moderate success by means of the following mechanisms:

1. Electrostatic precipitation.
2. Filtration through porous barriers.
3. Impaction and diffusion of particles on the surface of liquids
4. Agglomeration by sound waves followed by centrifugal separation.

Various pieces of equipment and processes for particle removal by the methods outlined above are commercially available. However, each of these processes has definite disadvantages when applied to the incineration problem. Electrostatic precipitators require safety devices to prevent explosions in view of the fact that explosive gases may be present in the flue gas (carbon monoxide and excess oxygen). Effective and reliable performance of a precipitator demands that it be operated within rather narrow limits of temperature, humidity, and size and type of dust. Where these conditions are changing in a process, the performance of a precipitator becomes almost unpredictable. Cleaning and maintenance of a precipitator would also present a serious problem. The Chemical Warfare Service (CWS) filter (porous barrier type) had been shown in previous tests at this laboratory to be only about 95 per cent efficient on radioactive particles. Use of several of these filters in series would not increase the efficiency sufficiently to make the process feasible. Processes involving the use of Pease-Anthony and Venturi scrubbers acting on the impaction-diffusion principle yield low overall efficiencies. The process of sound agglomeration was discarded because information was sparse and somewhat vague at the time the investigation was initiated.

Therefore, a new method, the condensation center principle, was considered and showed promise of being very efficient, simple, and inexpensive. It was decided to investigate this method first.

(2) Principle of Operation

It is a well known fact that water vapor will condense with greater ease upon reaching its dew point if ions or small dust particles are present to act as nuclei for the water droplets formed. Yellot² thinks that coaggregated molecules of air probably act as nuclei for the drops formed in the condensation of steam in convergent-divergent nozzles. Probably the best known application of this phenomenon is the tracing of alpha and beta radiation paths in the Wilson cloud chamber. Endebrock¹ proposed the thought that the same principle might be applied in a steam nozzle to form water drops around small particles in a gas stream so that they may be easily removed from the gas

Steam, in expanding through a simple convergent-divergent nozzle, completes an adiabatic cycle. The energy used to obtain the high velocities involved in such nozzles is obtained at the expense of pressure and temperature, and condensation takes place. If the expansion proceeds far enough, the velocity energy is recovered, the pressure and temperature of the gas rise, and the condensed particles re-evaporate.

Condensation in this type nozzle appears abruptly and very near the orifice. However, because of rate lag effects and heat losses some condensation occurs further along in the expansion. If the nozzle is built as a steam exhauster so that another gas stream containing small particles of matter in suspension may enter and mix with the steam very near the orifice and if this gas steam is at a considerably lower temperature than the steam stream condensation may be expected to take place on the particles present. Limited stabilization of this condensation may be assumed because of the heat losses occurring from the mixing of hot steam and cool gas streams. Use of wet steam would stabilize the condensation further because of the availability of the water drops in the wet steam to absorb some of the energy released by the velocity decrease towards the mouth of the nozzle. The water droplets emerging from the nozzle could be made to grow large enough in a condenser system so that they could be removed almost completely by conventional equipment.

Steam aspirators or exhausters as made commercially, have their suction ports placed in such a position that the gas stream is mixed with steam at some distance from the steam orifice. Figure 1. In all probability most of the steam has condensed before the mixing occurs. However, because of the rate lag effects and heat losses there is some further condensation taking place throughout the length of the nozzle as the steam continues to expand and cool. Moreover, the effects of impaction and diffusion should be great where the mixing of the steam and gas streams first occurs. The entering gas and its particles should be subjected to terrific bombardment by multitudes of very small water droplets (in angstrom range) traveling at speeds exceeding that of sound. This effect plus that of condensation center effects further along the barrel of the nozzle might possibly give high efficiencies with standard steam exhausters. Therefore the first tests were carried out with this type of nozzle.

(3) Use of Standard Steam Exhauster on Incinerator Flue Gases

A small conventional, firebrick incinerator was constructed for burning radioactive wastes. The waste consisted of wood, paper, cloth, rubber, plastic tubing, etc. A standard Schutte Koerting steam exhauster, capable of moving 20 to 30 cubic feet per minute of air under two inches of water vacuum with 90 pounds gauge steam pressure, was used to furnish draft for the incinerator. The flue-gas steam mixture from the nozzle was exhausted into a water-cooled expansion chamber.

The sudden drop in temperature and pressure in this chamber caused more moisture to condense on the small drops exhausted by the nozzle. Many of these drops then became large enough to fall out in this chamber and were drained off to a collecting tank. The noncondensable gases and smaller entrained drops were then passed through a combination spray and packed column until all fog was eliminated and scrubbed gases passed out into the atmosphere. Spray water was collected in tank. A known fraction

of escaping gases was continuously withdrawn and assayed for radioactive content. A schematic diagram of this pilot plant is given in Figure 2.

A series of five runs was made with this apparatus, and an average decontamination factor of 10^2 was obtained in the off gas. By difference, since waste was charged with a known amount of activity, approximately 75 per cent of the activity originally present in the waste remained in the ash in the incinerator. Since all the known errors in this system would tend to lower the efficiency of the process, the results looked promising enough to warrant further investigation.

(4). Laboratory Tests and Nozzle Design

The next step was to find exactly where condensation occurred in the simple convergent-divergent type nozzle used in the incinerator tests. If most of the condensation had taken place before the flue gases entered, then better results might be expected from a nozzle design in which the sequence of condensation and gas entry was reversed. A nozzle very similar to that used by Yellott² in his studies of steam condensation in nozzles was built, Figure 3.

The nozzle was designed with an opening in the top into which was placed a section of Pyrex glass plate which served as a window and enabled the operator to study the effects of steam condensation in the nozzle.

A zircon arc lamp was used as a source of illumination. Condensation in the nozzle was observed through the window at right angles to the beam of light. No light could be seen when live steam, air, or both was present, the nozzle appearing totally dark. However, when condensation occurred light was immediately visible in the condensation region because of reflection and/or refraction of the light beam by the small water droplets.

Angle of divergence of all nozzles were held between 10° and 12° . However, orifice size, position of suction ports, distance from orifice to diffusion throat, steam pressure, and quality of steam were all varied over fairly large limits. In every case, no matter what the physical configuration of the nozzle or the condition of the steam used, the condensation area was unaffected, i.e., condensation, when it occurred, took place in the same area relative to the orifice - very soon after passing the orifice, Figure 4A. It was also apparent that most of the condensation in the nozzle occurred at the initial condensing point, and very little occurred farther along the barrel towards the exit.

The conclusions drawn from the tests were:

1. The steam exhauster used in the incinerator tests was accomplishing the removal of particles by an impaction - diffusion process and not by condensation center effects.

2. Since the condensation in this type steam aspirator occurs so near the orifice, it is impossible to admit the noncondensable gases through suction ports and mix them with the steam before condensation occurs

Observations of a double convergent-divergent type nozzle were made next. It was hoped that by using a double orifice in which the second orifice was larger than the first, the water droplets formed at the first orifice might be made to evaporate upon approaching the second constriction so that the noncondensable gases (admitted at the first orifice) might be in contact with live steam in the area of the nozzle preceding the second constriction. Condensation after the second orifice might then accomplish what the initial condensation failed to do - form water drops about any particles present as nuclei.

Condensation areas were obtained as desired, Figure 4B, but in so doing an inherent disadvantage of this type nozzle was encountered. The simple convergent-divergent nozzle acted as an aspirator, moving the noncondensable gases through the nozzle. However, these suction characteristics were immediately impaired by adding a second orifice. As the cross-sectional area of the second orifice approached that of the first (diminishing within limits), the evaporation and second condensation effects became increasingly better while the suction characteristics became increasingly worse. Three nozzles of this type were set aside for future particle-removal tests. The performance of these nozzles included:

1. Good suction but poor double condensation (large second orifice)
2. Fair suction and fair double condensation (smaller second orifice).
3. Poor suction but good double condensation (smallest second orifice).

(5). **D. O. P. Smoke Machine Tests**

The D. O. P. (dioctylphthalate) smoke machine was borrowed from the Chemical Corps, U.S.A. and assembled for the nozzle test, Figure 5. In general the machine operates as follows:

1. Manufactures constant size smoke particles.
2. Measures their size optically.
3. Delivers the smoke to a filter at constant volume and concentration.
4. Gives an accurate assay of smoke penetration of the filter to as low as 0.01 per cent.

Dioctylphthalate was chosen because the smoke particles formed from its vapors can be maintained at a constant size of about 0.3 microns under set conditions. The smoke penetration of the filter is determined by the use of a light scattering chamber, photoelectric cell, and a Naval Research Laboratory smoke penetration meter.

(a) Particle Removal Apparatus

This apparatus consisted of the following major units. Figure 6

1. Steam Superheater
2. Nozzle
3. Expansion Chamber
4. Heat Exchanger
5. Pease-Anthony Scrubber

It was hoped that this system would effect the removal of small particles from a gas stream as follows: the particles introduced into the steam nozzle in the air stream would act as nuclei for the condensation of steam in the nozzle, and the liquid drops so formed would grow large enough in process to be removed practically 100 per cent by a conventional scrubber of the Pease-Anthony type.

These five units were integrated with the smoke machine by replacing the filter with the gas train described above

(b) Tests Results

Four nozzles, each with a different configuration, were used in the tests, Figure 7. In addition, one commercially available nozzle was also tested. The comparative effectiveness of each of the nozzles on particle removal are given in Table I. The results shown are the best obtainable with each nozzle. Each nozzle was tested with steam pressures from 0 to 100 pounds gauge and both wet and superheated steam. The results shown in Table I were obtained in each case from at least one hour of continual operation with a maximum fluctuation of plus or minus 0.1 per cent. Nozzle No. 5 is a commercial steam exhauster of the same type as Nozzle No. 1 and is the same nozzle which had been used in the original incinerator pilot plant runs. Two tests were carried out with Nozzle No. 1. In one test the conditions were such that condensation took place in the nozzle. However it had been noted previously that no condensation occurred in this nozzle if the steam were superheated about 30 degrees, all of the condensation occurring in the expansion chamber. A probability existed then for the particles to act as nuclei for condensation in the expansion chamber instead of the nozzle. As can be seen from the table, the results were very poor

The results of these tests showed conclusively the value of double condensation effects. Nozzle No. 1 had good suction characteristics and no double condensation. The mechanism involved here was probably one of impaction, diffusion, or both. Nozzle No. 2 had a slight double condensation, and its particle removal efficiency was slightly better. In Nozzle No. 3 the suction characteristics were beginning to be impaired by the condition which causes double condensation. Results here were improved over Nozzle

TABLE I

PENETRATION EFFICIENCIES OF
VARIOUS TYPES OF NOZZLES

NOZZLE	STEAM PRESSURE (LB. GAUGE)	STEAM CONDITION	SMOKE FLOW (CFM.)	PARTICLE SIZE (MICRON)	PARTICLE CONCENTRATION ⁹ (PARTICLES/FT. ³)	BLANK (PER CENT)	ASSAY TOTAL (PER CENT)	PENETRATION (PER CENT)
1	60	WET	15	0.3	5.9×10^{11}	0.03	8.0	8.0
2	60	WET	13	0.3	5.9×10^{11}	0.06	4.0	4.0
3	60	WET	10	0.3	5.9×10^{11}	0.04	3.0	3.0
4	40	WET	15	0.3	5.9×10^{11}	0.20	0.35	0.15
5	90	WET	13	0.3	5.9×10^{11}	0.20	7.0	6.8
1	90	30° (SUPERHEAT)	15	0.3	5.9×10^{11}	0.80	30.0	29.2

No. 2. Nozzle No. 4 had no suction but had very good double condensation and as results showed, was excellent for particle removal.

b. Pilot Plant Work

Theoretical considerations and test results showed that this type of flue-gas scrubbing process as a means of handling contaminated combustible wastes seemed practical and feasible. This process in the early work had not been applied in its entirety to the actual combustible waste that accumulated at the laboratory. To determine the capabilities of the process when applied to this waste, a pilot plant unit of the entire process was planned, constructed, and operated, Figure 8. The results desired from this unit were those associated with the operation of the gas decontamination train rather than the incinerator itself. The incinerator was included mainly to produce flue gases as raw material for the gas train. However, the incinerator design was a prototype of the actual design desired for a full-scale process, so that the operating characteristics of this type of furnace could be studied along with the primary gas-train studies. A description of the equipment used, the method of operation and results obtained follow.

(1). Incinerator

The incinerator was of the down-draft type, Figure 9. An air lock arrangement with two manually operated sliding gates permitted charging of the furnace while combustion was taking place without gas leakage to the surrounding atmosphere. These gates utilized a metal to metal seal and were spring loaded. An air-tight cover box surrounded the gates and served to contain any leakage at the seals. Since the furnace was of the down-draft type, the gates did not become hot while the furnace was in operation; thus preventing damage to the seals from galling or warping. The combustion area was a cylinder 10 1/2 inches in diameter and 24 inches high. The burning charge rested on a one-inch-thick, perforated, cast iron grate which could be rotated 90° to dump any foreign material or clinkers which would not pass through the grate. The burning area was surrounded by a stainless steel liner 1/8 inch thick, which was set down inside a section of 12-inch standard steel pipe. Two heater elements (connected in parallel) consisting of Nichrome IV ribbon (1/4 inch by 19 gauge) windings were placed between the liner and the shell. Each heater contained 65 feet of ribbon and carried 125 amperes (total) at 220 volts, single phase. This was sufficient to heat the liner to a dull red heat in eight minutes.

Air and/or oxygen to support combustion entered just above the burning area and below the first gate through four ports placed 90° apart. These ports were located so that the air entered tangentially to the shell. The air or oxygen passed down through the burning mass in a twisting, whirling motion for better mixing and more complete combustion.

The ash hopper was made of 1/4-inch steel boiler plate and had sloping walls which tapered to a 3-inch opening provided with a sliding gate for ash removal. The hopper was fitted with a rupture disk and a door.

The flue gases after passing through the grate made a 180° turn and passed out through a 3-inch pipe at the top of the ash hopper. A perforated metal basket containing 1/4-inch Raschig rings extended down into the hopper from this line. This packing offered negligible resistance to the gas flow and filtered out of the flue gas stream large pieces of fly-ash.

The whole assembly was positioned on an angle iron base so that the ash removal gate was approximately 21 inches from the floor.

(2) Gas Train Equipment

All of the gas train equipment was located on or below a 3-inch angle iron table which was 17 1/2 feet long, 5 feet wide, and 40 inches high. Figure 10

Flue gases leaving the incinerator passed through a rough washer where they were subjected to a counter-current water spray which removed the larger particles of ash and soot and cooled the gases somewhat. The exhaust then passed through a heat exchanger where the gases were cooled to room temperature. From the heat exchanger the gases passed to a Pease-Anthony scrubber. This scrubber removed most of the particles larger than two to five microns in size. A Nash pump was placed in the stream immediately after the scrubber to provide the motivation for the entire system in transferring the combustion and flue gases through the incinerator to the steam nozzle. A heat exchanger was introduced in the process between the Nash pumps and the steam nozzle to reduce the flue-gas temperature to the lowest possible point before entry into the nozzle system. A proportional sample of the gases was removed before the nozzle in an attempt to assay the flue gas at this point for radioactivity content.

The contaminated flue gases were introduced into the nozzle. Figure 11, through four entry ports and were mixed with the partially condensed steam beyond the first orifice. This condensed steam vaporized just before the second orifice and recondensed after the second orifice; the particulate matter entrained in the moving stream acting as nuclei. Four very small water jets were injected into the stream at this point to help stabilize the condensation. The presence of flue gas itself when mixed with the live steam probably acts as a condensation stabilizer. This mixture from the nozzle was exhausted into a large water-cooled expansion chamber. The sudden drop in pressure and temperature in this chamber and in the heat exchanger immediately following it caused more moisture to be condensed on the small droplets already formed. A Pease-Anthony scrubber followed this heat exchanger serving to remove the enlarged water droplets enveloping the small, contaminated soot particles. A gas sample was taken again for

radioactivity assay purposes, the gases passed through a blower and a CWS filter which removed any minute particles penetrating the system to that point. A final activity assay sample was then taken, and the cleaned gases were exhausted to the building ventilation system.

Two water lines serviced the equipment. One line furnished all cooling water, while the other furnished spray water for the various decontamination equipments. The used cooling water, which was not contaminated, was discharged into the plant sewer system. The spray water was collected in drums, assayed for activity content and were then discharged into the "hot" drainage system for further treatment at the Liquid Waste Disposal Building.

(3). Instrumentation and Sampling

The incinerator instrumentation was direct and simple. A thermocouple lead was extended into the flue-gas stream directly beneath the grate. Air and oxygen flow to the incinerator was measured by means of rotameters. Pressure inside the incinerator was indicated by a draft gauge. An ammeter and timing circuit was connected to the electrical system for starting combustion, so that the liner in the combustion zone could be heated for any predetermined time.

Instrumentation of the gas train involved steam and air pressure gauges, water manometers, water and gas thermometers, and gas flow measuring devices which were located at strategic points throughout this system.

In addition to the gas sampling taps provided before the nozzle and before and after the CWS filter, samples of the spray and/or condensate water from each of the wet units of the gas train were taken. These water samples in all cases amounted to the complete usage of each piece of equipment and were kept separate one from the other. Activity assays were made on the drainage from each piece of equipment in the following manner. The individual drainage drums were stirred until thoroughly mixed and a small portion removed by thief sampling. This was acidified and a known volume was mounted on a glass slide for counting. Multiplying the count of the slide by the necessary volume factors yielded a value indicative of the total amount of activity in the original sample. This activity was considered to be the amount removed from the flue-gas stream by that particular piece of equipment.

In the gas-stream samples, known proportions of the stream were removed from the system and passed through Hollingsworth and Vose filter paper. This filter paper was counted for activity content and the count multiplied by the necessary factors to yield the total activity in the original gas streams sampled. Only the two samples taken before and after the CWS filter were considered to be accurate when assayed in this manner. The sample taken before the nozzle contained so many large particles of soot and fly-ash that counting was erratic and results inconclusive.

(4). Pilot Plant Results

The pilot plant was tested first with the D O P Smoke Machine valved into the system, replacing the incinerator as a smoke generating mechanism. These tests were made to measure the efficiency of the pilot plant steam nozzle system on 0.3-micron particles and to note the effect of the other pieces of equipment on particles of this size. The second tests were run with the incinerator on stream but "cold" waste used. These tests were carried out to investigate the operational characteristics of the complete pilot plant, so that any defects might be remedied before beginning "hot" operations. In the third series of runs, "hot" waste was burned and the systems tested for its activity-removal characteristics.

(a). D. O. P. Smoke Machine Tests

The pilot plant described above was tested with the D. O. P. Smoke Machine. Smoke from this machine was routed into the gas train at the incinerator flue gas exit line, the incinerator being by-passed. Two runs were made with this set-up, the first with the best nozzle developed in the early work and the second with a circular nozzle designed specifically for this pilot plant. Equally good results were obtained with both nozzles, and in both cases with the CWS filter removed from the system, a removal efficiency of 99.90 per cent could be obtained. A steam pressure of 48 pounds gauge (minimum) and a gas flow of 25 cubic feet per minute were used to get this efficiency. When the steam flow to the nozzle was cut-off, the removal efficiency immediately dropped to zero, thus showing the ineffectiveness of the conventional scrubbers in removing 0.3-micron D. O. P. smoke. Then when the steam was turned on again efficiencies of 99.90 per cent were obtained.

(b). Pilot Plant "Cold" Runs

After the D. O. P. smoke machine tests were completed, the incinerator was placed on stream and five "cold" runs made with the circular nozzle, designed for the pilot plant, in place. In each run the charges used consisted of approximately 50 per cent wood, 15 per cent rubber, 20 per cent paper and cardboard, and 15 per cent plastics (Vinylite, Lucite, Tygon, etc.) by weight. They were contained in paper bags and weighed from 3 to 5 pounds per charge. The total amount of spray water and steam condensate collected in each run averaged between 100 and 125 gallons per hour of operation. A steam pressure of 48 pounds gauge was used on the nozzle with a steam consumption of between 250 to 300 pounds per hour. The gas flow at the exit of the system, measured at 85°F. and atmospheric pressure, averaged between 22 and 25 cubic feet per minute. A brief account of each run is given in Table II.

TABLE II

"COLD" RUN OPERATING DATA

RUN NO	BURNING TIME (HR.)	NO. OF CHARGES	MAXIMUM TEMPERATURE* (°F.)	OXYGEN FLOW (CFM.)	AIR FLOW (CFM.)	GAS PRESSURE AT NOZZLE (LBS.)
1	1	4	1,150	0	15	25
2	1 1/2	6	1,400	3	12	26
3	2 1/2	8	1,500	5.5	10	24
4	1 3/4	8	2,000	6	9	25
5	2	9	2,100	VARIED	VARIED	23

* TEMPERATURE OF GASES BELOW GRATE IN INCINERATOR.

During the first several runs gas leaks were discovered and corrected. The gas compressors used in these early runs caused a great deal of trouble and after much trouble shooting proved fruitless, were replaced by a single Nash air compressor. After the fifth run, the cast iron grate disintegrated and was replaced by one made of 25-12 stainless steel. Temperatures in the ash hopper varied from 1,300°F with 15 cubic feet per minute of pure air, to 2,100°F with 9 cubic feet per minute of air plus 6 cubic feet per minute of oxygen. After 150 pounds of waste had been burned including three CWS filters, the total ash volume that had accumulated amounted to one gallon.

Analysis of the off-gases for carbon monoxide gave the following results:

	AIR ONLY (15 CFM.) (PER CENT)	AIR (12 CFM.)	OXYGEN (3 CFM.) (PER CENT)	AIR (9 CFM.)	OXYGEN (6 CFM.) (PER CENT)
CARBON MONOXIDE	1.2		0.2		0.2

The incinerator was operated under one to two inches of water vacuum. Pressure fluctuation was of the order of one inch of water during combustion with a maximum of about five inches for about 30 seconds after adding a new charge.

(c) Pilot Plant "Hot" Runs

Seven hot runs were made with the pilot plant after the installation of the Nash pump and the new stainless steel grate. The overall results of these runs are shown in Table III.

The breakdown of the activity removal efficiencies in the various pieces of equipment is shown in Table IV.

The activity removal efficiencies shown in Table III and Table IV were calculated in the following manner:

The total activity leaving the incinerator in the flue gases for the period of the run was taken as the total activity collected in the various drainage drums plus that collected on the CWS filter. The amount entering the stack is so small as to be of no consequence here. It is assumed that there is no appreciable buildup of activity in the system itself after a short time. If there should be a significant buildup occurring, the efficiency of any one piece of equipment would vary widely, which did not occur.

The methods of calculating the efficiency of the first three pieces of equipment are given as examples.

$$(A) \text{ Rough Washer Eff. (\%)} = \frac{\text{Activity removed by Rough Washer}}{\text{Total activity}} \times 100$$

$$(B) \text{ Pease-Anthony Eff. (\%)} = \frac{\text{Activity removed by Pease Anthony}}{(\text{Total activity}) - (\text{Activity removed by R. W.})} \times 100$$

$$(C) \text{ Nash Pump Eff. (\%)} = \frac{\text{Activity removed by Nash pump}}{(\text{Total activity}) - (\text{Activity removed by R. W. + P. A.})} \times 100$$

The improvement in the efficiency of the nozzle system from 78.6 per cent to 97.0 per cent (Runs 7 through 11) was caused by the use of increased steam pressure; this being the only factor varied in these runs. The increase from 97.0 per cent to 98.6 per cent occurred when the water sprays in the nozzle were not used. An increase in air velocity and an improvement in the water sprays in the second Pease-Anthony scrubber seemed to be responsible for the improvement in the nozzle system from 98.6 per cent to 99.2 per cent.

TABLE III

PILOT PLANT NO. 2 OPERATING DATA

RUN No.	WASTE BURNED TOTAL WEIGHT (LBS.)	TIME OF BURNING (MIN.)	COMBINED** ACTIVITY REMOVED (PER CENT)	NOZZLE SYSTEM STEAM PRESSURE (PS.I.G.)	ACTIVITY REMOVED (PER CENT)	CWS FILTER ACTIVITY REMOVED (PER CENT)	ACTIVITY* REMOVED (MC.)	OFF GAS COUNT (DIS./M ³)	OVERALL DECONT. FACTOR
7	15	40	99.9	48	78.6	99.9	87.35	486	$10^7 - 10^8$
9	25	60	99.4	52	92.5	99.9	2057	64,230	10^7
10	35	75	99.6	56	97.0	99.9	1060	1,145	$10^7 - 10^8$
11	45	90	99.4	60	97.0	99.9	1779	952	10^8
12	45	75	99.4	58	98.6	99.9	2472	813	$10^8 - 10^9$
13	30	75	99.0	60	99.2	99.9	364.5	451	10^8
14	25	75	92.7	60	99.8	99.9	243.3	670	10^8

* THE ACTIVITY VALUES HERE SHOULD NOT BE CONSTRUED AS BEING PURELY REPRESENTATIVE OF THE GENERAL WASTE TO BE BURNED. IT DOES INDICATE, HOWEVER, THAT THESE LEVELS SHOULD BE ANTICIPATED AND USED FOR DESIGN PURPOSES

** ROUGH WASHER, PEASE-ANTHONY, AND NASH PUMP.

TABLE IV

EQUIPMENT ACTIVITY REMOVAL EFFICIENCIES

RUN NO.	INCINERATOR* ASH (PER CENT)	ROUGH WASHER (PER CENT)	PEASE ANTHONY (PER CENT)	NASH** PUMP (PER CENT)	NOZZLE SYSTEM (PER CENT)	CWS FILTER (PER CENT)	OVERALL DECONT. FACTOR
7	75	68.7	96.7	89.0	78.6	99.9+	$10^7 - 10^8$
9	75	51.4	91.3	79.3	92.5	99.9+	10^7
10	75	78.6	83.5	87.0	97.0	99.9+	$10^7 - 10^8$
11	75	62.0	82.6	89.7	97.0	99.9+	10^8
12	75	78.8	79.4	84.4	98.6	99.9+	$10^8 - 10^9$
13	75	77.7	73.4	81.6	99.2	99.9+	10^8
14	75	50.1	57.0	66.0	99.8	99.9+	10^8

* THESE VALUES WERE NOT MEASURED BUT ARE ASSUMED VALUES. A MINIMUM OF 75 PER CENT OF THE ACTIVITY CONTAINED IN THE CHARGE WAS LEFT IN THE ASH IN THE FIRST BRICK INCINERATOR (SEE EARLY WORK).

** THE SEAL WATER FROM THIS PUMP WAS COLLECTED AND ASSAYED.

Run No. 14 was accomplished in most part without oxygen. All other runs used combustion air of approximately 35 per cent oxygen content. Visual observation showed that the fire smoked very badly in Run No. 14, whereas no smoke was evident in the other runs. The results shown in Table IV are interesting in that they show the efficiencies of the large particle removal apparatus (Rough Washer, Pease-Anthony, and Nash Pump) to have fallen off considerably in Run 14, while the nozzle system and CWS filter efficiencies remained the same or improved. The overall decontamination remains unchanged.

The CWS Filter was not changed and showed no signs of clogging, thus promising a long life

The average contaminated water output per hour was about 285 gallons. Most of this (150 gallons) was from the Nash pump seal water.

All runs were made with wastes made up of rubber gloves, plastic gauntlets, glove liners, cardboard cartons, paper, Vinylite, wood, rags, plastic tubing, Lucite, and rubber tubing and stoppers.

The total volume of ash accumulated from the seven runs was about two gallons.

The importance of maintaining an air-tight system was well illustrated during these runs. A slight amount of leakage occurred at threaded connections and seal glands. This amount was sufficient to raise the activity level in the room housing the pilot plant equipment considerably above the level in the exit flue gases from the gas-train system. Every precaution should be taken on the full-size incinerator to insure that no leakage occurs.

During these "hot" runs and the earlier "cold" runs, the ash hopper became cherry red during burning and scaled badly. Because of this, cooling of the incinerator must be a requisite feature in any model designed for continuous operation. Stainless steel (25-12) should be used as the material of construction for this equipment.

3. Present Method of Handling Wastes

The following account describes the present method of collecting, storing, and shipping of wastes; the types, condition, and quantity of the wastes; and the estimated cost of disposing of the waste in this manner.

a Description of Method

The CWS filters when no longer useful as filter mediums are crated in their original shipping boxes and are stored for periodic shipment to Oak Ridge for burial.

The waste material from the areas where high levels of activity are used is collected in water-proof paper bags. These bags are gathered and packed in 55-gallon steel drums.

The waste material from the areas where low levels of activity are handled is collected in bags inserted in waste baskets or in the baskets directly. This waste is then placed in 55-gallon drums which, with the above mentioned drums containing the hotter waste, are stored in an outside location until shipped. Before the drums are moved to the central loading site, they are surveyed for activity and about 10 per cent must be cleaned on the outside prior to shipment. In general the waste is classified at the source into combustible and noncombustible portions and separate containers are provided for each.

Approximately 24 man-days are required per load (Trailer Truck) for the collecting, sorting, and packaging of the waste and 8 man-days per load are required for drumming, moving the drums to the loading site, surveying, cleaning, and loading the trailer. One load is composed of forty-five 55-gallon steel drums, plus some crates and 30-gallon drums.

A large per centage of this time is spent in changing clothes, which is necessary when moving the waste from one risk area to another.

When possible, used drums are purchased for the storage and shipment of the waste. Some of these drums corrode badly both from inside and out. Outside corrosion takes place even in the short storage period before the loading is done. Inside corrosion is caused by the wet and acid condition of some constituents in the waste.

b. Types of Waste

The wastes requiring burial are comprised of paper, cardboard, cloth, rubber, CWS filters, wood, metal, plastics, glass, and ceramic materials or articles. A small percentage of the total volume is made up of chemical process waste concentrates, usually as thick slurries or cakes. The paper and cloth items in most cases are damp or wet with water, cleansing solutions, and acids. As mentioned before, the metal, glass, ceramic, and other noncombustible materials are bagged separately. They are not at the present drummed separately, but this could easily be done.

c. Quantity of Waste

The amounts of waste that accumulate in a year's time are shown in Table V. They are based on the actual amounts shipped during the period between November 1, 1949 and November 1, 1950.

TABLE V

ANNUAL SOLID WASTE ACCUMULATIONS

ITEM No.	WASTE DESCRIPTION	TYPE OF CONTAINER	No OF CONTAINERS	VOLUME (GALS.)	PER CENT COMBUSTIBLE
1	MISCELLANEOUS	55-GAL. DRUMS	1,756	96,580	80 - 85
2	24" x 24" x 6" CWS FILTERS	WOODEN CRATES	57	12,365	100
3	24" x 24" x 3" CWS FILTERS	WOODEN CRATES		90	100
4	8" x 8" x 6" CWS FILTERS	WOODEN CRATES		25	100
5	8" x 8" x 3" CWS FILTERS	WOODEN CRATES		134	100
6	CHEMICAL WASTE CONCENTRATES	30-GAL. DRUMS			7,800
7	CHEMICAL CONCENTRATES	30-GAL. DRUMS		5,250	0
TOTAL				122,244	

The overall percentage for the combustible portion amounts to about 75 per cent. The total volume was shipped to Oak Ridge for burial in approximately 35 trailer loads.

d Estimated Cost

The following estimated cost is based on the anticipated burial volume of waste five years hence. The number of shipments is expected to very nearly double in this period because of increases in both space and personnel, the latter being the more influential. The entire personnel of the laboratory is not considered here but only those doing work directly associated with radioactivity. For this reason these costs are calculated on the basis of 70 trailer loads per year rather than the 35 loads shipped during 1949 and 1950.

The cost of transporting the shipment to Oak Ridge amounts to \$300.00 per load. This includes the cost of the trailer truck driver, escort, etc. The cost at Oak Ridge for handling and burying per load is \$200.00. This covers the unloading, geological surveying, land purchase, etc. The Mound Laboratory costs are estimated to be \$125.00 per load. This comprises the costs for loading, surveying, cleaning, etc. The total cost for all waste shipped would therefore be $70 \times \$625.00$ or \$43,750 per year. Because only 75 per cent of the total waste is combustible, the cost for the combustible portion only is $(0.75 \times 70) (\$625)$ or \$32,812 per year. The cost of the metal drums in which the waste is shipped for burial is at present \$4.75 each. Of the estimated usage rate of 2,400 drums per year, this represents a cost of \$11,400. Also, the storage space required for these drums (before usage) will cost approximately \$2,400. Therefore the total cost of disposing of combustible waste is \$32,812 plus \$13,800 or \$46,612 per year. These are the costs that should be compared with the incinerator cost, shown later in this report, to determine savings.

4. Comparison of Present and Proposed Methods

A comparison can be made of the two methods in four ways: feasibility of method, control of activity, storage space, and cost.

a. Feasibility of Method

The feasibility of the incineration method has been well established by the pilot plant work. Satisfactory decontamination factors were consistently obtained, and volume reductions of between 100 and 150 to 1 were realized.

The present method of shipping and burying the waste, although feasible, does not seem to be the final answer for disposing of this material. The volumes are large and bulky, transportation over long distances is necessary, and the handling is awkward and time consuming. The gathering and packaging of the waste for incineration would be greatly simplified over this procedure.

b. Control of Activity

Under the incineration scheme the whereabouts of the activity is known. The activity is concentrated in the ash from the incinerator proper and in the soot and fly-ash collected by the wet process of the gas decontamination train. This material will be under the same control as any process stream and can be routed at will wherever desired. It is planned to transfer the ash and soot with the associated activity to the waste disposal process (liquid) as a slurry where further concentration of the activity can probably be effected. Future research may show the feasibility of recovering some of the activity from the waste disposal concentrates, in which case, the amount recoverable would be increased by the amount supplied by the incinerator process. On the basis of activity levels found in pilot plant operations, the amount of activity concentrated from incineration is likely to be a very considerable quantity.

The present waste burial method does not lend itself to the complete control of activity. The long distance transportation of activity over well traveled roads by truck has obvious hazards. Some loss of activity from the shipping drums during shipment may occur, because at intervals the trucks must be decontaminated. To insure against such leakage is expensive when the total bulk of the waste is considered. However, when the volume is reduced (by incineration) such insurance could be more cheaply achieved. Even after burial under the present disposal method, the activity may not be under complete control.

c. Storage Space

The proposed scheme of waste incineration will require much less storage space both for the waste and materials incidental to it. The cardboard cartons can be stored before use in the knocked-down form, while the steel drums and wooden crates in current use necessitate a large storage area. The cartons will be immediately disposed of by incineration while the drums and crates must be stored until a complete truck load has accumulated. The actual burial space required will be less by a factor of four or five under the proposed method. With this method it might be possible to dispose of the lesser amount locally.

d. Cost

Accurate cost estimates are not possible for the proposed scheme until complete drawings have been prepared. However, the following costs are offered as rough estimates for comparison purposes.

Construction Costs

Total cost* for the building housing incinerator and equipment	\$100,000
Total cost* for incinerator	35,000
Total cost* for associated equipment	<u>35,000</u>
Total cost	\$170,000

Per cent depreciation on building per annum	2%
Per cent depreciation on incinerator per annum	10%
Per cent depreciation on associated equipment per annum	5%
Annual amortization for building	\$2,000
Annual amortization for incinerator	3,500
Annual amortization for associated equipment	<u>1,750</u>
Total annual cost	\$7,250

* Includes design, overhead, services, ventilation, etc.

Operating Costs

Utility Costs

Annual steam costs @ \$0.80/1000 lb.	\$1,620
Annual treated water costs @ \$0.41/1000 gal.	640
Annual raw water cost @ \$0.17/1000 gal.	1,050
Annual power costs @ \$0.0113/kw. hr.	680
Annual oxygen costs @ \$0.0075/cu. ft.	4,900
*Annual liquid waste processing cost @ \$0.0005/gal.	<u>780</u>
Total utility cost	\$9,670

* Increasing the volume of waste to the liquid waste plant by 6,000 gallons per day does not materially increase the operating cost of this plant. Therefore the figure above represents only the cost of additional chemicals.

Labor Costs

Operation (75 per cent overhead)	\$6,700
Maintenance (100 per cent overhead)	<u>7,500</u>
Total labor	\$14,200

Material Costs

Cardboard cartons per annum @ \$0.51 each	\$1,160
CWS filters and miscellaneous items per annum	<u>400</u>
Total material	\$1,560
Total operating costs per annum	\$25,430
Total construction costs (amortized)	<u>7,250</u>
Annual total costs	\$32,680

This cost of \$32,680 should be compared with the estimated cost of the present disposal method of \$46,612 to indicate savings. The annual savings of approximately \$14,000 represented by the difference between these two costs is the apparent direct savings.

B. Description of Process

1. Combustible Waste

a. Packaging and Storage

The miscellaneous waste will be collected in cardboard cartons 2 feet by 2 feet by 2 feet. In places where very wet waste is to be expected, a waterproof paper liner may be placed in the carton. All possible precautions must be taken to insure that the majority of waste collected in the cartons is combustible. Glass and metal objects will be collected in separate 55-gallon drums for burial (as before). All used CWS filters will be placed in cartons. The cartons can be completely filled with any of the filter sizes now used.

When a carton is filled, it will be sealed with paper tape and delivered (daily, weekly, etc.) to the incinerator building. The incinerator operations should keep up with the waste supply so that there will be a minimum amount of full cartons in storage at any one time. However, there will be enough space in the storage area of the incinerator building to store all waste for approximately two weeks (80 cartons) in case the incinerator process would have to shut down for maintenance or repair work.

b. Incinerator Loader

The incinerator will be loaded by two mechanical loaders located in the waste storage room directly above the incinerator room. The loading chute of the incinerator will extend through the floor and into this area. Each loader will hold four cartons which will be placed in the loaders by hand. The loader tripping mechanisms will be activated from the incinerator panel board in the operating (cold) area. The loaders will deliver a carton to the incinerator loading chute at approximately 45-minute intervals. The loader tripping mechanism may be actuated mechanically, electrically, or by hydraulic or pneumatic control.

2. Incinerator

The incinerator is of the same general design as the pilot plant model. The down-draft feature allows a rather simple, trouble-free air lock system of loading to be used, since the loading gates are not subjected to any of the high temperatures of the combustion areas. The details of design follow.

a. Air Lock System

The air lock system allows the charging of the incinerator while burning is in progress without appreciable loss of activity to the atmosphere. Any loss of activity will be to the waste storage room which is classified as a high-risk area and which is not occupied by personnel when the incinerator is in operation.

Two sliding type gates are provided which have positive, rubber-gasketed seals when closed. The pressure of the gates upon these seals may be regulated by the hydraulic or pneumatic pressure used to operate the seal mechanism. The gates are provided with an interlock system so that both may not be opened at the same time. Another interlock makes it impossible to actuate the gate-opening mechanism until the seals are released. Both the seal and gate-opening mechanisms are controlled from the panel board in the operating area. Mechanical trips indicate by light on the panel board when there is a charge (carton) in the loading chute above the top gate or in the air lock between the gates. Thus, if a carton, due to a deformity, should fail to pass the gate system, the operator will know immediately its position and can take steps to remedy the situation.

b. Combustion Chamber

The combustion chamber is that portion of the furnace between the delivery chute and the grate. It is cylindrical in shape and contains the various openings near the top for combustion air, water sprays, kerosene injectors, and a pressure-gauge outlet. It will hold two cartons, although only one is to be burned at a time.

c. Ignition System

The ignition system consists of the shielded electrical windings around the conical lower section of the combustion chamber and the kerosene injectors in the top of the combustion chamber. The windings are in the form of two semicircular heating elements and are placed directly against the metal wall of the furnace. They are connected in parallel across a 220-volt, single-phase circuit and should draw enough current to heat the furnace wall with which they are in contact to a dull red heat in 10 to 15 minutes. The incinerator charge (carton) rests upon this heated metal section. If the charge should be wet or otherwise difficult to ignite, the two kerosene injectors may be used. Each of these injectors will deliver a definite volume of kerosene on to the combustion chamber walls, where it will run down on to the heated metal section and ignite. The injectors may be actuated as often and as many times as is necessary for ignition of the charge.

The section of the incinerator cooling jacket surrounding the electrical windings is hinged to allow their replacement or repair if necessary. Note that the furnace does not have to be opened to the atmosphere for this operation. The electrical controls and injector controls are located on the panel board in the operating area.

d. Grate

The grate is constructed of heavy-wall, 25-12 stainless steel tubing in a lattice work pattern. It is supported by two stainless steel pipes which are an integral part of the grate and through which cooling air passes to and from the grate. These pipes extend from the incinerator through double packing glands with a pressure air seal between the two glands. Thus any leakage past the incinerator gland will be into the furnace. The grate can be rotated through 90° so that unburnable material larger than the grate openings may be dumped into the ash hopper. The grate may be rapped against a mechanical stop to free sticking material. The rotation of the grate is accomplished from the operating area by means of mechanical linkages (reach rods).

The grate is air cooled because of the high temperatures to which it is subjected (down draft). In case of grate failure, the entire grate assembly may be removed easily and quickly and replaced by a new assembly.

e. Deflector Plate

The deflector plate is a hollow, circular metal shell made of 25-12 stainless steel. It contains a spiral passageway through which cooling air is circulated. It is not subjected to as high a temperature as is the grate therefore the exit cooling air from the grate is sufficient to cool it. This plate is supported by two stainless steel pipes in a manner similar to that used for the grate, and has a similar packing gland, air seal, and rotating mechanism. The deflector plate is placed immediately above the water level in the ash hopper of the incinerator. Its function is to deflect the hot flue gases from the combustion area so that they do not impinge upon the water surface in the hopper. It also cuts off any flame radiation which would reach the water surface. Thus water loss from evaporation is reduced and the attendant flue gas volume held to a minimum. The amount of make-up water and hence volume of contaminated liquid waste is also kept to a minimum.

The deflector plate supporting shafts are connected to the plate by means of coupling so that if necessary to be replaced, the pipes may be screwed out of the couplings and the plate dropped out of the incinerator through the drum opening in the bottom.

f. Ash Collection System

This is a wet-type system where the ash is collected in water and pumped as a slurry to the Liquid Waste Disposal Building for further processing. The water-ash slurry is circulated between a water make-up tank and the incinerator ash hopper at a rapid rate to effect adequate stirring and mixing and to prevent settling and sludge formation. A 55-gallon drum is connected to the bottom of the incinerator and forms

an integral part of the ash hopper. This drum is detachable and serves to collect all glass, clinkers, metal pieces, etc., which do not burn and which do not go into suspension in the water slurry. A sight port allows the operator to see when this drum becomes filled, at which time the ash hopper is pumped down, the drum removed and capped for burial, and a new drum attached in its place. The frequency of this operation will depend upon how much noncombustible material is contained in the original cartons.

The amount of make-up water for this system is automatically controlled by a float-control mechanism in the make-up tank. The amount of slurry bled off the circulatory system to Liquid Waste Disposal Building plus the water lost by evaporation in the furnace will determine the amount of the automatic feed to the make-up tank.

g. Combustion Air

The air used for combustion is also used as the cooling air for the grate and deflector plate. It is thus preheated for better combustion before entering the furnace. An oxygen system is provided for enriching the air up to a total enriching oxygen rate of 10 cubic feet per minute. A Roots-Connorsville blower is used to pump the air-oxygen mixture through the grate, deflector plate, and then into the furnace. This blower also furnishes the pressure required for the grate and deflector plate packing-gland seals. The oxygen system is provided for the following reasons.

- (1) Allows a flexibility of burning rate while keeping off-gas volume constant.
- (2) Allows higher temperatures to be obtained than with plain air. This might be found necessary when burning objects such as dead animals.
- (3) Carbon monoxide content of flue gases can be reduced.
- (4) More complete combustion can be effected by the use of small amounts of oxygen, therefore effecting better overall volume reduction and reducing clinker formation.

h. Cooling

Since the temperature in the incinerator may go above 2,000°F. at times (as it did in the pilot plant), it is necessary to cool the metal walls to keep them from being damaged by excessive heat. However, if the walls are kept too cool, combustion difficulties will ensue. Since 25-12 stainless steel holds up very well at a continuous temperature of 1,500°F., this value was chosen as the operating temperature of the incinerator walls. Therefore air was indicated as the cooling medium. Since relatively large volumes of air will be used (on the order of 5,000 cubic feet per minute), the incinerator cooling system is designed so that these blowers may act as the room ventilation blowers also, thus avoiding duplication of blower systems.

Two cooling jackets are used on the incinerator. The upper jacket covers the combustion area down to the grate, while the other jacket covers the area around and directly beneath the grate. The intake ends of the jackets, which are slightly above grate level, are open to the room, while the cooling air discharge is from tangential openings at the opposite ends of the jackets. The blowers are placed on the discharge side of the jackets so that an even air flow may be maintained throughout the jackets, eliminating the formation of dead spaces and hot spots. If the blowers were placed on the intake side of the jackets (discharging cool air into the jackets), a complex manifolding system of ducts would be required to insure that no hot spots developed. The amount of cooling air is regulated automatically by damper control to keep the walls at even temperature regardless of the temperature changes within the incinerator.

i Materials of Construction

The incinerator is constructed entirely of 25-12 stainless steel and is of all welded construction except for bolted flanges on the grate covers and the grate and deflector-plate packing-gland air seals. These flanges have asbestos gaskets and are sealed with a heat-resisting cement. The incinerator must withstand a pressure test of five pounds per square inch without appreciable leakage. A relief valve, set at three pounds per square inch, will be placed in the ash slurry make-up tank. This tank is connected directly to the incinerator and will be under the same pressure as the incinerator. The relief valve will discharge to a line which leads directly to the stack. In case the incinerator should receive anything of an explosive nature in a waste charge, the force of the explosion will be vented to the stack. The choice of 25-12 stainless steel as the material to be used was a compromise between the heat resisting, acid resisting, and fabrication qualities desired. Ceramic materials were disregarded because of the rapid and frequent heating and cooling cycles to which the incinerator will be subjected.

3. Flue-Gas Decontamination Train

The flue-gas decontamination equipment is so arranged that the gases are treated in successive stages to remove suspended particles from the largest down to the small submicron sizes. The gases upon leaving the furnace first pass through a baffled spray tower (rough washer). This tower effectively washes out soot and ash particles larger than 50 microns and at the same time cools the flue gases considerably. The gases next pass through a Pease-Anthony Venturi scrubber and cyclone where entrained particles down to one to five microns are effectively removed. Some cooling of the gases is also effected here. The gases next pass through a heat exchanger where they are cooled to room temperature before entering the Nash compressor. The volume of flue gas is greatly reduced in this heat exchanger both by cooling and by condensation of water vapor. The Nash compressor which follows furnishes the motivating force which moves the gases from the incinerator through the entire gas train equipment. This compressor

also acts as a very efficient scrubber because of its water action, and removes many more entrained particles of all sizes which have escaped the rough washer and the venturi scrubber. Upon leaving the compressor the gases pass through the steam nozzle into the expansion chamber. Small submicron particles in the gas act as condensation nuclei for the steam in the nozzles, and the resulting water drops increase in size as they pass through the expansion chamber and the following heat exchanger because of further condensation phenomena. Most of these water drops grow large enough to fall out in the expansion chamber and heat exchanger, those which do not are removed in the final venturi scrubber which follows the heat exchanger. Finally the gases are picked up by a blower, forced through a CWS filter, and exhausted to the stack. The filter removes any minute particles which penetrate that far and also acts as a safety device in case of failure of any of the previous equipment.

a. Rough Washer

The rough washer contains three water-spray nozzles of the full-cone type and four baffle plates. Each nozzle is rated at 1/2 gallon per minute. The washer will be under two to three inches of water vacuum and, therefore, is fitted with a water-seal trap on the drain line to prevent leakage of atmospheric air back into the washer.

b. Pease-Anthony Venturi Scrubber

This scrubber replaces the Pease-Anthony cyclone type used in the pilot plant. The venturi type is more effective for submicron particle removal. Water is sprayed into the throat of the venturi through perforations in a small pipe at the rate of two gallons per minute. The water sprays form a complete spray curtain at the venturi throat. The particle removal mechanism involved here is one of impaction and diffusion. A small cyclone is connected to the venturi piece to remove the water spray. Since the cyclone will be under approximately nine inches of water vacuum, a water-seal trap is provided in the drain line to prevent atmospheric air from leaking back into the scrubber from the drain line.

c. Heat Exchanger

The heat exchanger is a conventional tube-and-shell type with baffles. It has a cooling area of approximately 50 square feet. It will be under approximately 15 inches of water vacuum, so that the condensate drain line is equipped with a water-seal trap to prevent air leakage from the atmosphere.

A manually operated flushing water line is connected to the gas side so that it may be washed down daily, thus preventing fouling of the tubes by soot and fly-ash which escapes the first two washers.

d. Nash Compressor

This compressor is the driving force of the flue-gas train. The Nash utilizes water for its pumping action and for a seal. The size required for this process will use approximately 30 H.P. and will use seal water at the rate of six gallons per minute. A manually operated by-pass valve in the gas line allows regulation of pump output from zero to maximum. A factory-set relief valve guards the pump against overwork. This relief valve will discharge into a line leading back to the heat exchanger on the suction side, thus preventing room contamination if it is actuated. The pump can be damaged badly if it is run without seal water. Therefore, a solenoid valve in the seal-water line is connected into the electrical push-button starting control so that water is available to the pump immediately after it is started.

e. Steam-Nozzle System

This includes the five steam nozzles, expansion chamber, heat exchanger, and venturi scrubber.

The steam nozzles are of special design and are of the double-orifice type. Steam pressure to these nozzles is controlled by throttling valves in the operating area. Normal operating pressure will be about 60 pounds gauge and saturated steam will be used. Each nozzle has four entry ports between the two orifices for flue-gas entry. Flue-gas pressure to the nozzles from the compressor will be in the neighborhood of 30 pounds gauge. The flue-gas line to each nozzle has a low-pressure drop-diaphragm valve in it so that only the number of nozzles required at any one time may be used. Normal operations should require the use of three nozzles only if the maximum oxygen flow rate is used in the incinerator.

Each nozzle is to be supplied with three first-orifice sections of different sizes so that they may all be tested in operations in the plant, the best one to be used for operations. The particle removal mechanism employed in these nozzles is one of condensation center effects. The nozzles exhaust their mixture of steam, flue-gas, and water into the expansion chamber.

The expansion chamber is a large cylindrical tank which has an annular cooling jacket. It contains five full-cone spray nozzles and five vertical baffles at the nozzle entries. Each spray nozzle delivers approximately 1/2 gallon per minute of water. The exhaust from the nozzles penetrates these sprays and impinges on the baffle plates before swirling up through the main body of the chamber and out the top. Thus many of the water drops formed in the nozzle are removed immediately in the spray. The spray water and steam condensate from this chamber goes to drain through a water-seal trap. Pressure in this chamber should not exceed 15 inches water, and exit-gas temperature should be around 175°F.

The heat exchanger which follows the expansion chamber is a tube-and-shell type double pass with 100 square feet of cooling area. More condensate is formed in this condenser and goes to drain through the same water-seal trap used by the expansion chamber. The function of this condenser is to cool the steam-flue gas mixture to room temperature and to remove more of the entrained water drops before the venturi scrubber is reached.

The venturi scrubber is identical to that described before except that the throat sizes vary. The spray-water drain line is again equipped with a water-seal trap to prevent contamination of the room air from flue-gas leakage. This scrubber removes the last traces of the fog formed in the nozzles before the gases reach the CWS filter.

f. Flue-Gas Blower

This blower is used to force the cleaned flue-gases through the CWS filter and into the stack. Although this blower would probably not be necessary for the functioning of the system, it does insure a more even flow of exit gases to the stack regardless of the amount of filter fouling or variations in stack draft.

g. CWS Filter

Since this filter will have to be replaced at intervals, it must be fitted into a holder from which it is easily removed yet tight enough to insure that there is no flue-gas leakage around its edges into the room. The expected life of this filter cannot be stated definitely, but is expected to be very long because of the thorough cleaning of the gases effected before the filter is reached.

h. Materials of Construction

(1). All equipment is to be fabricated of 25-12 stainless steel with the exception of the heat-exchanger tubes (copper), the Nash compressor housing (bronze), and the steam nozzles (Type 420 F stainless steel). The acid vapors in the incinerator flue-gases require the use of stainless steel of the most acid-resisting qualities. The nozzle metal was chosen as being the most resistant to the erosion encountered here. The tubes of the heat exchangers must be copper for best heat transfer.

(2). All flue-gas piping and ductwork from the incinerator to the flue-gas blower is to be fabricated of 25-12 stainless steel. Galvanized ductwork may be used from blower to stack.

(3). All contaminated-water drain lines and traps are to be fabricated of 25-12 stainless steel. Main drain line to sump should also be stainless steel.

(4). All flushing water lines, cooling water lines, steam lines, and air lines are to be galvanized iron. Oxygen lines should be high pressure (2,000 pounds) copper tubing,

(5). All stainless steel lines should have stainless steel valves. Iron lines may have iron or brass valves.

4. Sampling

It is expected that the only samples to be taken during routine operations will be two gas samples. One sample will be of the flue-gas immediately after leaving the gas process train, the other will be of this gas plus the incinerator cooling air after they are mixed and before entering the stack. However, other samples will be necessary for a time after operations begin to indicate the performance of the various pieces of equipment. Therefore, 30-gallon sample drums have been provided for each piece of equipment which exhausts contaminated drainage. Representative fractions of the total flow from these pieces is collected for radioactivity assay. All drum samples are collected by gravity flow. Since this procedure is not planned to be routine, these drums are placed in the high-risk area close to the actual equipment they serve. They may be removed later when they are no longer needed.

Three gas samplers are provided. These are the standard air-sample devices used throughout the laboratory for sampling room air. The samplers are connected to a vacuum supply, the gas is drawn through Hollingsworth and Vose Type HV 70 filter paper and exhausted to the room ventilation system. The absolute filtering efficiency of this paper is 70 per cent. Gas flow is regulated by an air screw on the sampler and is indicated by a small rotameter in the sampler housing. The filter papers are counted for alpha activity by machine. The counting geometry is 50 per cent. The samplers following the CWS filter are located in the cold operating area. These are permanent. The gas lines they sample should be run along the separating wall (operating area, high-risk area) immediately opposite the samplers so that the sample lines may be kept as short as possible. The sample preceding the CWS filter may be placed in the high-risk area immediately next to the line it samples. This sampler will not be needed for routine operations.

It will be noted on the flow sheet that several flanged pipe sections are provided in the gas process line. These flanged sections are for two purposes. First, they make it possible to remove and install any piece of equipment in the gas train. Secondly, if research should be initiated (in the future) as to the particle sizes, loadings, etc., encountered in various regions of the system, these flanged sections would be removed and appropriate sampling devices, such as cascade impactors, installed.

Sampling of the incinerator-ash slurry system is accomplished by bleeding off a portion of the slurry from the pump discharge line into a 30-gallon drum.

5. Contaminated Liquid Waste

All water discharged into contaminated lines and equipment is supplied by a flushing water system. Thus the migration of any radioactivity back into the plant water lines is avoided. The total usage from this system, and, therefore, the approximate

total contaminated waste water is in the order of 1,000 gallons per operating hour. This amount of contaminated waste will be discharged to the building "hot" sump and pumped from there to the Liquid Waste Process Building

6. Instrumentation

a. Incinerator

All incinerator instruments controls indicating light etc. will be on a panel board in the operating area directly opposite the incinerator location. The instruments will consist of the following (see Section 7 for other controls).

(1) Pressure in the incinerator will be indicated by a draft gauge connected to the top of the combustion chamber. Ten-foot suction and pressure legs should be provided on this gauge to prevent loss of indicating oil in case of large pressure fluctuations within the furnace. Operating pressure is expected to vary from zero to minus three inches of water.

(2) Combustion air is indicated by a calibrated draft gauge (orifice plate in line). Range is from zero to 150 standard cubic feet per minute.

(3) Oxygen flow is indicated by a rotameter. Range is 0 to 10 standard cubic feet per minute.

(4) Incinerator metal wall and grate temperatures will be indicated and recorded on a Speedomax recorder. Temperature range is from 500°F to 2,000°F.

(5) Temperature of combustion air is indicated by a remote-reading dial thermometer. Range is from 0 to 1,000°F.

(6) Combustion air blower discharge pressure is indicated by pressure gauge. Range is from 0 to 5 pounds per square inch.

(7) Incinerator off-gas temperature is indicated by a remote-reading dial thermometer. Range is from 0 to 2,200°F.

(8) Electrical ignition circuit contains an ammeter and a timing device (on pilot circuit). Timing range is from 0 to 30 minutes, and the ammeter should have a maximum reading of 250 amperes.

(9) Position of charge in air-lock system is indicated by lights - single light for each position. Light on indicates charge in that position.

(10) Amount of make-up water to incinerator make-up tank is indicated by a water meter. Maximum flow is three gallons per minute.

(11) Temperature of ash slurry is indicated by a remote-reading thermometer. Range is from 0 to 212°F.

(12) A small telescope is provided for observing the interior of the incinerator through the mirror system.

(13) Maximum liquid level allowable in ash hopper of incinerator is indicated by red light and buzzer connected to the high-level alarm electrode.

b. Flue-Gas Decontamination Train

The instruments provided for this system are located in both the operating area and the process area. However, all those in the process area must be readable (through the windows) from the operating area. The first five listed below are located in the process area, the others being in the operating area.

(1). Pressure drop "U" tube manometers are connected across both venturi scrubbers and the CWS filter. One differential-pressure (to atmosphere) manometer is connected to the expansion chamber. The manometers across the venturi's should read a maximum pressure drop of 20 inches of water. The CWS manometer should read a maximum pressure drop of three inches of water. The expansion-chamber manometer should indicate a maximum pressure of three inches of mercury.

(2). The temperature of the gas-steam mixture between the expansion chamber and the heat exchanger is indicated by a dial thermometer. Temperature range is from 0 to 250°F.

(3). The temperature of the flue gas between the Nash compressor and the steam nozzles is indicated by dial thermometer. Range is from 32°F. to 150°F.

(4). The temperature of the exit flue-gases from the gas train is indicated by a dial thermometer. Range is from 32°F. to 150°F.

(5). The combined drainage from the expansion chamber and heat exchanger is measured by a water meter in the trap drain line. Expected drainage is five gallons per minute.

(6). The discharge pressure of the Nash pump is indicated by a pressure gauge. Range is from 0 to 35 pounds per square inch.

(7). Main steam line pressure and steam pressure to nozzles are indicated by pressure gauges. Range of main line gauge is 0 to 150 pounds per square inch and range of nozzle pressure gauges in 0 to 100 pounds per square inch.

(8). Low pressure in the flushing water system is indicated by a red light and a buzzer.

(9). Flow of flue-gases from exit of gas train is indicated on a calibrated draft gauge (orifice plate in line). Range is from 0 to 200 standard cubic feet per minute.

(10). The supply of flushing water to the rough washer and both venturi scrubbers is indicated by rotameters. Range is from 0 to 5 gallons per minute.

(11). The supply of flushing water to the Nash compressor is indicated by a water meter. Consumption will be approximately six gallons per minute.

7. General Specifications

All service lines should enter the process area from the operating area. These lines should be divided and sub-divided in the operating area so that individual equipment lines may have their instruments, strainers, alarms, control valves, etc.,

in the operating area. Thus the need for remote-reading instruments and control-valve reach rods is eliminated. Maintenance of instruments and valves is also made easier because it can be done in a cold area.

The flue-gas processing equipment should be placed upon an iron table as in the pilot plant. This allows gravity drainage from all wet equipment and avoids congestion and maintenance difficulties by running most service lines beneath the table. The gas-train equipment should be placed as near the operating-area barrier as possible.

This table should be 40 inches high and 6 feet wide. The length depends upon the distance allowed between the various equipment; however, an approximate length of 25 to 30 feet should be adequate.

The incinerator will require the use of three reach rods. These will be for (1) grate rotation, (2) deflector plate rotation, and (3) combustion-air control valve. The operating handles for these reach rods should be on the incinerator panel board.

The gas train equipment will require the use of five reach rods. These are for the five diaphragm cut-off valves in the gas lines to the five steam nozzles. The operating handles for these reach rods should be near the steam throttling valves in the operating area.

The push button start stop controls for the combustion air blower, the ash-slurry recirculating pump, the incinerator cooling blowers, and the Nash compressor should be on the incinerator panel board. The Nash discharge pressure gauge and the by-pass valve should be on the panel board or within a few feet of it.

The operating levers for the incinerator loader, for the air-lock gates, and for the kerosene injectors should be placed on the panel board.

The cooling water for the gas-process train may be either raw water or the effluent from the Liquid Waste Disposal Building. Expected consumption is about 4,000 gallons per hour. If "WD" effluent were used, it would be pumped directly from the effluent tanks and either returned to them or discharged to the river. If raw water is used, cooling towers might be feasible so that it could be recycled.

Flushing water can be obtained from the present system in the "HH" Building. The capacity of this system is 25 gallons per minute at a 100-foot head. Push-button control of this pump should be installed in the operating area. A low-pressure alarm system, consisting of a light and buzzer, is connected to the main flushing water line. This is necessary because of the damage which would immediately result to the Nash compressor if this system failed. A raw-water emergency line is connected in case of flushing water system failure.

It is suggested that the process area be ventilated by means of the incinerator-cooling air blowers, since they take their air directly from the process room.

The heat content and flow of the various gases and liquids are indicated on the flow sheet as exact calculated values for normal operations. However, the incinerator-cooling blowers, ash-slurry recirculating pump, combustion air blowers, Nash compressor, and CWS blower are deliberately specified oversize. No further overdesign is therefore necessary.

All water lines which service spray nozzles must have two strainers commensurate with the size of the spray nozzle openings. One strainer is to be located in the operating area, the other immediately preceding the nozzles.

The flue-gas process piping and equipment should be of welded construction insofar as it is possible in order to minimize the possibility of leakage. All flanged and screwed joints which are necessary should be treated with a good cement or sealing compound to make them leakproof. In particular, the piping from the Nash compressor to the steam nozzles should be all welded and tested for leaks at 50 pounds per square inch.

Sufficient window space should be provided in the wall separating the operating area from the process area so that the entire processing system is visible.

The optical system for observing the interior of the incinerator should be placed on the panel board near the gate and deflector plate operating handles, and within reach of the kerosene injector control and air and oxygen controls.

CONCLUSIONS

The original process premises for the incineration of combustible waste have been satisfactorily proven by pilot plant operation. It has been shown that the disposal of this type of waste by incineration as outlined in the attached flow sheet is a practical and feasible method and that savings up to \$14,000 per annum can be realized over the present scheme of disposal, if it is adopted. The proposed method allows better control of the activity and will greatly reduce the storage and burial space for waste and for the containers incidental to the handling and storage of this material. Based on the pilot plant runs, fast and complete combustion is anticipated in the recommended down-draft type incinerator. In these runs the three major pieces of gas-decontamination equipment gave decontamination factors of very nearly 10^3 each or an overall factor of 10^8 to 10^9 . The first of these (Rough Washer, Pease-Anthony, and Nash pump) and the last (CWS filter) are standard pieces of equipment, and together should yield a decontamination factor of 10^5 to 10^6 . This would probably suffice for the greatest majority of the waste to be burned. However, it is felt that an additional factor of 10^2 to 10^3 should be incorporated into the design to safeguard against "hot" batches which have been encountered during pilot-plant operations and to

add to the life of the CWS filter. Most of the work at Mound Laboratory has been directed toward the use of a steam nozzle that utilizes the condensation center effect for this additional decontamination. It should not be construed that this is necessarily the only method for obtaining the required results, but the tests here have shown that this equipment will satisfactorily do the job with a minimum of maintenance and operating attention. The installation cost of such a mechanism amounts to only three per cent of the total equipment cost or one per cent of the total project cost including building, equipment, etc. Also the operating cost of the nozzle system will be only 10 per cent of the total operating cost for all the equipment. This, therefore, was the method selected to increase the capabilities for the gas decontamination train from 10^8 to 10^9 .

SUMMARY

Because of the large amount of contaminated combustible waste that accumulates daily at Mound Laboratory, an incineration process was investigated as a means of reducing the volume of the material that must be buried. As a result of this investigation a feasible and practical process has been developed for this purpose. The process is based on a "wet" method for the removal of activity from the flue gases which will integrate very well with the local liquid waste processing plant. Standard equipment has been incorporated into the recommended design for the incineration process with the main exception of the nozzle system. This system is used to enlarge submicron particles to proportions removable by standard methods. Decontamination without this mechanism would be sufficient for the majority of wastes but because of the ease and economy of operation, it was added as insurance against the penetration of activity when "hotter" batches are burned. When compared with normal air-treatment processes, the cost per cubic foot for flue gas treatment is high although savings in the order of \$14,000 per year can be realized over the present method of disposal of this waste. Also, the adoption of the recommended method would greatly simplify waste handling, allow greater control of the activity, and may make possible the eventual recovery of activity if this is ever desirable.

The recommendation for the entire incineration process is shown on the attached flow sheet. This includes a material balance, a heat balance, and is sufficiently complete to allow a preliminary cost estimate for the process. As part of this report a description of, need for and mode of operation of each piece of equipment is also offered.

REFERENCES

1. Endebrook, R. W., The Steam Expansion Method for Cleaning Air, January 30, 1947
2. Yellott, J. I., Trans. Am. Soc. Mech. Engrs., 56, 417 (1934).

FIGURE 1

MLM-567

STANDARD STEAM EXHAUSTER.

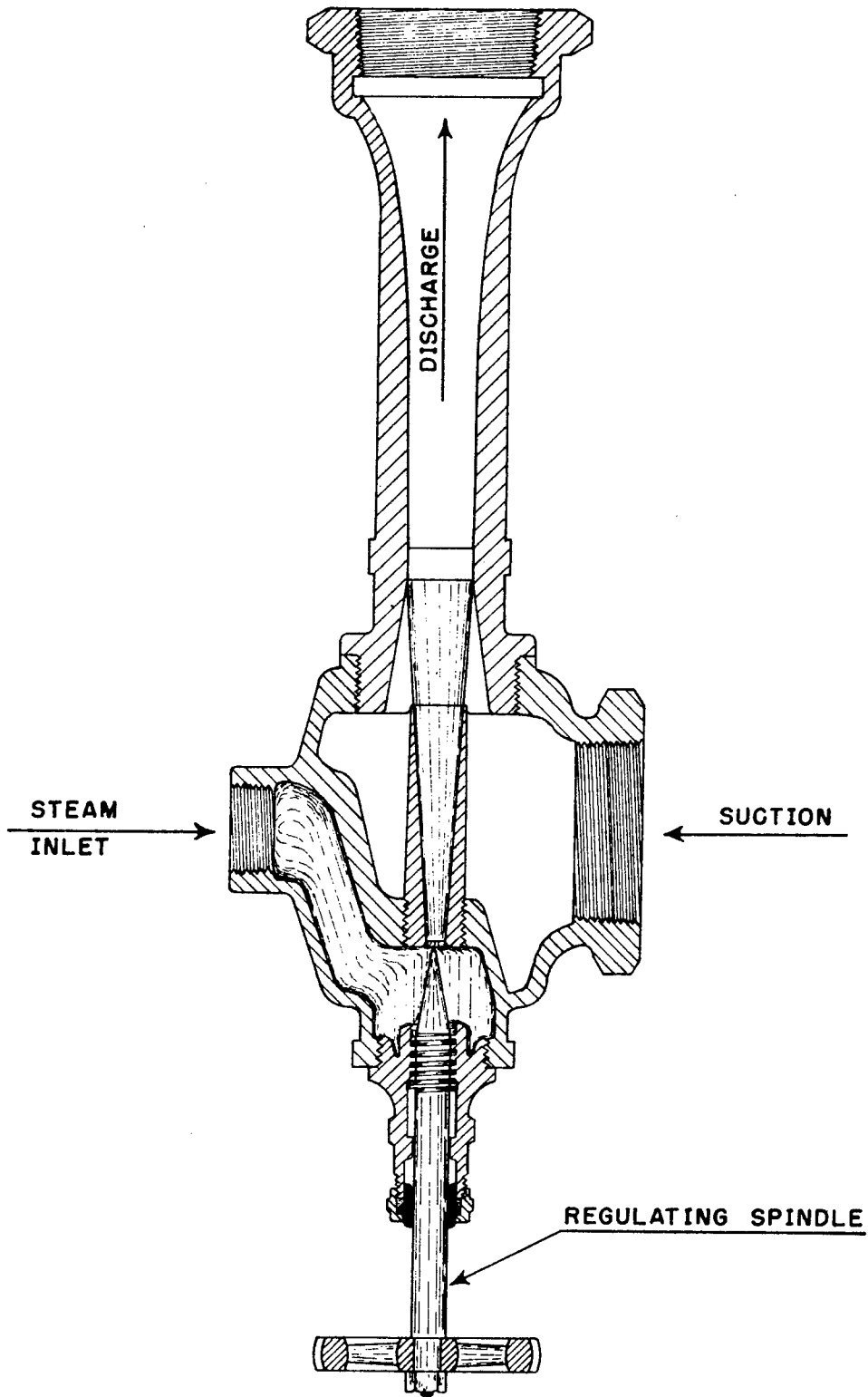
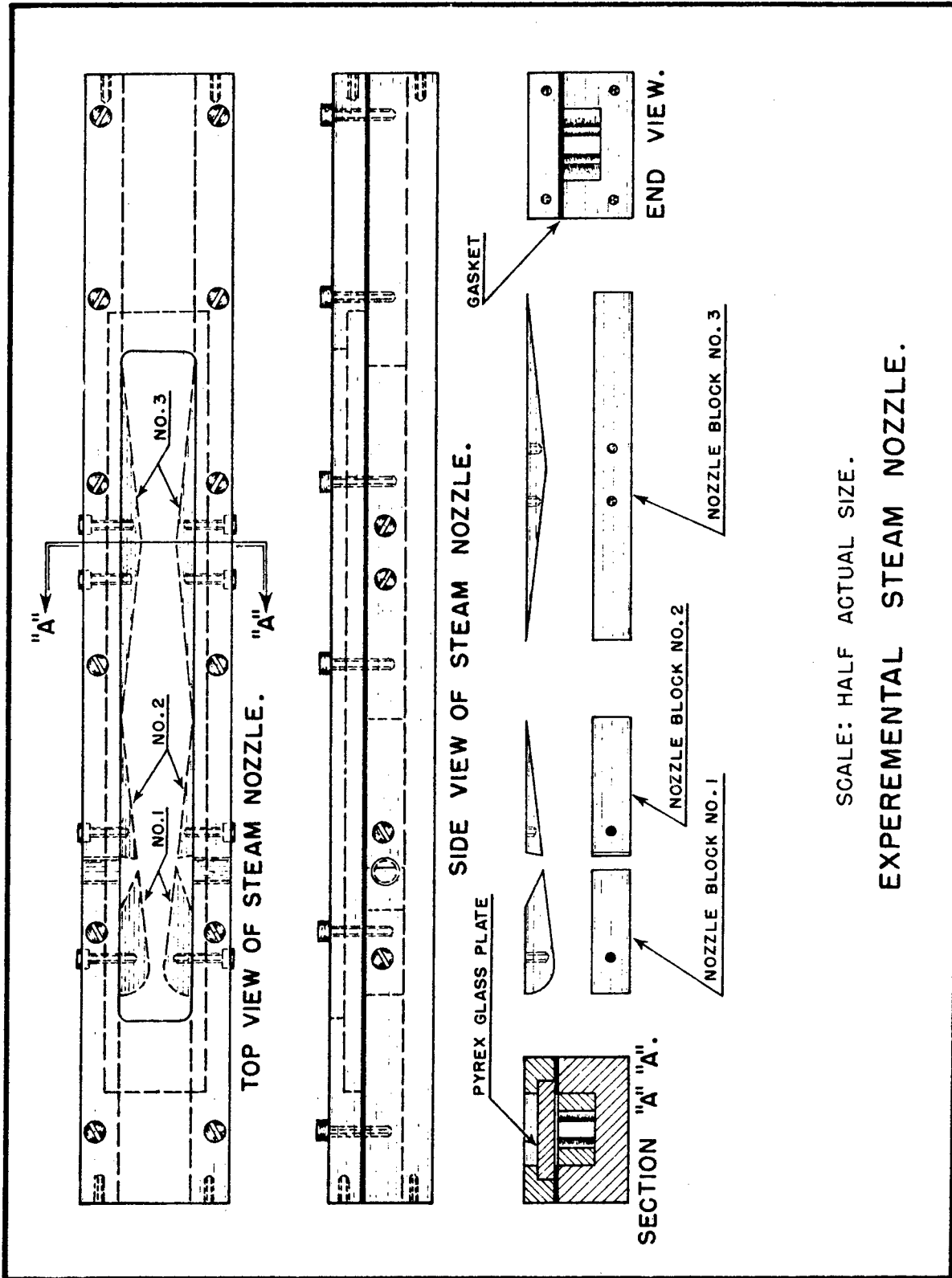


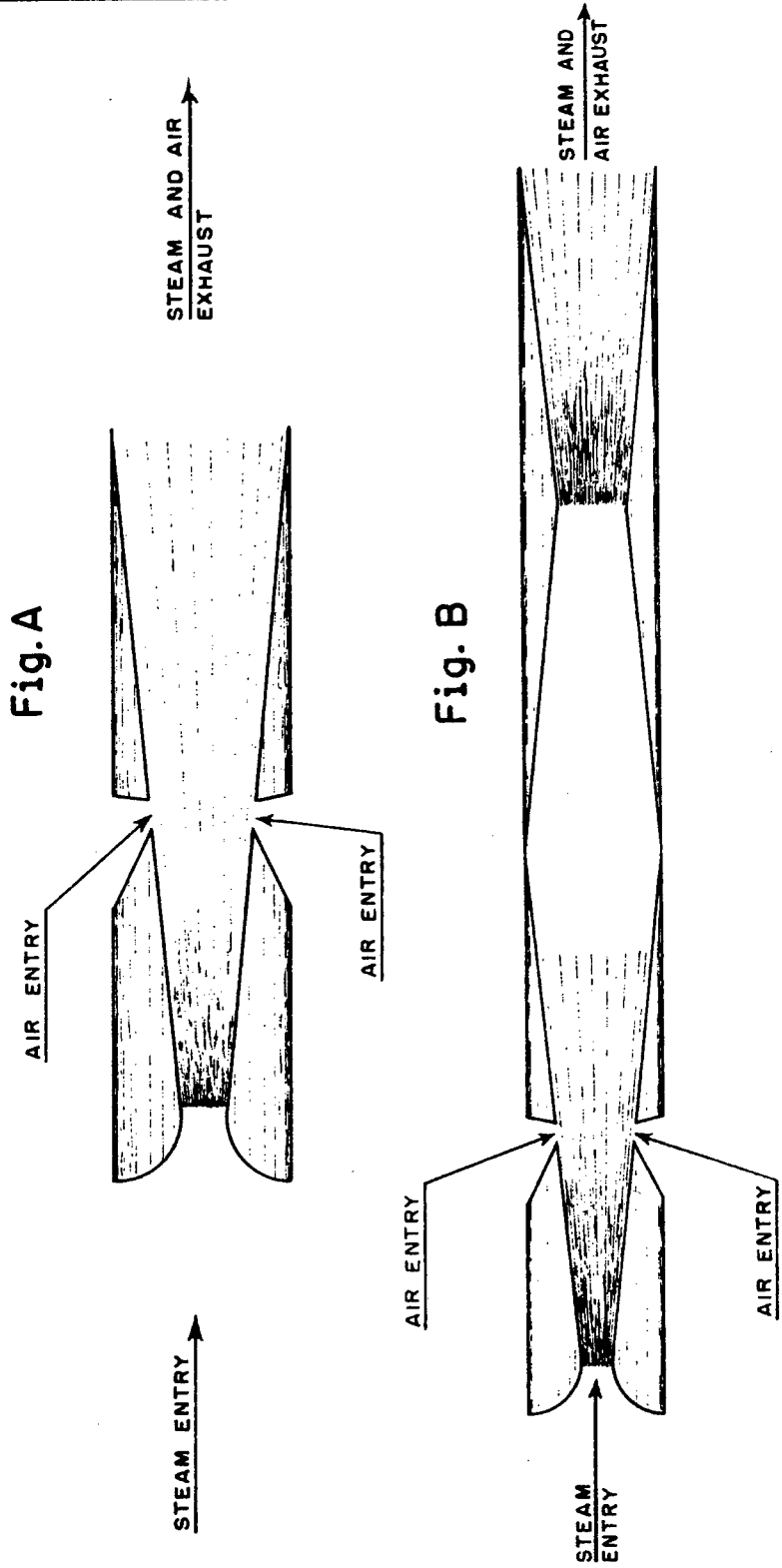
FIGURE 3

MLM-567



SCALE: HALF ACTUAL SIZE.

EXPERIMENTAL STEAM NOZZLE.

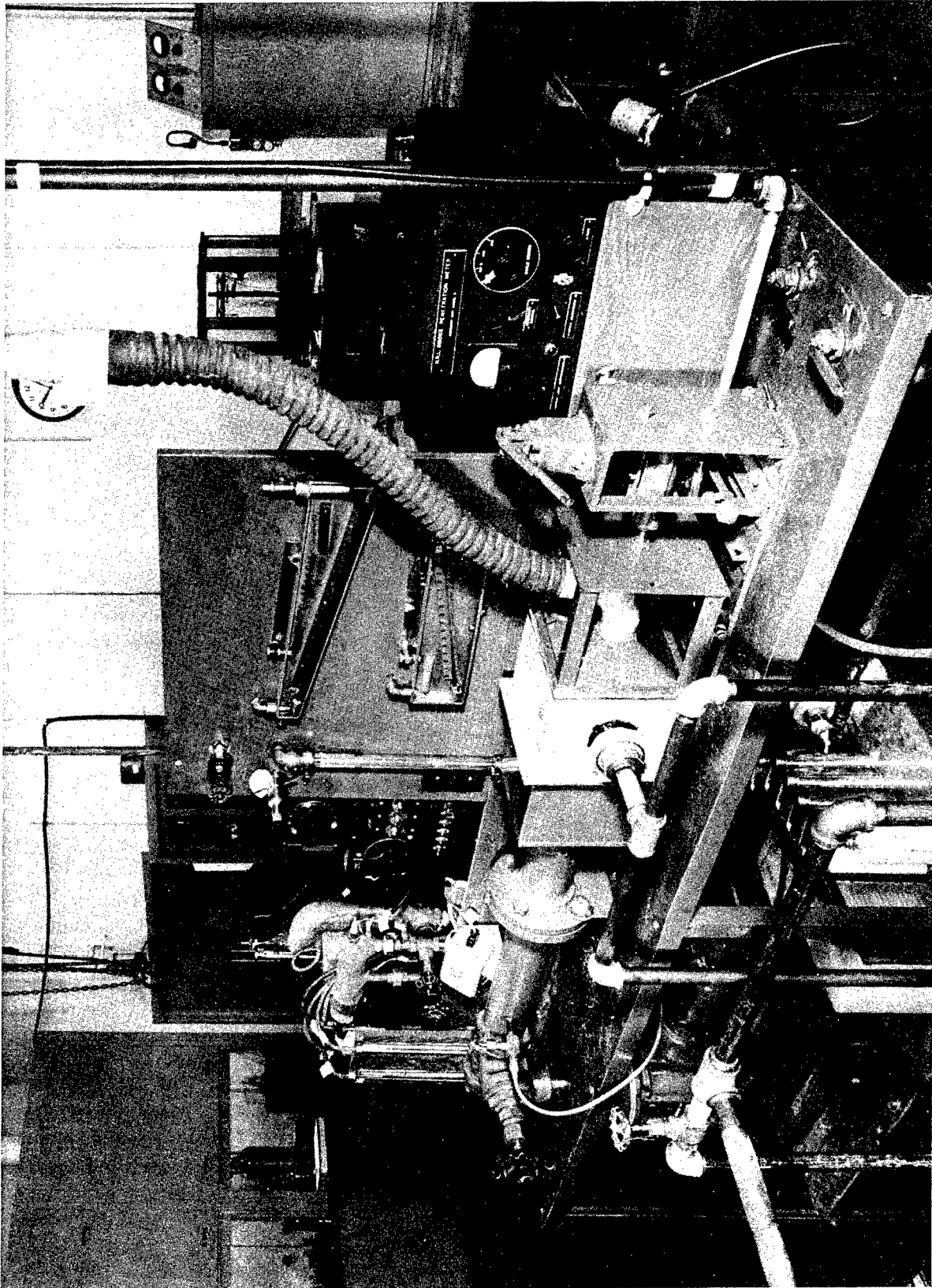


NOTE: SHADED AREAS REPRESENT CONDENSATION (BLUE LIGHT)
WHITE AREA REPRESENT LIVE STEAM (TRANSPARENCY)

CONDENSATION AREAS IN STEAM NOZZLES.

FIGURE 5

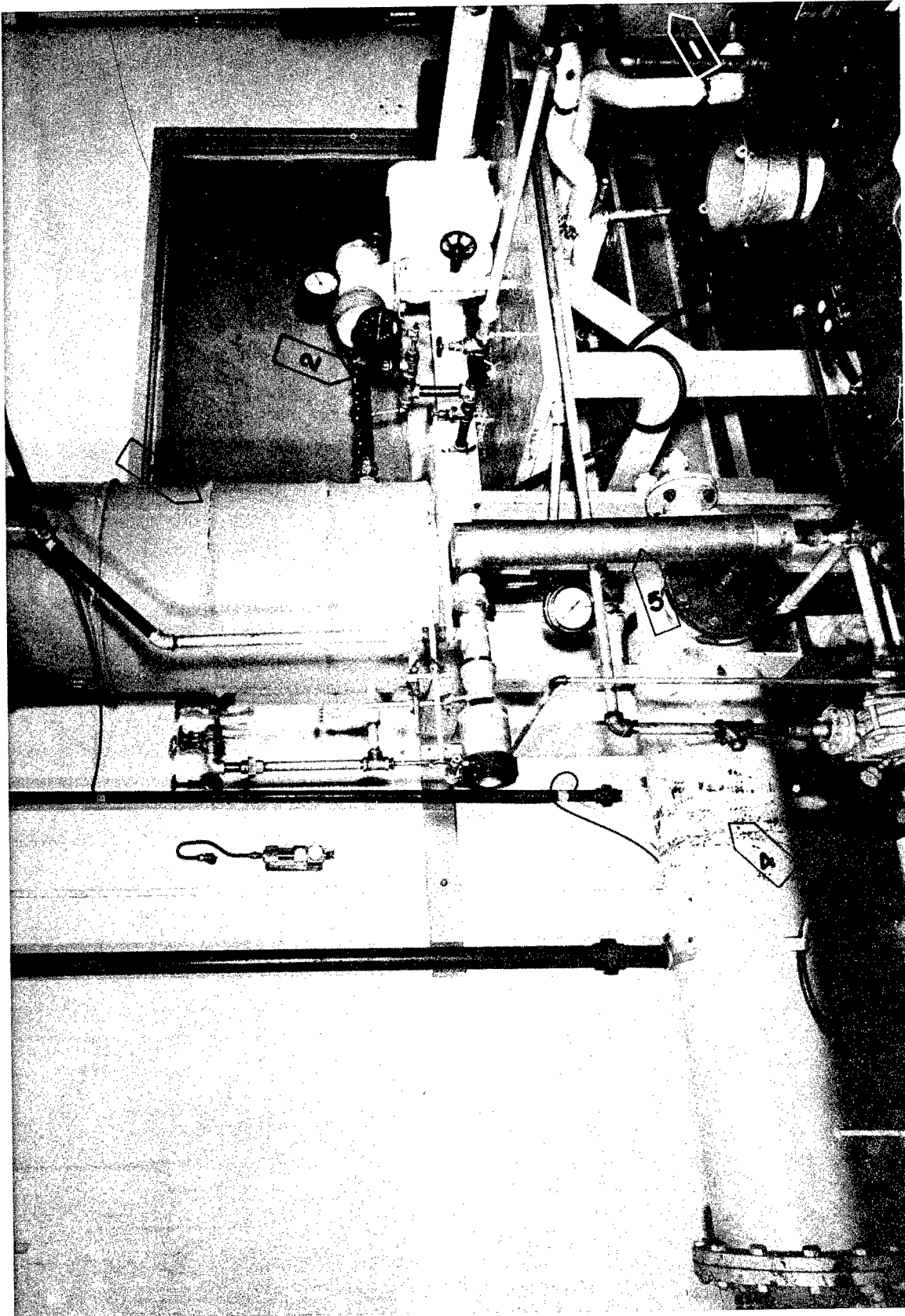
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Diethylphthalate Smoke Machine

FIGURE 6

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Particle Removal Apparatus

FIGURE 7

MLM-567

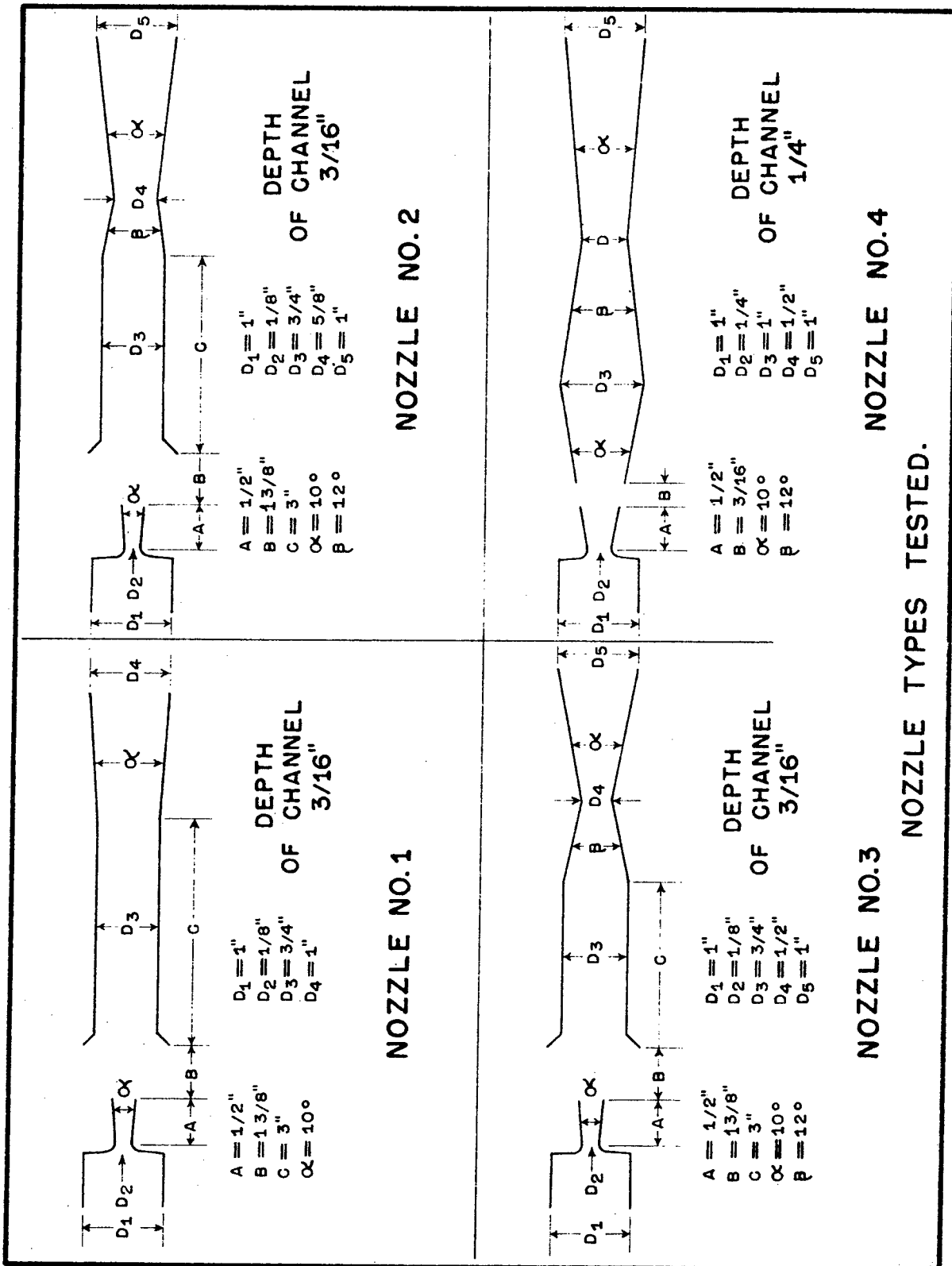
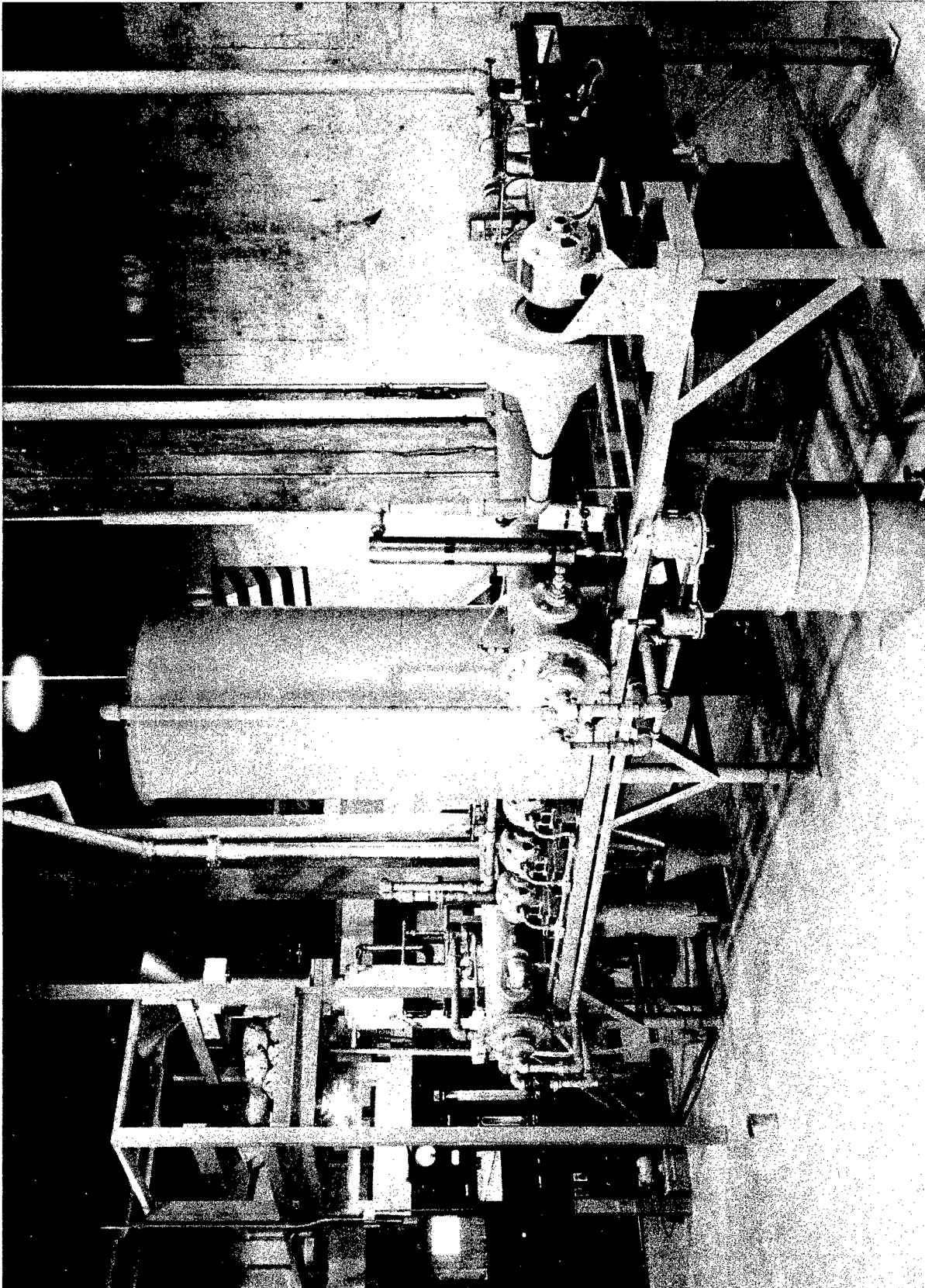


FIGURE 8

MLM-567



Incinerator Pilot Plant No. 2

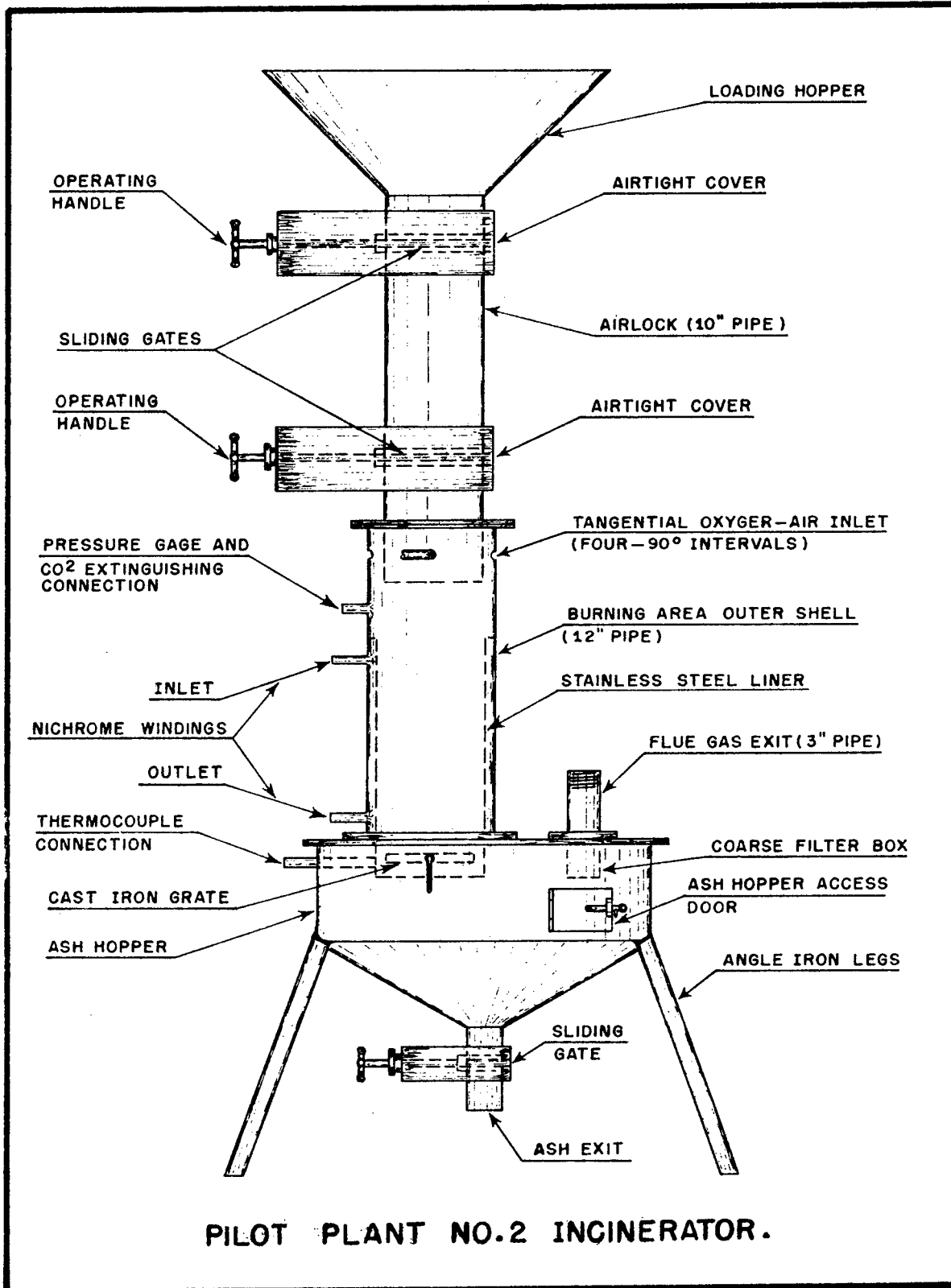
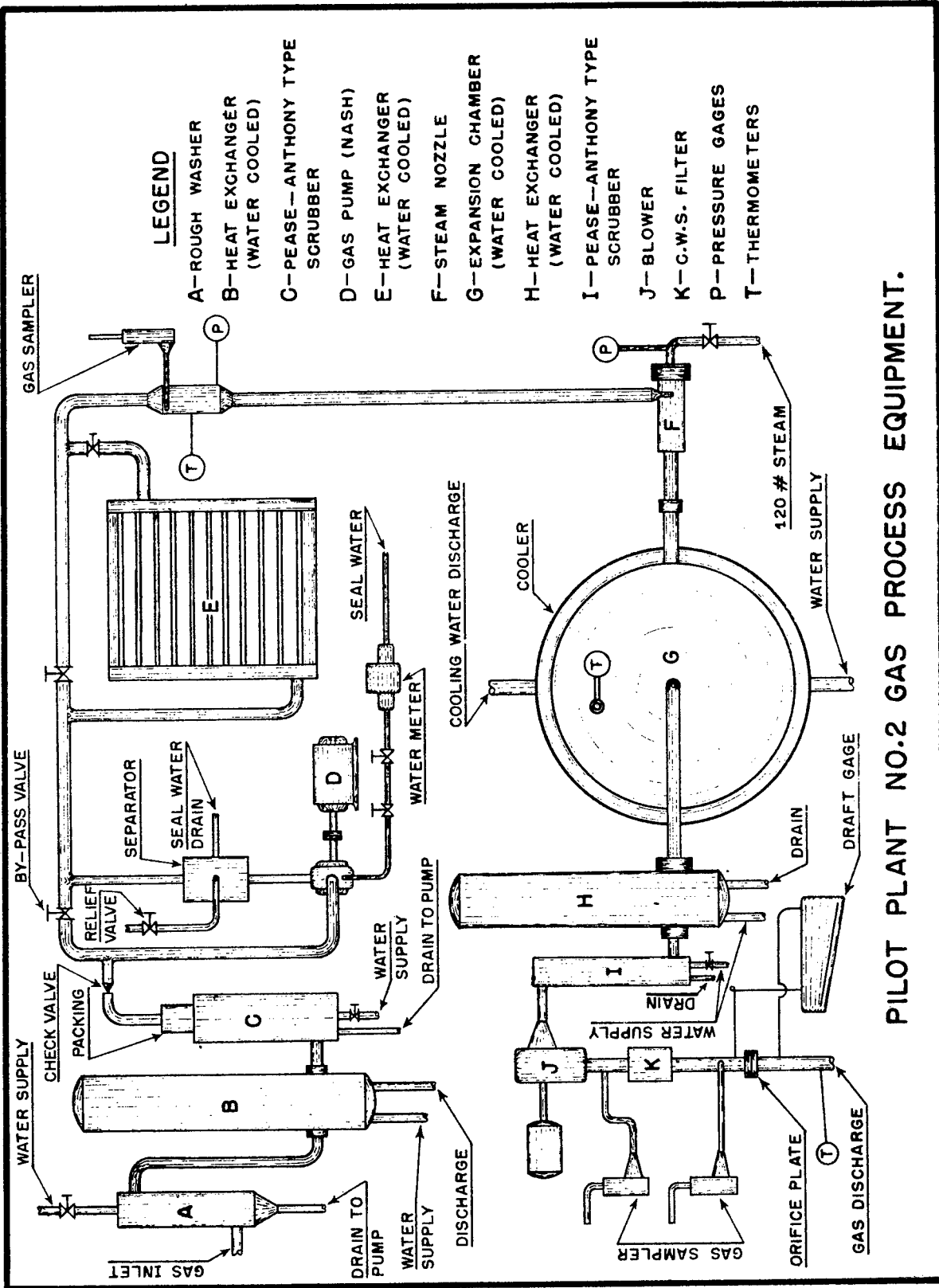


FIGURE 10

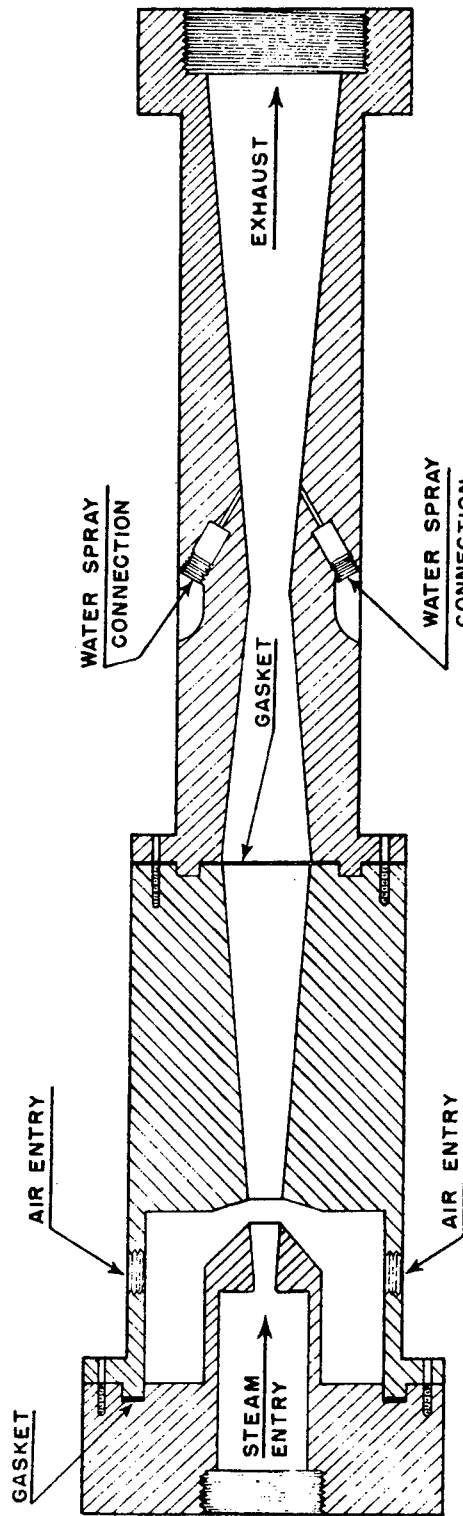
MLM-567



PILOT PLANT NO.2 GAS PROCESS EQUIPMENT.

FIGURE 11

MLM-567



DIMENSIONS OF NOZZLE

- 1 - 1ST. ORIFICE — 0.283" DIA.
- 2 - 2 ND. ORIFICE — 0.400" DIA.
- 3 - ANGLES OF DIVERGENCE 11°
- 4 - ANGLES OF CONVERGENCE 11°
- 5 - STEAM ENTRY — 1" DIA.
- 6 - EXHAUST — 1 1/2" DIA.
- 7 - OVERALL LENGTH 15 5/8"
- 8 - WATER SPRAY OPENINGS (4) — 0.0135" DIA.
- 9 - AIR ENTRY OPENINGS (4) — 3/8" DIA.

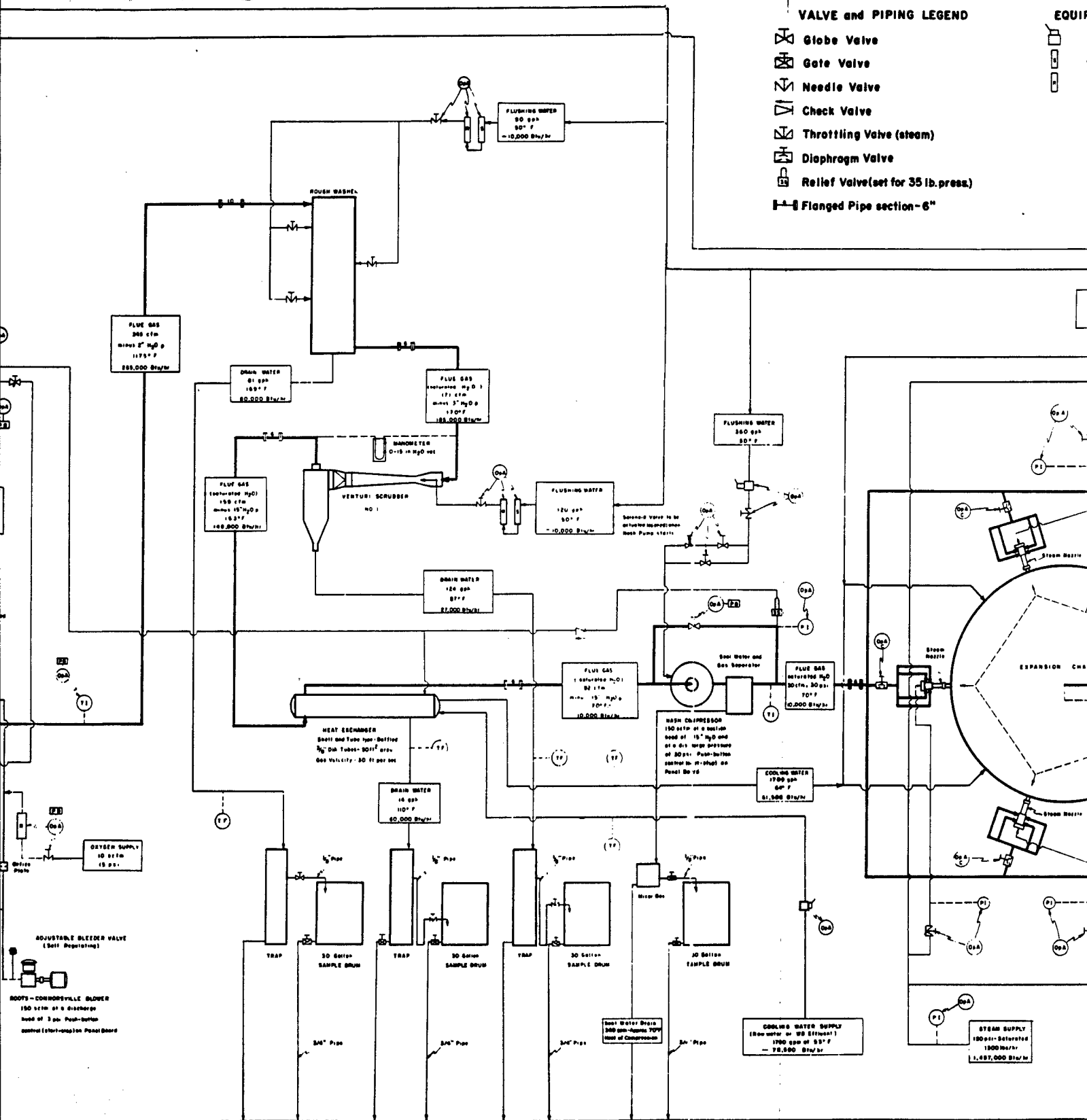
PILOT PLANT NO.2 STEAM NOZZLE.

2

VALVE and PIPING LEGEND

EQUIP

- Globe Valve
- Gate Valve
- Needle Valve
- Check Valve
- Throttling Valve (steam)
- Diaphragm Valve
- Relief Valve (set for 35 lb. press.)
- Flanged Pipe section - 6"



INCINERATOR PROCESS FLOW SHEET

3

Figure 12

VALVE and PIPING LEGEND

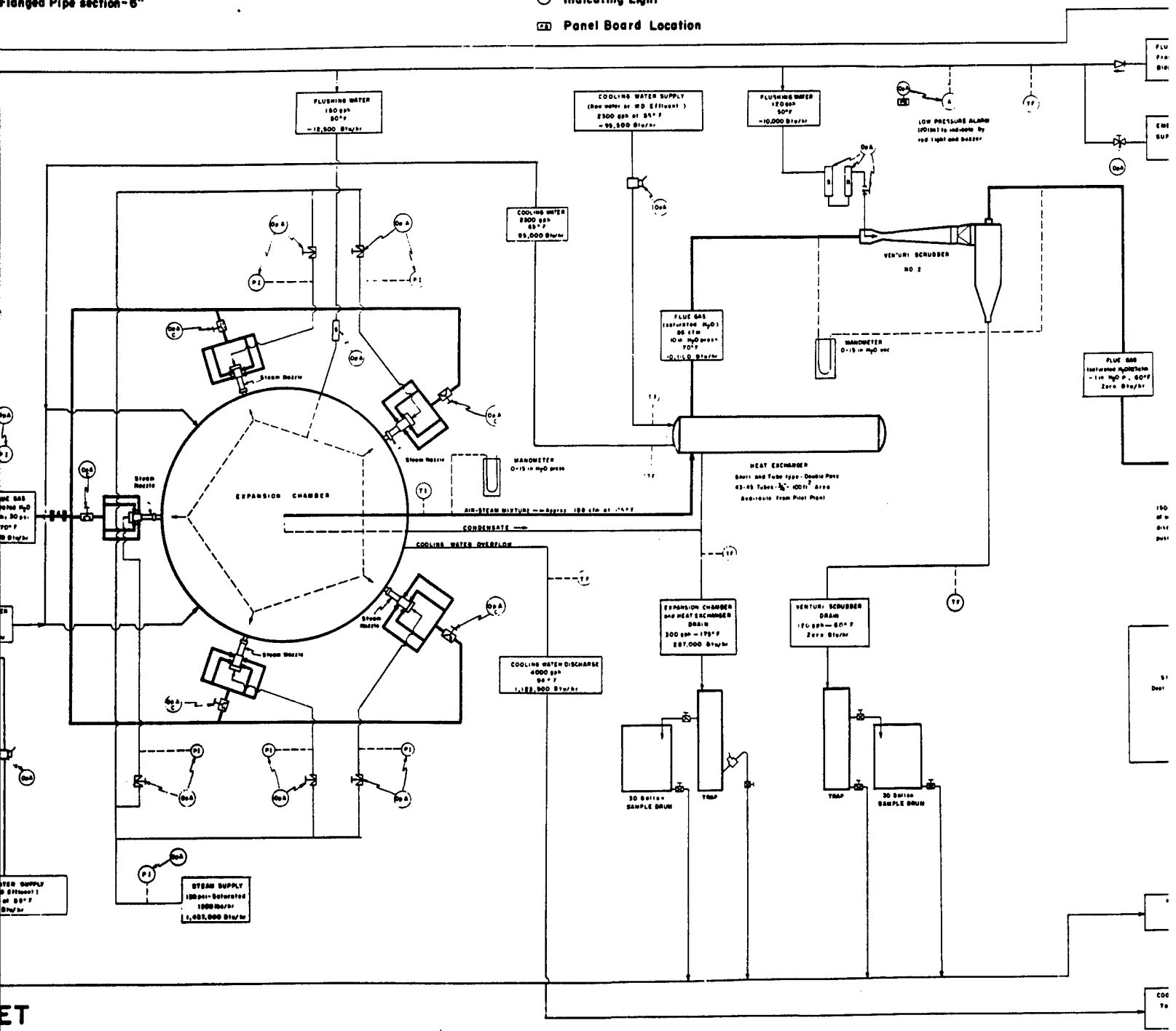
- Globe Valve
- Gate Valve
- Needle Valve
- Check Valve
- Throttling Valve (steam)
- Diaphragm Valve
- Relief Valve (set for 35 lb. press.)
- Flanged Pipe section-6"

EQUIPMENT LEGEND

- Water Meter
- Water Strainer
- Rotameter

MISCELLANEOUS LEGEND

- Located in operating area (cold side)
- Located in process area-controlled from operating area by reach rods
- Temperature Indicating-visible from operating area
- Thermometer Fitting-blanked off.
- Pressure Indicating- visible from operating area.
- Alarm Signal
- Temperature controlling and recording (Speedomez)
- Indicating Light
- Panel Board Location



ET

FLU
Pro
Btu/hr

COI
Btu/hr

LOW PRESSURE ALARM
(1000) to indicate by
red light and buzzer

PI

TI

IL

FLU GAS
100 cfm at
100°F
0.115 Btu/hr

VENTURI SCRUBBER
NO 2

MANOMETER
0-15 in H₂O vac

FLU GAS
100 cfm at 100°F
Zero Btu/hr

HEAT EXCHANGER
Shell and Tube Type- Double Pass
43-45 Tubes- $\frac{3}{4}$ " ID
Area
Available from Pilot Plant

EXPANSION CHAMBER
AND HEAT EXCHANGER
DRAIN
300 gpm - 175°F
127,000 Btu/hr

VENTURI SCRUBBER
DRAIN
170 gpm - 80°F
Zero Btu/hr

CONDENSATE

COOLING WATER OVERFLOW

COOLING WATER DISCHARGE
4000 gpm
80°F
1,122,000 Btu/hr

30 BOTTLE
SAMPLE DRUM

TRAP

30 BOTTLE
SAMPLE DRUM

STEAM SUPPLY
100 gpm - Saturated
1,051,000 Btu/hr

COI
Btu/hr

COI
Btu/hr

US LEGEND
cold side)

Figure 12

MLM-567

controlled from operating area by reach rods
able from operating area
ed off.
e from operating area.
recording (Speedomax)

