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DESIGN OF AN ENGINEERING-SCALE, VACUUM DISTILLATION
EXPERIMENT FOR MOLTEN-SALT REACTOR FUELW. L. Carter
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DESIGN OF AN ENGINEERING-SCALE, VACUUM DISTILLATION
EXPERIMENT FOR MOLTEN-SALT REACTOR FUEL

W. L. Carter
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L. E. McNeese

ABSTRACT

Experimental equipment has been designed for an engineering-scale demonstration of vacuum distillation of molten-salt reactor fuel. The distillation is carried out at about 1000°C and 1 mm Hg to separate LiF-BeF₂ carrier salt from less volatile fission products, primarily the rare earths. Uranium tetrafluoride is not present during the distillation. The experiment is designed for continuously feeding a molten-salt-fission-product mixture into a still at the same rate that distillate is being removed, thereby concentrating fission products in the still. Also, the still may be operated batch-wise to give large concentration factors. Frequent sampling of the distillate furnishes data on the separation between carrier and fission products as a function of concentration in the still bottoms.

The equipment consists of a 48-liter feed tank, a 12-liter still, a 10-in. diam x 51-in. condenser, a 48-liter condensate receiver, plus associated temperature, pressure and level control instrumentation. All vessels and parts contacted by molten salt are made of Hastelloy N. The unit is electrically heated by shell-type, ceramic heaters.

About 90% of the experimental program will be devoted to nonradioactive operation using mixtures of LiF, BeF₂, ZrF₄, and selected rare earth fluorides. The experiment will be concluded by distilling a 48-liter batch of uranium-free spent fuel from the Molten-Salt Reactor Experiment.

INTRODUCTION

This report describes the design and proposed use of experimental equipment to demonstrate vacuum distillation of fuel carrier salt from a molten-salt reactor. The purpose of this experiment is to demonstrate the feasibility of distilling a large portion of the carrier from contained fission product fluorides. Vacuum distillation is the key step in one method of processing a molten-salt breeder (see Fig. 1) because it separates the bulk of the valuable LiF-BeF₂ carrier from less volatile fission products, primarily the rare earths, and recovers this carrier salt for recycle to the reactor. Feasibility of distilling fluoride salts was established in batch, laboratory experiments by Kelly¹; this design is of an experiment that will demonstrate the operation on an engineering scale.

In the interest of simplicity, fabrication time, and economy, no attempt was made in this experiment to reproduce the actual operating conditions, such as high internal heat generation rate in the molten salt, or to use a still design of the type to be used in a processing plant for a breeder. Such advances are the next logical step after an engineering-scale demonstration. However, it is the purpose of this experiment to show that molten salt, containing fission products, can be fed continuously to the still at the rate at which it is being distilled, with the simultaneous accumulation of fission products in the bottoms. Furthermore, the still can be operated batchwise to concentrate fission products in some small fraction of the salt volume. In this way the still meets a requirement of a still for processing breeder fuel since large fission product concentration factors are necessary to minimize the amount of carrier salt discarded as waste.

The experiment is designed to obtain throughput data and relative volatility data between rare earth fluorides and the carrier components of molten salt fuel, which are LiF, BeF₂, and ZrF₄. Zirconium fluoride will not be a component of breeder reactor fuel, but it is included here because the still will be operated with salt of the composition of the Molten-Salt Reactor Experiment (MSRE), which is 65 mole % LiF, 30 mole % BeF₂, and 5 mole % ZrF₄. Progress of distillation is followed by sampling the flowing condensate at several times during the course of an experiment. Samples can be removed under vacuum without interrupting the run and will be analyzed to determine the amount of separation being obtained between components being fed to the still. It is also possible to sample the contents of the still, but this necessitates interrupting the run during the time a sample is being removed.

The experimental program is in two parts: About 90% of the time will be devoted to nonradioactive operation, and the remaining 10% to radioactive operation in distilling a small quantity of fuel carrier salt from the MSRE. The first phase is expected to log about 500 hr of operation. The same equipment will be used in the radioactive experiment after being thoroughly inspected at the conclusion of nonradioactive operation. Radioactive runs will be carried out in an MSRE cell

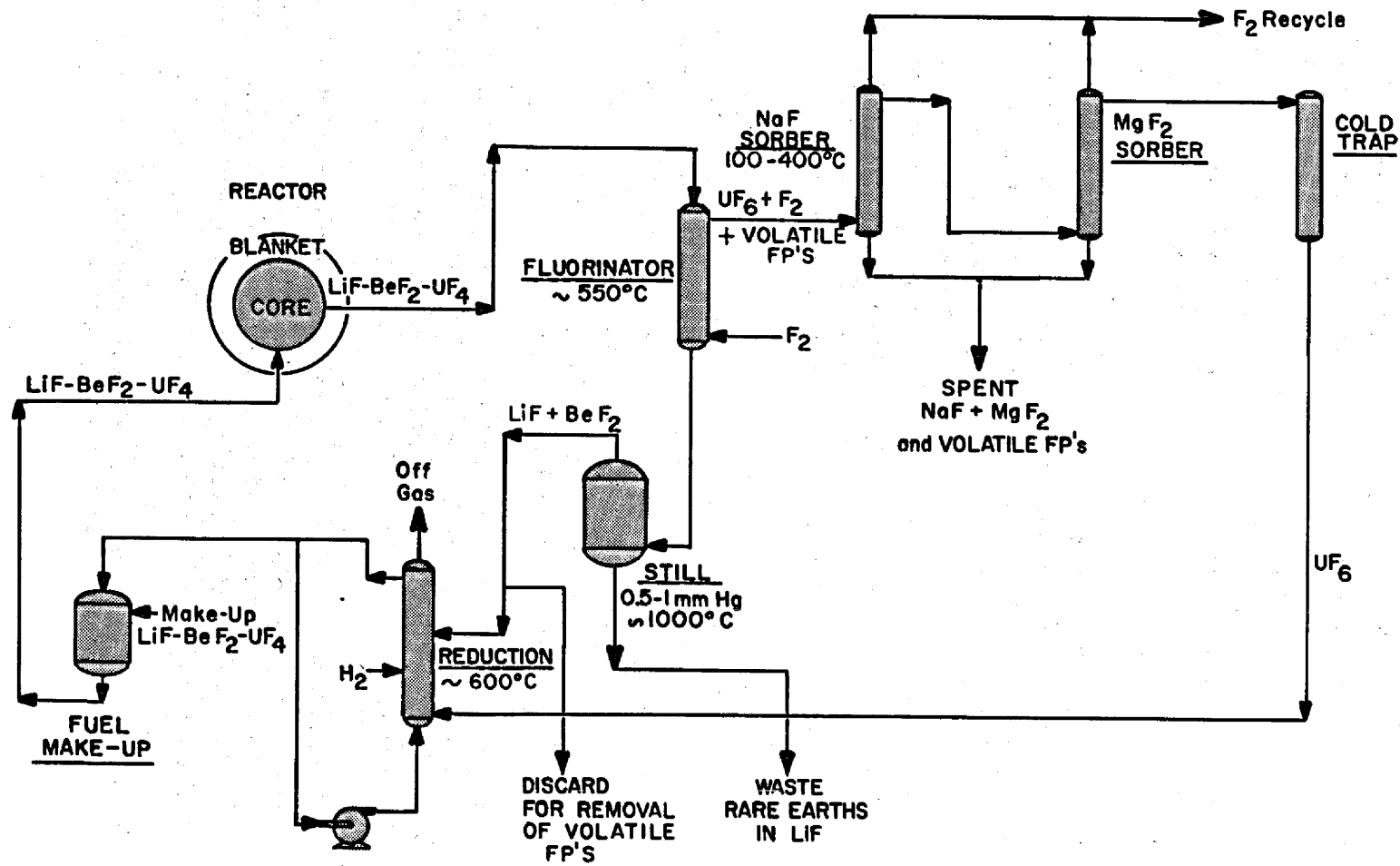


Fig. 1. Principal Steps in Processing Irradiated Fuel from a Molten Salt Reactor.

on a 48-liter batch of uranium-free MSRE fuel that has been decayed at least two months.

Components of the experiment are a feed tank (48 liters), still (12 liters), condenser, condensate receiver (48 liters), associated temperature and pressure instrumentation, and a vacuum system. The still, condenser, and receiver are fabricated as a unit. The vessels are mounted in an angle-iron frame, which is 3 x 6 x 7 ft high, allowing transport of the entire facility as a unit once instrumentation, power, and service lines have been disconnected. The equipment is heated by shell-type electric heaters which are enclosed in 4 to 8 in. of thermal insulation.

An experimental run is carried out by charging a molten mixture of carrier salt and fission product fluorides into the feed tank, which is held at a temperature slightly above the salt liquidus, which is 450°C for MSRE carrier salt. Concurrently the still, condenser, and condensate receiver are heated and evacuated, and the space above the liquid in the feed tank is evacuated. The final pressure is adjusted to about 0.5 atm in the feed tank and 0.2 to 5 mm Hg in the rest of the equipment, depending upon the desired operating pressure. When the still temperature reaches 900°C, a 12 liter charge is forced into the still through a heated line, and the temperature is raised to the operating temperature range of 950 to 1000°C.

The still pot is the highest point of the system and is an annular volume surrounding the top of the condenser (see Fig. 2). Salt vapors flow into the top of the condenser and condense along its length by losing heat to the surroundings. Freezing is prevented by supplying the necessary external heat to keep the condenser surface above the liquidus temperature. In leaving the condenser the distillate passes through a small cup from which samples can be removed for analyses. Sampling can be done under vacuum without interrupting an experiment.

Liquid-level instrumentation in the still allows control of feed rate to correspond to the distillation rate, which is estimated to be 400 to 500 cm³ distillate per hour. Determining the actual distillation rate for molten-salt systems is an important part of this experiment.

All vessels and lines that contact molten salt are fabricated of Hastelloy N. In the region of the still and upper section of the condenser, the normal use temperature for this alloy may be exceeded by as much as 200°C. Consequently, the vessels are to be examined thoroughly by dimensional, radiographic, and ultrasonic methods before and after nonradioactive operation.

Provision is made for hanging test specimens of candidate metals of construction in the still. The materials that will be tested are:

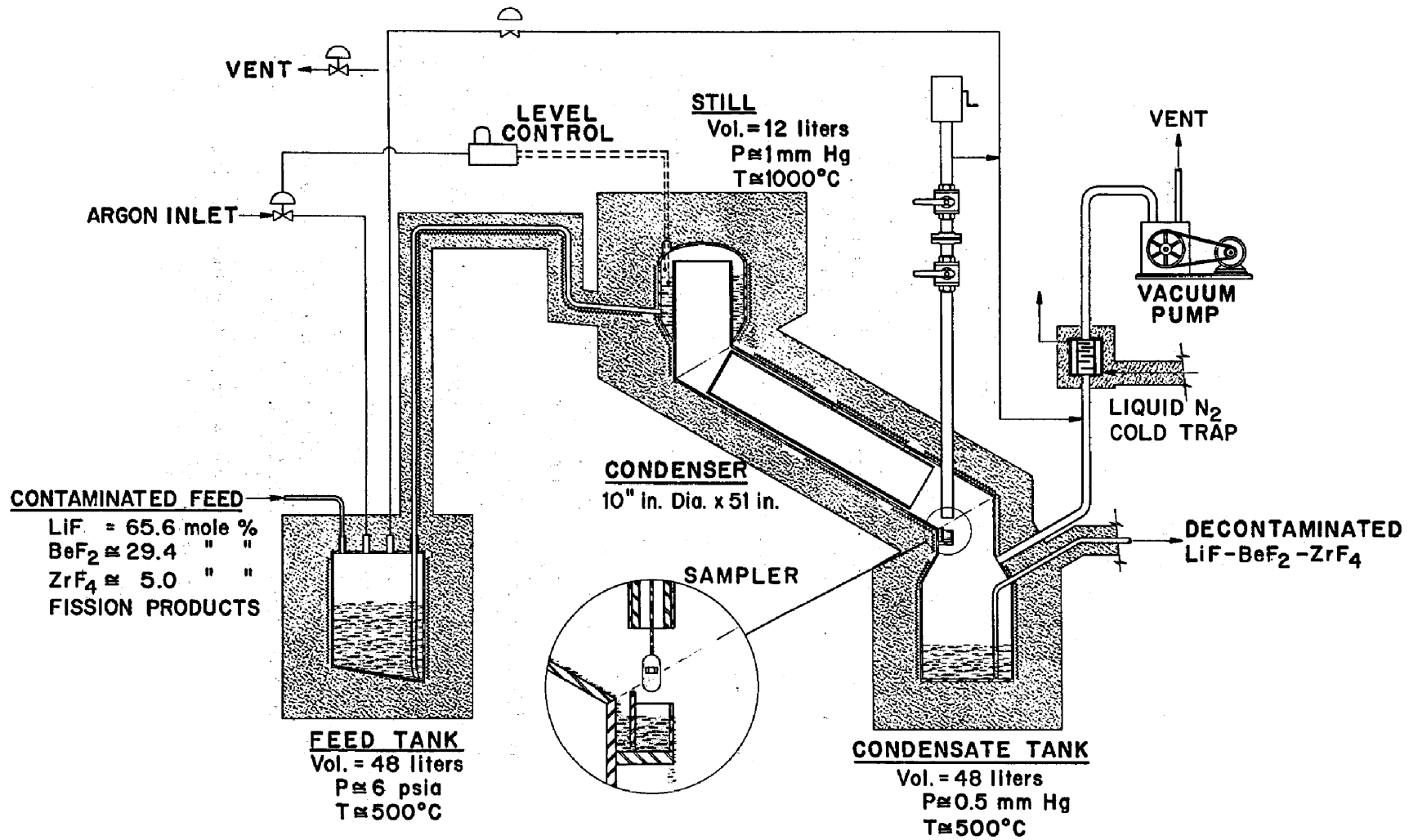


Fig. 2. Vacuum Distillation of LiF-BeF₂-ZrF₄.

1. Hastelloy N (referee sample of still composition)
2. Moly TZM (a Ti-Zr-Mo alloy)
3. Haynes Stellite No. 25
4. Graphite (grade AXF-SQBG, isotropic)
5. Ni-18 Mo-0.2 Mn-0.05 Cr

Samples will be removed and inspected at the end of nonradioactive operation.

DESIGN CRITERIA AND FEATURES

Basic Design Requirements

Factors which influenced equipment design included the following:

1. The total operating time and the total volume of salt distilled during operation with irradiated material should be sufficient to conclusively demonstrate the feasibility of molten-salt distillation.
2. Operation with irradiated material should be preceded by successful operation with unirradiated material.
3. The same equipment should be used for work with irradiated and unirradiated materials.
4. The equipment size should be compatible with space suitable for containment of BeF_2 during nonradioactive operation.

Other factors of importance included:

1. Either semicontinuous or batch operation should be possible.
2. Condensate samples should be taken during an experiment without upsetting operating conditions.
3. The latent heat of condensation of the molten-salt vapor should be removed from the condenser by loss of heat to the surroundings.
4. The pressure drop in the passage connecting the vaporization and condensation surfaces should be low.

The experimental program will consist of both nonradioactive and radioactive operation, with the former being about 90% of the program. Nonradioactive operation will be carried out over a period of three to six months in the

Unit Operations Section, and then the equipment will be moved in toto to the MSRE site to demonstrate vacuum distillation of irradiated MSRE carrier salt. Equipment size was governed by the space in an available hood, and the overall installation is limited to about 6 x 3 x 8 ft in length, width, and height respectively. Unitized installation of all components within a supporting framework was designated to facilitate transport between sites. Radioactive operation will be carried out in the spare cell of the MSRE.

The duration of the radioactive experiment is an important factor because of the technological significance that can be associated with a conclusive demonstration using recently irradiated fuel. For this purpose, an operating period of 10 to 14 days was considered adequate, and, during this time, 48 liters of the fuel carrier salt will be distilled.

Another design feature is that provision be made for sampling the condensate stream at any time during the course of a distillation experiment. This requirement is made so that the composition of the still vapor can be measured as a function of still composition and/or temperature. Condensed vapors flow continuously through a cup at the condenser outlet (see drawing M-12173-CD-011D in the Appendix) from which a 10-g sample can be taken by lowering a thimble into the cup. The sampling operation is carried out at the operating pressure, causing no interruption or upset in the run.

Simplicity of design and ease of operation were primary considerations in planning this experiment. The only auxiliary systems are the necessary heaters, instruments, and vacuum equipment. Vapor condensation is brought about by radiative and convective heat loss to the surroundings, obviating the need for an auxiliary, high-temperature cooling system. This somewhat limits the maximum distillation rate, the calculated range being 350 to 500 cm³/hr with 3.5 to 4-in. insulation around the condenser.

Material of Construction

All major pieces of equipment and connecting lines are built of Hastelloy N. This material has excellent resistance to corrosion by molten LiF-BeF₂-ZrF₄ mixture at the lower temperatures (500 to 700° C) of the experiment. A limited amount of data at the higher operating temperatures (900 to 1000° C) indicate that the corrosion resistance is probably quite good at these temperatures. This characteristic of Hastelloy N will be evaluated in the distillation experiment.

The still and condenser, which will be exposed to the higher temperatures, are constructed of 3/8-in.-thick plate to allow for uncertainty in the strength of Hastelloy N in the neighborhood of 1000° C. The ASME Unfired Boiler and Pressure Vessel Code makes no provision for the use of this alloy for service above 700° C. This

design is based on the creep data of McCoy* and the stress analysis of Hahs and Pickel,* which substantiate the use of this equipment for an operating time up to 1000-hr duration. At no time will the unit be exposed to a positive internal pressure, the largest ΔP being 1 atm external pressure.

Use was made of on-hand material from the MSRE stockpile of Hastelloy N plate, sheet, tubing, rod, and pipe. Design and fabrication changes were made to conform to the available material. For example, cylindrical vessels are made of rolled and welded plate instead of the more obvious choice of using standard pipe if it were available; directional changes are made with mitered joints because pipe fittings were not available; some nozzles are made of tubing or drilled rod when a more conventional choice would have been standard pipe.

EXPERIMENTAL PROGRAM

The vacuum distillation experiment will be carried out in two phases. The first phase will consist of a large number of nonradioactive experiments to thoroughly evaluate the still, obtain operating experience, and gather data that are pertinent to the distillation process. The second phase will be a 10 to 14 day demonstration in which irradiated carrier salt of the Molten Salt Reactor Experiment will be distilled in a cell at the MSRE site.

Nonradioactive Operation

The experiment is described by the simplified flow diagram presented in Fig. 2; a detailed flowsheet is given in Appendix H, Drawing No. E-12173-CD-012D. The system consists of a feed tank, still, condenser, condensate receiver, cold trap, vacuum pump, and auxiliary instrumentation for controlling pressures, temperatures, and liquid level. All vessels and lines are heated with ceramic, clam-shell-type heaters or Calrod-type elements.

Initially the system is purged and filled with argon to remove oxygen, and all vessels are heated to about 500°C. A 48-liter charge of molten $\text{LiF-BeF}_2\text{-ZrF}_4$ of MSRE carrier salt composition containing a fission product fluoride is then put into the feed tank, and the entire system is evacuated. Pressure above the salt in the feed tank is adjusted to about 5 psia, sufficiently low to prevent salt from being pulled into the still when the still is at full vacuum. The evacuation is continued

*H. E. McCoy, Metal and Ceramics Division; C. A. Hahs and T. W. Pickel, General Engineering Division. See later sections of this report treating the metallurgical study and stress analysis.

until the still, condenser, and condensate receiver are at the desired operating pressure of 0.2 to 2 mm Hg. Concurrently with the evacuation, the still temperature is raised to about 850°C, the temperature at which the salt charge has a vapor pressure of around 1 mm Hg. The condenser temperature is adjusted 100 to 200°C lower than the still temperature to facilitate condensation of the salt vapor without solidification. Condenser heat is applied in four zones so that a high-to-low temperature gradient can be maintained down its length. The condensate receiver is heated to 500 to 550°C, a temperature that will keep the condensate molten but not cause undesired vaporization into the vacuum system.

When all parts of the system have reached the desired temperature and pressure, 12 liters of the feed salt are transferred through a heated line into the annular section of the still by pressurizing the feed tank with argon. The gas is added slowly through a capillary, and a liquid-level device, which senses the upper level in the still, stops the argon addition when this level is reached. The still temperature is controlled so that the vapor pressure of the salt is near 1 mm Hg; and, as distillation progresses, changing the salt composition, this temperature is allowed to increase to keep the vapor pressure at about 1 mm Hg. Pressure at the condenser exit is held at about 0.5 mm Hg. The calculated distillation rate is about 350 ml/hr.

The liquid-level instrument in the still is set to detect a low level that corresponds to vaporization of 2 liters and to begin argon flow into the feed tank to push more salt into the still. The upper-level setting stops the addition, and this cyclic operation is repeated throughout the run. Smoother, more continuous operation can be obtained by regulating the argon flow to the feed tank to be very near the predicted vaporization rate so that salt flows into the still at about the same rate that it is being vaporized.

In leaving the condenser, the condensate flows through a small cup that is centered beneath a sample tube. A 4-cm³ sample is obtained by lowering a 1-1/2-in. by 3/4-in.-diameter thimble into the cup. Sampling is done under operating conditions with no interruption in the experiment; a double-valve arrangement (shown schematically in Fig. 2) permits removal of a sample from the system without upsetting the still pressure. The sample cup is continuously flushed with fresh condensate, giving a sample that is representative of the still vapor at the time the sample is taken.

Finally, the condensate collects in a receiver from which it might be recycled for subsequent experiments. Level-detecting instrumentation allows an independent check of distillation rate. The condensate receiver can be sampled for a cumulative analysis only if the run is terminated because the tank must be pressurized to force the salt out the drain line. The vacuum line passes through a baffled trap cooled by liquid nitrogen to remove particulates or vapors that might clog the vacuum pump.

The still residue cannot be withdrawn during the course of an experiment. A dip tube is provided for draining all but about 154 cm³ from the conical bottom

section when a positive pressure is applied above the liquid surface. However, if desired, all liquid fed into the still may be evaporated. The maximum still temperature (1000°C) is high enough to vaporize the least volatile component (LiF) of the carrier but considerably below the point at which rare earth fluorides have a significant vapor pressure. Fission product fluorides, which the carrier salt contains during some runs, are allowed to accumulate in the still. A flush salt can be used to purge the still between different types of experiments.

Because of the toxic nature of beryllium, nonradioactive experiments are carried out in a hood, and all work areas are monitored for beryllium contamination. Containment is based on maintaining adequate air velocities at all hood openings.

Radioactive Operation

At the conclusion of the nonradioactive experiments, the equipment will be moved intact to the spare cell at the MSRE site for a similar experiment using irradiated salt. Distillation is carried out in the same way as described above; however, all operations must be remote. A 48-liter batch of LiF-BeF₂-ZrF₄ MSRE carrier salt, which has been fluorinated to remove uranium and volatile fission products, will be transferred from the chemical processing cell through an existing pipe line into the feed tank. The salt will then be distilled over a period of 10 to 14 days. Frequent samples will be withdrawn for analysis. It is anticipated that the extensive operating experience with nonradioactive experiments will allow specifying operating conditions to obtain maximum decontamination and trouble-free operation.

The cell ventilation system is used for disposal of gases from the experiment. This system contains the necessary filters for removing activity from the gas before exhausting it to the atmosphere.

METHODS OF OPERATION

The distillation system can be operated in either of two modes: semicontinuous operation followed by batch operation or batch operation with heel retention. These methods are not necessarily the best for MSBR processing; they are, however, well suited for demonstration of molten salt distillation at the MSRE site.

Instrumentation for measuring liquid level in the still includes a liquid-level probe which operates when the still inventory is between 10 and 12 liters and a level probe which operates when the still inventory is between 0.78 and 6 liters. Salt can be fed to the system continuously or intermittently; however, no provision is made for removing liquid from the vaporizer during the operation. During a given

run, the total salt volume which will be distilled by either method of operation is approximately 48 liters.

Semicontinuous Operation

For semicontinuous operation, the still will be charged with 12 liters of MSRE fuel salt (65 mole % LiF-30 mole % BeF₂-5 mole % ZrF₄) containing rare earth fluorides. An additional 36 liters of fuel salt will then be fed to the still at a rate equal to the desired distillation rate. The liquid volume in the still will be maintained between 10 and 12 liters during this period. After feeding 36 liters of salt, the salt feed will be stopped and vaporization will be continued until the salt liquid volume is 0.78 liter.

The variation of BeF₂ concentration in the condensate and the fraction of rare earth fluoride vaporized are shown in Fig. 3 for this mode of operation. The liquid volume in the still was assumed to be perfectly mixed and the relative volatilities of BeF₂ and rare earth fluoride were assumed to be 4.0 and 5×10^{-4} , respectively. The BeF₂ concentration in the condensate is observed to decrease from an initial value of 67 mole % to 35 mole % at the end of semicontinuous operation and then to drop sharply to essentially zero during batch operation. The fraction of rare earth vaporized is seen to continuously increase to a value of 0.0018 at the end of operation. Approximately 98.5% of the salt fed to the still will be vaporized.

Batch Operation

For batch operation with heel retention, the still is charged initially with 12 liters of MSRE fuel salt containing rare earth fluorides. Vaporization is then carried out until the liquid volume in the still is 0.78 liter. Fuel salt (11.22 liters) will be fed to the still to yield a total liquid volume of 12 liters and the above sequence repeated. Four cycles of batch operation with heel retention can be carried out with 48 liters of salt.

The variation of BeF₂ concentration in the condensate and the fraction of rare earth fluoride vaporized is shown in Fig. 4. The liquid volume in the still was assumed to be uniform in concentration and the relative volatilities of BeF₂ and rare earth fluoride referred to LiF are assumed to be 4.0 and 5×10^{-4} , respectively. The fraction of rare earth fluoride vaporized is based on the total quantity of rare earth fluoride which has been fed to the still during a given cycle. The BeF₂ concentration is observed to decrease from an initial value of 67 mole % to essentially zero during each cycle. The fraction of the rare earth fluoride vaporized after four cycles is 0.0027. Approximately 98.2% of the salt fed to the still will be vaporized.

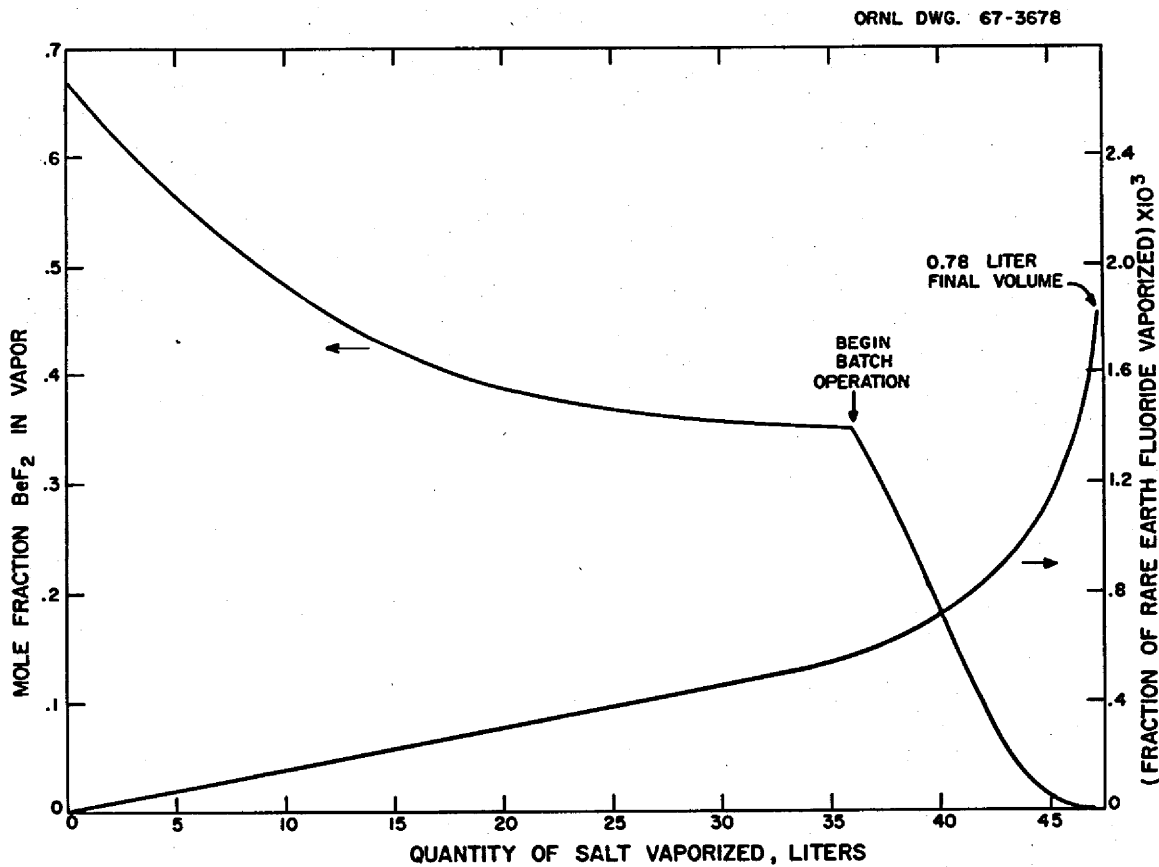


Fig. 3. Semicontinuous Vaporization of Fluoride Salts.

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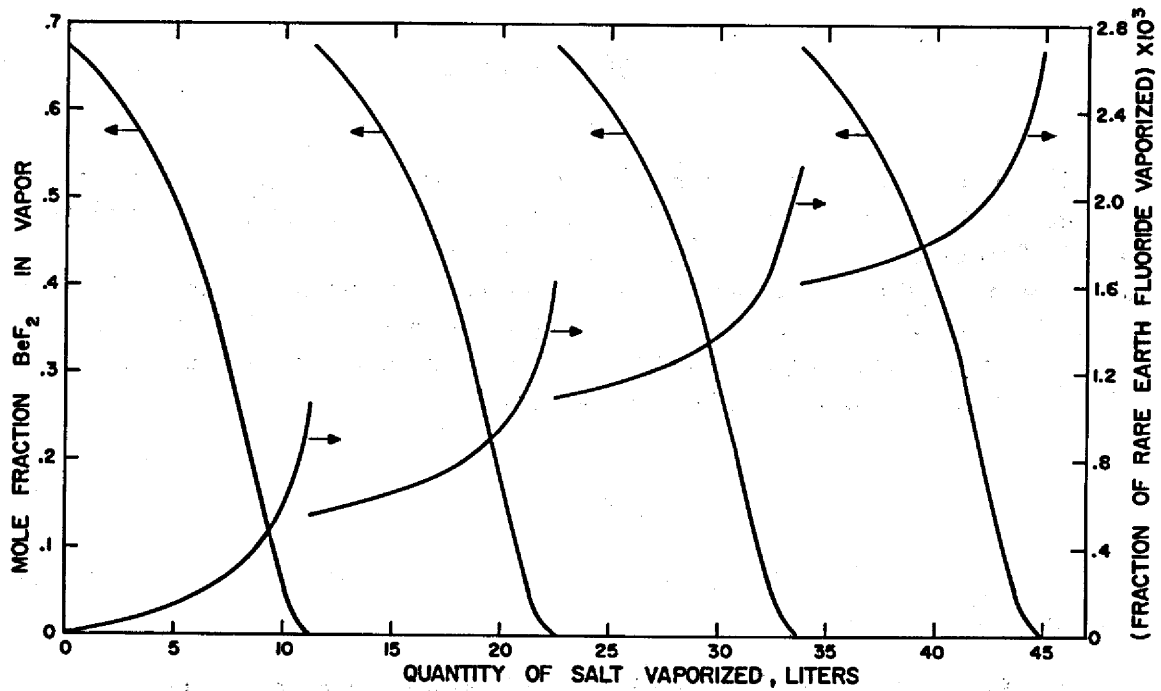


Fig. 4. Batch Vaporization of Fluoride Salts.

The distillation experiment will be operated with unirradiated fuel salt for approximately 500 hr prior to operation with MSRE fuel salt which will require approximately 150 hr. Experimental work using nonirradiated fuel salt will provide general information on optimum operating conditions for the subsequent work using irradiated salt as well as specific data such as relative volatilities of rare earth fluorides and fuel salt components, vaporization rates and factors affecting rate, and concentration polarization at the vapor-liquid interface. Experimental work using irradiated fuel salt will provide additional information on relative volatilities of rare earth fluorides and other fission product fluorides and will point out problems associated with the remote operation of a distillation system with irradiated material.

DESIGN OF EQUIPMENT

The major pieces of equipment for this experiment are designed for semicontinuous or batch operation to conclusively demonstrate vacuum distillation of molten-salt reactor fuel on an engineering scale. The vessels are sized so that batch runs of 30 to 36 hr duration can be made. A batch operation can consist of distilling up to 12 liters of salt, whereas a semicontinuous experiment can distill up to 48 liters and operate for more than one week. The following paragraphs discuss the pertinent design characteristics of each piece of equipment.

Feed Tank

Design Features

The feed tank is described in Fig. 5, and the following values characterize the vessel and its operation:

Total volume	58.6 liters
Operating volume (full)	48.0 liters
Operating pressure	5.0 to 6.7 psia
Operating temperature	500 to 550° C
Heater capacity	20 kw
Material	Hastelloy N
Material thickness (sides, top, and bottom)	1/4 in.

Detailed design of the feed tank is shown on Drawing No. M-12173-CD-013-D in Appendix H.

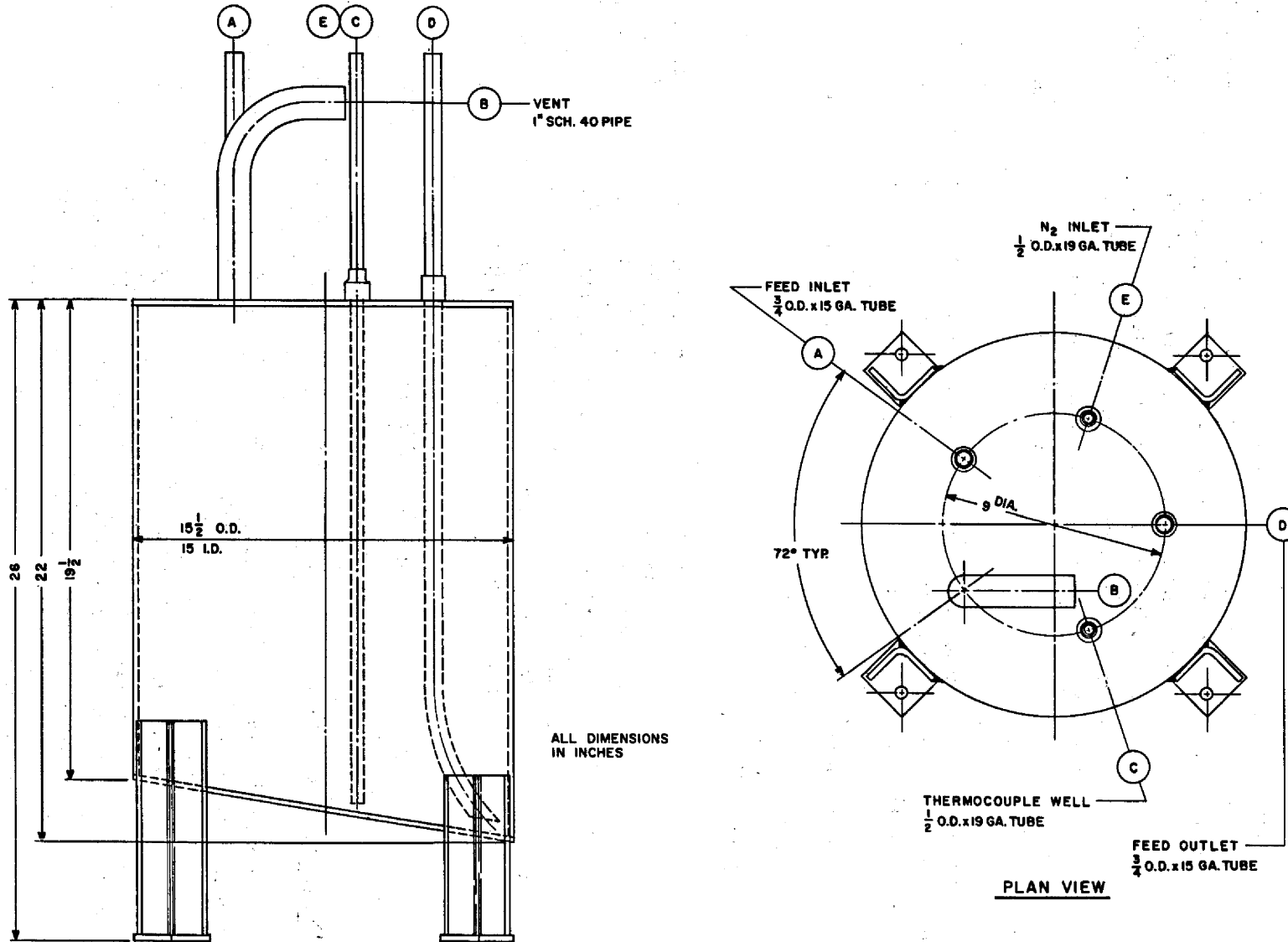


Fig. 5. Molten Salt Distillation Experiment. Schematic diagram of the feed tank.

Thermal Design

The thermal design of the feed tank was concerned only with determining the required heat input rate to give a tolerable heat-up time from room temperature to operating temperature ($\sim 500^\circ\text{C}$). After the vessel and contents have been heated to 500°C , the only heat required is that needed to balance the heat loss to the surroundings. The heat-up time was calculated for several heat input rates, and these are plotted in Fig. 6. An arbitrary upper limit of about 2 hr was chosen for the heat-up period, and on this basis a 20-kw heat input is specified. The calculations are based on the tank's being full (48 liters) of LiF-BeF₂-ZrF₄ (65-30-5.0 mole %) mixture.

At operating temperature, the calculated heat loss from the feed tank is 1.2 kw through the 6-in.-thick insulation. Heaters are arranged so that about 6 kw are applied to the tank bottom, 4 kw to the top, and 10 kw to the sides.

A more complete treatment of the thermal analysis is given in Appendix D.

Operating Pressure

The feed tank is connected to the still via an open line that rises to a point higher than the still and loops down to the still. When the feed tank is filled, molten salt must be raised 5.25 ft to the top of the loop; when near empty, salt must be raised 7 ft (Drawing No. M-12173-CD-010-D in Appendix H). Since the still operates at a pressure of about 1 mm Hg, the salt (sp gr = 2.22 at 500°C) will be drawn into the still unless the feed tank is partially evacuated. Feed tank pressure must be kept in the range 5.0 to 6.7 psia, depending on the salt level in the tank.

Condensate Receiver

Design Features

The condensate receiver is described in Fig. 7, and the following values characterize the vessel and its operation:

Total volume	57.5 liters
Operating volume (full)	48 liters
Operating pressure	0.5 mm Hg
Operating temperature	500 to 550°C
Heater capacity	20 kw
Material	Hastelloy N
Material thickness (sides and neck)	1/4 in.
(bottom)	3/8 in.

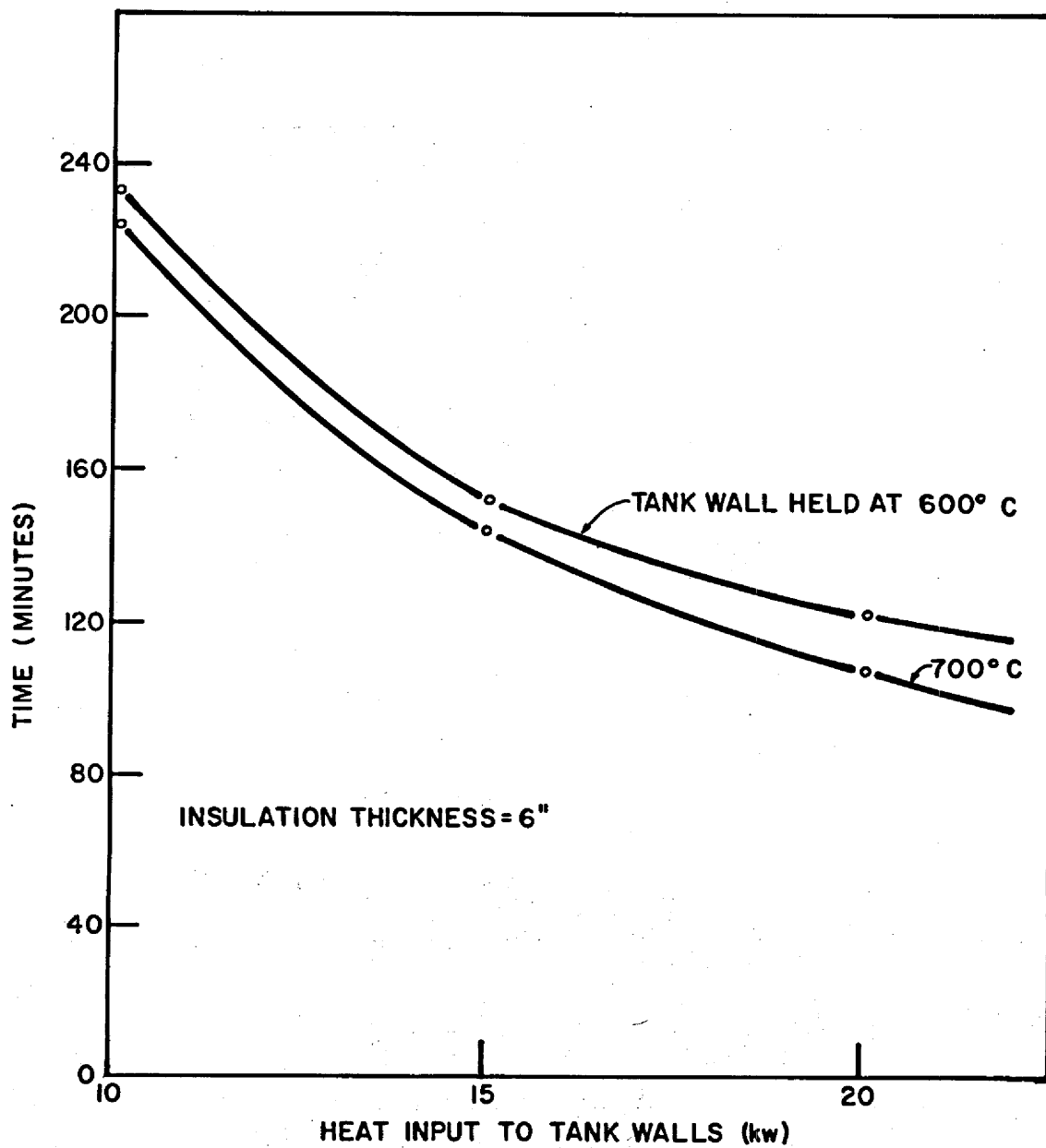


Fig. 6. Calculated Time Required to Heat the Feed Tank or Condensate Receiver from Room Temperature to 500°C When Tank Contains 48 liters of $\text{LiF}-\text{BeF}_2-\text{ZrF}_4$ Salt.

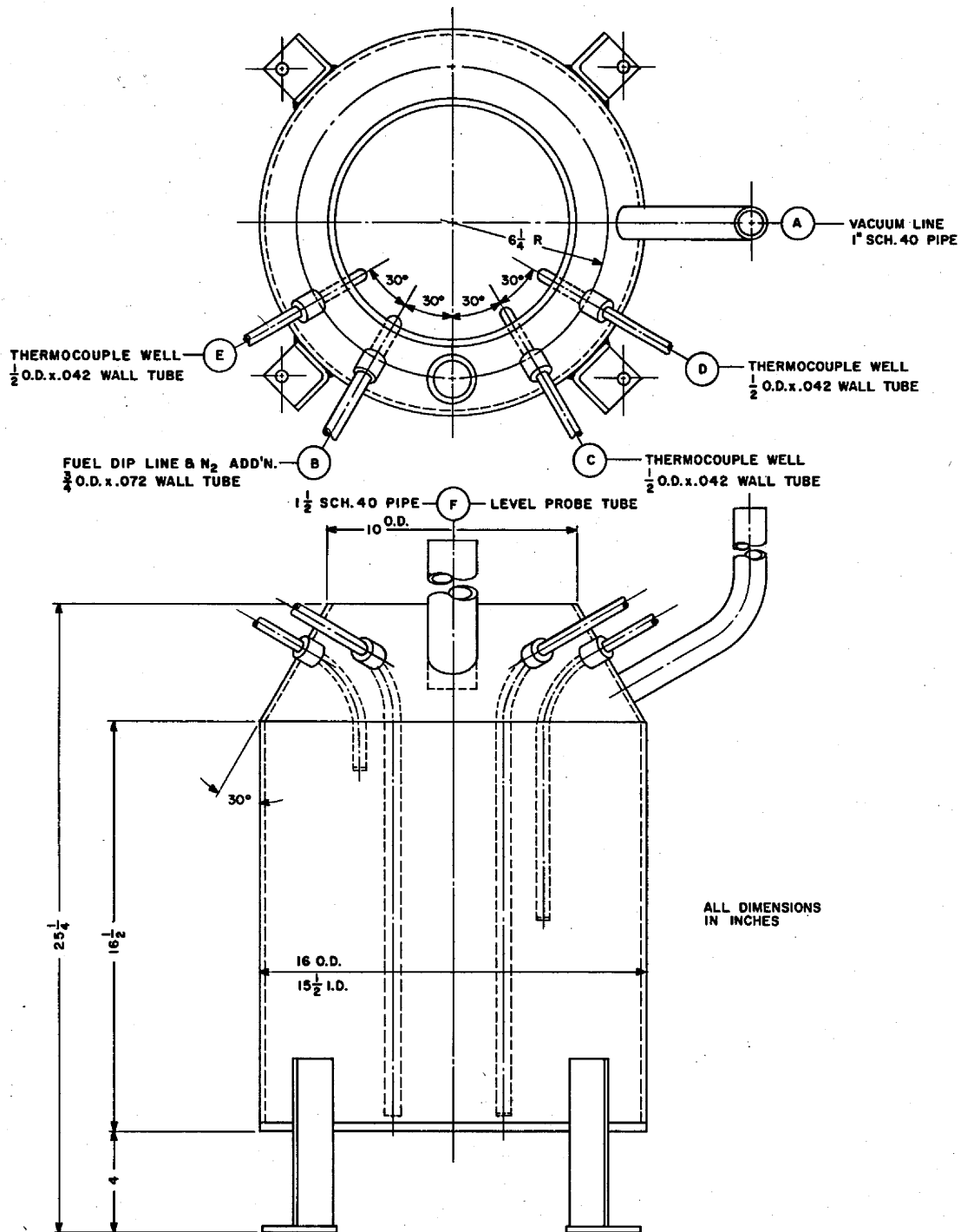


Fig. 7. Molten Salt Distillation Experiment. Schematic diagram of the condensate receiver.

Detailed design of the condensate receiver is shown on Drawing No. M-12173-CD-009-D in Appendix H.

Thermal Design

The same thermal design was used for the condensate receiver and the feed tank because the dimensions and use of the two vessels are almost identical. The receiver is surrounded on the sides and bottom by heaters rated at 20 kw, capable of heating a full charge of salt from room temperature to 500°C in about 2 hr. At operating temperature, heat loss to the surroundings through 6-in. insulation is about 1.1 kw.

The heaters are arranged so that about 6 kw are applied to the tank bottom and 14 kw to the sides.

The temperature of the condensate tank is kept just slightly above the liquidus of the contained salt so that the salt vapor pressure is negligible. A high temperature at this point would cause salt vapors to flow into the vacuum system.

Operating Pressure

Pressure in the condensate receiver must be kept lower than the vapor pressure of the salt in the still so that these vapors will flow from the still into the condenser. The receiver is kept at a pressure in the range 0.2 to 0.5 mm Hg, allowing a pressure difference of at least 0.5 mm Hg between the still and receiver.

Still and Condenser

The still and condenser are designed as a unit with the condenser's vapor inlet actually extending into the still. The still reservoir is the annular space between the vapor line and the outer wall. No provision is made for removing still bottoms from the annulus during the course of an experiment; however, a dip-tube is provided to allow removal of liquid between experiments. As shown in Fig. 8, the still and condenser are joined in an angular configuration; this was necessitated by the limited headroom in the operational area.

Design Features

The data given in Table 1 characterize the still-condenser unit and its operation. Detailed design of the unit is shown on Drawing M-12173-CD-011-D and M-12173-CD-014-D in Appendix H.

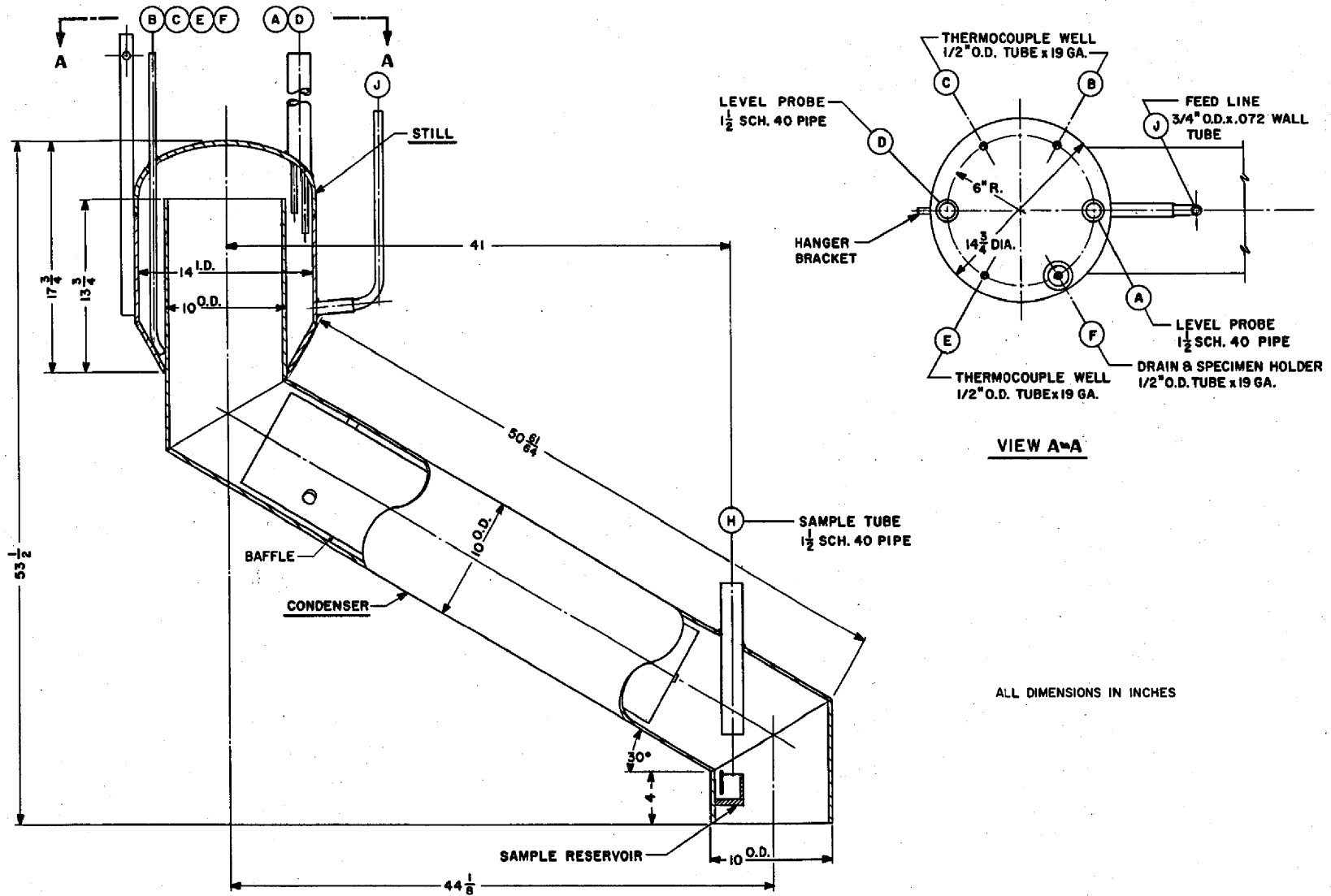


Fig. 8. Molten Salt Distillation Experiment. Schematic diagram of the vacuum still and condenser.

Table 1. Design Data for the Vacuum Still and Condenser

Still	
Material	Hastelloy N
Dimensions	14 in. diam x 16 in. high
Wall thickness	3/8 in.
Insulation thickness	8 in.
Thermal conductivity of insulation	0.1 Btu hr ⁻¹ ft ⁻¹ °F ⁻¹
Operating volume in annulus	12 liters
Depth of salt for 12-liter volume	8.08 in. (measured from top of conical bottom)
Height between high- and low-level control points	1.62 in.
Volume of salt between high- and low-level control points	2 liters
Operating temperature	900 to 1000° C
Operating pressure	0.5 to 1 mm Hg
Surface wetted by 12 liters of salt (excluding vapor line)	2.64 ft ²
Surface area of salt	0.52 ft ²
Heat flux during distillation	~ 1615 Btu hr ⁻¹ ft ⁻²
Distillation rate (calculated)	~ 5.24 × 10 ⁻⁴ g/cm ² sec
Time required to evaporate 12 liters of salt	~ 30 hr
Heater rating	15 kw
Condenser	
Material	Hastelloy N
Dimensions	10 in. OD x 51 in. long
Wall thickness	3/8 in.
Surface area (outside)	11.3 ft ²
Insulation thickness	4 in.
Thermal conductivity of insulation	0.1 Btu hr ⁻¹ ft ⁻¹ °F ⁻¹

(continued)

Table 1. (Continued)

Operating pressure	0.5 to 1 mm Hg
Operating temperature	550 to 875°C
Cooling method	Conduction through insulation to surroundings
Condenser duty	4000 to 5000 Btu/hr
Heater rating (equally divided in four zones over length)	20 kw

The still annulus is about 13 in. deep by 2 in. thick and, when charged with 12 liters of salt, will be filled within about 1.43 in. of the top. Heat for distilling the fluoride mixture is supplied by electric heaters surrounding the sides and top. The heat flux is small, being only about $1615 \text{ Btu hr}^{-1} \text{ ft}^{-2}$ at a distillation rate of $420 \text{ cm}^3/\text{hr}$. The top of the still is kept a few degrees hotter than the still liquid to preclude condensation.

In designing the still, care was used to avoid junctions that would produce large stresses in the metal parts when the unit is heated from room temperature to 1000°C . The still-condenser unit elongates about 1 in. when heated over this temperature range. The unit is supported by a cable and counterweight attached to the still so that movement is not restricted.

The condenser is made relatively large (10 in. OD) to facilitate heat loss by the greater surface area, thereby increasing the attainable distillation rate. A cylindrical core is placed inside the condenser to channel salt vapor into the annulus adjacent to the outside wall where it is condensed and cooled. Three radiation shields are placed inside this core at the high-temperature end to decrease the amount of heat received by the condenser from the 1000°C zone of the still.

Temperature Measurement

Temperature measurements are made at a number of points on the outside surfaces of the still and condenser by attaching thermocouples to these surfaces. These exterior readings should be very close to the temperatures inside the vessel because of the very low heat flux ($\sim 1615 \text{ Btu hr}^{-1} \text{ ft}^{-2}$); the calculated temperature drop across the wall is only 1.5°C . However, interior temperature measurements are made in the still liquid at three different elevations by introducing thermocouples into wells extending through the vessel head. The temperature of either a surface or interior thermocouple can be selected as the reference temperature at which the still is operated.

As to the condenser, only outside-surface thermocouples are installed and selected ones are used to control the wall temperature. There will be a temperature gradient along the length of the condenser to allow the condensed vapor to cool to a temperature of only 25 to 30°C above the liquidus as it drops into the condensate receiver. When the condensate composition is that of the MSRE carrier salt, $\text{LiF}-\text{BeF}_2-\text{ZrF}_4$ (65-30-5.0 mole %), the condenser temperature can be as low as 500°C ; but for experiments in which nearly 100 mole % LiF is distilled, the condenser surface needs to have a minimum temperature of about 875°C .

Operating Pressure and Distillation Rate

The upper limit of 1000°C on the operating temperature requires that the still pressure be no greater than 1 mm Hg during most of a distillation experiment if

vaporization is to occur. The initial salt composition has a vapor pressure of perhaps 10 mm Hg at 1000°C, but the more volatile BeF₂ quickly boils out, leaving an equilibrium mixture whose vapor pressure is about 1 mm Hg. A pressure gradient is maintained through the condenser by evacuating the condensate receiver to 0.5 mm Hg or less. The volumetric flow rate of vapor from the still to the condenser depends upon the pressure differential. The graph in Fig. 9 is a plot of the calculated flow rate of condensate as a function of the pressure at the condenser outlet. The pressure at the liquid surface in the still was taken to be 1 mm Hg, and the vapor composition was assumed to be that of MSRE carrier salt, namely, LiF-BeF₂-ZrF₄ (65-30-5 mole %). The calculations indicate that the still will have a capacity of about 400 cm³/hr when 4-in. insulation surrounds the condenser.

The same plot also shows the calculated distillation rate as a function of the temperature of the condensing surface for insulation thicknesses of 3 in. and 4 in. Satisfactory operation of the still is realized in the area to the left of these temperature curves. Although the pressure curve was calculated for vapor of MSRE carrier composition, it may be used with little error for vapors richer in LiF. For pure LiF vapor the pressure at the condenser outlet needs to be about 3.5% lower than that of MSRE carrier for comparable flow rates. However, the condensation temperature must be considerably higher (>855°C) to preclude freezing.

Heat Rejection by Condenser

As stated above, the condenser rejects the latent heat of condensation of the salt vapor by conduction through the thermal insulation to the surrounding atmosphere. For this purpose the insulation is purposely made thinner (4 in.) than on other parts of the equipment. The temperature of the condenser is maintained above the salt liquidus by providing adequate heat input to the condenser. The rate of heat rejection is directly dependent on the temperature difference between the condenser wall and the surroundings, and the curves of Fig. 10 show this relationship over the temperature range of interest in this experiment. The temperature at which the wall is held depends on the vapor composition; that is, the wall temperature must be above the liquidus yet low enough so that the vapor pressure of the condensate is small in comparison with the total pressure in the condenser. Salt of MSRE carrier composition can be condensed in the temperature range 550 to 700°C; whereas, compositions containing greater than 90 mole % LiF require condenser temperatures of 800° to 900°C.

The dashed curves in the figure give the condensation rates for a vapor of MSRE carrier composition and of pure LiF for values of the heat rejection rate. The volumetric rate for the carrier salt was calculated for condensate at a reference temperature of 600°C; for LiF the condensate temperature was taken as 875°C.

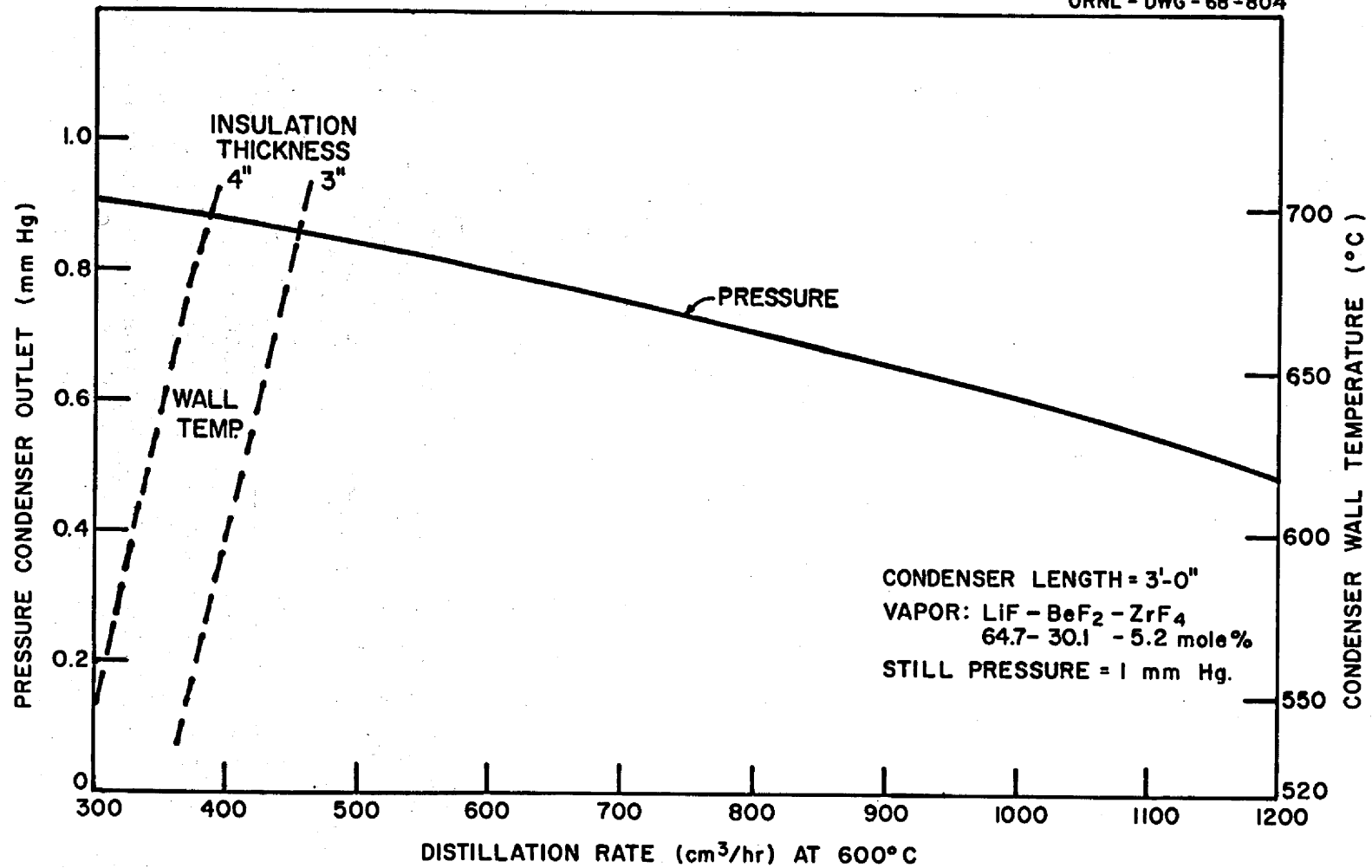


Fig. 9. Distillation Rate as a Function of Pressure at Condenser Outlet and Condenser Wall Temperature.

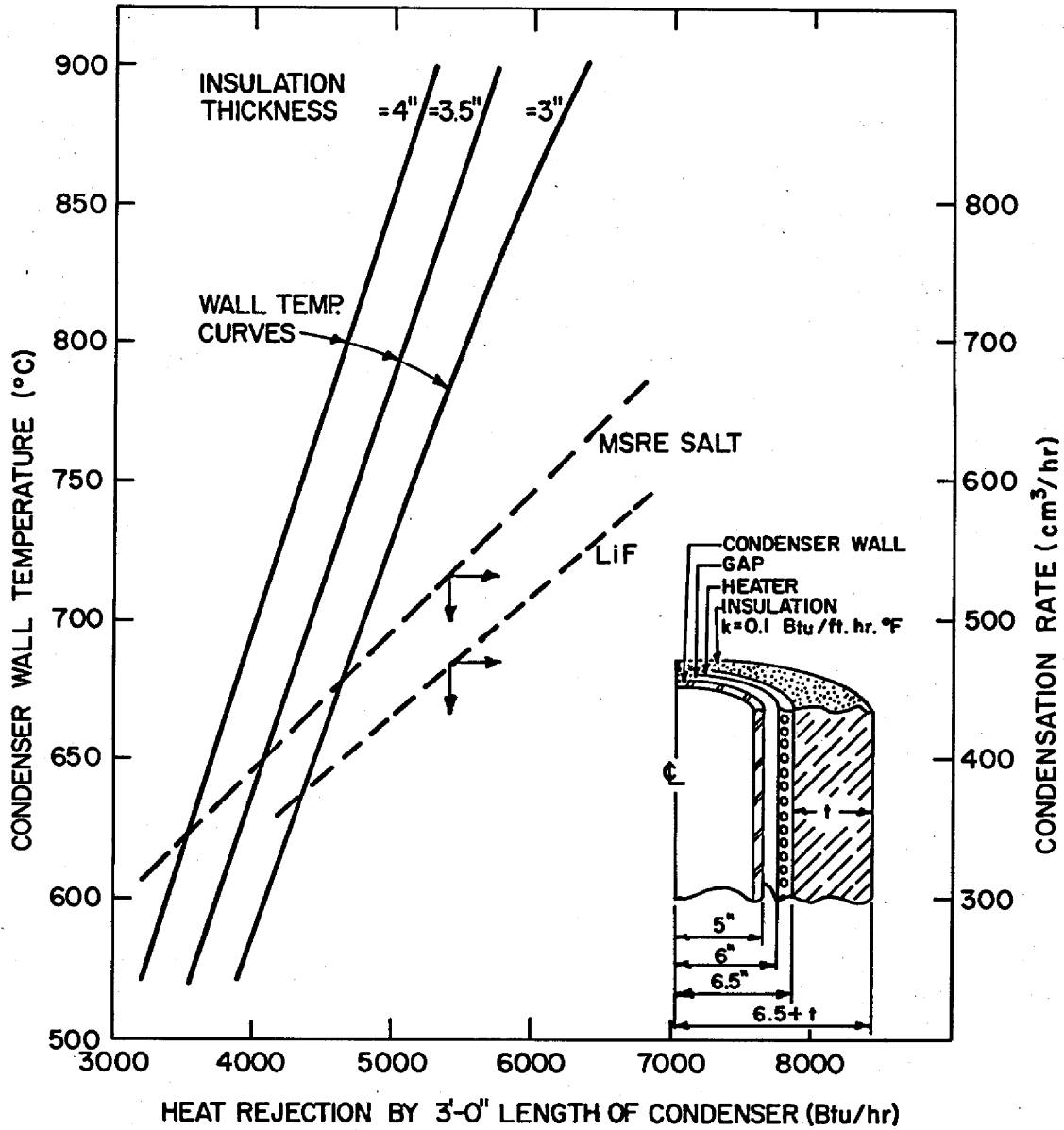


Fig. 10. Condensation Rate of MSRE Carrier Salt as a Function of Wall Temperature and Insulation Thickness.

The curves of Fig. 10 are based on an effective condenser length of 36 in.; the actual length is 51 in. The diagram on the figure depicts the wall configuration used in the calculations.

Thermal Design

The governing requirement in determining the amount of heat that should be supplied to the still and condenser is the time that can be tolerated in heating from room temperature to operating temperature. Independent calculations were made for the still section and condenser section for this transient period to find the relation between time and installed heater capacity. This relation is shown on Fig. 11. From these data arbitrary choices of 15 kw for the still and 20 kw for the condenser were made. These heat input rates will permit heating the unit to 1000°C in about 1.5 hr if desired; however, a heat-up time of 2 to 4 hr will probably be employed. The 20-kw capacity on the condenser is adequate to allow using a thinner insulation than the specified 4 in. if it is desirable to increase the distillation rate (see Figs. 9 and 10.)

In steady-state operation the heat demand by the still is only a small part of the installed capacity. For example, the vaporization of 500 cm³/hr of MSRE carrier salt requires about 1.5 kw, adding a calculated heat loss from the still of 1.1 kw, there obtains a steady state requirement of 2.6 kw. Similarly for the condenser liquefying MSRE salt at 700°C, the calculated heat loss to the surroundings is 2.1 kw. Subtracting the latent heat of vaporization of the salt (1.5 kw) gives a steady-state demand on the heaters of only 0.6 kw.

Heaters are arranged on the still so that about 11 kw are applied to the vertical sides and 4 kw to the top. Separate controls are provided so that the top can be held at a slightly higher temperature than the boiling salt to preclude condensation and refluxing. The 20 kw on the condenser are divided into four approximately equal parts covering the entire length. Each section has separate temperature control.

Cold Trap

The cold trap is inserted in the vacuum line upstream of the vacuum pump to remove mists and vapors that could impair operation of the pump. The unit is shown in Fig. 12. It is cooled by liquid N₂ in the jacket surrounding the baffled vapor chamber. Liquid N₂ additions are made manually upon a signal from a level device in the jacket. Nitrogen vapor is vented to the surroundings.

Vacuum Pump

The vacuum pump is a Cenco Hi-Vac capable of evacuating the system from atmospheric pressure to 0.5 mm Hg in about 3 hr. This time corresponds with the

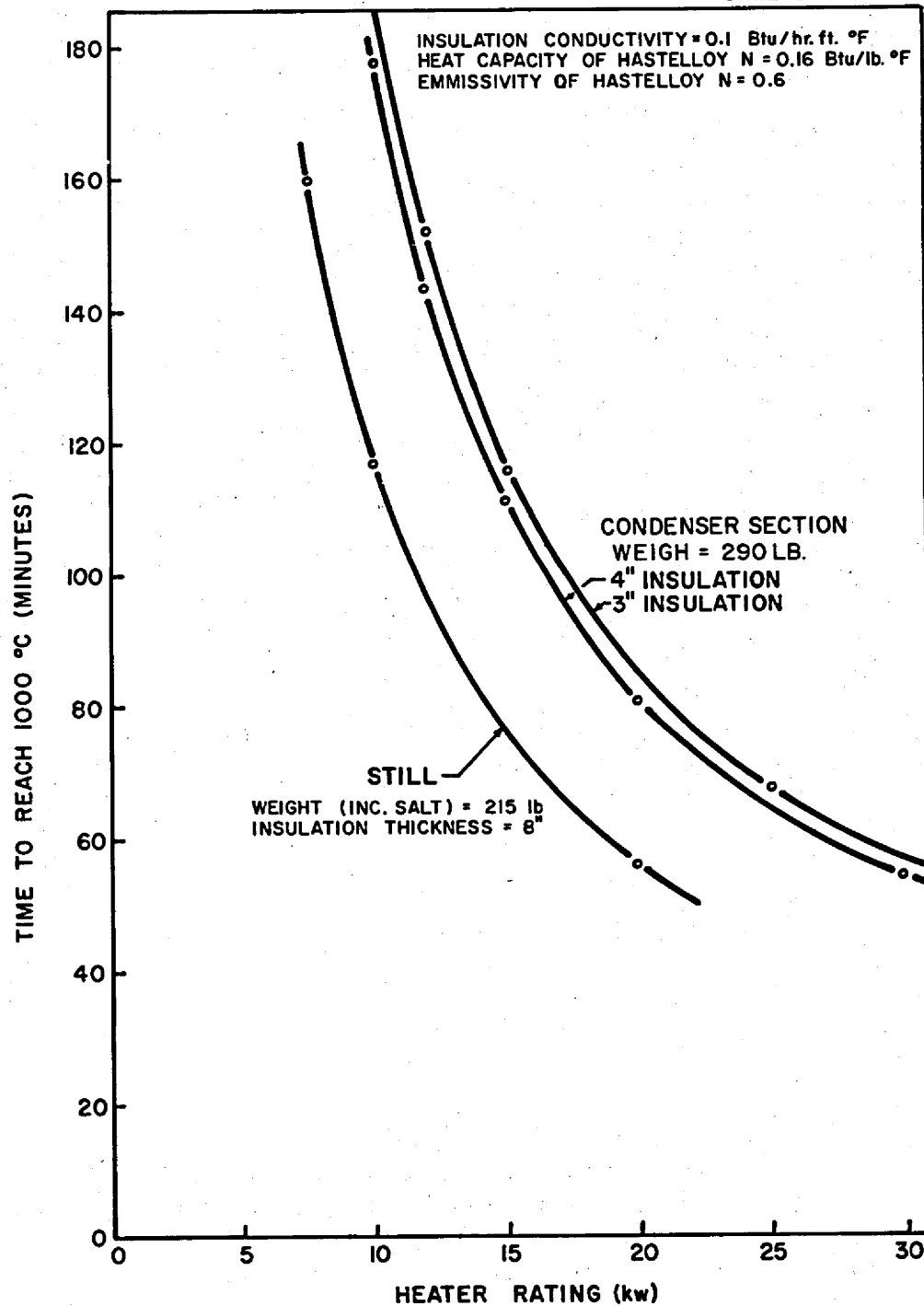


Fig. 11. Time Required to Heat Vacuum Still and Condenser from Room Temperature to 1000°C.

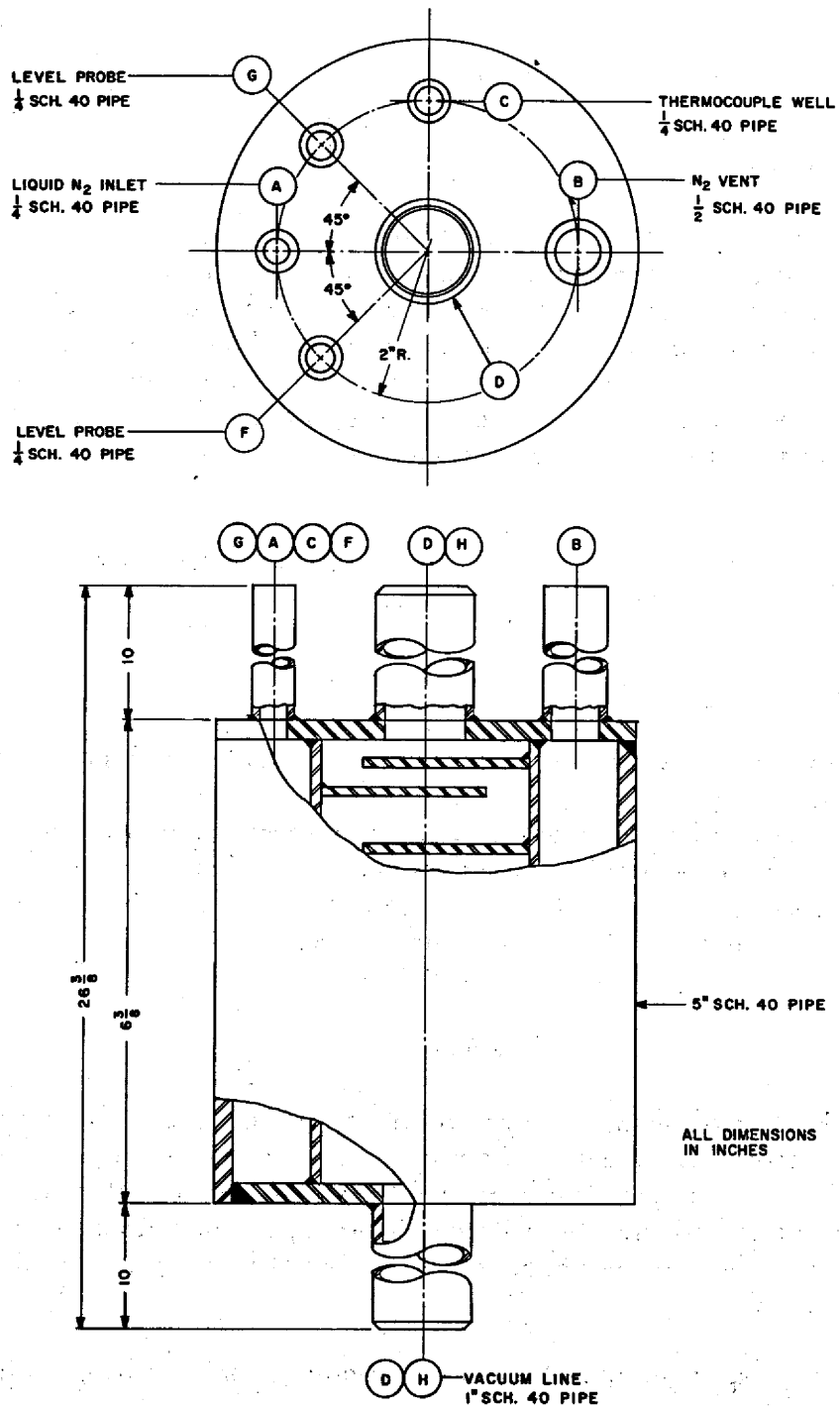


Fig. 12. Molten Salt Distillation Experiment. Schematic diagram of the liquid N₂ cold trap.

transient heat-up time for the system. Heating and evacuating would be carried out simultaneously.

Sampler

Nonradioactive Operation

The two photographs of Figs. 13 and 14 show the sampler. The unit is installed directly above the sample cup at the condenser outlet (see Fig. 8). The small line above the top valve is used to evacuate the chamber just prior to sampling; the 3/4-in.-diam by 1-3/4-in.-long capsule is then lowered by means of the crane into the sample cup, filled with molten salt, and retracted to a position above the flange. After freezing, the sample is removed for analysis by closing the lower valve and opening the flange. The frequency of sampling is limited by the time required for these operations.

This sampler was designed for use in molten salt test loop experiments and is being reactivated for this experiment.

Radioactive Operation

The same sampling device will be used to sample radioactive salt at the MSRE site when irradiated fuel is distilled. The 1-1/2-in. pipe, through which the sample capsule is lowered, will be lengthened to extend through the cell roof plugs, and shielding will be installed around the valves and flange that are above the roof plugs. A sample of condensate will be obtained as described above. The sample is then put into a shielded container for transport to the hot analytical laboratory.

Heaters

Electric heating elements are used on all vessels and lines. For the vessels, the heaters are fabricated of ceramic, refractory material in which the elements are totally embedded. The heaters were molded by the manufacturer* to fit the geometry of the vessels and to be removable without disturbing any nozzles or other connections to the equipment. All ceramic heaters are capable of holding the vessel that they surround at 1000° C.

A copy of the specifications to which the heaters were purchased is included in Appendix G.

*Cooley Electric Manufacturing Company, 50 South Shelby Street, Indianapolis, Indiana

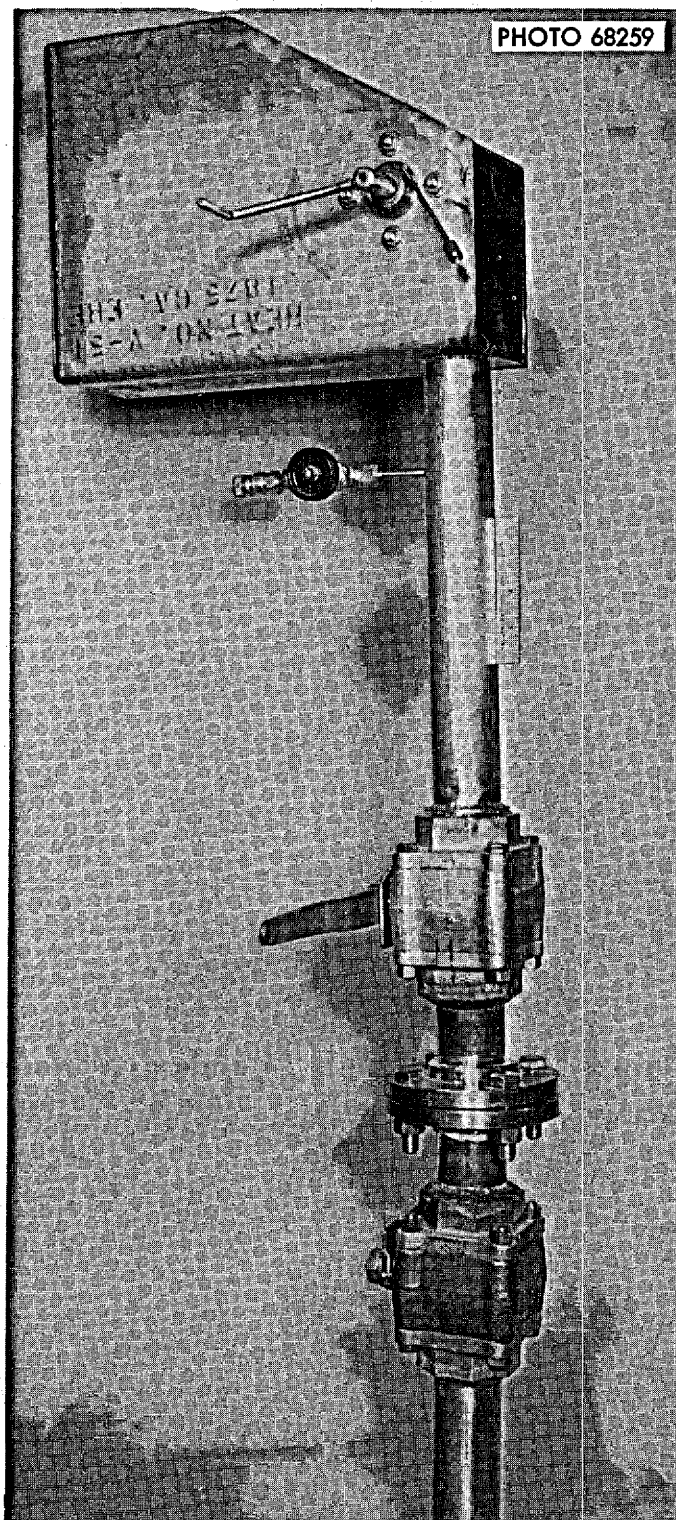


Fig. 13. Sampler for Vacuum Distillation Experiment.

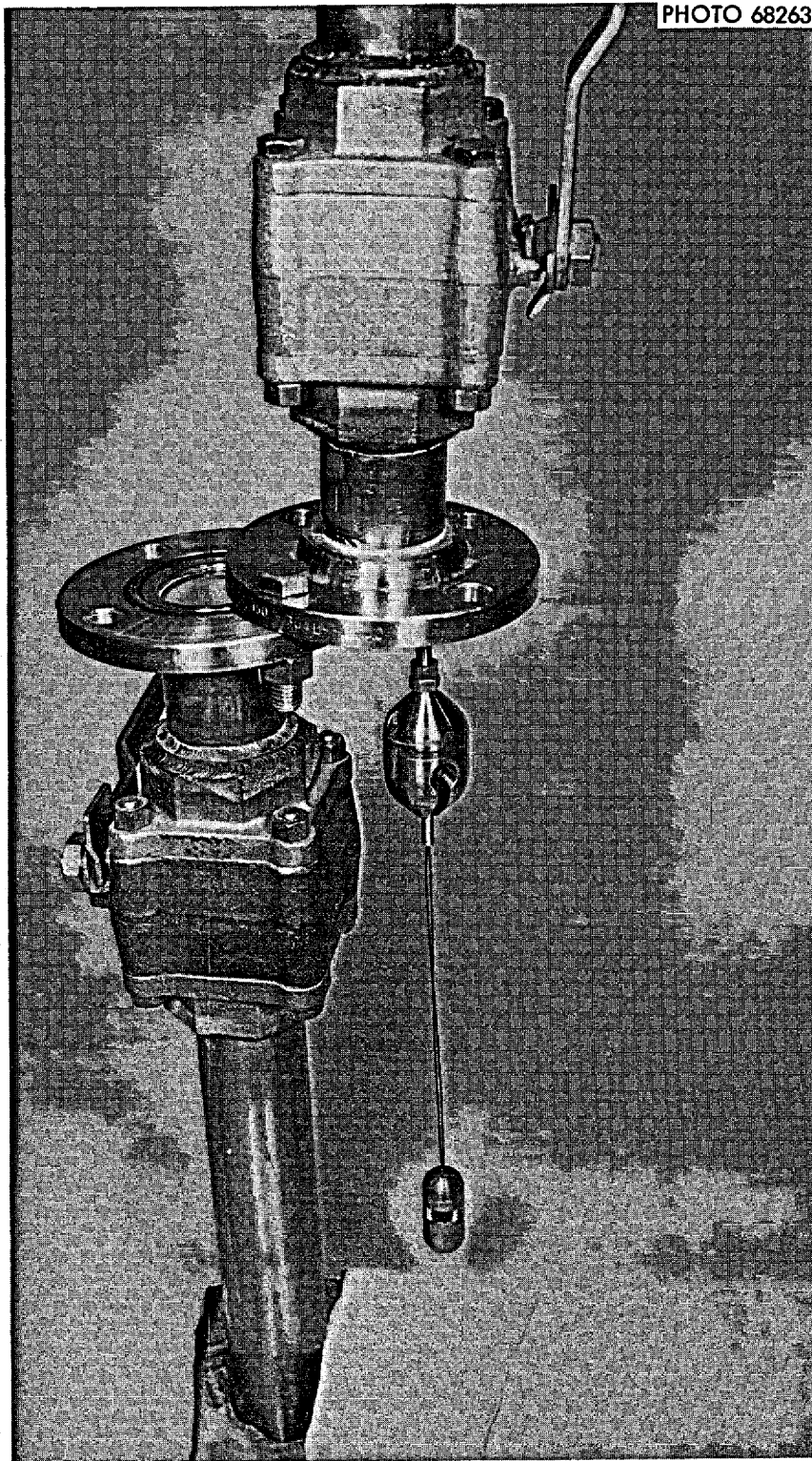


Fig. 14. View of Sampler Showing Sampling Capsule.

Wherever heat was needed on pipes or vent lines, the lines were traced with tubular electric elements.

Thermal Insulation

Two types of thermal insulation are used. Adjacent to the heaters where the temperature might be as high as 1200°C, a 2-in.-thick blanket of Fiberfrax* is used; outside this layer, Careytemp 1600** is applied to the desired total thickness. The Fiberfrax used here is Type 970-JH, having the composition 50.9% Al₂O₃, 46.8% SiO₂, 1.2% B₂O₃, 0.8% Na₂O, and 0.3% inorganics by weight. It contains no organic binders and is recommended for temperatures to 2300°F. Careytemp 1600 is an expanded silica insulation reinforced with inorganic fibers and is recommended for use to temperatures of 1600°F. Molded, segmented, cylindrical shapes are used to cover the equipment. The outside surface is finished with asbestos cement and glass cloth plus a bonding adhesive to give a glazed appearance.

The following tabulation ² lists the thermal conductivity of these insulating materials:

	Density (lb/ft ³)	Thermal Conductivity at Indicated Mean Temperature (Btu-in. hr ⁻¹ ft ⁻² °F ⁻¹)				
		<u>600° F</u>	<u>1000° F</u>	<u>1200° F</u>	<u>1400° F</u>	<u>1600° F</u>
Fiberfrax						
Blanket form	6	0.58	0.86	1.09	1.34	1.62
Paper form	12	0.48	0.69	0.83	1.0	1.27
Careytemp 1600			0.76			

METALLURGICAL CHARACTERIZATION OF HASTELLOY N

The metallurgical properties^{3,4} of Hastelloy N at elevated temperatures are well documented in the temperature range 600 to 800°C where it is commonly used. However, data in the neighborhood of 1000°C are nonexistent since there have been no previous occasions to consider the alloy for use at such a high temperature. In this experiment the still will be at about 1000°C during most of its operation, and the upper portion of the condenser will be at 800°C or higher a large part of the time. However, in light of the initial distillation work of Kelly¹ using small stills made of Hastelloy N, this alloy appeared suitable for the engineering-scale unit. Furthermore,

*A product of Carborundum Company, Niagara Falls, New York.

**A product of Philip Carey Manufacturing Company, Cincinnati, Ohio.

a time-consuming alloy developmental program would have been necessary to identify a more suitable material.

The results of an abbreviated testing program indicated that Hastelloy N should be satisfactory for a short-term experiment and gave the data that were needed to ensure a safe design. In addition, these tests revealed characteristics of Hastelloy N, which, although not of serious consequence in this short experiment, would make this alloy unsuitable for use at 1000° C in a reactor processing plant. Three such properties are the oxidation resistance, intergranular cracking, and the effect of thermal cycling on high- and low- temperature ductility.

Creep-Rupture Properties

A brief, creep-rupture program⁵ was undertaken by McCoy* to determine data at 982° C (1800° F), and the results are given in Table 2. These data were obtained on test specimens of a typical heat of air-melted Hastelloy N (Heat 5065). The specimens were small rods having a gage section 1 in. long by 0.125 in. diam.

The cumulative time that the vacuum still would be at 1000° C during the lifetime of the experiment was estimated to be 1000 hr, and it was agreed that a satisfactory design point would be one that limited the still to 1% creep over this length of time. The data of Table 2 were plotted as shown in Fig. 15 to extend the creep-rupture characteristics over the expected lifetime. The curves show that the stresses producing rupture and 5% creep over the 1000-hr period are reasonably well defined; whereas, the 1% and 2% curves, in particular, are not defined sufficiently by the experimental data. More data are needed for times greater than 100 hr. Nevertheless, the allowable design stress was chosen by extrapolating the 1% curve to 1000 hr to obtain a value of about 780 psi; this figure was rounded off on the lower side to 700 psi which was used in the design calculations.

Ductility

The ductility of Hastelloy N at 982° C (Fig. 16) exhibits a minimum for test specimens having rupture lives in the approximate range of 50 to 200 hr. The minimum ductility is slightly greater than 20%. The reduction in area decreases rapidly with increasing rupture life to a value of about 15%. The increase in the elongation for long rupture lives is thought to be associated with the extensive intergranular cracking that was observed.

*The data and discussion of this section are a summarization of the work of H. E. McCoy, Metals and Ceramics Division. His contribution to this design is gratefully acknowledged.

Table 2. Creep Properties of Hastelloy N at 982°C^a

Test No.	σ (psi)	Time to Indicated Strain (hr)					Rupture	$\dot{\epsilon}$ (%/hr)	ϵ (%)	% Reduction in Area	Remarks
		1%	2%	5%	20%						
5768	2000	35	73	185	495	644.9	0.0276	41.50	16.22	-----	
5765	3000	1	7.6	33	117	123.9	0.123	22.36	13.4	Temperature control not adequate at start of test.	
5762	4000	0.7	2.0	11	47	51.5	0.282	21.88	15.47	Temperature control not adequate at start of test.	
5761	6000	0.75	1.3	3.2	10.5	16.15	1.65	48.44	36.57	-----	
5763	10000	<0.1	0.2	0.5	1.9	2.95	9.0	50.0	37.86	-----	
5867	1880	35	72	165	407	520.8	0.026	52.0	15.6	-----	
5868	3000	12	25	60	154	157.9	0.081	22.22	15.6	-----	

^aHeat 5065 tested in the as-received condition (1/2 hr at 1176°C mill anneal).

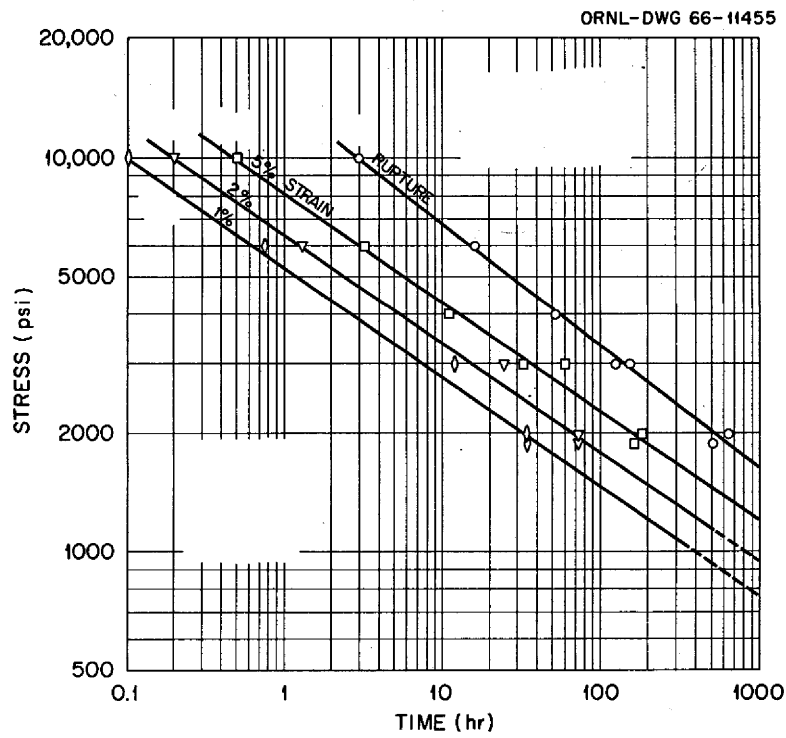


Fig. 15. Creep-Rupture Properties of Hastelloy N at 982°C Test Specimens from Heat No. 5065.

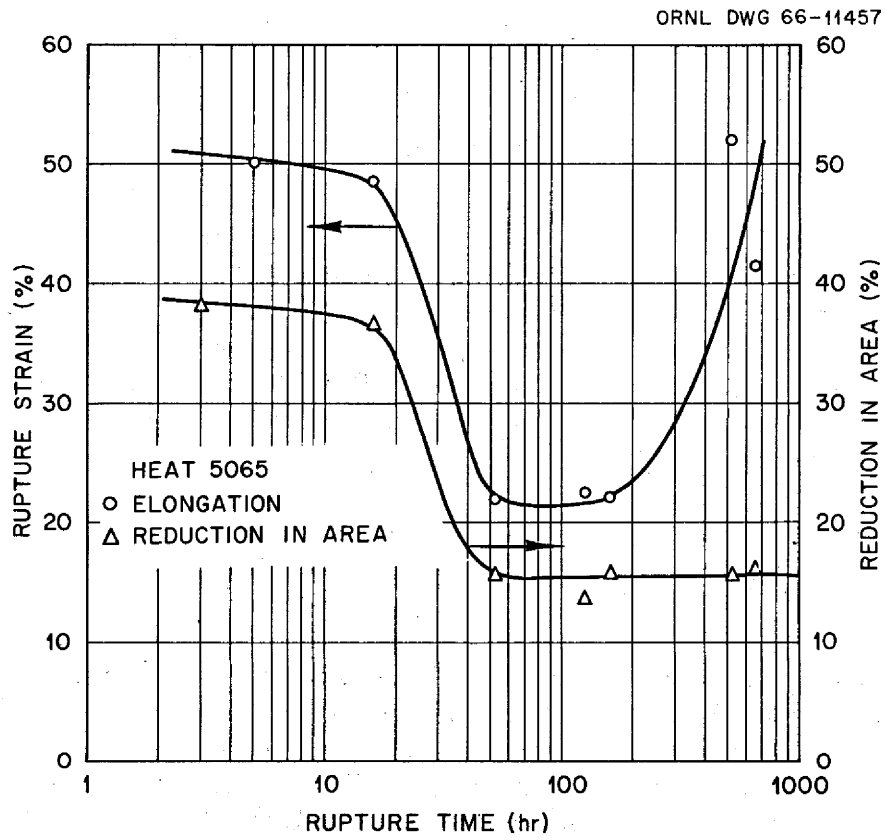


Fig. 16. Ductility of Hastelloy N at 982°C.

Metallographic Examination

Metallographic examination revealed that the quantity of precipitate after testing at 982°C and 2000 psi was much greater than that present before testing. The tested material contained larger particles of precipitate, which are thought to be induced by the thermal and mechanical history; also the smaller precipitate in the as-received metal appeared to be a different composition than that found in the tested sample. The precipitate apparently does not impair the ductility at 982°C, but its effect on low-temperature ductility was not established. This effect could be important in a vessel that undergoes a number of thermal cycles.

STRESS ANALYSIS

This experiment requires the use of Hastelloy N considerably above its usual upper temperature (600 to 700°C) in molten-salt service. To ensure the adequacy of the design, a thorough stress analysis* was made using the data of McCoy discussed in the preceding section. The principal concern was with the still-condenser unit which experiences temperature as high as 1000°C in some areas. For the feed tank and condensate receiver, which are not expected to be above 600°C, the stress analysis was confined to calculating the resistance of the flat heads to external pressure for full vacuum operation.

Vacuum Still and Condenser

This analysis was based on the 1% creep property of 700 psi allowable stress at 1000°C and the rupture property of 1650 psi at this temperature (see Fig. 15). In addition, it was assumed that the unit would undergo 50 to 100 thermal cycles during its 1000-hr lifetime. The analysis considered the stresses induced on the walls, head, and nozzle penetrations by full vacuum operation; the stresses imposed by the dead weight of the system and the method of support; and thermal stresses due to heat flux through the wall and expansion-contraction from thermal cycling.

The conclusions of this study are that:

1. the vessel be limited to a total operating life of 1000 hr and to processing nonradioactive salts;

*This section is a summary of the work of C. A. Hahs and T. W. Pickel, General Engineering and Construction Division. Mr. Hahs's detailed analysis is included in Appendix F.

2. the vessel be observed after the nonradioactive experiments to determine the effects of external oxidation and internal corrosion, and that the effects be evaluated to determine if protective measures are required;
3. before use the vessel be given a thorough inspection (ultrasonic, dimensional, photographic, visual, or other nondestructive tests) and that the initial inspection be compared with a similar inspection after the non-radioactive operation.

An inspection of the still-condenser unit will be conducted before use and compared with an inspection after the nonradioactive tests. This precaution is being taken because of the lack of experience in using Hastelloy N at these elevated temperatures, and, before use with radioactive salt, the integrity of the vessel must be ensured. Even though conclusion 1 above states that the still not be used for distilling radioactive salts, it was thought that this portion of the program was important and should not be abandoned. Consequently, the vessel will be thoroughly inspected after nonradioactive operation, and, if further integrity of the vessel is ensured, radioactive operation will proceed as planned.

The ASME Boiler and Pressure Vessel Code Sections III and VIII does not include the operating conditions specified for this equipment; the analysis was made on the basis of meeting the intent of the Code, specifically Section VIII. The final design meets the intent of the Code, and the calculated stresses are below the 700 psi allowable stress. No fatigue analysis of the vessel was made because the data for such an analysis were not available. However, the vessel will undergo a number of thermal cycles, and fatigue may be an important factor in the design. This useful information will be obtained from the experiment.

Feed Tank and Condensate Receiver

Stress calculations for these vessels were made for the flat heads only since these were the weakest areas of the two tanks. The feed tank is 15.5 in. OD by 16.5 in. high. The physical data of Appendix A, Table A-4, were used to confirm the use of 3/8-in.-thick plate for these heads in the 500 to 600° C temperature range.

INSTRUMENTATION

The vacuum distillation experiment is operated primarily from temperature and pressure measurements; to a lesser degree, level measurements are also used. There are two distinct zones over which temperature must be measured and controlled: a 500 to 600° C range for feed and condensate and an 800 to 1000° C range for the

salt in the still. Pressure is controlled at about 0.5 atm in the feed tank and in the 0.3- to 1-mm-Hg range in the rest of the system. Thermocouples are liberally employed on vessel surfaces and internally to the vessels for monitoring all areas of the equipment. Identifications and descriptions of all instruments are given in Table 3.

Temperature Measurement

For the high temperature part of the system (still and condenser) where exact temperature measurement is most important, platinum-rhodium thermocouples are used because of their high stability. Throughout the system standard Chromel-Alumel thermocouples are used for signals to the temperature controllers in order to standardize on readily available Chromel-Alumel controllers. For control in the high-temperature zones, the control points will be changed to make the Chromel-Alumel thermocouple agree with the Pt-Rh thermocouple in that zone if any temperature shift is observed. The less expensive Chromel-Alumel thermocouples are the primary units on the feed tank, condensate receiver, and salt lines; however two Pt-Rh thermocouples are installed on each tank to indicate any drift. All thermocouples are enclosed in a 1/8-in.-diam Inconel sheath, and insulated junctions are used.

Most of the thermocouples are attached to the outer surface of the vessel or pipe by inserting the junction into a tab welded to the vessel. Before installation each thermocouple is tested to ensure that its function has not been impaired. In addition to the surface thermocouples, there is one thermowell in the feed tank, four in the still, and three in the condensate receiver. These are made of 1/2-in.-OD by 0.042-in.-wall Hastelloy N tube. There is also a thermowell drilled into the base of the sample cup below the condenser for monitoring condensate temperature, since it is desirable to keep this temperature as low as practicable to avoid excessive salt vapors leaving via receiver vent.

For readout there is one 24-point recorder for the Pt-Rh thermocouples and one 24-point recorder for the Chromel-Alumel thermocouples.

The other required temperature indication is of the liquid N₂ cold trap in the condensate receiver off-gas line. There is also a liquid N₂ pressure bulb in the jacket of the cold trap to actuate an alarm at low N₂ level. Upon manual addition of liquid N₂, a high-level signal from a similar bulb actuates another alarm. A Chromel-Alumel thermocouple is used as an alternative level indication at both points.

Temperature Control

There are nine individually heated zones on the feed tank, still, condenser, and receiver. Heaters on each of these zones are controlled separately by a Pyrovane

Table 3. Identification and Description of Instrumentation

Panel Board Number	Application Number	Input Range	Output Range	Location	Scale	Function	Type of Device
1	PI-5	3-15 psig		Panel	0-20 psia	Monitor still pressure above range of PE-1	3-15 psig receiver gage
2	LI-5	3-15 psig		Panel	0-40 in. H ₂ O	Monitor condensate receiver level	3-15 psig receiver gage
3	PI-7	3-15 psig		Panel	0-10 mm Hg	Monitor sampler pressure	3-15 psig receiver gage
4	PI-2	3-15 psig		Panel	0-10 psia	Monitor Ar pressure in feed tank	3-15 psig receiver gage
5	PdI-1	3-15 psig		Panel	0-2 psia	Monitor level in feed tank by reading ΔP	3-15 psig receiver gage
6	LR-1	3-15 psig		Panel	0-40 in. H ₂ O	Monitor salt level in feed tank	Foxboro 2-Pen Pneu.-Recorder
6	LR-5	3-15 psig		Panel	0-40 in. H ₂ O	Monitor condensate level in condensate receiver	Foxboro 2-Pen Pneu.-Recorder
7	PR-1	0-14 mv		Panel	0-2 in. Hg	Monitor, record and control still vacuum	Foxboro Electric-Recorder
8	PR-2	3-15 psig		Panel	0-10 psia	Monitor and record Ar pressure in feed tank	Foxboro 2-Pen Pneu.-Recorder
8	PR-5	3-15 psig		Panel	0-20 psia	Monitor and record still pressure above range of PE-1	Foxboro 2-Pen Pneu.-Recorder
9	TR-1	0-44.9 mv		Panel	0-2000° F	Monitor various temperatures in system (Ch/Al thermocouples)	Brown 24-Pt. Recorder
10	LR-2	0-50 mv AC		Panel	8-10 in. H ₂ O	Control salt level in still	Fox. Resistance Dynalog Rec.
11	PC-1	0.2-2 in. Hg		Panel	Multirange	Monitor and transmit to PR-1 signal proportional to still vacuum	NRC Alphatron Vacuum Gauge
13	TIC-9	0-44.9 mv		Panel	0-2000° F	Control temperature of salt in feed tank	Honeywell Pyrovane
14	TR-2	0-10.7 mv		Panel	0-2000° F	Monitor various temperatures in system (Pt/Rh thermocouples)	Brown 24-Pt. Recorder
15	LR-3	0-50 mv AC		Panel	0-8 in. H ₂ O	Monitor and record low level of salt in still	Fox. Resistance Dynalog Rec.
16	LR-4	0-50 mv AC		Panel	0-20 in. H ₂ O	Monitor and record condensate level in receiver	Fox. Resistance Dynalog Rec.
17	TIC-2	0-44.9 mv		Panel	0-2000° F	Control temperature along condenser	Honeywell Pyrovane
18	TIC-3	0-44.9 mv		Panel	0-2000° F	Control temperature along condenser	Honeywell Pyrovane
19	TIC-4	0-44.9 mv		Panel	0-2000° F	Control temperature along condenser	Honeywell Pyrovane
20	TIC-6	0-44.9 mv		Panel	0-2000° F	Control temperature of condensate receiver	Honeywell Pyrovane
21	TIC-7	0-44.9 mv		Panel	0-2000° F	Control temperature of top of still	Honeywell Pyrovane
22	TIC-8	0-44.9 mv		Panel	0-2000° F	Control temperature of salt in still	Honeywell Pyrovane
23	HCO-11	0-208 VAC	0-208 VAC	Panel		Provide line heat for condensate receiver outlet line	Variac Unit
24	HCO-12	0-208 VAC	0-208 VAC	Panel		Provide line heat for line between condensate receiver and cold trap	Variac Unit

Panel Board Number	Application Number	Input Range	Output Range	Location	Scale	Function	Type of Device
25	HCO-13	0-208 VAC	0-208 VAC	Panel		Provide line heat for line between feed tank and still	Variac Unit
26	TCO-2	0-208 VAC	0-208 VAC	Panel		Control temperature along condenser	Powerstat
27	HCO-16	0-208 VAC	0-208 VAC	Panel		Provide line heat for salt feed line into feed tank	Variac Unit
28	HCO-17	0-208 VAC	0-208 VAC	Panel		Provide heat for top of feed tank	Variac Unit
29	HCO-18	0-208 VAC	0-208 VAC	Panel		Provide heat for bottom of feed tank	Variac Unit
30	HCO-19	0-208 VAC	0-208 VAC	Panel		Provide heat for bottom of condensate receiver	Variac Unit
32	TCO-3	0-208 VAC	0-208 VAC	Panel		Control temperature along condenser line	Powerstat
33	HCO-10	0-208 VAC	0-208 VAC	Panel		Provide line heat for sampler line	Variac Unit
34	TCO-4	0-208 VAC	0-208 VAC	Panel		Control temperature along condenser line	Powerstat
36	TCO-6	0-208 VAC	0-208 VAC	Panel		Control temperature of condensate receiver	Powerstat
37	HCO-14	0-208 VAC	0-208 VAC	Panel		Provide line heat for transmitter LT-1	Variac Unit
38	TCO-7	0-208 VAC	0-208 VAC	Panel		Control heat input to top of still	
39	HCO-15	0-208 VAC	0-208 VAC	Panel		Provide line heat for transmitter LT-1	Variac Unit
40	TCO-8	0-208 VAC	0-208 VAC	Panel		Control temperature of still	Powerstat
41	TCO-8	0-208 VAC	0-208 VAC	Panel		Control temperature of still	Powerstat
42	TCO-9	0-208 VAC	0-208 VAC	Panel		Control temperature of feed tank	Powerstat
43	TCO-9	0-208 VAC	0-208 VAC	Panel		Control temperature of feed tank	Powerstat
	HCV-1			Containment Cubicle		Spurge feed tank	
	HCV-2			Containment Cubicle		Vent feed tank	
	HCV-3			Containment Cubicle		Purge feed tank vent line and equalize LT-1	
	HCV-4			Containment Cubicle		Evacuate between sampler line valves	
	HCV-5			Containment Cubicle		Spurge condensate receiver	
	HCV-8			Containment Cubicle		By-pass vacuum pump	
	HCV-9			Containment Cubicle		Vacuum pump suction valve	

Panel Board Number	Application Number	Input Range	Output Range	Location	Scale	Function	Type of Device
	HCV-10			Containment Cubicle		Vacuum pump discharge valve	
	HCV-20						
	HCV-21						
	PS-1A			Panel		Provide alarm on low vacuum	Microswitch
	PS-1B			Panel		Control vacuum pump	Microswitch
	PS-2	3-15 psig		Panel		Provide alarm on high Ar pressure in feed tank	Barksdale pressure switch
	PS-5A	3-15 psig		Panel		Close FSV-1 on loss of vacuum	Barksdale pressure switch
	PS-5B	3-15 psig		Panel		Provide alarm on loss of vacuum	Barksdale pressure switch.
	PT-2		3-15 psig	Containment Cubicle		Monitor Ar pressure in feed tank	Foxboro d/p cell
	PT-5		3-15 psig	Containment Cubicle		Monitor still pressure outside range of PE-1	Foxboro d/p cell
	PT-7		3-15 psig	Containment Cubicle		Monitor sampler tube pressure	Foxboro d/p cell
	LE-2		0-50 mv AC	Still		Sense salt level at upper section of still	Special level probe
	LE-3		0-50 mv AC	Still		Sense salt level at lower section of still	Special level probe
	LE-4		0-50 mv AC	Condensate receiver		Sense level in condensate receiver	Special level probe
	XwM-2) XwM-3) XwM-4)			Panel		Supply low voltage, high frequency current (1000 cycles/sec) to LE-2, LE-3, LE-4	Hewlett-Packard Power Supply
	LS-136		Contact closure	Cold Trap		Sense N ₂ level in trap and actuate hi-level alarm	Special level switch
	LS-138		Contact closure	Cold Trap		Sense N ₂ level in trap and actuate low-level alarm	Special level switch
	PI-1			Field	0-15 psig	Indicate Ar supply pressure	Pressure indicator
	PI-3			Field	0-30 psig	Indicate control valves header pressure	Pressure indicator
	PI-6			Field	0-30 psig	Indicate Ar pressure to feed tank	Pressure indicator
	PI-7	3-15 psig		Panel	0-10 mm Hg	Indicate pressure in sampler tube	Receiver gage
	PI-9	0.2-2 in. Hg		Field	Multirange	Used for calibration check on PC-1	McLeod vacuum gage
	FC-1			Containment Cubicle		Limit Ar flow rate	Capillary

Panel Board Number	Application Number	Input Range	Output Range	Location	Scale	Function	Type of Device
	LCV-2A			Panel		Actuate LCV-2B	3-way solenoid valve
	LCV-2B			Containment Cubicle		Control level of salt in still	Pneumatic control valve
	HV-1			Panel		Argon to feed tank	Manual valve
	HV-2			Panel		Argon to condensate receiver	Manual valve
	HV-3			Field		Liquid N ₂ addition	Manual valve
	FI-1			Panel	0-10 l/min	Indicate Ar flow into feed tank	Rotameter
	FI-2			Panel	0-10 l/min	Indicate Ar flow into condensate receiver during agitation or condensate removal	Rotameter
	FSV-1			Panel		Shut off Ar supply to feed tank on loss of vacuum	Pneumatic control valve
	FSV-2			Containment Cubicle		Prevents backflow into system from off-gas system	Check valve
	FSV-3			Panel		Control FSV-1. Operates on loss of vacuum detected by PS-5A	Solenoid valve
	PV-1			Panel		Regulates Ar pressure to feed tank	Pneumatic regulator
	PV-3			Panel		Regulates air supply pressure for all pneumatic control valves	Pneumatic regulator
	LT-1	0-40 in. H ₂ O	3-15 psig	Containment Cubicle		Monitors feed tank salt level	Foxboro d/p cell
	LT-5	0-40 in. H ₂ O	3-15 psig	Containment Cubicle		Monitors condensate receiver level	Foxboro d/p cell
1-1	TA-102	Contact closure	Contact closure	Panel		Alarms on low feed tank temperature	Annunciator
1-2	TA-110	Contact closure	Contact closure	Panel		Alarms on low still feed line temperature	Annunciator
1-3	TA-134	Contact closure	Contact closure	Panel		Alarms on low condensate receiver temperature	Annunciator
1-4		Contact closure	Contact closure	Panel			Annunciator
1-5		Contact closure	Contact closure	Panel			Annunciator
1-6		Contact closure	Contact closure	Panel			Annunciator

Panel Board Number	Application Number	Input Range	Output Range	Location	Scale	Function	Type of Device
2-1	TA-112	Contact closure	Contact closure	Panel		Alarms on low still temperature	Annunciator
2-2	TA-1B	Contact closure	Contact closure	Panel		Alarms on low condenser temperature	Annunciator
2-3	TA-2B	Contact closure	Contact closure	Panel		Alarms on low condenser temperature	Annunciator
2-4	TA-3B	Contact closure	Contact closure	Panel		Alarms on low condenser temperature	Annunciator
2-5	TA-4B	Contact closure	Contact closure	Panel		Alarms on low condenser temperature	Annunciator
2-6	TA-7B	Contact closure	Contact closure	Panel		Alarms on low still temperature	Annunciator
3-1	PA-1	Contact closure	Contact closure	Panel		Alarms on low vacuum in still	Annunciator
3-2	PA-2	Contact closure	Contact closure	Panel		Alarms on high Ar pressure in feed tank	Annunciator
3-3	TA-5	Contact closure	Contact closure	Panel			Annunciator
3-4	LA-136	Contact closure	Contact closure	Panel		Alarms when liquid N ₂ trap is filled	Annunciator
3-5	LA-138	Contact closure	Contact closure	Panel		Alarms on low liquid N ₂ level in cold trap	Annunciator
3-6		Contact closure	Contact closure	Panel			Annunciator
4-1		Contact closure	Contact closure	Panel			Annunciator
4-2		Contact closure	Contact closure	Panel			Annunciator
4-3		Contact closure	Contact closure	Panel			Annunciator
4-4		Contact closure	Contact closure	Panel			Annunciator
4-5		Contact closure	Contact closure	Panel			Annunciator
4-6		Contact closure	Contact closure	Panel			Annunciator

Panel Board Number	Application Number	Input Range	Output Range	Location	Scale	Function	Type of Device
	TE-131	0-2000° F		Condensate receiver		Monitor temperature	Ch/A1
	TE-132	0-2000° F	0-10.7 mv	Condensate receiver		Monitor temperature	Pt/Rh
	TE-133	0-2000° F	0-10.7 mv	Condensate receiver		Monitor temperature	Pt/Rh
	TE-134	0-2000° F	0-44.9 mv	Condensate receiver		Monitor temperature	Ch/A1
	TE-136	0-2000° F	0-44.9 mv	Cold Trap		Alarm on high liquid N ₂ level in cold trap	Ch/A1
	TE-138	0-2000° F	0-44.9 mv	Cold Trap		Alarm on low liquid N ₂ level in cold trap	Ch/A1
	TE-141	0-2000° F	0-10.7 mv	Condenser		Monitor temperature	Pt/Rh
	TE-140	0-2000° F	0-44.9 mv	Condensate receiver Exit line		Monitor temperature	Ch/A1
	TE-1A	0-2000° F	0-44.9 mv	Condenser		Monitor temperature	Ch/A1
	TE-1B	0-2000° F	0-10.7 mv	Condenser		Monitor temperature	Pt/Rh
	TE-2A	0-2000° F	0-10.7 mv	Condenser		Control	Ch/A1
	TE-2B	0-2000° F	0-10.7 mv	Condenser		Monitor	Pt/Rh
	TE-3A	0-2000° F	0-44.9 mv	Condenser		Control	Ch/A1
	TE-3B	0-2000° F	0-10.7 mv	Condenser		Monitor	Pt/Rh
	TE-4A	0-2000° F	0-44.9 mv	Condenser		Control	Ch/A1
	TE-4B	0-2000° F	0-10.7 mv	Condenser		Monitor	Pt/Rh
	TE-7A	0-2000° F	0-44.9 mv	Still		Control	Ch/A1
	TE-7B	0-2000° F	0-10.7 mv	Still		Monitor	Pt/Rh
	TE-8A	0-2000° F	0-44.9 mv	Still		Control	Ch/A1
	TE-8B	0-2000° F	0-10.7 mv	Still		Monitor	Pt/Rh
	TE-9A	0-2000° F	0-44.9 mv	Feed tank		Control	Ch/A1
	TE-9B	0-2000° F	0-44.9 mv	Feed tank		Monitor	Ch/A1
	TE-5B	0-2000° F	0-44.9 mv			Monitor	Ch/A1
	TE-6B	0-2000° F	0-44.9 mv			Monitor	Ch/A1
	TE-139	0-2000° F	0-44.9 mv			Monitor	Ch/A1
	TE-6A	0-2000° F	0-44.9 mv			Monitor	Pt/Rh

Panel Board Number	Application Number	Input Range	Output Range	Location	Scale	Function	Type of Device
	TE-100	0-2000°F	0-44.9 mv	Feed tank		Monitor temperature	Ch/A1
	TE-101	0-2000°F	0-10.7 mv	Feed tank		Monitor temperature	Pt/Rh
	TE-102	0-2000°F	0-44.9 mv	Feed tank		Monitor temperature	Ch/A1
	TE-103	0-2000°F	0-44.9 mv	Feed tank		Monitor temperature	Ch/A1
	TE-104	0-2000°F	0-44.9 mv	Feed tank		Monitor temperature	Ch/A1
	TE-105	0-2000°F	0-10.7 mv	Feed tank		Monitor temperature	Pt/Rh
	TE-106	0-2000°F	0-44.9 mv	LT-1 line		Monitor temperature	Ch/A1
	TE-107	0-2000°F	0-44.9 mv	LT-1 line		Monitor temperature	Ch/A1
	TE-108	0-2000°F	0-44.9 mv	Still input line		Monitor temperature	Ch/A1
	TE-109	0-2000°F	0-44.9 mv	Still input line		Monitor temperature	Ch/A1
	TE-110	0-2000°F	0-44.9 mv	Still input line		Monitor temperature	Ch/A1
	TE-111	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-112	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-113	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-114	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-115	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-116	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-117	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-118	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-120	0-2000°F	0-10.7 mv	Still		Monitor temperature	Pt/Rh
	TE-122	0-2000°F	0-44.9 mv	Still		Monitor temperature	Ch/A1
	TE-123	0-2000°F	0-10.7 mv	Condenser		Monitor temperature	Pt/Rh
	TE-124	0-2000°F	0-10.7 mv	Condenser		Monitor temperature	Pt/Rh
	TE-125	0-2000°F	0-10.7 mv	Condenser		Monitor temperature	Pt/Rh
	TE-126	0-2000°F	0-44.9 mv	Condenser		Monitor temperature	Ch/A1
	TE-127	0-2000°F	0-44.9 mv	Sampler line		Monitor temperature	Ch/A1
	TE-128	0-2000°F	0-10.7 mv	Condenser		Monitor temperature	Pt/Rh
	TE-129	0-2000°F	0-44.9 mv	Condensate receiver		Monitor temperature	Ch/A1
	TE-130	0-2000°F	0-44.9 mv	Condensate receiver		Monitor temperature	Ch/A1

on-off controller. The voltage to heaters in each zone is controlled by Variacs. There are seven heated lines on which heaters are controlled by on-off, manual switches and Variacs. All heater controls are mounted on four 24-in. standard instrument racks which adjoin two additional racks containing the temperature recorders plus pressure and level instruments.

Temperature Annunciators

Each of the nine heated zones on the equipment and the salt feed line to the still are provided with low-temperature annunciators. The alarm points are set to provide indication of instrument or heater failure before the temperature falls low enough to freeze the salt.

Pressure Measurement

Feed Tank

An absolute pressure D/P cell connected to the feed tank vent line in the containment cubicle measures the pressure in the feed tank. This pressure will vary between 5 and 7 psia as the salt is pressurized into the still, the increase in pressure being caused by the decreasing level in the feed tank. Pressure in excess of 7 psia probably indicates a restriction in the still feed line.

Condensate Receiver

The pressure in the condensate receiver is used as an indication of the pressure in the still after adding the calculated ΔP through the condenser. Measurement of the pressure in the still itself was felt to be impractical because of the high temperature and because introduction of an inert purge into the still would make control of vacuum more difficult. The pressure tap for this measurement is on the 1-in. vacuum line very near the condensate receiver. Two pressure instruments are used: (1) an MKS Baratron pressure measuring device with ranges of 0 to .003, 0 to 0.01, 0 to 0.03, 0 to 0.1, 0 to 0.3, 0 to 1, 0 to 3, and 0 to 10 mm Hg; and (2) an absolute pressure D/P cell covering the range from 0 to 15 psia.

Sample Line

A pressure transmitter measures the pressure between the two valves in the 1-1/2-in. salt sample line. During operation at vacuum these valves may not seal tightly enough, and it may be necessary to maintain this pressure near the operating pressure.

Pressure Control

The system pressure is controlled by feeding argon to the inlet of the vacuum pump. The Baratron pressure instrument is used to regulate the flow.

In order to protect the still against excessive internal pressure (at high temperature, pressures in excess of 2 atm could be unsafe), the argon supply to the system will be cut off if the system pressure exceeds 1 atm. The absolute pressure transmitter in the condensate receiver off-gas line is used for this purpose.

Liquid Level Measurement and Control

Feed Tank

The pressure differential between the outlet of a dip tube extending to the bottom of the tank and the gas space above the salt is used to measure the salt level. Difference in level provides a check on the salt distillation rate. The dip-tube purge is provided by the argon which displaces the salt being fed to the still. The feed tank and condensate receiver liquid levels are transmitted to a two-pen recorder.

Still

A conductivity-type level probe (see Fig. 17) is used in the still for measuring and controlling the liquid level. This probe is similar to the single-point level probes being used in the MSRE drain tanks but with two concentric tubes instead of one for the excitation length because of the limited head room in the still. Tests have shown that a variable output is obtained over at least one-third the length of the sensing probe. A 6-in. sensing probe is therefore used to control the liquid level between 1 in. and 3 in. below the top of the annulus. The bottom joint of the two concentric tubes in the excitation length is located at this upper control point. When the salt is below this point, the control valve in the argon line to the feed tank is open and argon flows through a capillary restrictor to the feed tank. The restrictor is sized so that the gas displaces salt to the still at a rate slightly in excess of the desired distillation rate. A recorder shows the rising liquid level. When the bottom joint of the excitation length is reached, the valve closes and the level falls for about 2 hr until it reaches the bottom of the sensing probe. At this point a signal causes the valve to open to start charging salt to the still again.

A second conductivity probe with a straight excitation length extends as close as possible to the tapered bottom of the still pot. This provides salt level measurement during the final boildown.

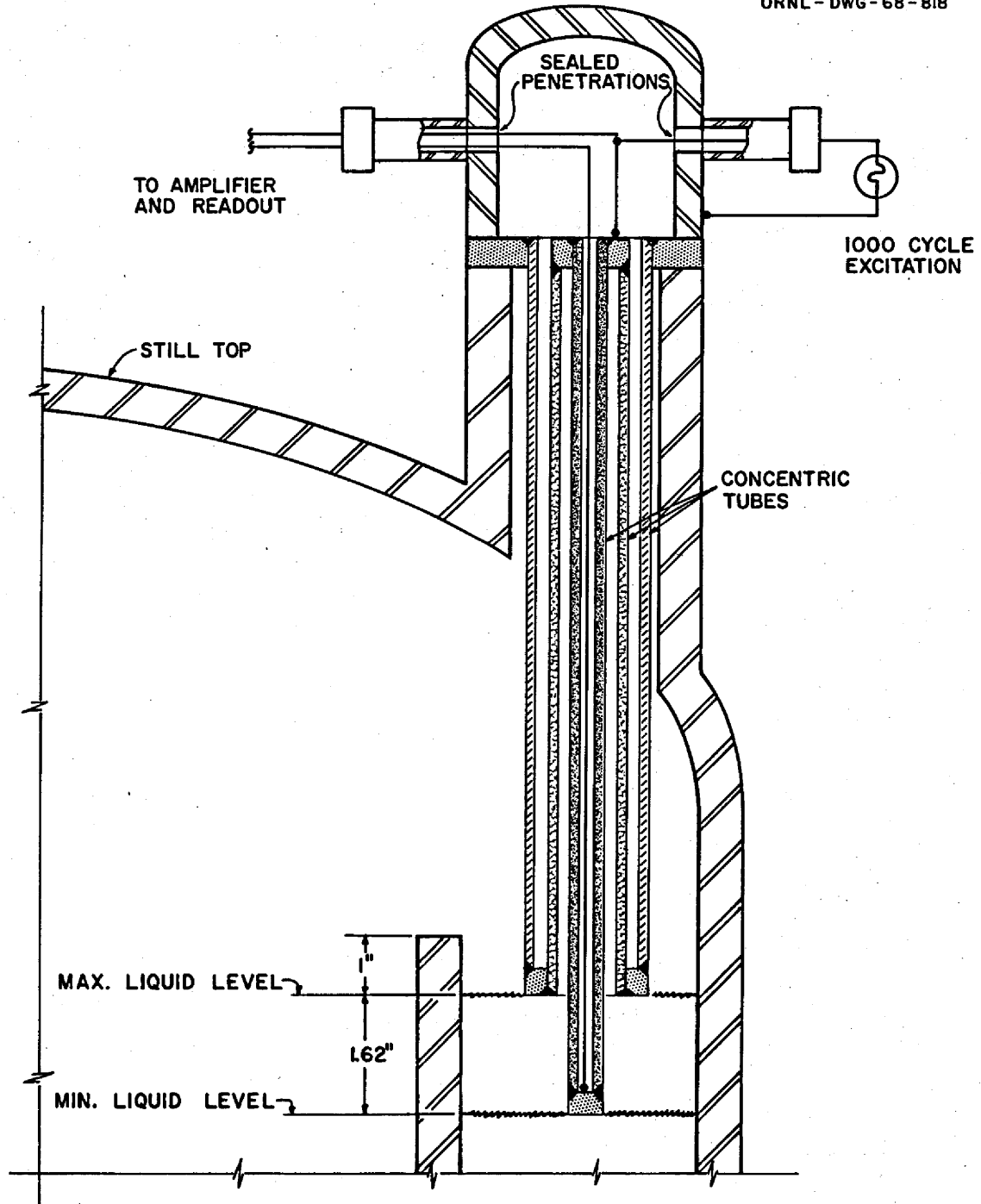


Fig. 17. Liquid Level Probe.

Condensate Receiver

A third conductivity probe is installed in the condensate receiver to permit following the distillation rate. The probe is long enough to provide continuous measurement for the entire volume of the tank. It was felt that the alternate choice of a continuous bubbler-type instrument would require too much purge gas, causing excessive pressure drop in the line to the vacuum pump. A bubbler-type instrument, however, is installed for periodic checks and calibration of the conductivity probe.

PREOPERATIONAL INSPECTION

The use of Hastelloy N at temperatures of 800 to 1000°C is not well enough known to predict the condition of the vacuum distillation equipment after extended periods of operation. Since the second phase of the experiment involves the use of radioactive materials, it will be necessary to thoroughly inspect the vessel after non-radioactive operation. The basis or reference for this inspection is a set of radiographic observations plus direct and ultrasonic dimensional measurements made on the assembled equipment before initial operation.*

An inspection program was planned that completely described the still, condenser and condensate receiver assembly. As shown on drawings No. M-12173-CD-019D, M-12173-CD-020D, and M-12173-CD-021D of Appendix H, a mapping of 247 points for radiographic and ultrasonic measurements of wall thickness is specified on the vessel surfaces. In addition, locations in the form of center-punched tabs are provided for 55 length and diameter measurements. Data points are concentrated in regions where highest material stresses are expected.

The referenced drawings contain a record of the initial measurements, showing that thicknesses were measured to the nearest 0.001 in. and linear measurements to the nearest 1/32 in. Because of equipment and geometrical limitations, it was not possible to check every ultrasonic measurement with a direct measurement. Length and diameter measurements were made after the unit had been installed in supporting framework at the location where it was to be operated. This precaution precluded a measurement bias due to handling and transport.

After nonradioactive operation, insulation and heaters will be removed, and all measurements and observations will be repeated. The new data will be recorded on the referenced drawing for easy comparison with initial values. At that time the suitability of the equipment for further experiments will be decided.

*Inspections and measurements were made by R. M. Fuller and co-workers of the Inspection Engineering Division.

EQUIPMENT INSTALLATION

Unitized Construction

The entire distillation unit consisting of the feed tank, still, condenser, condensate receiver, and cold trap with the associated heaters, insulation, and thermocouples is installed in a 3 ft x 6 ft 4 in. x 8 ft-high angle-iron frame designed to be moved as a unit. The base supports for the feed tank and condensate receiver are bolted to the bottom of the frame. The still is supported by a counter weight on a pulley to allow for thermal expansion during operation but will be rigidly supported while in transit. The cold trap, being small, is supported by the 1-in. vent line from the condensate receiver. An electrical junction box and two thermocouple junction boxes are provided on the frame.

Hood Installation

The distillation unit will be installed in a walk-in hood, 4 ft 4 in. x 8 ft x 9 ft high, located in Building 3541, for nonradioactive operation. The 12-ft-long instrument and heater control panel, the containment cubicle for D/P cells, remote valves, and the vacuum pump are mounted near the hood. The vacuum pump discharges through absolute filters. The directly operated sampler, described above, is located inside the hood. Nonradioactive operation will test all of the equipment to be used in the radioactive demonstration.

Cell Installation

At the completion of nonradioactive testing, the unit will be thoroughly inspected to determine its suitability for radioactive operation. If this inspection is affirmative, all electrical, instrumentation, and piping connections will be broken and the unit moved to Building 7503. The unit will be installed in the spare cell to the east of the fuel processing cell, as shown in Figs. 18 and 19. Electrical and thermocouple leads will be brought through penetrations in a roof plug to the high-bay area over the cell where control panels are located. These panels contain heater controls, temperature recorders, and pressure and level readout instruments.

Salt is charged to the feed tank through line No. 112, which is connected to the fuel storage tank and contains a freeze valve. All other piping connections including the sample line passes through a roof plug to the high-bay area where the sampler, vacuum pump, liquid N₂ supply, and instrumentation are located.

Additional concrete shielding will be provided in the cell surrounding the unit to prevent excessive radiation in the operating areas to the east and south of the cell.

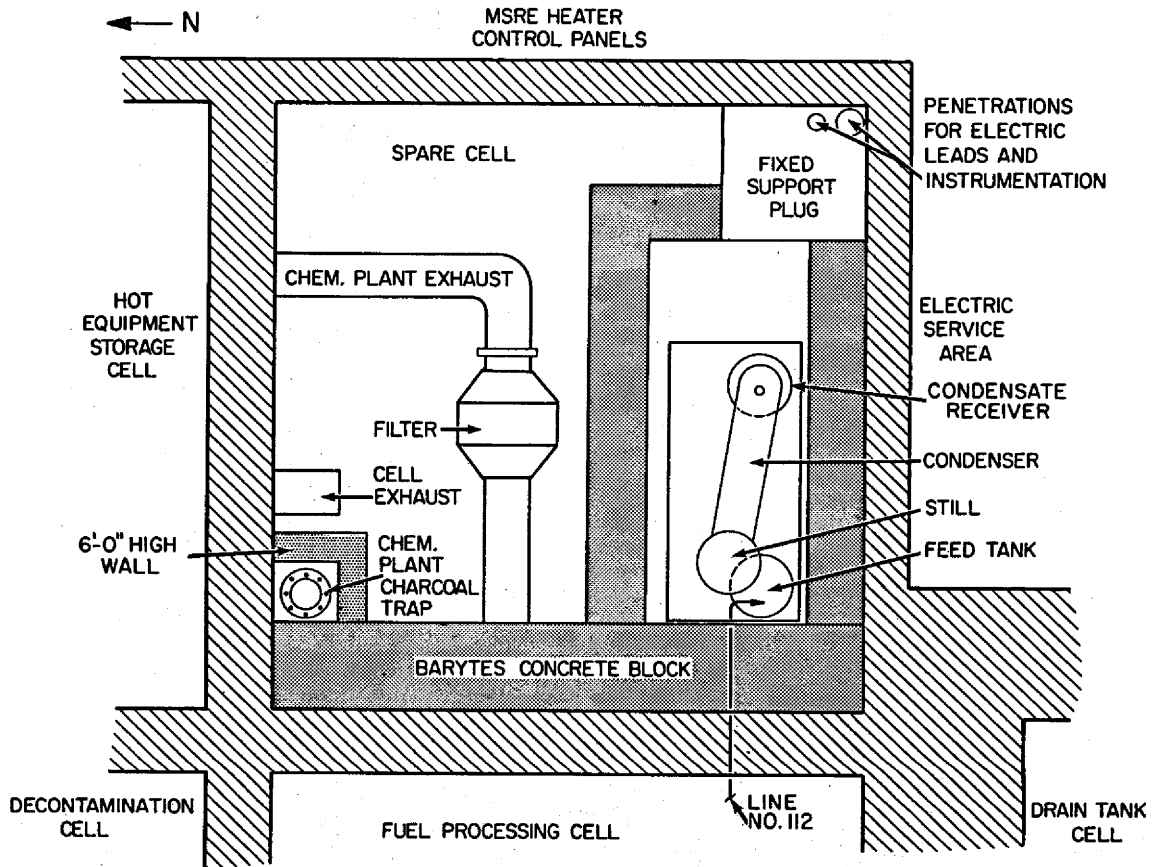


Fig. 18. Layout of MSRE Spare Cell.

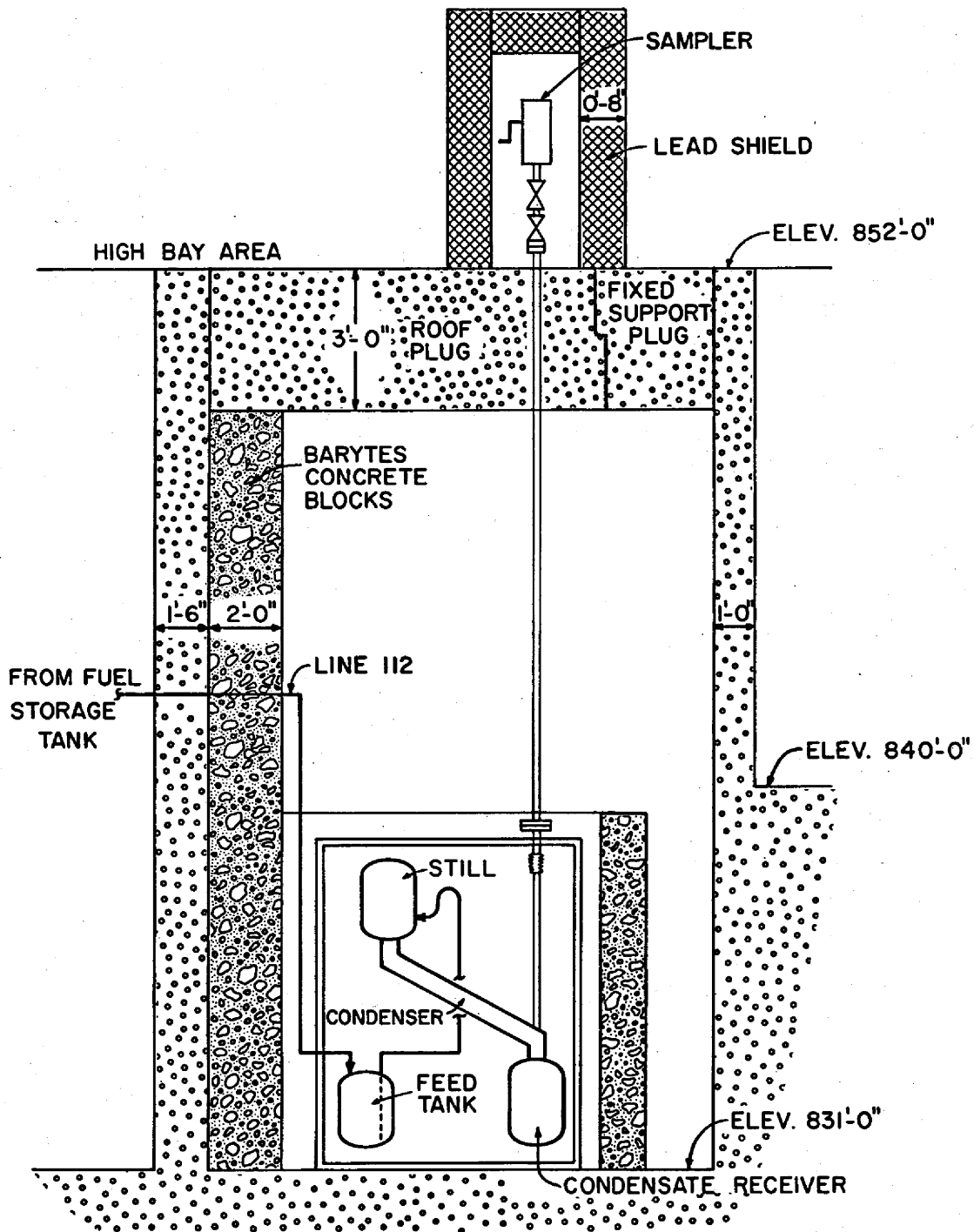


Fig. 19. South Elevation of MSRE Spare Cell Showing Distillation Unit and Sampler Locations.

Since the salt will have been fluorinated before distillation, no volatile activities are expected to pass through the liquid N₂ trap. The vent from this trap and the three instrument lines for pressure measurements in the feed tank and receiver are routed to a sealed, monitored cubicle in the high-bay area. This cubicle contains all equipment and instruments that are connected directly to the process equipment (vacuum pump, control valves, and instrument transmitters) as shown in Fig. 20. In case of activity backup in the lines, a radiation alarm will indicate the difficulty and the lines or cubicle can be purged. The top and one side of the cubicle is sealed with a gasketed, removable cover to facilitate maintenance.

FINAL DISPOSITION

At the end of the radioactive salt distillation, the salt will be distilled until the level is just below the low-level probe. All heat will then be turned off the equipment and the salt allowed to freeze in the still and the receiver. The feed tank will have been emptied as much as possible. The vacuum pump will be turned off and the system allowed to reach atmospheric pressure and temperature under an argon blanket.

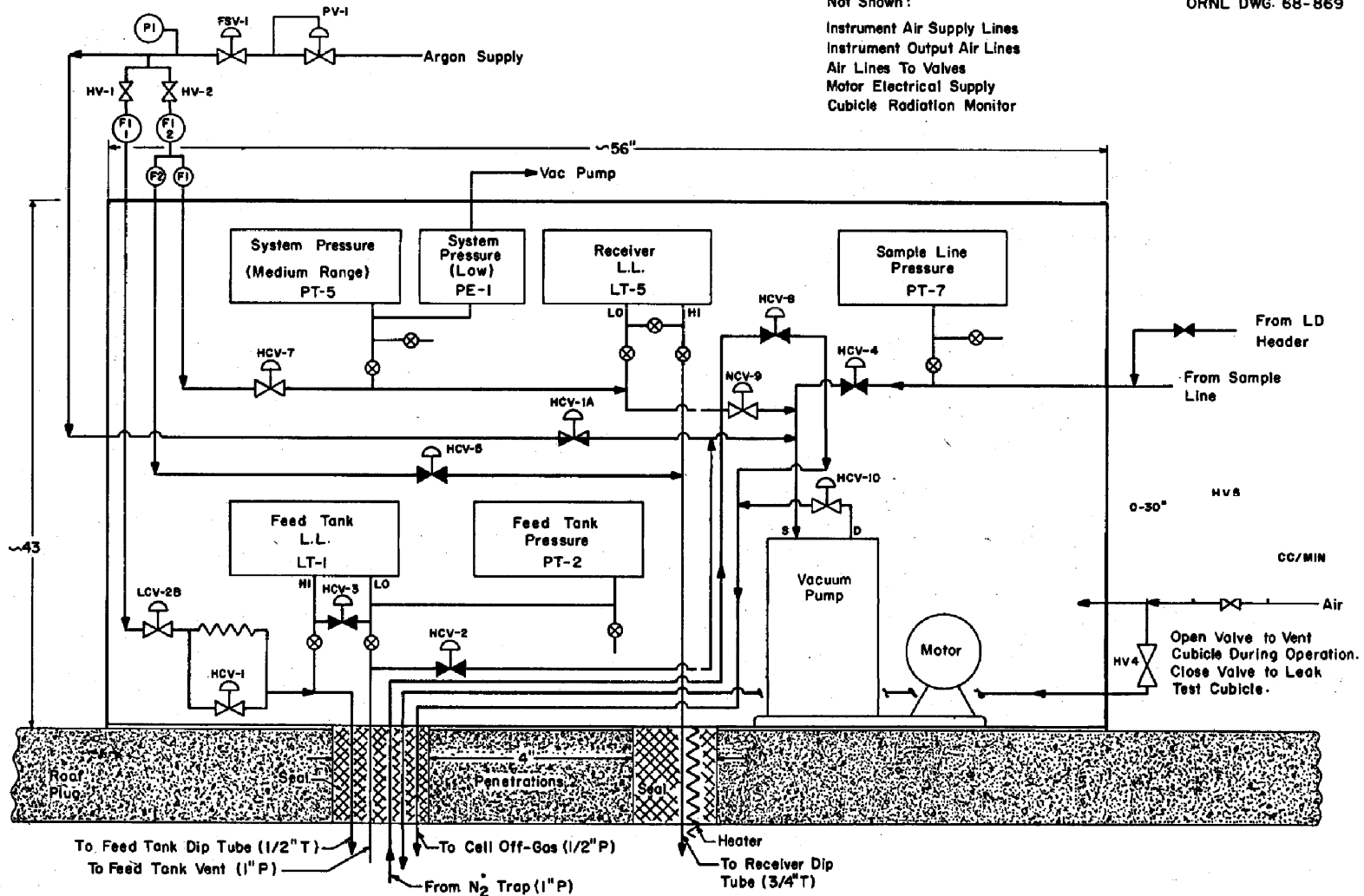
The level probe line to the receiver is heated and insulated and can be used to remove a composite sample (or the entire amount of condensate). In that case a shielded, sample-transport cask will be connected to the line in the high-bay area and the salt pressurized from the receiver.

After the system is cool, all electrical and thermocouple leads will be severed as close to the unit as possible. The flanged lines will be disconnected and blanked; tubing lines will be cut and crimped. The entire unit will be removed from the cell using remote maintenance techniques and taken to a burial ground for storage.

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Not Shown:
 Instrument Air Supply Lines
 Instrument Output Air Lines
 Air Lines To Valves
 Motor Electrical Supply
 Cubicle Radiation Monitor

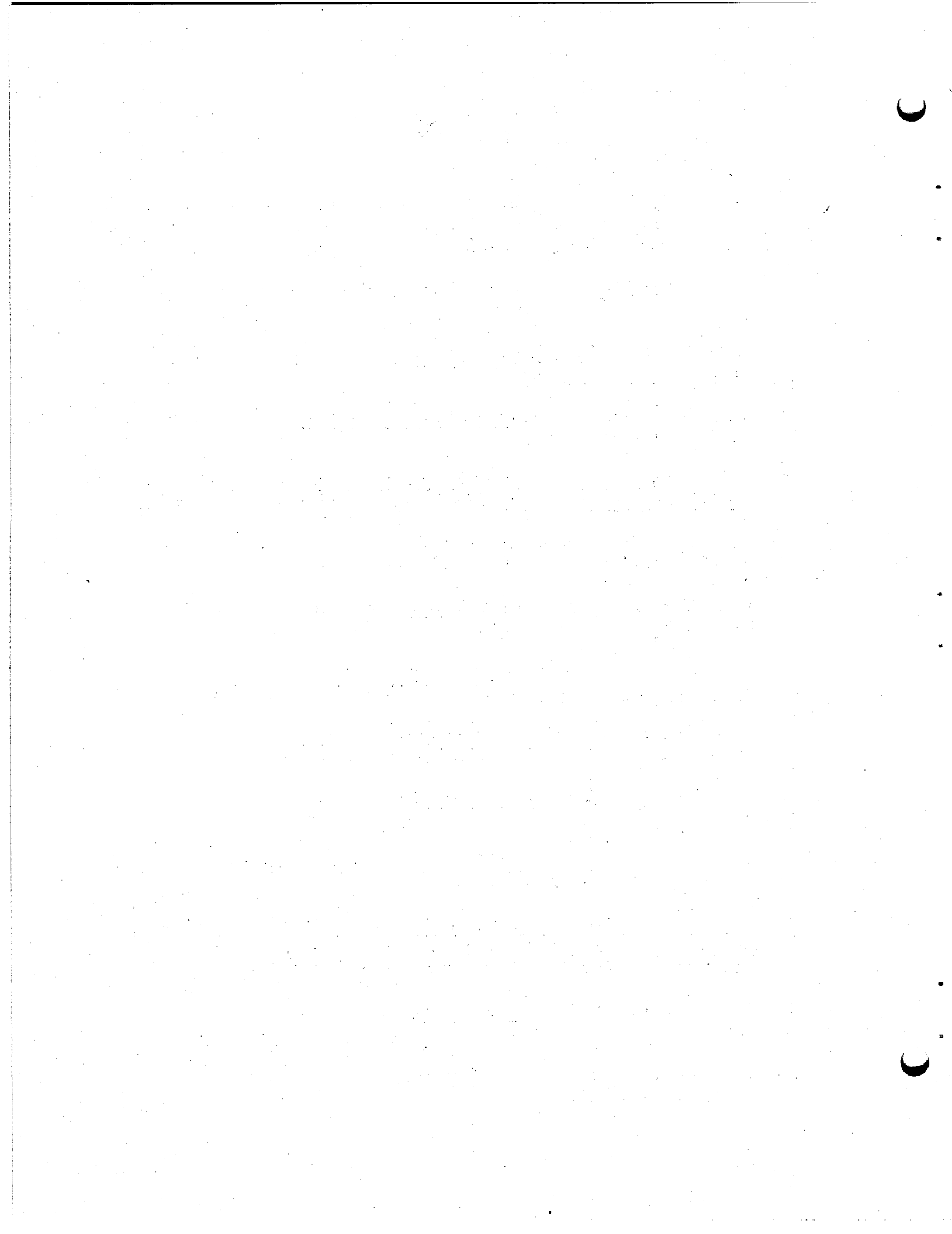


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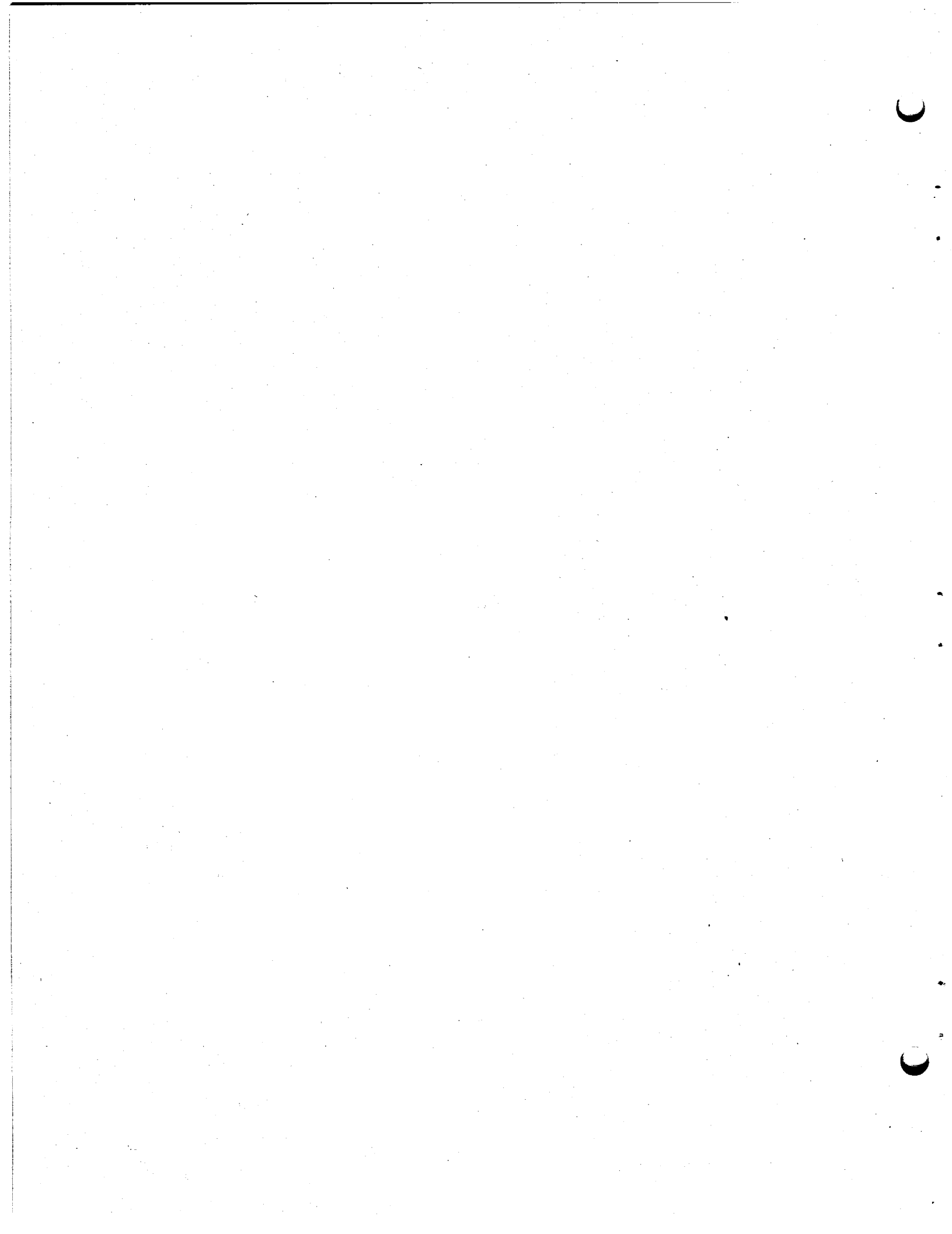
Fig. 20. Diagram of Sealed Cubicle.

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APPENDICES



APPENDIX A

Physical Properties of Hastelloy N

Table A-1	Chemical Composition
Table A-2	Density and Melting Range
Table A-3	Thermal Conductivity
Table A-4	Modulus of Elasticity
Table A-5	Specific Heat
Table A-6	Mean Coefficient of Thermal Expansion
Table A-7	Mechanical Properties

Table A-1. Chemical Composition

	Weight %
Nickel	Balance (~66-71)
Molybdenum	15.0 to 18.0
Chromium	6.0 to 8.0
Iron, max.	5.0
Titanium plus Aluminum, max.	0.50
Sulfur, max.	0.02
Manganese, max.	1.0
Silicon, max.	1.0
Copper, max.	0.35
Boron, max.	0.010
Tungsten, max.	0.50
Phosphorus, max.	0.015
Cobalt, max.	0.20
Vanadium, max.	0.5
Carbon	0.04 to 0.08

Table A-2. Density and Melting Range

Density at 25° C, g/cm ³	8.79
lb/in. ³	0.317
Melting range, °F	2470 to 2555
°C	1353 to 1400

Table A-3. Thermal Conductivity

Temperature (°F)	Btu ft hr ⁻¹ ft ⁻² °F
212	6.600
400	7.409
600	8.293
800	9.160
1000	10.37
1050	10.81
1100	11.10
1150	11.41
1200	11.71
1250	12.02
1300	12.68
1350	13.26
1400	13.55

Table A-4. Modulus of Elasticity

Temperature (°F)	psi × 10 ⁻⁶
57	31.7
430	29.3
770	27.8
930	27.1
1070	26.3
1170	26.2
1290	24.8
1470	23.7
1570	22.7
1660	21.9
1750	20.7
1800	19.7
1830	19.1
1920	17.7

Table A-5. Specific Heat

Temperature (°F)	Btu lb ⁻¹ °F ⁻¹
140	0.0977
212	0.1005
392	0.1052
572	0.1091
752	0.1120
896	0.1139
1004	0.1155
1058	0.1248
1094	0.1347
1148	0.1397
1220	0.1387
1256	0.1384
1292	0.1380

Table A-6. Mean Coefficient of Thermal Expansion

Temperature (°F)	in./in.-°F	ΔT (°F)	$\Delta L/L$ (in./in.)
70-400	6.45×10^{-6}	330	2.13×10^{-3}
70-600	6.76×10^{-6}	530	3.58×10^{-3}
70-800	7.09×10^{-6}	730	5.18×10^{-3}
70-1000	7.43×10^{-6}	930	6.81×10^{-3}
70-1200	7.81×10^{-6}	1130	8.83×10^{-3}
70-1400	8.16×10^{-6}	1330	10.85×10^{-3}
70-1600	8.51×10^{-6}	1530	13.02×10^{-3}
70-1800	8.85×10^{-6}	1730	15.31×10^{-3}

Table A-7. Mechanical Properties

Temp. (°F)	1/4 Min. Spec. Tensile Strength (psi)	2/3 Min. Spec. Yield Strength (psi)	4/5 Rup. Str. for 10 ⁵ hr (psi)	Stress for 0.1 CRU (psi)	Max. Allow. Stress (psi)
0 - 100	25,000	26,700	-	14,500	25,000
200	24,400	24,100	-	-	24,000
300	23,900	22,800	-	-	23,000
400	23,500	21,700	-	-	21,000
500	23,100	20,800	-	-	20,000
600	22,700	20,000	-	-	20,000
700	22,250	19,300	-	-	19,000
800	21,800	18,700	-	-	18,000
900	21,200	18,150	18,150	-	18,000
1000	20,500	17,650	16,000	-	17,000
1050	19,900	17,400	14,500	-	-
1100	19,100	17,200	12,400	14,500	13,000
1150	18,100	17,000	10,400	10,200	-
1200	17,100	16,800	8,300	7,400	6,000
1250	16,100	16,600	6,200	5,400	-
1300	15,000	16,400	4,800	4,100	3,500
1350	13,800	16,300	3,600	3,100	-
1400	12,700	16,200	2,900	2,400	1,900

Physical Properties of LiF, BeF₂, ZrF₄ and Their Mixtures

Fig. B-1	Calculated Densities of Molten LiF, BeF ₂ , and ZrF ₄
Fig. B-2	Density-Temperature Curves for LiF-BeF ₂ -ZrF ₄ Mixtures
Fig. B-3	Vapor Pressure-Temperature Relationships for LiF, BeF ₂ , ZrF ₄ , and Their Mixtures
Fig. B-4	Calculated Viscosity of LiF-BeF ₂ -ZrF ₄ Vapor
Table B-1	Latent Heat of Vaporization of LiF, BeF ₂ , ZrF ₄ , and Their Mixtures
Table B-2	Thermal Properties of MSRE Salt A

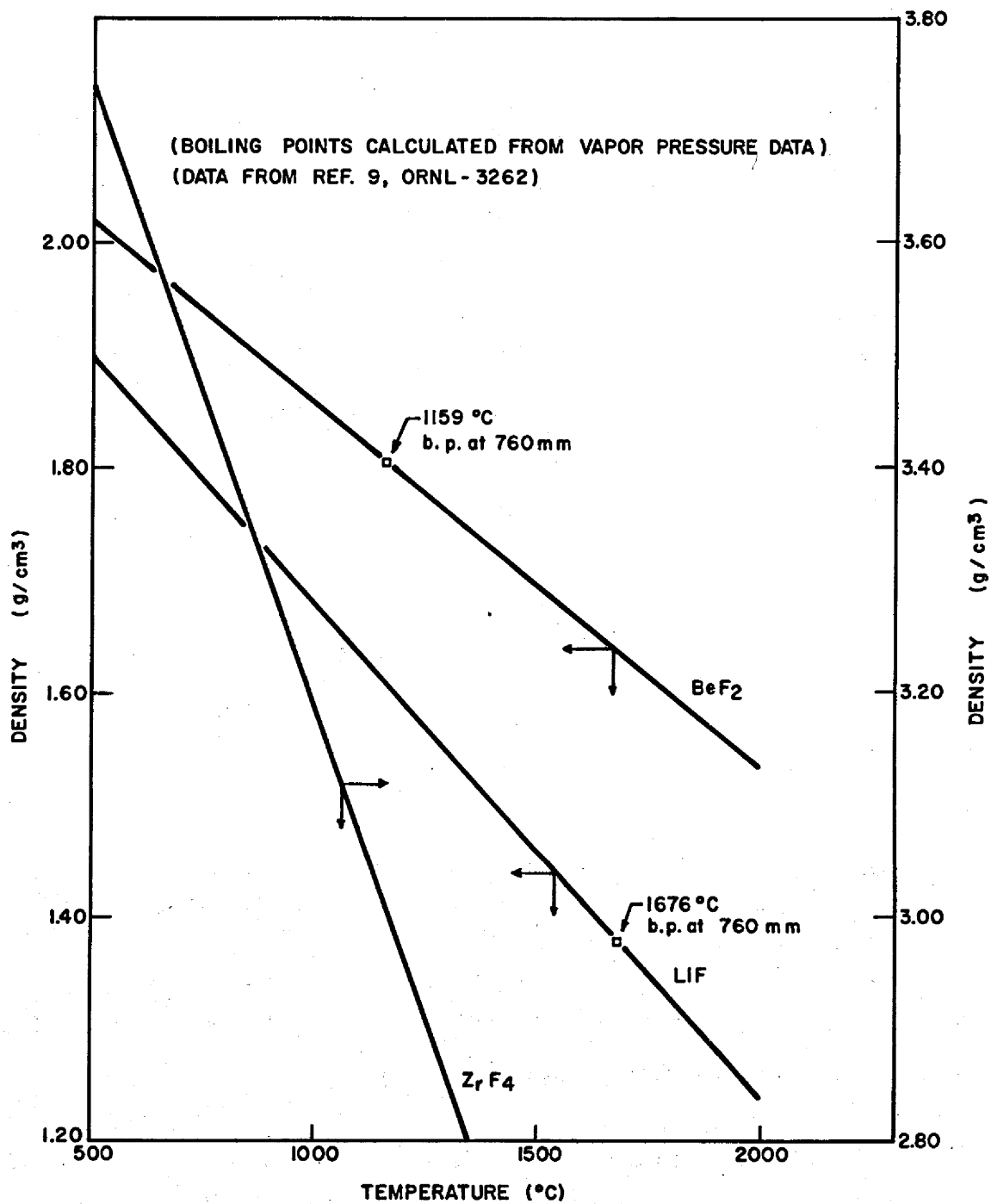


Fig. B-1. Calculated Densities of Molten LiF, BeF, and ZrF₄.

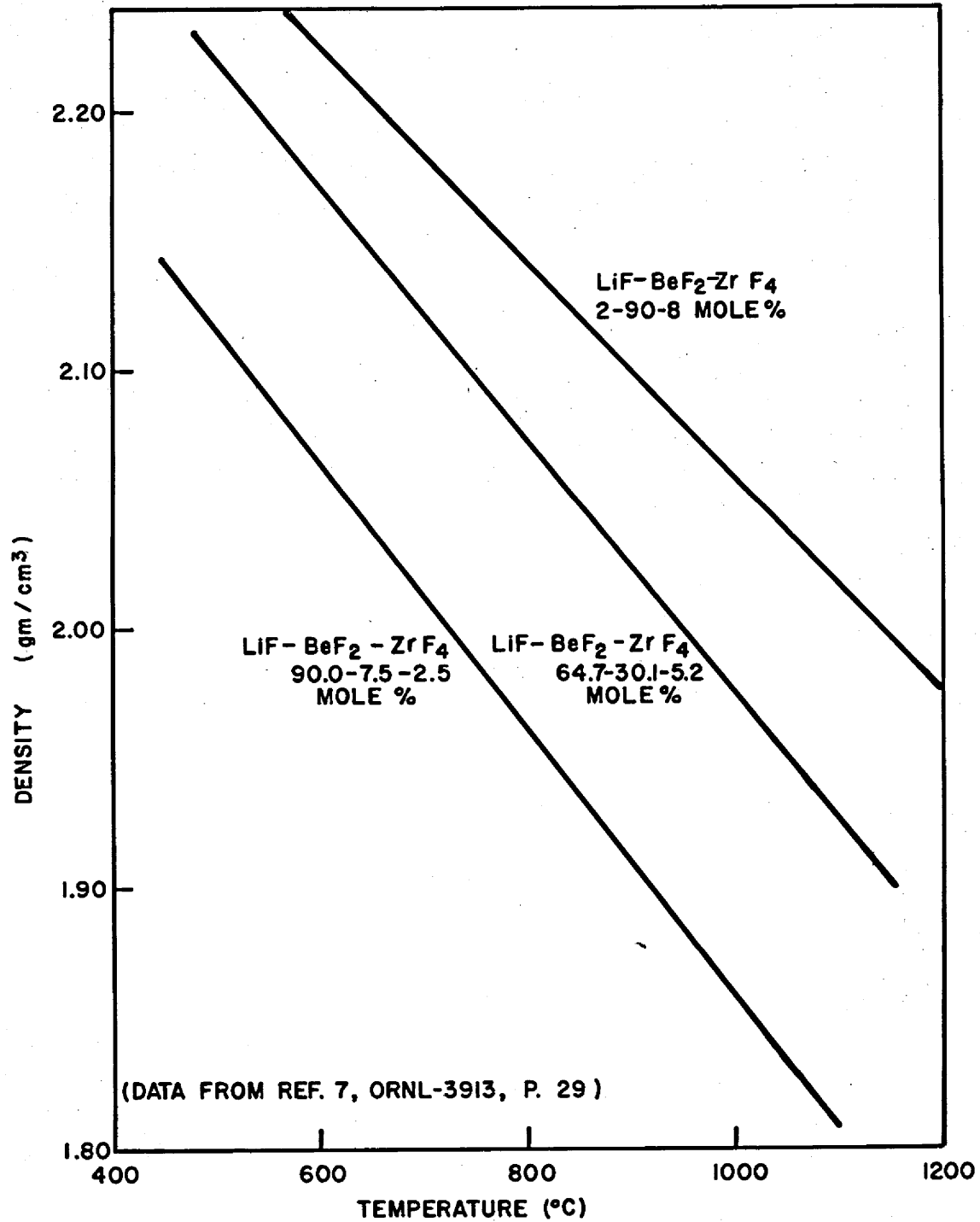


Fig. B-2. Density-Temperature Curves for LiF-BeF₂-ZrF₄.

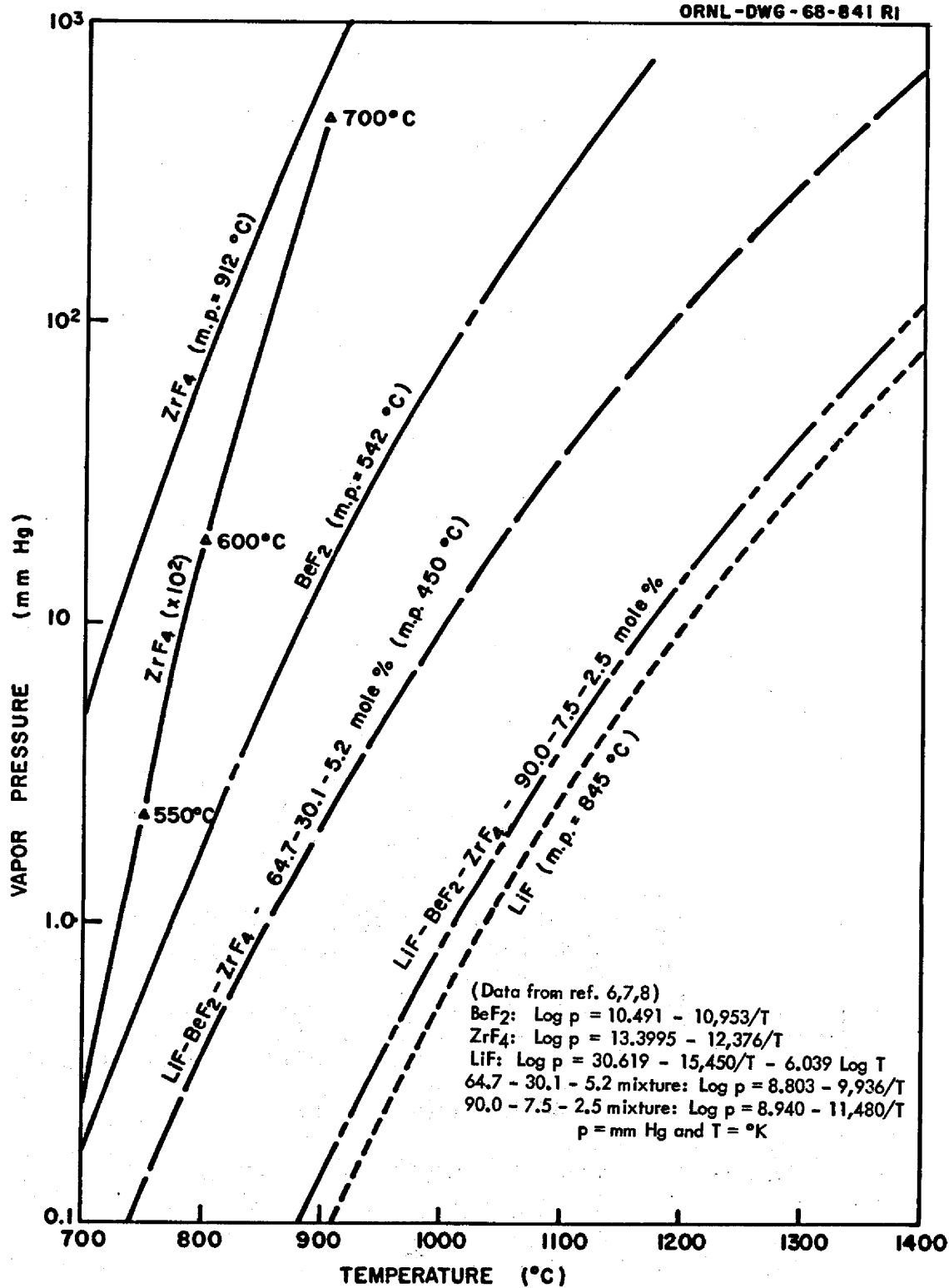


Fig. B-3. Vapor Pressure-Temperature Relationships for LiF, BeF₂, ZrF₄, and their Mixtures.

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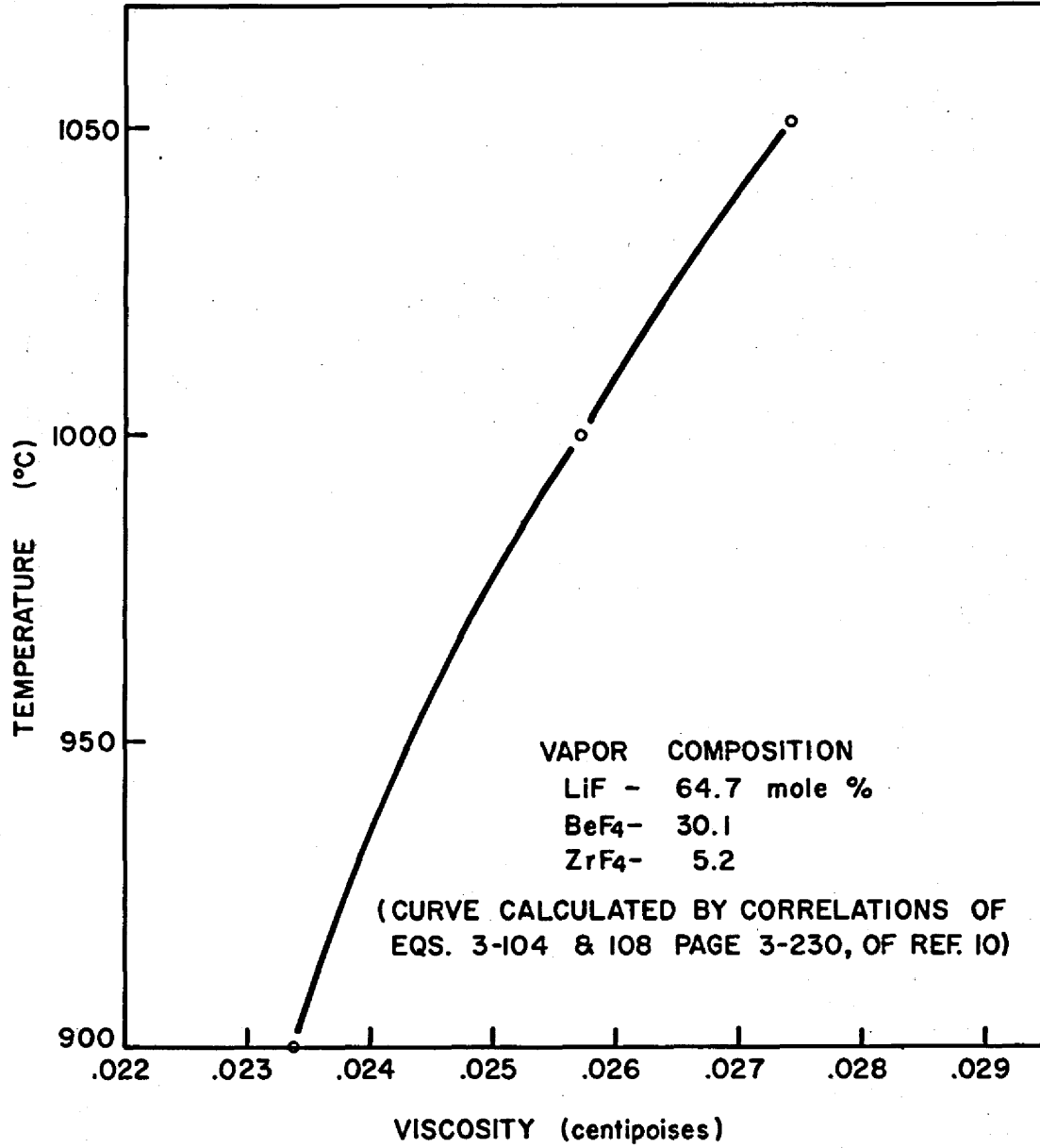
Fig. B-4. Calculated Viscosity of LiF-BeF₂-ZrF₄ Vapor.

Table B-1. Latent Heat of Vaporization of LiF, BeF₂, ZrF₄ and Their Mixtures

(Values estimated from vapor pressure data)

Composition	cal/g-mole
LiF	44,000
BeF ₂	50,400
ZrF ₄	50,000
LiF-BeF ₂ -ZrF ₄ (64.7-30.1-5.2 mole%)	46,200 ^a
LiF-BeF ₂ -ZrF ₄ (90.0-7.5-2.5 mole%)	44,600 ^a

^aCalculated by assuming that the latent heat of each component in the mixture is proportional to its molar composition.

Table B-2. Thermal Properties of MSRE Salt A

(data from Ref. 11)

Composition of Salt A	Mole %
LiF	70
BeF ₂	23.6
ZrF ₄	5
ThF ₄	1
UF ₄	0.4
Melting point	840° F
Latent heat of fusion at 840° F	139 Btu/lb
Heat capacity of solid (212° to 806° F)	0.132 + 0.000433 t (° F)
Heat capacity of liquid (887° to 1472° F)	0.575 - 0.0000999 t (° F)

APPENDIX C

Estimation of Pressure Drop for Salt Vapor
in the Still-Condenser System

The highest pressure in the still-condenser system during distillation is about 1 mm Hg which occurs just over the surface of the liquid in the still. A vacuum pump connected to the condensate receiver develops a lower pressure in this vessel to induce vapor flow through the condenser. Because the average pressure in the condenser is low and the diameter is relatively large (9.25 in. ID), the possibility was foreseen that vapor could channel, resulting in incomplete condensation. It was not desirable to make the condenser smaller in diameter because the larger surface is needed for heat rejection; therefore, to avoid channeling, a core was placed in the condenser (Fig. C-1) to route vapor to the condenser wall.

The calculations that follow were made on the system shown schematically in Fig. C-1. They consider pressure drops for various flow rates beginning at the vapor line opening in the still to the neck of the condensate receiver. The objective of the calculations is to determine the annulus width that easily passes the amount of vapor that can be condensed. In other words, the condenser is to be made non-channeling but with sufficient annular area that pressure drop is not the controlling characteristic. The results indicate that a 3/4-in. annulus very nicely fulfills these requirements, whereas a 1/2-in. annulus limits the distillation rate to about 500 cm³/hr.

Properties of the System

In addition to the dimensional properties of the system, the following data are tabulated:

Vapor composition, mole %	
LiF	64.7
BeF ₂	30.1
ZrF ₄	5.2
Molecular weight of vapor, g/mole	39.66
Vapor temperature, °C	1000
Pressure in still, mm Hg	1.0
Vapor density at 1000°C, lb/ft ³	3.12 × 10 ⁻⁵
Vapor viscosity at 1000°C, centipoises	0.0257
Condensate temperature, °C	600
Condensate density at 600°C, g/cm ³	2.17

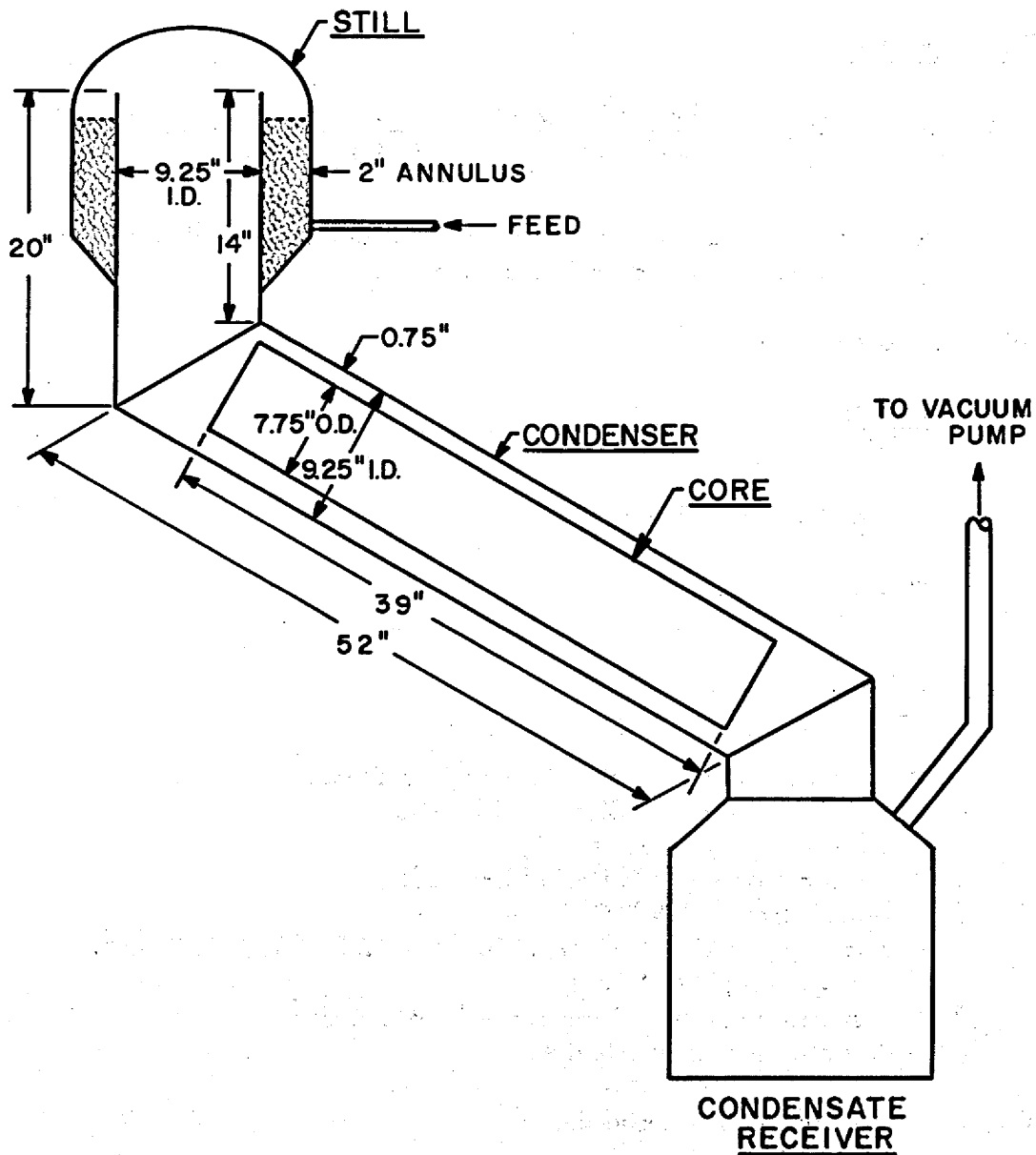


Fig. C-1. Diagram of Still-Condenser System Showing Dimensions Used in Pressure Drop Calculation.

The pressure drop is calculated in three steps: (1) the ΔP in the vapor line from its entrance to the beginning of the core, (2) entrance loss into the annulus, and (3) ΔP in the annulus. It was chosen to find the pressure drop for a condensation rate of 800 cm^3 liquid per hour for a sample calculation.

ΔP in Vapor Line

$$\text{Vapor flow rate, } w = \frac{800 \text{ cm}^3}{3600 \text{ sec}} \times \frac{2.17 \text{ g}}{3 \text{ cm}} \times \frac{\text{lb}}{453 \text{ g}} = 0.001063 \text{ lb/sec}$$

The vapor is in laminar flow so use the correlations of Perry¹⁰, Table 5-11, page 5-21, to find the pressure drop in the vapor line.

The weight rate of flow is

$$w = \frac{\pi D^4 N}{128},$$

where $D = \text{diameter} = 0.771 \text{ ft}$.

N is defined by

$$N = \frac{g_c M}{2zRT\mu} \left(\frac{P_1^2 - P_2^2}{L} \right),$$

where $g_c = \text{conversion factor} = 32/17 \text{ ft-lb/lb force-sec}^2$,

$M = \text{molecular weight} = 39.66 \text{ lb/lb mole}$,

$z = \text{compressibility factor} = 1.0$,

$R = \text{gas constant} = 1,543 \text{ ft-lb/}^\circ\text{R-lb mole}$,

$T = \text{temperature} = 2292^\circ\text{R}$,

$\mu = \text{viscosity} = (0.0257) (6.72 \times 10^{-4}) = 1.73 \times 10^{-5} \text{ lb/ft sec}$,

$L = \text{average length} = 1.42 \text{ ft}$,

$P_1 = \text{upstream pressure} = 1 \text{ mm Hg} = 2.7845 \text{ lb/ft}^2$,

$P_2 = \text{downstream pressure, lb/ft}^2$.

Using the above values, it is found that

$$N = 7.372 \left(P_1^2 - P_2^2 \right) \quad (3)$$

From Eq. 1,

$$N = \frac{128 w}{\pi D^4} = \frac{(128) (0.001063)}{(\pi) (0.771)^4} \quad (4)$$

Using Eqs. 3 and 4, the downstream pressure is found to be

$$P_2 = 2.7815 \text{ lb/ft}^2 \approx 0.9989 \text{ mm Hg.} \quad (5)$$

Contraction Loss Entering Annulus

The correlation given in Perry¹⁰, Fig. 5-34, page 5-31, was used to estimate this effect. The hydraulic diameter D_H of the annulus is 0.125 ft; the "equivalent" length L_e of the annular entrance is taken as one-half this value or 0.0625 ft. The correlation term for Fig. 5-34 is

$$\frac{L_e \mu}{D_H^2 G}$$

where $G = \text{mass flow rate in annulus} = \frac{w}{\text{area of annulus}} = 0.00764 \text{ lb/sec-ft}^2$.

Other terms have been previously defined.

The value of the correlation term is

$$\frac{L_e \mu}{D_H^2 G} = 0.00904,$$

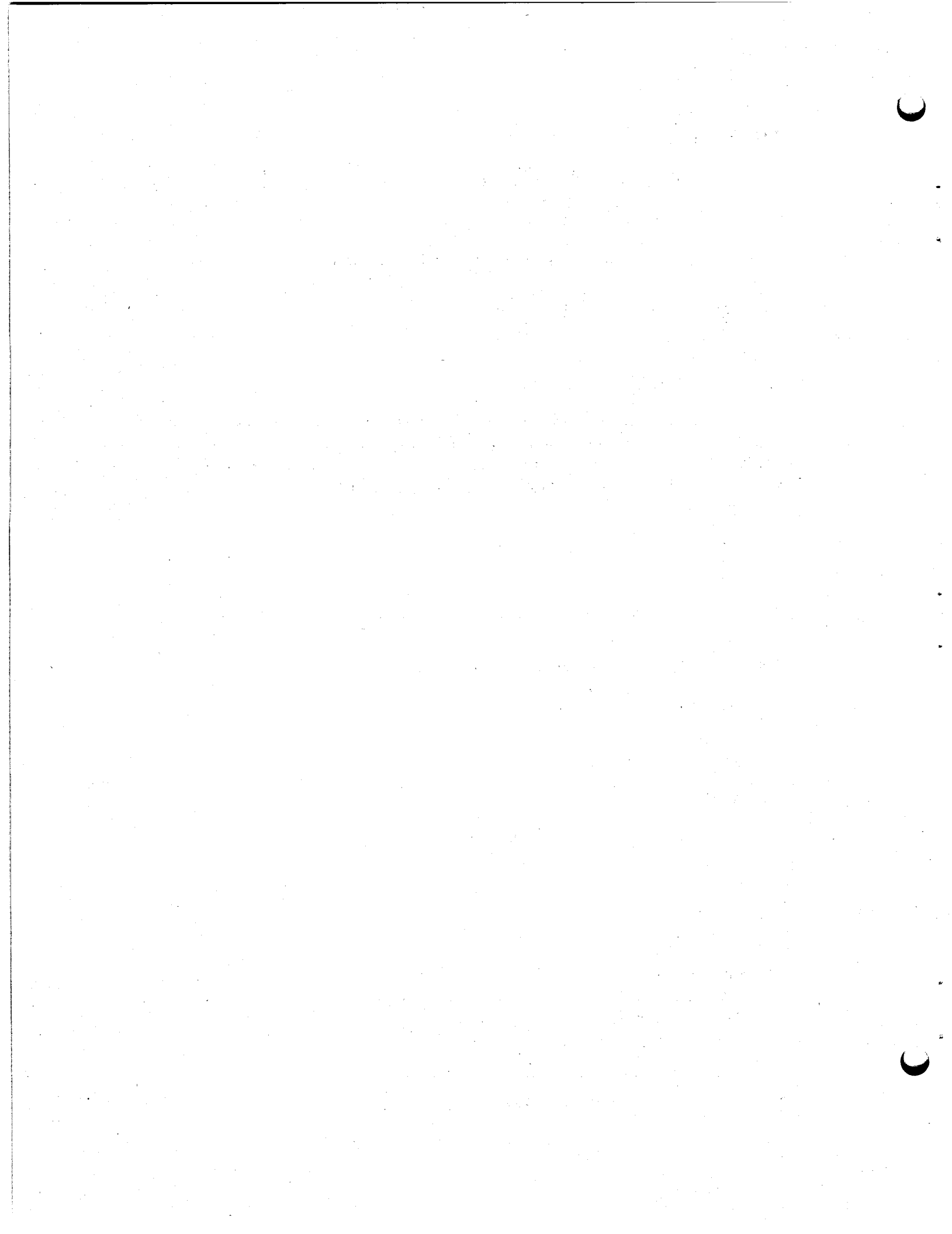
which is used in Fig. 5-34 to determine that

$$\frac{P_2 - P_3}{\rho V^2 / 2 g_c} - 1 = 1.5, \quad (6)$$

where $\rho = \text{vapor density} = 3.12 \times 10^{-5} \text{ lb/ft}^3$,
 $V = \text{vapor velocity in entrance} = 245 \text{ ft/sec}$,
 $P_2 = \text{pressure just upstream of entrance} = 2.7815 \text{ lb/ft}^2$
 $P_3 = \text{pressure after entrance losses, lb/ft}^2$.

From Eq. 6, the pressure after entrance losses is

$$P_3 = 2.7087 \text{ lb/ft}^2 \approx 0.9728 \text{ mm Hg.} \quad (7)$$



flow rates above and below this range, and the results are plotted in Fig. C-2. Also included in the figure is a curve showing the pressure drop for an annulus width equal to 1/2 in. For an annulus this narrow, the pressure drop in the 400 to 600 cm³/hr operating range is significantly greater than for the 3/4-in. annulus. In fact, it appears that in a 1/2-in. annulus the distillation rate might be limited to about 550 cm³/hr. The 3/4-in. spacing was chosen for the condenser design because this eliminates pressure drop as a factor in controlling distillation rate.

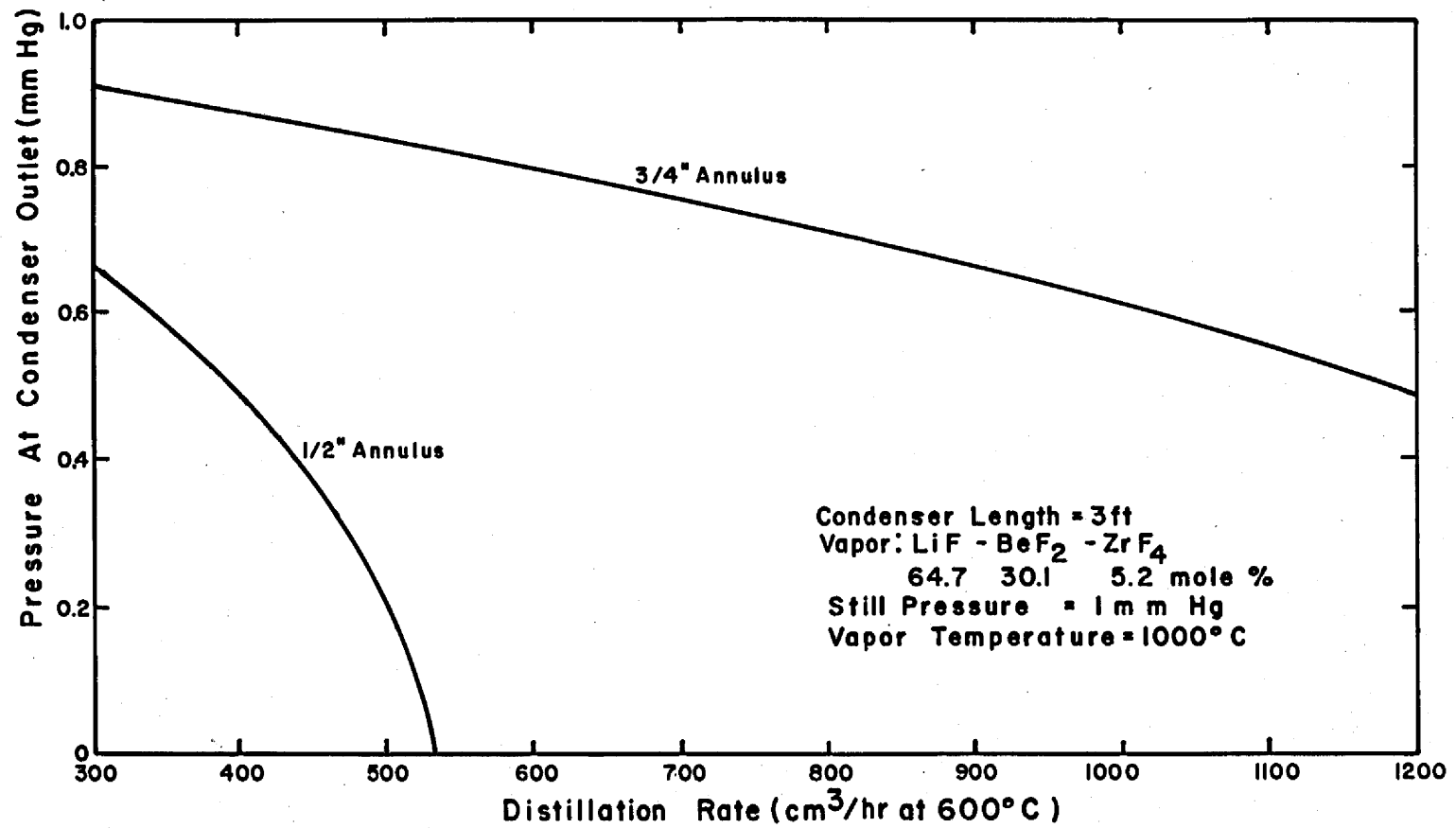


Fig. C-2. Distillation Rate as a Function of Pressure at Condenser Outlet.

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APPENDIX D

Estimation of Time to Heat Condensate Receiver
and Feed Tank to Operating Temperature

The condensate receiver and feed tank are so nearly the same size and geometry that one calculation of time-temperature characteristics is assumed to apply to both vessels. The purpose of the calculation is to find the proper rating for heaters attached to the outside of the vessel that permit heating from room temperature to 500° C in about 2 hr. The results of the calculation, presented above in Fig. 6, page 17, show that a heat input of about 20 kw is required; the following discussion illustrates the computational procedure.

Data and Computational Model

The condensate receiver, shown schematically in Fig. 7, page 18, and detailed in Dwg. M-12173-CD-009 of Appendix H, was chosen as the model for the calculation. Elements of the model are shown in Fig. D-1. The vessel as installed is covered with ceramic heaters that provide a uniform heat source to the vertical sides and bottom; however, for calculational convenience it is assumed that all heat enters through the vertical sides, the sides being made longer to include the heated area that would be on the bottom. It is assumed that the vessel contains a full charge (48 liters) of salt having the properties of MSRE Salt A (see Table B-2, Appendix B). This salt was chosen because heat capacity and heat of fusion data are available and its composition very closely approximates that of MSRE carrier salt.

The following data are pertinent properties of the vessel and its contents:

Vessel material	Hastelloy N
Vessel weight, lbs	125
Vessel surface area, ft ²	6.89
Average specific heat of metal, Btu lb ⁻¹ °F ⁻¹	0.11
Average thermal conductivity of metal, Btu hr ⁻¹ °F ⁻¹	10.3
Emissivity of metal	0.5
Weight of salt (48 liters), lbs	235
Melting point of salt, °C	450
Heat of fusion, Btu/lb	139
Average specific heat of solid salt (70 to 842° F), Btu lb ⁻¹ °F ⁻¹	0.316
Average specific heat of liquid salt (842 to 932° F), Btu lb ⁻¹ °F ⁻¹	0.486
Thermal conductivity of insulation, Btu hr ft ⁻¹ °F ⁻¹	0.1

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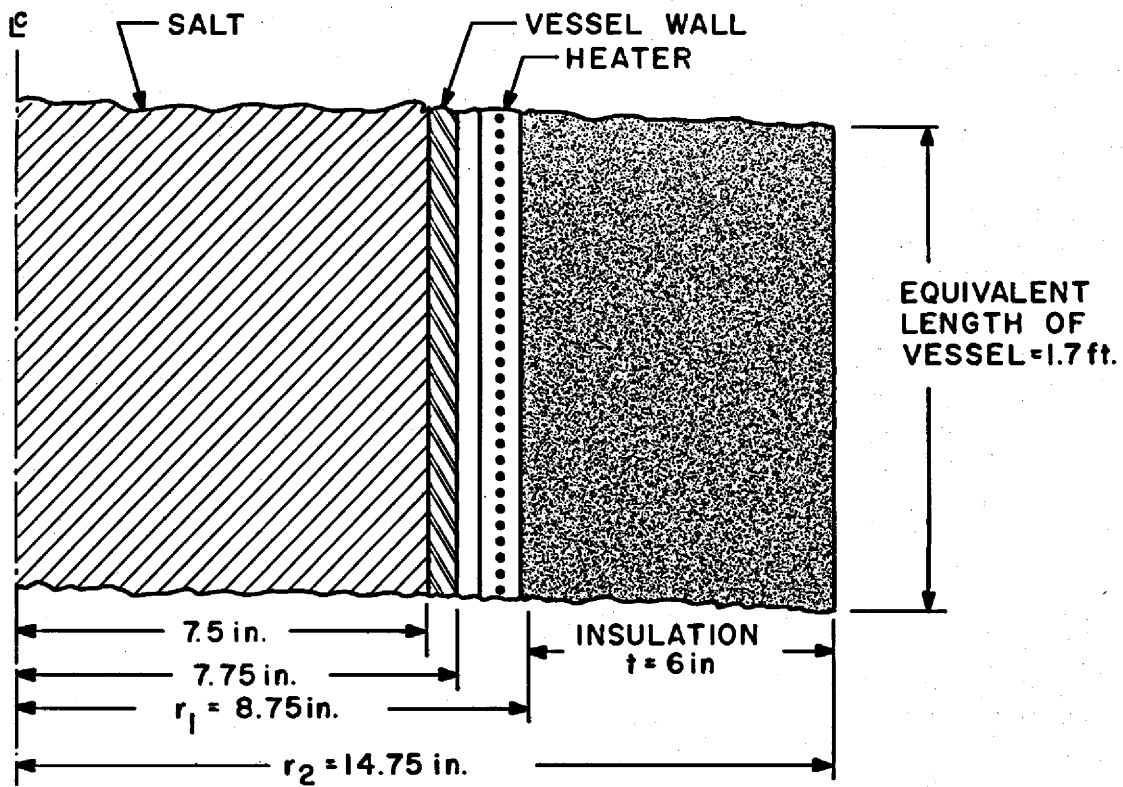


Fig. D-1. Model for Calculating Time to Heat Condensate Receiver to Operating Temperature.

Definitions q_h = heater output, Btu/hr A_m = heat transfer area, ft^2 ϵ = emissivity L = length of vessel, ft r_1 = radius to outside of heater, ft r_2 = radius to outside of insulation, ft k = thermal conductivity of insulation, $\text{Btu hr}^{-1} \text{ft}^{-1} \text{ } ^\circ\text{F}^{-1}$ T_h = heater temperature, $^\circ\text{R}$ T_s = salt temperature, $^\circ\text{R}$ T_m = metal temperature, $^\circ\text{R}$ T_a = temperature at outside surface of insulation, $^\circ\text{R}$ θ = time, hr C_s = specific heat of salt, $\text{Btu lb}^{-1} \text{ } ^\circ\text{F}^{-1}$ C_m = specific heat of metal, $\text{Btu lb}^{-1} \text{ } ^\circ\text{F}^{-1}$ W_s = weight of salt, lb W_m = weight of metal, lb k_m = thermal conductivity of metal, $\text{Btu hr}^{-1} \text{ft}^{-1} \text{ } ^\circ\text{F}^{-1}$ h_c = coefficient of heat transfer for salt film, $\text{Btu hr}^{-1} \text{ft}^{-2} \text{ } ^\circ\text{F}^{-1}$ x = thickness of metal wall, ftHeat Balance

The output of the heaters is radiated to the vessel or is lost by conduction through the insulation.

$$q_h = 0.173 \times 10^{-8} A_m \epsilon \left(T_h^4 - T_m^4 \right) + \frac{2\pi kL (T_h - T_a)}{\ln (r_2/r_1)} \quad (1)$$

The energy received by the vessel wall is partially used to heat the metal and partially to heat the salt inside the vessel. In a small time increment $d\theta$ there would be a small rise in temperature of the vessel and the salt, and we can write

$$q_h d\theta = W_s C_s dT_s + W_m C_m dT_m + \frac{2\pi kL (T_h - T_a)}{\ln(r_2/r_1)} d\theta. \quad (2)$$

Both T_s and T_m are variables in this equation, and one must be eliminated before integration. If we make the simplifying assumption that the amount of heat going into the salt is proportional to the amount of heat going into the metal, the proportionality constant is probably the ratio of the relative conductances of the metal and the salt film adjacent to the wall. In this case the proportionality constant becomes

$$\frac{k_m/x}{h_c} = \frac{10.3/0.0208}{20} = 24.72. \quad (3)$$

The value of h_c ($= 20 \text{ Btu hr}^{-1} \text{ ft}^{-2} \text{ }^\circ\text{F}^{-1}$) is estimated from physical properties.

Using the value 24.72 as the proportionality between the first two terms to the right of the equality sign in Eq. 2, we write

$$q_h d\theta = \frac{W_m C_m dT_m}{24.72} + W_m C_m dT_m + \frac{2\pi kL (T_h - T_a)}{\ln(r_2/r_1)}. \quad (4)$$

Upon rearrangement and integration this becomes

$$\int_{T_o}^{T'_m} \frac{dT_m}{q_h - \frac{2\pi kL (T_h - T_a)}{\ln(r_2/r_1)}} = \int_0^{\theta'} \frac{d\theta}{1.04 W_m C_m} \quad (5)$$

The initial conditions are T_o equals room temperature at time equals zero; final conditions are T'_m , a predetermined upper limit for the temperature of the vessel wall, and θ' , the time required for the vessel wall to reach temperature T'_m .

Time to Heat Metal Wall to 600°C

Since the metal temperature rises much faster than the bulk or "mixed" temperature of the salt, it is necessary during this transient period to limit the metal temperature to some reasonable value, for example, 600 to 700°C, and hold the temperature at this value until the salt melts and heats to operating temperature, which is taken to be 500°C. While the metal is being heated, the relationship between metal and bulk salt temperatures can be found from the assumption used to get the proportionality factor of Eq. 3.

$$\frac{T_s - T_o}{T_m - T_o} = \frac{W_m C_m}{24.72 W_s C_s} = \frac{(125)(0.11)}{(24.72)(235)(0.495)} = 0.00477 \quad (6)$$

$$T_s = 0.00477 (T_m - T_o) + T_o \quad (7)$$

The value of C_s ($=0.495 \text{ Btu lb}^{-1} \text{ }^\circ\text{F}^{-1}$) used in Eq. 6 is a weighted specific heat which includes in one number the effect of heating the solid, of the heat of fusion, and of heating the liquid to 500°C.

The left member of Eq. 5 contains the variables T_m and T_h , which are related through Eq. 1 for any chosen heater capacity q_h ; other quantities in Eq. 1 are defined in Fig. D-1 and the paragraph titled Definitions. If we choose a heater of 15 kw (51,195 Btu/hr) capacity and a surface temperature for the insulation of 530°R, we obtain for Eq. 1:

$$51,195 = (0.173 \times 10^{-8}) (6.89) (0.5) \left(T_h^4 - T_m^4 \right) + \frac{(2\pi) (0.1) (1.7) (T_h - 530)}{\ln(14.75/8.75)}$$

$$51,195 = 0.596 \times 10^{-8} \left(T_h^4 - T_m^4 \right) + 2.046 (T_h - 530) \quad (8)$$

We need to use Eq. 8 to eliminate either T_h or T_m from Eq. 5 and then integrate Eq. 5; however, the fourth-power relationship in Eq. 8 makes integration of Eq. 5 difficult unless graphical methods are used. Equation 8 is plotted in Fig. D-2; the "mixed" temperature of the salt, computed by Eq. 7, is shown on the same plot. When values are substituted into Eq. 5, we obtain

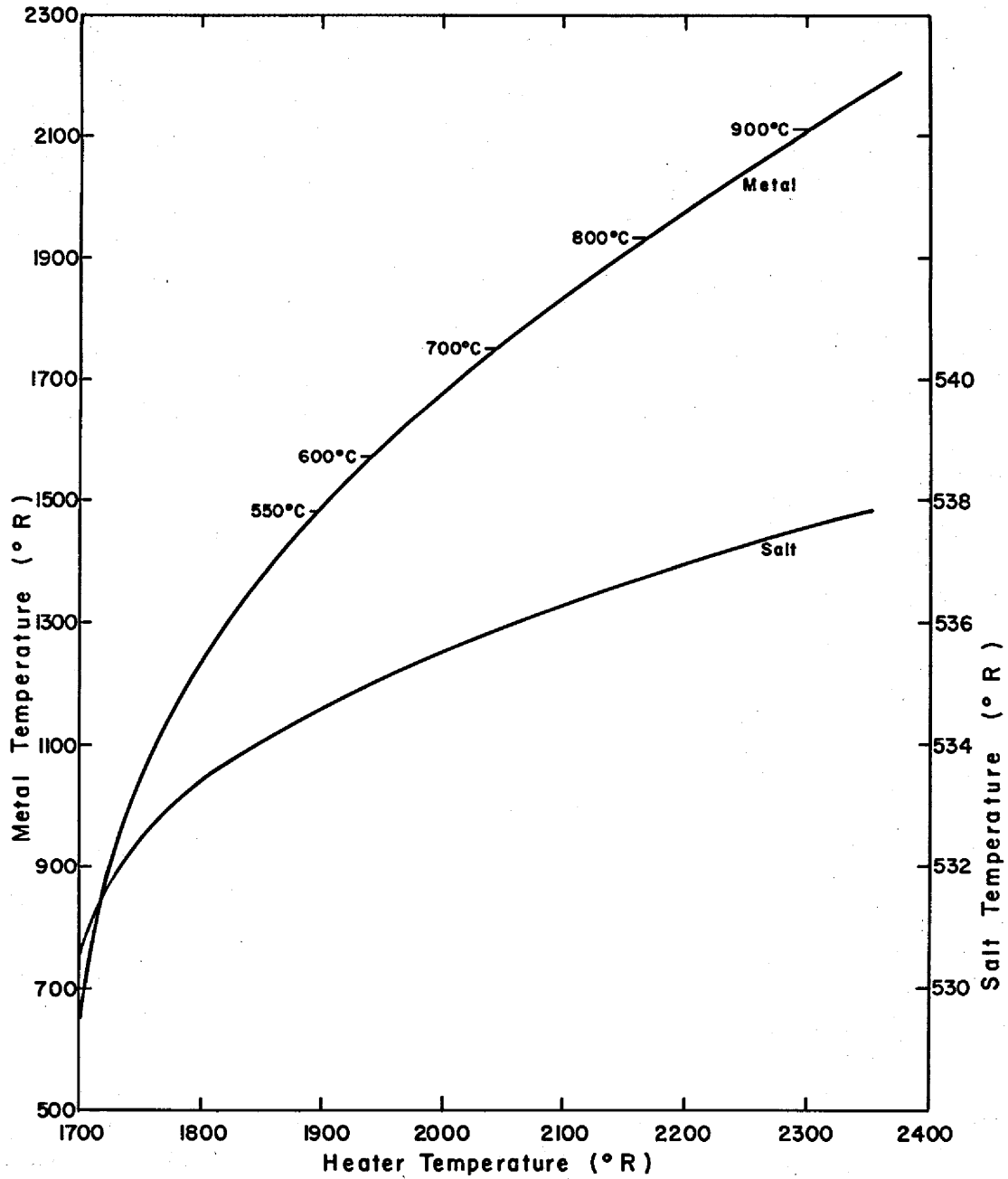


Fig. D-2. Temperature of Vessel Wall and Salt as a Function of Heater Temperature (15-kw Heater).

$$\int_{530^{\circ}\text{R}}^{T'_m = 1571^{\circ}\text{R}} \frac{dT_m}{51,195 - 2.046 (T_h - 530)} = \int_0^{\theta'} = \frac{d\theta}{(1.04)(125)(0.11)} = \int_0^{\theta'} = \frac{d\theta}{14.3'} \quad (9)$$

which, when integrated graphically with the aid of Fig. D-2, gives a value of $\theta' = 18.5$ minutes. This is the time for heating the vessel to 600°C (1571°R). During this transient period, the "mixed" temperature of the salt has risen only about 5°R to 535°R ($\sim 25^{\circ}\text{C}$).

Heating Salt to 500°C While Holding Vessel Walls at 600°C

Choosing at this point to hold the vessel walls at 600°C by on-off control of the heaters, we examine the mechanism for transferring heat from the heaters through the walls and then into the salt. The rate at which heat is received by the walls, assumed to be by radiation only, is

$$0.173 \times 10^{-8} A_m \epsilon (T_h^4 - T_m^4).$$

The rate of heat transfer into the salt depends upon convection which is

$$h_c A_m (T_m - T_s).$$

These two expressions must be equal since the wall temperature is held constant. Therefore,

$$h_c A_m (T_m - T_s) = 0.173 \times 10^{-8} A_m \epsilon (T_h^4 - T_m^4). \quad (10)$$

In Eq. 10, T_s increases with time, and the heat transfer rate into the salt drops off because of the decreasing value of $(T_m - T_s)$. At the outset this temperature difference is large enough to permit all radiated energy to be conducted into the salt. However, eventually $(T_m - T_s)$ becomes small enough that the heater output must be curtailed (through the on-off control that holds wall temperature constant). During the time that the large value of $(T_m - T_s)$ prevails, the energy balance is

$$0.173 \times 10^{-8} A_m \epsilon \left(T_h^4 - T_m^4 \right) d\theta = W_s C_s dT_s.$$

Integrating from the lower limits θ^1 and T_s^1 , respectively, the time (18.5 minutes) and temperature (535°R) at which the metal reaches 600° C, to the upper limits θ'' and T_s'' , we have

$$\begin{aligned} \theta'' - \frac{18.5}{60} &= \frac{W_s C_s \left(T_s'' - T_s^1 \right)}{0.173 \times 10^{-8} A_m \epsilon \left(T_h^4 - T_m^4 \right)} \\ &= \frac{(235) (0.495) \left(T_s'' - 535 \right)}{0.173 \times 10^{-8} (6.89) (0.5) \left[(1940)^4 - (1571)^4 \right]} \\ &= 0.00242 \left(T_s'' - 535 \right). \end{aligned} \quad (11)$$

The linear relation of Eq. 11 holds until the magnitude of $(T_m - T_s)$ decreases to the point at which convection transfer controls. The salt temperature at which this occurs is found by equating the radiation heat transfer rate to the convection transfer rate as was done in Eq. 10. We define this temperature to be T_s'' and obtain it by solving Eq. 10.

$$T_m - T_s'' = \frac{0.173 \times 10^{-8} \epsilon \left(T_h^4 - T_m^4 \right)}{h_c} \quad (12)$$

The value of T_s'' is

$$\begin{aligned} 1571 - T_s'' &= \frac{0.173 \times 10^{-8} (0.5) \left[(1940)^4 - (1571)^4 \right]}{20}, \\ T_s'' &= 1222^\circ \text{R} (406^\circ \text{C}) \end{aligned} \quad (13)$$

The elapsed time for the salt to reach 406° C is found from Eq. 11 to be $\theta'' = 118$ minutes.

Above a salt temperature of 406° C the heat transfer rate decreases with time, and the time-temperature relationship is found by equating the energy passing through the salt film to energy absorbed in the salt.

$$h_c A_m (T_m - T_s) d\theta = W_s C_s dT_s \quad (14)$$

Integration from initial conditions θ'' and T_s'' to the desired final temperature T_{sf} gives

$$\ln \frac{T_m - T_s''}{T_m - T_{sf}} = \frac{h_c A_m}{W_s C_s} (\theta_f - \theta'') \quad (15)$$

Upon substitution of numerical values Eq. 15 becomes

$$\begin{aligned} \ln \frac{1571 - 1222}{1571 - T_{sf}} &= \frac{(20)(6.89)}{(235)(0.495)} \left(\theta_f - \frac{118}{60} \right) \\ &= 1.185 \left(\theta_f - \frac{118}{60} \right). \end{aligned} \quad (16)$$

Using Eq. 16, the time (θ_f) required to heat the salt to 500°C is 152 minutes.

The relationships between time and temperatures of the heater, vessel wall, and salt were calculated from Eqs. 8, 11, 12, and 16 and are plotted on Fig. D-3. Two curves are presented for the salt temperature, one for the vessel wall at a constant temperature of 600°C and a second for a constant temperature of 700°C. The difference in time between the two cases is insignificant.

Choosing the Heater Sizes for the Condensate Receiver, Feed Tank, Still, and Condenser

Condensate Receiver and Feed Tank. — The calculations discussed above were repeated for heating jackets of 10 kw and 20 kw capacity around the sides and bottom of the condensate receiver. These data, presented previously in Fig. 6, page 17, were used to fix the heater capacity for the condensate receiver and feed tank. It was chosen to heat each tank with 20-kw heaters, having the distribution over the vessel surfaces specified in Paragraphs 4.6.2 and 4.6.3 of Appendix G. Since some heat is applied to upper surfaces that are not contacted by salt, the heater effectiveness for heating the salt is not the total 20 kw but perhaps about 16 kw. The required time (Fig. 6) for bringing the vessels to temperature is then about 140 minutes.

Still and Condenser. — An analysis similar to that described in this Appendix was made for the still and condenser, giving the time versus heater rating curves shown in Fig. 11, page 28. A 20-kw heater was chosen for the condenser and a 15-kw heater for the still giving a heat-up time of about 1.5 hr.

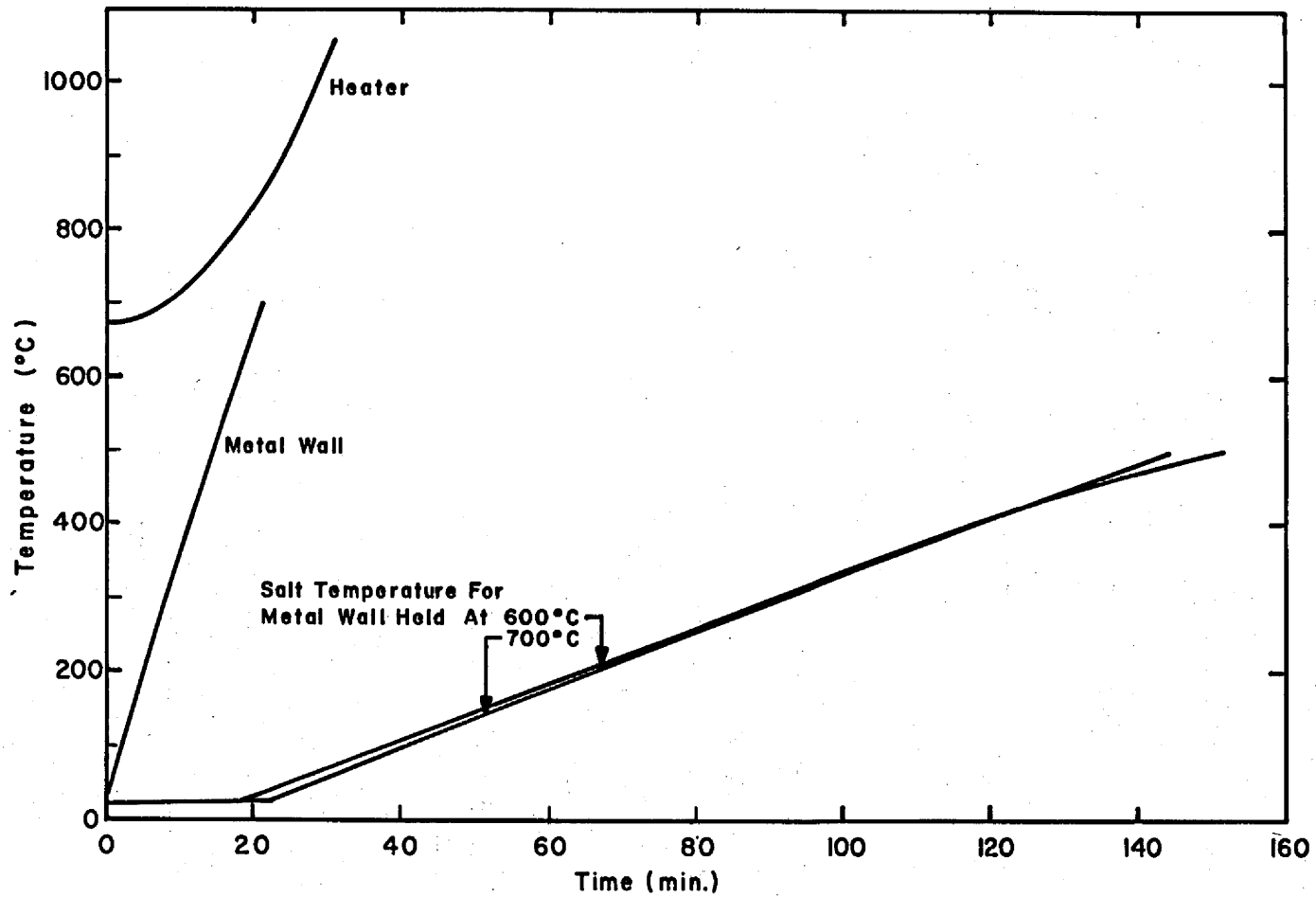


Fig. D-3. Temperature-Time Curves for Heating Up the Condensate Receiver with a 15-kw Heater.

Calculations for the still-condenser system were straightforward since it was not necessary to consider heating and melting a mass of salt. The small volume (12 liters) of salt that might be in the still was included in the weight of the metal thus simplifying the calculations.

Estimation of Heat Rejection Rate by Condenser

The condenser is designed to reject heat by conduction through the insulation and convection to the atmosphere. This characteristic was chosen for the design since it offers the simplest and most economical cooling method. More efficient methods, such as forced circulation of an inert gas or liquid metal, were evaluated and found to require a significant investment in circulating plus auxiliary heating and cooling equipment.

The following calculations illustrate the straightforward approach to finding the heat rejection capability of the condenser. A 3-ft length was chosen for the calculations since this was estimated to be the effective length of a unit that would fit the available space; the actual condenser length of the completed design is 51 in. Independent variables in the condenser wall temperature and insulation thickness. The object of the computations is to find the most suitable combination of these variables for the desired distillation rate; results for condensing MSRE carrier salt and pure LiF are presented in Fig. 10, page 26. For 4-in.-thick insulation and wall temperatures between 600 and 850°C, the 3-ft length of 10-in.-OD condenser can dissipate 5000 to 7000 Btu/hr; this is equivalent to condensing 500 to 600 cm³/hr of MSRE carrier salt. A 4-in. thickness is specified for the insulation on the installed unit; this may be increased or decreased with little inconvenience if operating experience does not agree closely enough with calculations.

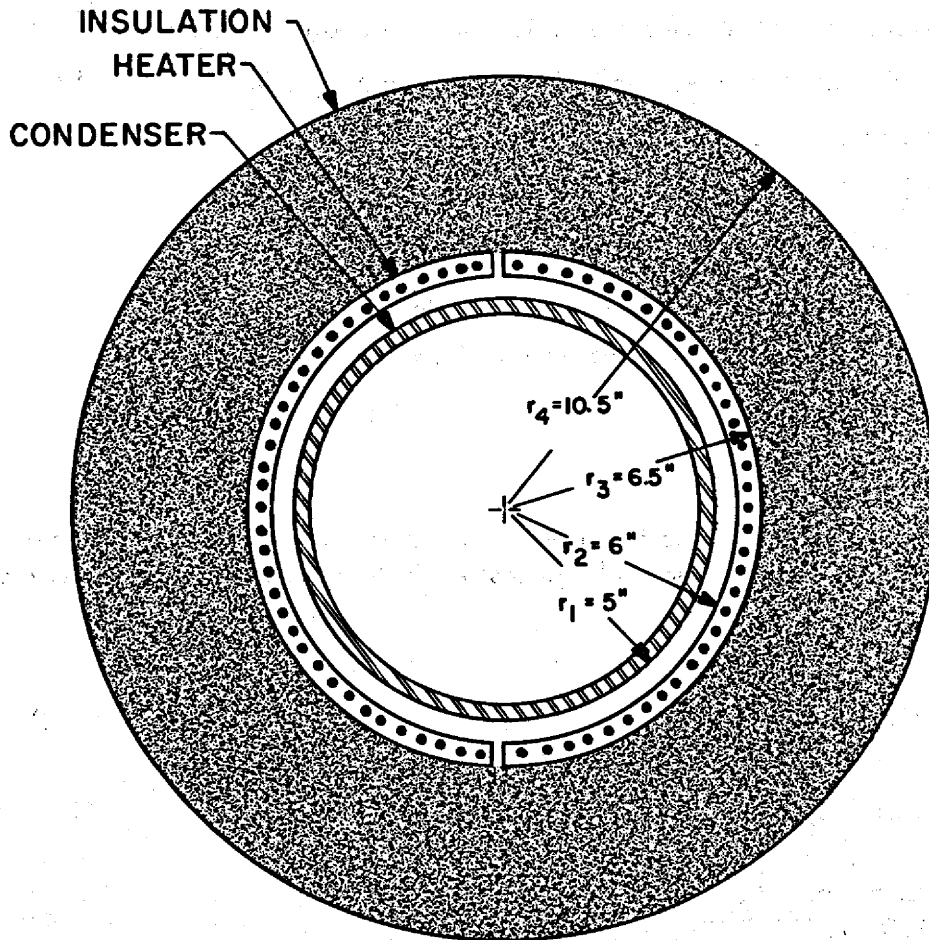
Model for the Calculation

Heat given up by condensing salt inside the condenser must pass across an air gap to the heater, through the heater, and then through the insulation to the surroundings as diagrammed in Fig. E-1. The heater is used to heat the condenser from room temperature to the desired condensation temperature. Once thermal equilibrium is established, the heat of condensation maintains the unit on temperature. For this calculation it is assumed that heat is radiated from the condenser to the heater and then passes by conduction through the heater and surrounding insulation before being dissipated to the atmosphere by convection and radiation.

Definitions

In addition to the dimensions shown on Fig. E-1, the following terms are defined:

q = heat transfer rate, Btu/hr



Thermal Conductivity Of Insulation = 0.1 Btu/ft hr. $^{\circ}$ F
Thermal Conductivity Of Heater = 8 Btu/ft hr. $^{\circ}$ F

Fig. E-1. Cross Section of Condenser, Heater and Insulation.

A = area normal to heat flow, ft^2

T = temperature, $^{\circ}\text{R}$

k = thermal conductivity, $\text{Btu ft}^{-1} \text{hr}^{-1} ^{\circ}\text{R}^{-1}$

ϵ = emissivity

L = length, ft

r = radius, ft

h_c = convective heat transfer coefficient to surroundings, $\text{Btu hr}^{-1} \text{ft}^{-2} ^{\circ}\text{F}^{-1}$

h_r = radiative heat transfer coefficient to surroundings, $\text{Btu hr}^{-1} \text{ft}^{-2} ^{\circ}\text{F}^{-1}$

Subscript 1 refers to conditions at condenser surface

Subscript 2 refers to conditions in heater

Subscript 3 refers to conditions in insulation

Subscript 4 refers to conditions at outer surface of insulation

Subscript 5 refers to conditions of surroundings

Heat Balance

In the closed confines of the insulated system heat transfer from the condenser surface to the ceramic heater should be almost entirely by radiation. For this the rate is given by

$$q_1 = 0.173 \times 10^{-8} A_1 \epsilon (T_1^4 - T_2^4) \quad (1)$$

Conduction through the heater is

$$q_2 = \frac{2\pi k_2 L (T_2 - T_3)}{\ln(r_3/r_2)} \quad (2)$$

Conduction through the insulation is

$$q_3 = \frac{2\pi k_3 L (T_3 - T_4)}{\ln(r_4/r_3)} \quad (3)$$

Radiation plus convection from the outer surface of the insulation is

$$q_4 = 2\pi r_4 L (h_c + h_r) (T_4 - T_5) \quad (4)$$

Solutions to Equations

Equations 2,3, and 4 are linear in temperature and are conveniently handled by determinants. To simplify the writing we define constants a_{ij} and express Eqs. 2,3, and 4 as follows:

$$a_{11} T_2 - a_{12} T_3 + a_{13} T_4 = q_2' \quad (5)$$

$$a_{21} T_2 + a_{22} T_3 - a_{23} T_4 = q_3' \quad (6)$$

$$a_{31} T_2 + a_{32} T_3 + a_{33} T_4 = q_4 + a_{33} T_5 \quad (7)$$

In these equations

$$a_{11} = a_{12} = \frac{2\pi k_2 L}{\ln(r_3/r_2)} \quad (8)$$

$$a_{22} = a_{23} = \frac{2\pi k_3 L}{\ln(r_4/r_3)} \quad (9)$$

$$a_{33} = 2\pi r_4 L (h_c + h_r) \quad (10)$$

$$a_{13} = a_{21} = a_{31} = a_{32} = 0 \quad (11)$$

When thermal equilibrium is established, $q_1 = q_2 = q_3 = q_4$, and Eqs. 5, 6, and 7 can be solved simultaneously. The convenient quantity to obtain is T_2 , since this temperature is needed to find the radiation rate from the condenser. The solution is

$$T_2 = \frac{q_2 a_{22} a_{33} + q_3 a_{12} a_{33} + (q_4 + a_{33} T_5) a_{12} a_{23}}{a_{11} a_{22} a_{33}}$$

$$= \frac{q_2}{a_{11}} + \frac{q_3}{a_{22}} + \frac{q_4}{a_{33}} + T_5 \quad (12)$$

Since each of the q 's is equal to q_1 ,

$$T_2 = q_1 \left(\frac{1}{a_{11}} + \frac{1}{a_{22}} + \frac{1}{a_{33}} \right) + T_5 \quad (13)$$

In Eq. 13 the desired quantity is q_1 , the heat that can be rejected by the condenser. Therefore Eq. 13 can be used to eliminate T_2 from Eq. 1 to obtain an expression in which q_1 is the dependent variable. This gives

$$\left[\left(\frac{1}{a_{11}} + \frac{1}{a_{22}} + \frac{1}{a_{33}} \right) q_1 + T_s \right]^4 + \frac{q_1}{0.173 \times 10^{-8} A_1 \epsilon} = T_1^4 \quad (14)$$

In this equation, T_1 , the temperature of the condenser wall, is the independent variable; T_5 is the temperature of the atmosphere surrounding the unit.

Presentation of Results

Equation 14 was used to calculate the rate of heat loss from the condenser for several values of the wall temperature; these results are given in Fig. 10, page 26. Insulation thickness, which affects the constants a_{22} and a_{33} , was treated as a parameter over the range 3 to 4 in. to completely cover the range of interest for this experiment. The rate of condensation is greater at the higher condenser temperatures because the larger temperature drop between condenser and surroundings causes more heat to flow. On the other hand, a higher condensate temperature implies a higher vapor pressure, which is undesirable from the viewpoint of salt mist migrating into the vacuum system.

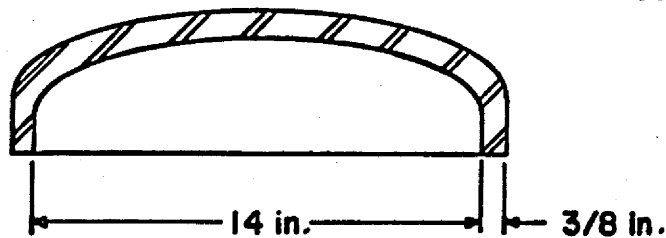
APPENDIX F

Stress Analysis of Vacuum Still and Condenser*

The stress analysis was made to comply with the intent of the ASME Boiler and Pressure Vessel Code, 12 Section VIII. This analysis examines all areas of anticipated stress concentration due to external pressure (internal pressure \cong 0.5 mm Hg), nozzle penetrations, weight of vessel plus contents, and thermal effects.

Allowable External Pressure for Elliptical Head

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Design data reference: Paragraph UA 4, Section VIII of ASME Pressure Vessel Code, 1965 edition.

The design pressure for elliptical heads shall be 1.67 x operating pressure.
Design Pressure = (1.67) (15) = 25 psi. See paragraph UG-33, (1).

Required thickness of elliptical head (t):

$$t = \frac{PDK}{2SE-0.2P} \text{ where } K = (1/6) \left[2 + \left(\frac{D}{2h} \right)^2 \right],$$

where $h = \frac{ID}{4}$,

$$h = \frac{ID}{4} = \frac{14}{4} \text{ in.} = 3.5 \text{ in.},$$

*Work performed by C. A. Hahs, General Engineering Division.

$$K = (1/6) \left[2 + \left(\frac{D}{2h} \right)^2 \right] = (1/6) \left[2 + \left(\frac{14}{2(3.5)} \right)^2 \right] = 1.00,$$

$$t = \frac{PDK}{2SE - 0.2P} = \frac{25(14)(1)}{2(700)(1) - 0.2(25)} = \frac{0.251 \text{ in. Maximum}}{}$$

Actual thickness (t_1) = 0.375 in.

Theoretical Stress (S_{th}):

$$S_{th} = \frac{PDK + 0.2Pt}{2Et} = \frac{25(14)(1.0) + 0.2(25)(0.375)}{2(1)(.375)} = 470 \text{ psi.}$$

Allowable internal pressure (P_U):

$$P_U = \frac{2SEt}{KD + 0.2t} = \frac{2(700)(1)(.375)}{1.0(14) + 0.2(0.375)} = 37.3 \text{ psi.}$$

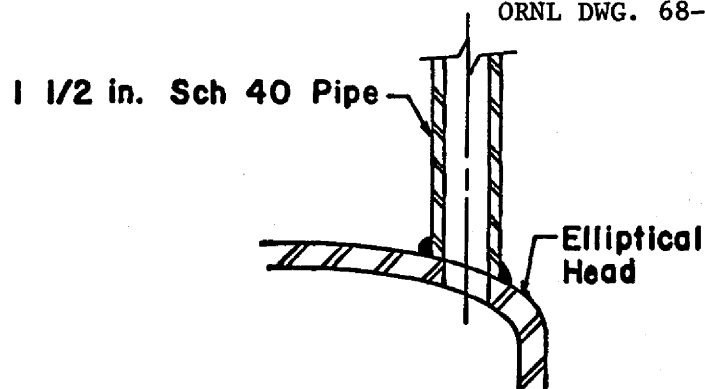
Allowable external pressure = $\frac{37.3}{1.67} = 22.4 \text{ psi.}$

Actual maximum external pressure = 15 psi.

Thickness of head is satisfactory.

Allowable External Pressure and Reinforcement for 1 1/2-in. Sched. 40 Pipe Nozzle

ORNL DWG. 68-9089



$$P_{all} = 0.55E \left(\frac{t}{d}\right)^3 = 0.55 \times 19.7 \times 10^6 \left(\frac{0.145}{1.920}\right)^3 = 4580 \text{ psi.}$$

For value of E, see Appendix A, Table A-4.

Required thickness of elliptical head $t_r = 0.251$ in. (See page 96).

Required thickness of nozzle t_{rn} :

$$t_{rn} = \frac{PR}{SE-0.6P} = \frac{15 \left(\frac{1.590}{2}\right)}{700(1)-0.6(15)} = \frac{15(0.795)}{700-9} = \frac{11.92}{6.91} = 0.01725 \text{ in.}$$

Area reinforcement required = $(d)(t_r) = (1.590)(0.251) = 0.399 \text{ in.}^2$

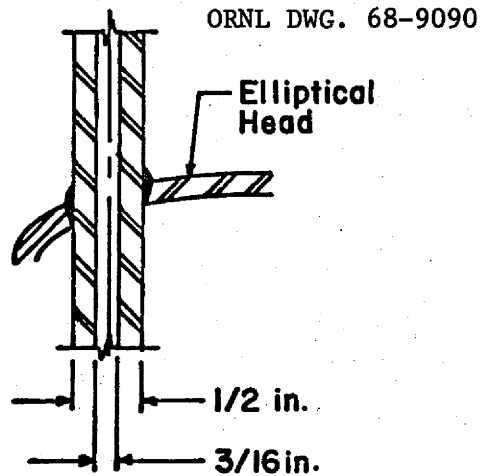
Area reinforcement available = $A_1 = (E_1 t - t_r)(d) = [(1)(0.375) - 0.251](1.880)$
 $= (0.124)(1.880) = 0.233 \text{ in.}^2$

$$\begin{aligned} A_2 &= (t_n - t_{rn})(5t) \\ &= (0.145 - 0.01725)(5)(0.375) \\ &= (0.1277)(5)(0.375) = 0.238 \text{ in.}^2 \end{aligned}$$

Total reinforcement available = $A_1 + A_2 = 0.471 \text{ in.}^2$

Reinforcement is adequate.

Allowable External Pressure and Reinforcement for 1/2-in.-OD x 3/16-in.-ID Tube



$$\begin{aligned}
 P \text{ allowable} &= 0.55E \left(\frac{t}{d} \right)^3 = 0.55 \times 19.7 \times 10^6 \left(\frac{0.147}{0.500} \right)^3 \\
 &= 10.8 \times 10^6 (0.294)^3 \\
 &= 10.8 \times 10^6 (0.0254) = 0.275 \times 10^6 \text{ psi.}
 \end{aligned}$$

Required thickness of elliptical head = $t_r = 0.251$ in. (See page 96).

Required thickness of nozzle (t_{rn}):

$$t_{rn} = \frac{PR}{SE - 0.6P} = \frac{15 (0.103)}{700 (1) - 0.6 (15)} = \frac{1.545}{691} = 0.0022 \text{ in.}$$

Area of reinforcement required = $A = (d) (t_r)$

$$= (0.207) (0.251) = 0.052 \text{ in.}^2$$

Area Available (A_1^1):

$$A_1^1 = (E_1 t - t_r) (t_n + t) \quad (2)$$

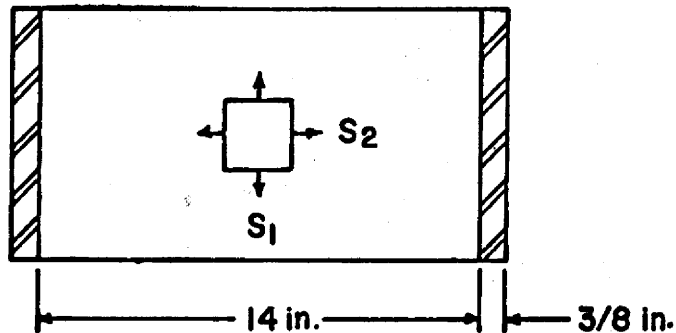
$$= (1 \times 0.375 - 0.251) (0.146 + 0.375) (2)$$

$$= (0.124) (0.521) (2) = 0.129 \text{ in.}^2$$

Therefore, reinforcement is adequate.

Stresses and Collapsing Pressure for Sides of Still

ORNL DWG. 68-9091



Stresses S_1 and S_2 were calculated by the method of Case 1, Page 268 of Roark ¹³

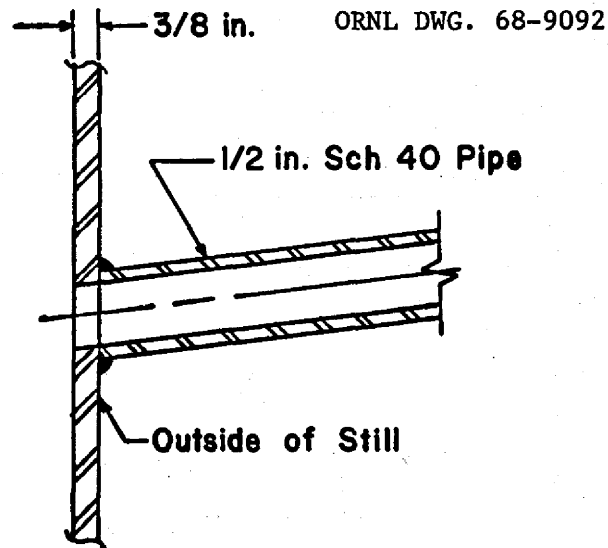
$$S_2 = \frac{PR}{t} = \frac{15 (7.187)}{0.365} = 295 \text{ psi}$$

$$S_1 = \frac{PR}{2t} = 147.5 \text{ psi}$$

The collapsing pressure may be evaluated from Eq. 8.26, page 144, of the text by Brownell and Young. ¹⁴ This equation is developed for design of long, thin cylindrical vessels operating under external pressure. A factor of safety of 4 may be applied to the theoretical value. Equation 8.26 includes this safety factor of 4.

$$P \text{ allowable} = 0.55E (t/d)^3 = 0.55 \times 19.7 \times 10^6 \frac{0.375^3}{14.375} = 192 \text{ psi.}$$

Note that this value provides a factor of safety against collapse of 12.8 based on an external design pressure of 15 psi.

Wall Thickness and Reinforcement for Feed Nozzle

Shell thickness required (t_r):

$$t_r = \frac{PR}{SE-0.6P} = \frac{15 (7.010)}{700 (1) - 0.6 (15)} = \frac{105.1}{691} = 0.152 \text{ in.}$$

Actual thickness = 0.375 in.

Nozzle thickness required (t_{rn}):

$$t_{rn} = \frac{PR_n}{SE-0.6P} = \frac{15 (0.311 + 0.010)}{700 (1) - 0.6 (15)} = 0.00697 \text{ in.}$$

Actual thickness = 0.109 in.

Area of reinforcement required (A):

$$A = (d) (t_r) = (0.642) (0.152) = 0.0976 \text{ in.}^2$$

Area reinforcement available:

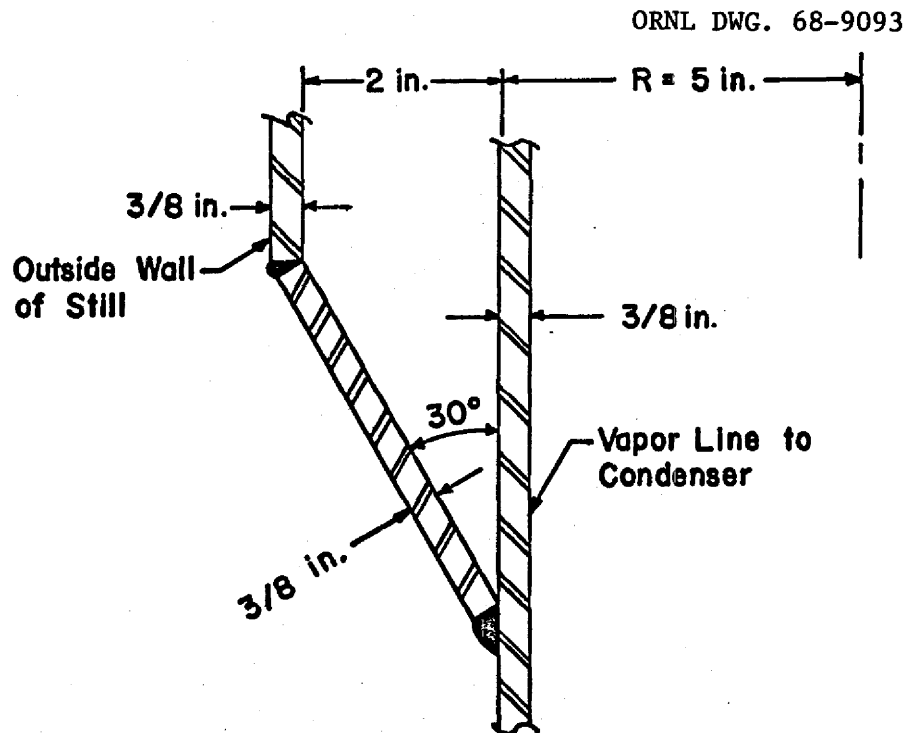
$$\begin{aligned} A_1 &= (E_1 t - t_r) d = [(1) (0.365) - 0.152] (0.642) \\ &= 0.213 (0.642) = 0.1366 \text{ in.}^2 \end{aligned}$$

Reinforcement is adequate.

Author's note:

Since Mr. Hahs made this calculation, a design change made the feed nozzle 1 in. OD x 3/4 in. ID.

Thickness of Conical Bottom of Annulus



Required thickness of head (See Par. UG 32-9, Section 8, of ASME Boiler and Pressure Vessel Code):

Assume half apex angle is 30°.

$$t = \frac{PD}{2 \cos 30^\circ (SE - 0.6P)} = \frac{15 (14)}{2 \cos 30^\circ (700 - 0.6 (15))} = \frac{210}{2 (0.866) (700 - 9)} = 0.175 \text{ in.}$$

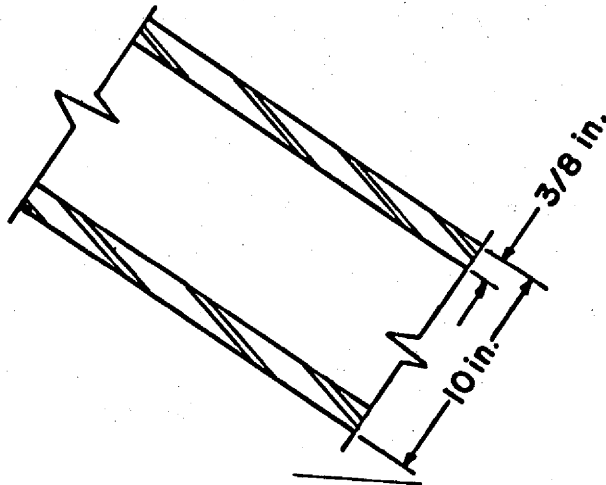
Assume external pressure = (1.67) (design pressure) = (1.67) (15) = 25 psi,

$$t = \frac{PD}{2 \cos 30^\circ (SE - 0.6P)} = \frac{25 (14)}{2 \cos 30^\circ (700 - 0.6 (25))} = \frac{350}{2 (0.866) (685)} = 0.295 \text{ in.}$$

Actual thickness = 0.375 in.

Allowable External Pressure on Condenser

ORNL DWG. 68-9094



Reference: Process Equipment Design, p. 142, by Brownell & Young.¹⁴

Allowable pressure P for long cylindrical vessels operating under external pressure may be calculated with a factor of safety of 4 applied to Eq. 8.25 giving the following:

$$\begin{aligned} P \text{ allowable} &= 0.55 E \left(\frac{t}{D} \right)^3 \\ &= 0.55 (19.7 \times 10^6) \left(\frac{0.375}{9.625} \right)^3 = 642 \text{ psi.} \end{aligned}$$

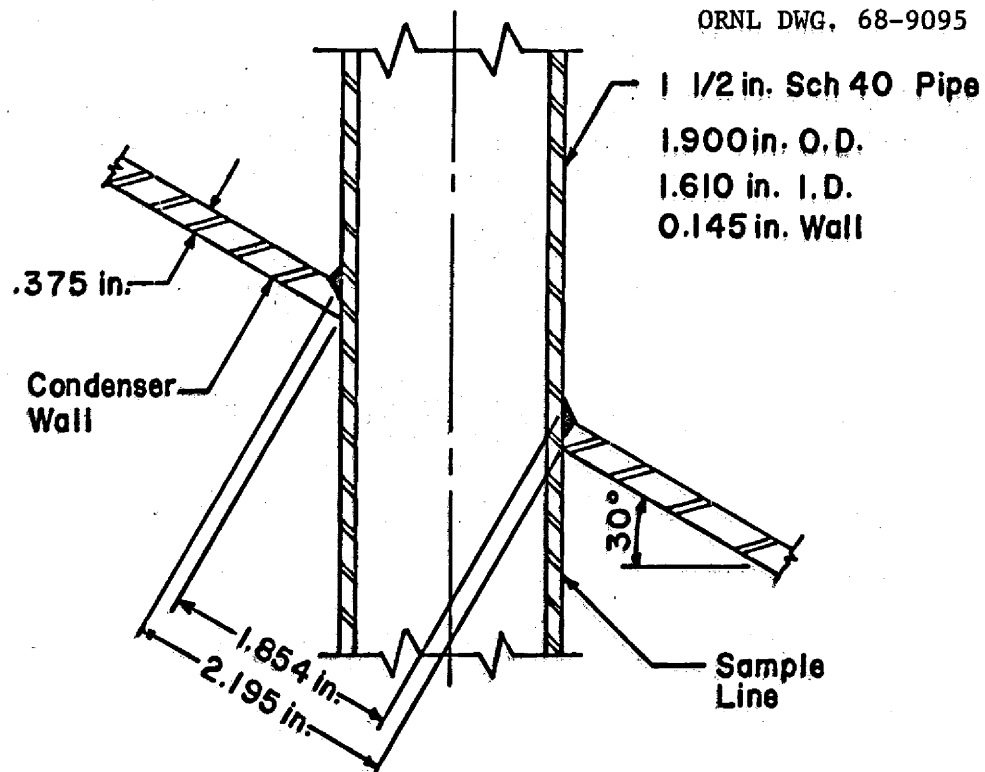
Note: The maximum external operating pressure is 15 psi.

$$\text{Maximum hoop stress} = \frac{PR}{t} = \frac{15 (4.635)}{0.375} = 185.4 \text{ psi}$$

Thickness of condenser shell is therefore adequate.

Allowable External Pressure and Reinforcement for Sample Line

ORNL DWG. 68-9095



Dimensions normal to condenser surface:

$$\text{Maximum opening} = \frac{1.900}{\cos 30^\circ} = 2.195 \text{ in.}$$

$$\text{Minimum opening} = \frac{1.610}{\cos 30^\circ} = 1.854 \text{ in.}$$

Allowable external pressure P_{all} :

$$P_{all} = 0.55 E \left(\frac{t}{d} \right)^3 = 0.55 \times 10.7 \times 10^6 \left(\frac{0.145}{1.90} \right)^3$$

$$= 0.55 \times 19.7 \times 10^6 (0.0755)^3$$

$$= 0.55 \times 19.7 \times 10^6 (0.00423) = 4660 \text{ psi}$$

Nozzle Reinforcement Requirements:

Reinforcement calculations will be made assuming the nozzle passes through the shell at right angles. The nozzle wall thickness remains 0.145 in.; however, an OD of 2.195 in. and ID of 1.854 in. is used in the calculations.

$$\text{Shell } t_r = \frac{PR}{SE - 0.6P} = \frac{15 \left(\frac{9.250}{2} \right)}{700 (1) - 0.6 (15)} = \frac{69.4}{691} = 0.100 \text{ in.}$$

$$\text{Nozzle } t_{rn} = \frac{PR_n}{SE - 0.6P} = \frac{15 (1.854/2)}{700 - 0.6 (15)} = \frac{15 (0.927)}{691} = 0.0201 \text{ in.}$$

$$\text{Area of reinforcement required} = dt_r = 1.854 (0.100) = 0.1854 \text{ in.}^2$$

A_1 = area available

$$= (E_1 t - t_r) d = (0.375 - 0.10) 1.610 = 0.275 (1.610) = 0.443 \text{ in.}^2$$

No additional area calculation is shown since A_1 is sufficient.

Stress Imposed by Dead Weight of Vessel

The following calculations are made to ensure that the structural design of the vessel is sufficient to allow it to be supported as shown on page 107.

Weight Calculations of Still Components:

$$\text{Area } 8\text{-}1/4 \text{ in. diam} = \pi (8.25)^2/4 = 53.456 \text{ in.}^2$$

$$\text{Area } 8 \text{ in. diam} = \pi (64)/4 = 50.265$$

$$\text{Difference} = 3.191 \text{ in.}^2$$

$$\text{Weight of } 8\text{-}1/4 \text{ in. OD} \times 8 \text{ in. ID Cyl.} = 3.191 \text{ in.}^2 \times .317 \text{ lb/in.}^3 = 1.01 \text{ lb/in.}$$

$$\text{Area of } 10 \text{ in. OD Cyl.} = \pi (10)^2/4 = 78.54 \text{ in.}^2$$

$$\text{Area of } 9\text{-}1/4 \text{ in. ID Cyl.} = \pi (9.25)^2/4 = 67.20$$

$$\text{Difference} = 11.34 \text{ in.}^2$$

$$\text{Weight of } 10 \text{ in. OD} \times 9\text{-}1/4 \text{ in. ID Cyl.} = 11.34 \text{ in.}^2 \times .317 \text{ lb/in.}^3 = 3.595 \text{ lb/in.}$$

$$\text{Weight of heaters on condenser wall} = 75 \text{ lb.}$$

Weight of insulation on condenser wall = 45 lb.

Combined weight of heaters and insulation = $\frac{(75 + 45) \text{ lb}}{47 \text{ in.}} = 2.56 \text{ lb/in.}$

Assume salt deposit on condenser wall = 0.335 lb/in.

Total combined weight of condenser shell, inner shell, heater, and insulation
= 7.5 lb/in.

Blank from which elliptical head is made may be 22.25 in. ID.

Weight of top cylindrical section 14 in. ID x 14.75 in. OD x 7.5 in. long:

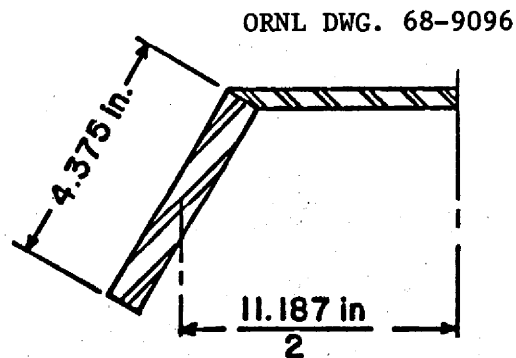
Area 14.75 in. diam. = 170.874 in.²

Area 14 in. diam = 153.938

Net Area = 16.936 in.²

Weight = 16.936 in.² x 7.5 in. x 0.317 lb/in.³ = 40.3 lb.

Weight of conical section:

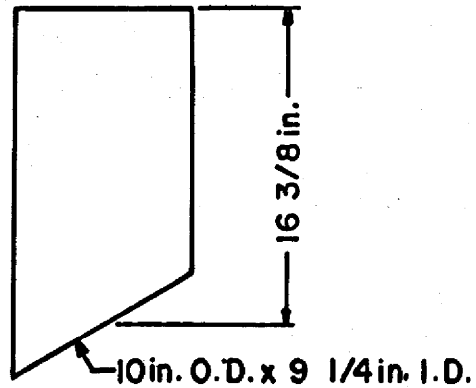


Volume of conical section = $\pi (11.187) (4.375) (0.375) = 57.65 \text{ in.}^3$

Weight = 57.65 in.³ x .317 lb/in.³ = 18.55 lb.

Weight of vapor line:

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$$\begin{aligned} \text{Area 10 in. diam} &= 78.540 \text{ in.}^2 \\ \text{Area 9-1/4 in. diam} &= 67.200 \text{ in.}^2 \\ &\underline{11.340 \text{ in.}^2} \end{aligned}$$

$$\text{Weight} = 11.34 \times 16.375 \times 0.317 = 58.8 \text{ lb}$$

Additional weight:

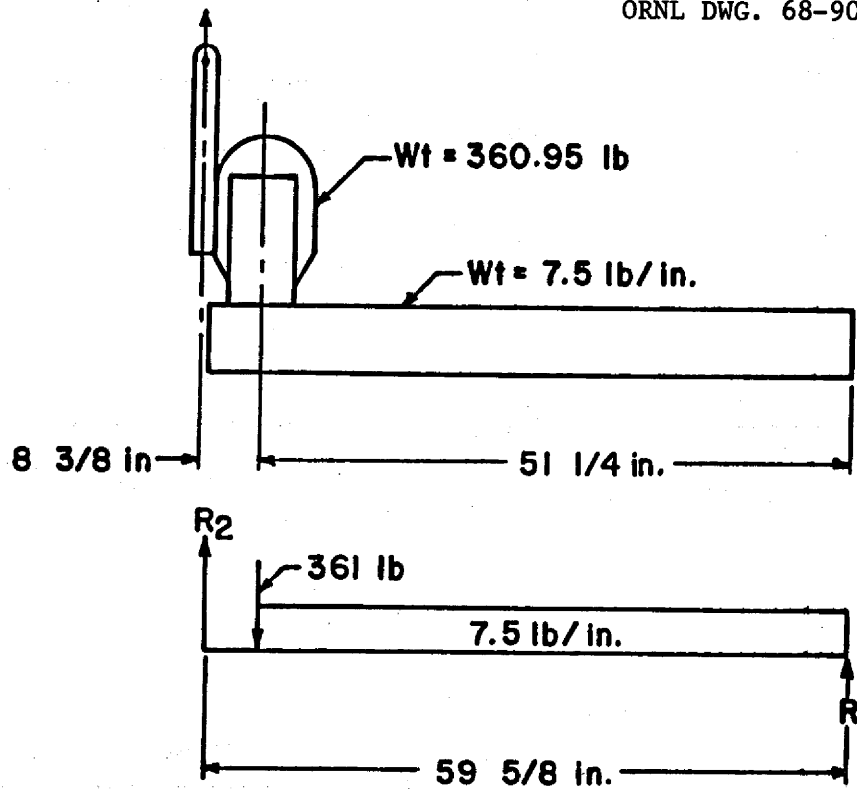
$$\begin{aligned} \text{Weight of heater equipment} &= 50 \text{ lb} \\ \text{Weight of insulation} &= 90 \text{ lb} \\ \text{Weight of salt} &= 18 \text{ lb} \\ &\underline{158 \text{ lb}} \end{aligned}$$

Total weight of top section of still:

$$\begin{aligned} \text{Weight total} &= 46.2 + 40.3 + 57.65 + 58.8 + 158.0 \\ &= 360.95 \text{ lb} \end{aligned}$$

Method of Support for Still and Forces Active on the Still:

ORNL DWG. 68-9098



$$\sum F_v = 0$$

$$R_1 + R_2 = 361 \text{ lb} + 51.25 (7.5)$$

$$= 361 + 384.5 = 745.5 \text{ lb}$$

$$\sum M_{R_1} = 0$$

$$59.625 R_2 = 51.25(361) + \left(\frac{51.25}{2}\right) (384.5)$$

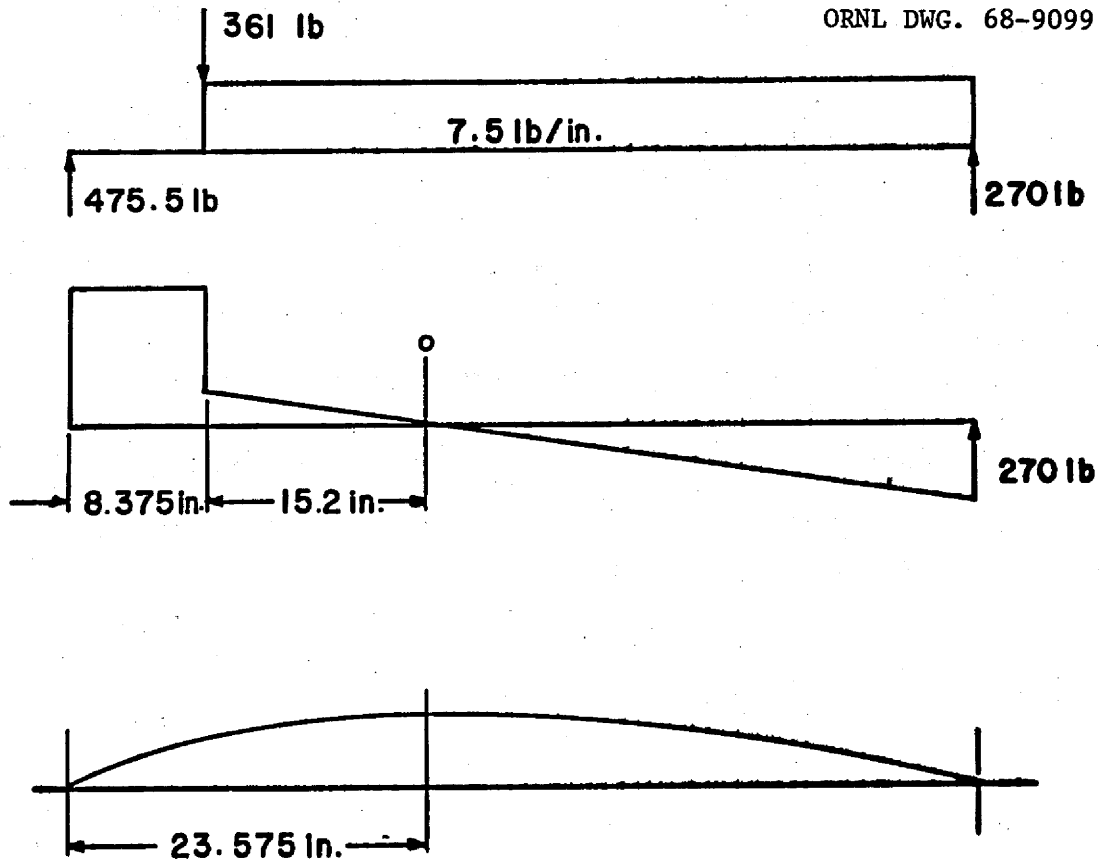
$$59.625 R_2 = 18500 + 9,850$$

$$R_2 = \frac{28,350}{59.625} = 475 \text{ lb}$$

$$R_1 = 745.5 - 475 = 270.5 \text{ lb}$$

Stresses and Moments in Condenser Shell:

ORNL DWG. 68-9099



$$\begin{aligned}\sum M_o &= - (7.5) (15.2) (7.6) - (361) (15) + (475) (23.575) \\ &= - 866 - 5420 + 11,160 \\ &= 4874 \text{ in.-lb}\end{aligned}$$

$$\begin{aligned}I &= \text{moment of inertia for 10 in. OD} \times 9.25 \text{ in. ID condenser} \\ &= \frac{\pi}{4} (R^4 - R_o^4) = \frac{\pi}{4} [(5)^4 - (4.625)^4] \\ &= \frac{\pi}{4} (625 - 455) = \frac{\pi}{4} (170) = 133.5 \text{ in.}^4\end{aligned}$$

$$\text{Stress } S_b = \frac{MC}{I} = \frac{4874 (5)}{133.5} = 182.5 \text{ psi}$$

Hoop Stress = 185.4 psi (See page 102)

Method of support is satisfactory.

Thermal Stress Calculation

Δt across wall of still = 5°C

Δt of $5^{\circ}\text{C} \sim 10^{\circ}\text{F}$

Still temperature = 1832°F .

Coefficient of thermal expansion at $1832^{\circ}\text{F} = 8.85 \times 10^{-6} \text{ in./in.-}^{\circ}\text{F}$
(See Appendix A, Table A-6).

Modulus of elasticity at $1832^{\circ}\text{F} = 19.7 \times 10^6 \text{ lb/in.}^2$

$$S_t = \frac{\Delta t \alpha E}{2(1-\nu)} = \frac{10 \times 8.85 \times 10^{-6} \times 19.7 \times 10^6}{2(1-0.33)} = 1320 \text{ psi.}$$

The maximum principal stress of 367.9 psi is the combined bending stress, 182.5 psi, as shown on page 108 and the hoop stress, 185.4 psi, as shown on page 102.

It should be noted here that the sum of the principal stress, 367.9 psi, and the maximum thermal stress, 1320 psi, is 1688 psi, which is 38 psi more than the stress rupture value of 1650 psi shown on Fig. 15. Since the thermal stress is self-relieving, these values are sufficient.

Additional test data will be obtained in the nonradioactive experiments, and the "used" physical condition of the still will be studied before this equipment is used for a radioactive salt experiment.

Minimum Thickness of Flat Head on Feed Tank

Reference: Paragraph 34-C-2, page 19, Section VIII of ASME Boiler and Pressure Vessel Code, 12

Minimum thickness of flat heads (t):

Operating temperature of vessel = 500°C or 923°F

$$t = d\sqrt{CP/S}$$

C = 0.4 See (e) page 21, Section 8 of the above reference

d = ID of shell

S = maximum allowable stress
= 17,000 psi at 1000°F

$$t = 15 \sqrt{\frac{0.4 (15)}{17,000}} = 15 \sqrt{\frac{6}{17,000}} = 15 \sqrt{3.53 \times 10^{-4}}$$
$$= 15 (0.01876) = 0.282 \text{ in.}$$

Actual thickness = 0.375 in.

Thickness of head is satisfactory.

111
APPENDIX G

SPECIFICATIONS FOR HEATERS FOR VACUUM
DISTILLATION EXPERIMENT FOR FLUORIDE SALTS

1.0 Scope

1.1 General

These specifications (identified as Specification No. CT-63, October 31, 1966) state the requirements for several electric heaters to be mounted on vessels described by the following drawings. These drawings are component parts of these specifications:

1.2 References (see Appendix H for first four drawings listed).

Drawing Number

M-12173-CD-009-D	Condensate Receiver - Assembly and Details
M-12173-CD-011-D	Vacuum Still and Condenser Assembly
M-12173-CD-013-D	Feed Tank for Vacuum Still
M-12173-CD-014-D	Sample Reservoir and Thermocouple Well Details
ORNL DWG. 68-866	Coil Location Within Heating Element

2.0 Codes and Standards

The latest revisions of the following Codes and Standards shall apply to these specifications: ASA, NEMA, and ASTM.

3.0 Type of Service

3.1 Temperature and Operation

The vessels on which the heaters are placed will be required to operate at temperatures as high as 1000° C for extended periods of time. Also during the course of the experimental program the heaters will undergo cyclic operation between room temperature to 1000° C at a frequency of one cycle per day. The heater shall be designed for a lifetime of at least 5,000 hr.

3.2 Vessels

All vessels will be fabricated of Hastelloy N for which the mean coefficient of thermal expansion may be taken as 8.85×10^{-6} in./in.-°F between

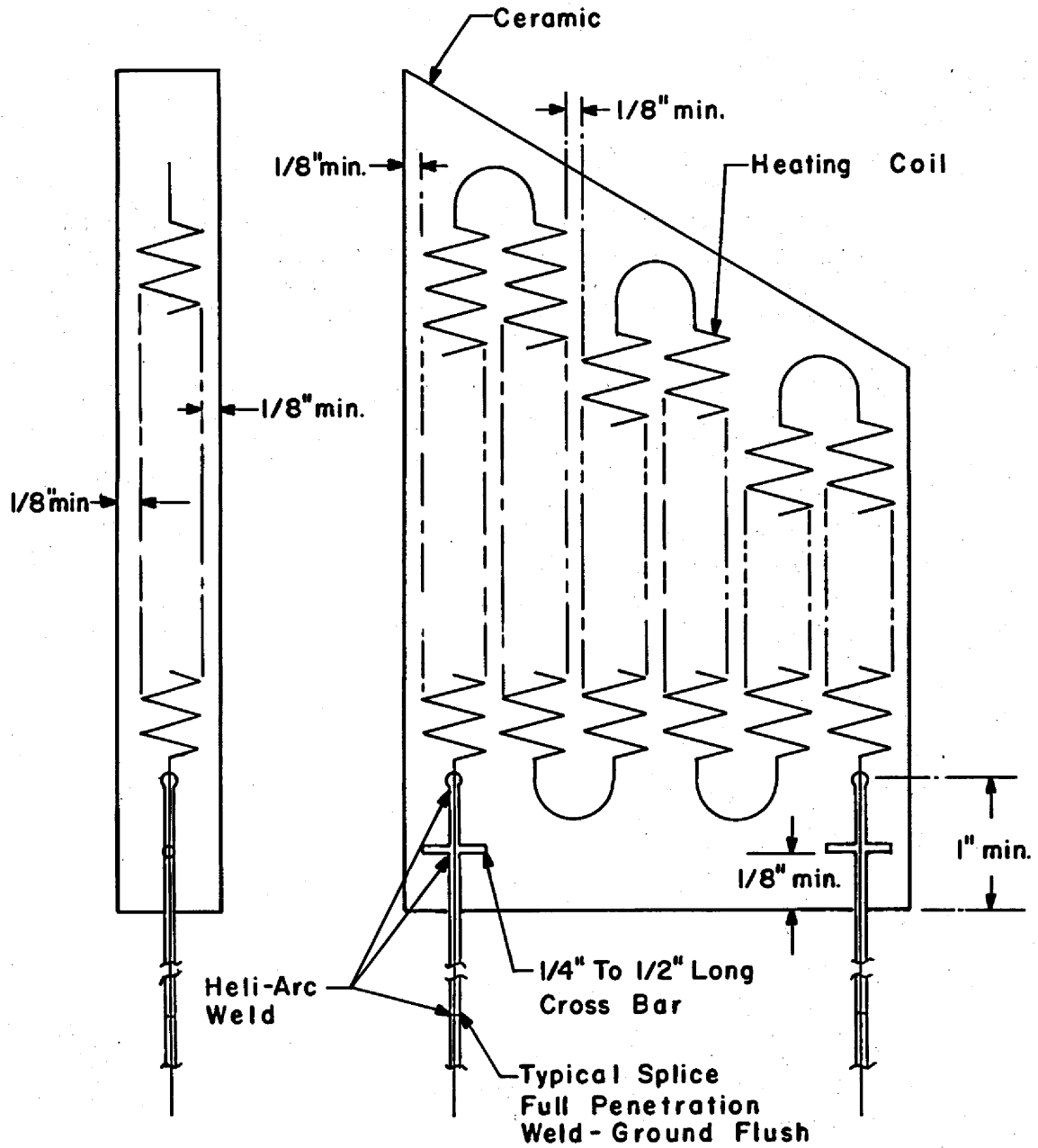


Fig. G-1. Coil Location within Heating Element.

70 and 1800° F.

3.3 Radiation

The heaters will not be used in service that will cause radiation damage.

4.0 Specifications

4.1 Mechanical Features

- (a) The heating elements shall be imbedded (totally enclosed) in a thermally conductive refractory material. In general, the total number of heaters should be kept as low as practicable.
- (b) The heaters will be supported by and on the vessels by the Company (UCNC) and shall be of the type that can be removed and replaced without disturbing the vessel or any nozzles on the vessel. Direct access to the vessels may be assumed for removal and replacement of heaters. Heaters shall be designed for $1/4 \pm 1/8$ in. clearance of vessel walls and surfaces to allow space for thermocouple leads and to supply heat uniformly over these surfaces within the limitations allowed by nozzles and supports.
- (c) The vessels are equipped with various nozzles which will be maintained at temperature as required by heaters supplied by the Company.

4.2 Heat Capacity

Heat capacity of the heaters shall not be greater than 1 cal/g° C.

4.3 Electrical Accessories

The manufacturer is not required to furnish any power supply or control equipment. These will be furnished by the Company.

4.4 Thermal Insulation

The manufacturer is not required to furnish thermal insulation.

4.5 Electrical Requirements

- (a) Available power is 230 v, single-phase, 60-cycle alternating current.
- (b) The manufacturer shall specify the power rating of each heater.

4.6 Geometrical Considerations

4.6.1 Still and Considerations

- (a) The markings on this drawing indicate the zonal heat requirements. Total heat input to the still section is 15 kw; this rating may be increased for manufacturing convenience by as much as 15% but no decrease will be allowed. The top of the still shall have a heat input of 4 kw; the remaining 11 kw shall be applied to the sides. Heaters for the top section shall conform to the geometry of the dome-shaped top. When the still is operating at a temperature of 1000° C the maximum loss rate to the surroundings of 1.5 kw may be assumed.
- (b) Total heat input to the condenser section is 20 kw with a 15% increase being allowed if needed for manufacturing convenience. This total requirement is to be divided into three approximately equal zones as shown on the drawing. When the condenser temperature is 1000° C, the maximum heat requirement including losses to the surroundings will be 10 kw.

4.6.2 Condensate Receiver, Drawing No. M-12173-CD-009-D.

This vessel will be heated along its bottom, vertical sides, and top. A total heat input of 20 kw is required with a 15% overage being allowed. The heat input is to be distributed over the vessel as follows: approximately 30% on the bottom, 50% on the sides, and 20% on the top. When the vessel is at a temperature of 1000° C, the maximum heat requirement including losses to the surroundings will be 3 kw.

4.6.3 Feed Tank, Drawing No. M-12173-CD-013-D.

This vessel will be heated along its bottom, vertical sides, and top. A total heat input of 20 kw is required with a 15% overage being allowed. The heat input is to be distributed over the vessel as follows: approximately 30% on the bottom, 50% on the sides, and 20% on the top. When the vessel is at a temperature of 1000° C, the maximum heat requirement including losses to the surroundings will be 3 kw.

4.7 Special Features

- (a) Terminal leads shall be at least 3 ft long and shall have a cross-sectional area more than twice that of the heater element and shall not be less than No. 14 AWG.

- (b) Terminal lead wires shall be imbedded a minimum length of 1 in. into the ceramic refractory and shall have a cross bar as shown on the accompanying Fig. G-1.
- (c) All weld joints shall be heli-arc welded including splices in the terminal lead wires.

5.0 Inspection and Test

5.1 Visual

Visual inspection shall be made to determine that

- (a) the ceramic is not cracked or broken,
- (b) the ceramic is not swelled or warped, and
- (c) the terminal lead wires do not move or rotate in the ceramic.

5.2 Liquid Penetrant

Liquid penetrant (dye check) inspect all terminal lead splice welds and remove or repair all dye indications.

5.3 Radiography

Each completed unit shall be 100% radiographed to establish that:

- (a) the heating element has a minimum spacing of 1/8 in.;
- (b) a minimum clearance of 1/8 in. is maintained between the heating element and surface of the refractory;
- (c) the terminal leads are imbedded a minimum length of 1 in. in the refractory;
- (d) Exposed radiographs shall be shipped with the heating elements.

5.4 Electrical Test

The electrical resistance of each heating element shall be measured, recorded, and compared with the design resistance. The resistance shall be measured at room temperature.

5.5 Observation of Tests

The tests described in this section shall be performed by the manufacturer at the manufacturer's plant prior to shipment. The manufacturer shall notify the Company at least five working days prior to start of tests so that a representative may be present to witness the tests.

APPENDIX H

Equipment Drawings

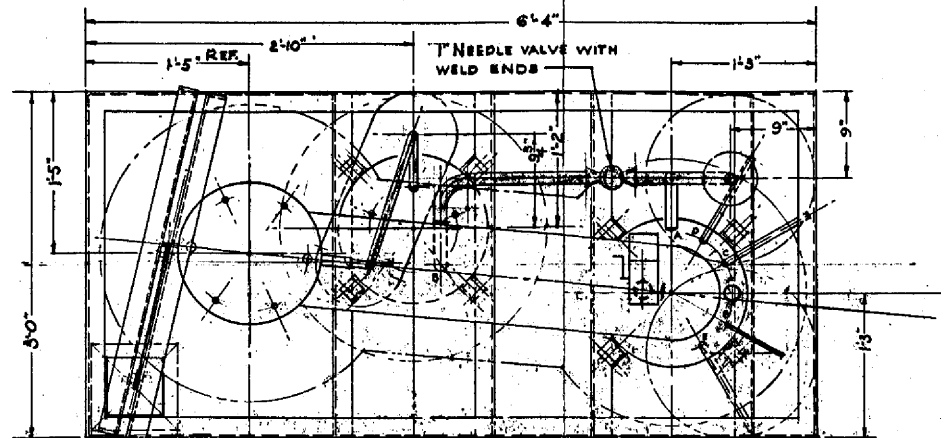
The following equipment drawings are included in this Appendix. Each drawing bears the primary title MSRE Distillation Experiment; drawing numbers and subtitles are as follows:

M-12173-CD-009-D	Condensate Receiver Assembly and details.
M-12173-CD-010-D	Installation of equipment and piping in Supporting Frame.
M-12173-CD-011-D	Vacuum Still and Condenser Assembly.
F-12173-CD-012-D	Flowsheet for Vacuum Distillation of Molten Salt Reactor Fuel (Hood Experiment)
M-12173-CD-013-D	Feed Tank for Vacuum Still.
M-12173-CD-014-D	Sample Reservoir and Thermocouple Well Details.
M-12173-CD-015-D	Liquid N ₂ Cold Trap for Vacuum Line.
M-12173-CD-016-D	Equipment Support Frame.
M-12173-CD-017-D	Temporary Vessel Support (for Transporting).
F-12173-CD-018-D	Flowsheet for Vacuum Distillation MSRE Fuel Salt (Radioactive Experiment).
M-12173-CD-019-D	Location of Points for Dimensional and Radiographic Measurements on Still and Condenser Assembly.
M-12173-CD-020-D	Tabulation of Data from Dimensional and Radiographic Measurements on Still and Condenser Assembly.
M-12173-CD-021-D	Location of Points for Linear Measurements and Tabulation of Data for Still - Condenser - Assembly.

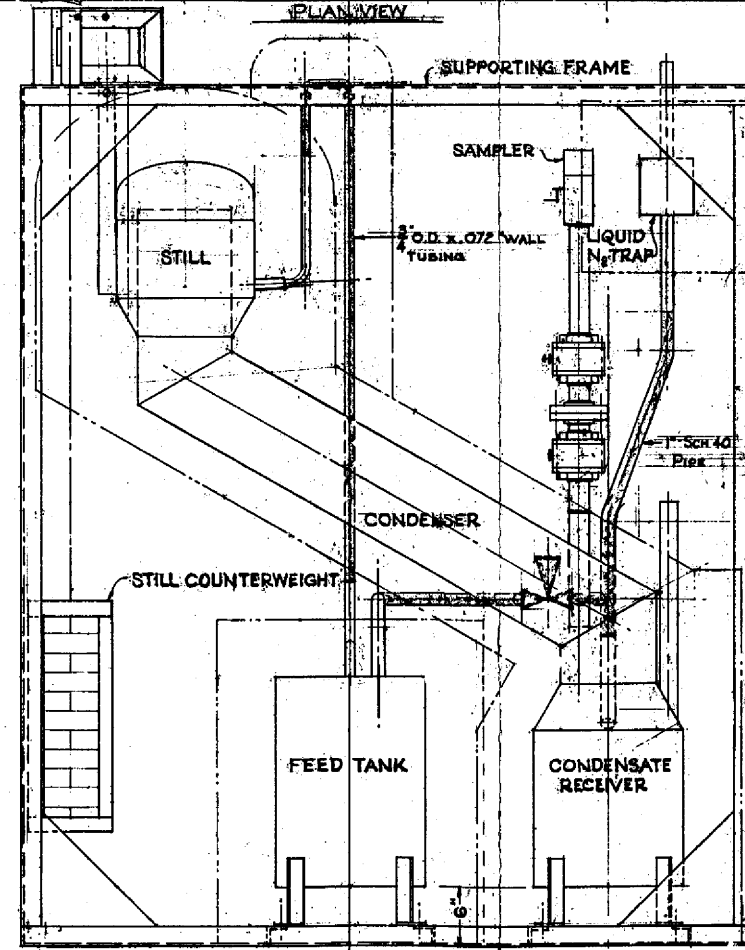
Drawings M-12173-CD-020-D and M-12173-CD-021-D as presented herein contain a complete tabulation of the data recorded immediately after construction of the still assembly. These data are to be compared with similar measurements made after the still has been operated at temperatures up to 1000° C for extended periods of time. This second set of data will not be available before publication of this report and cannot be included herein. However, when the measurements and observations are made, the results will be recorded on a revision of these drawings for a permanent record.

The following drawings are referenced but are not included in this Appendix. Each drawing bears the primary title MSRE Distillation Experiment; drawing numbers and subtitles are as follows:

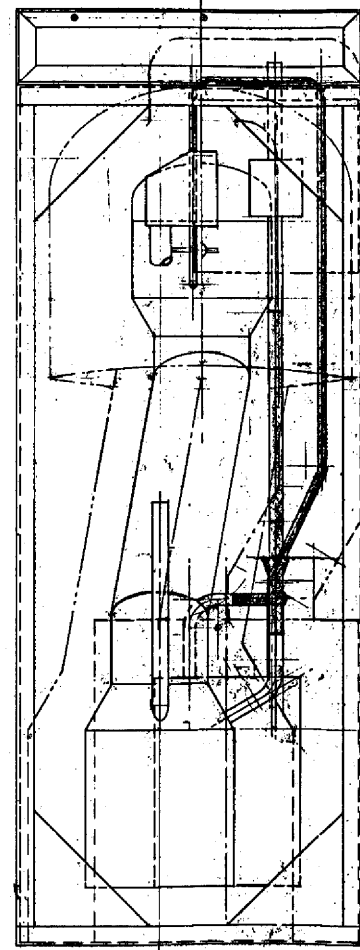
S-20794-EB-137-D	High-Density Concrete Shield Plug Plan and Sections.
S-20794-EB-138-D	High-Density Concrete Shield Plug Enlarged Plan and Sections.
S-20794-EB-139-D	High-Density Concrete Shield Plug Lifting Hook Details and Sections.
E-20794-ED-155-D	Electrical-Vacuum Distillation Experiment.



PLAN VIEW



FRONT ELEVATION



END ELEVATION

GENERAL NOTES

1 FIT, WELD & INSPECT SHADED PORTIONS OF PIPING & VALVE IN SHOP. SEE NOTE 5 Dwg M12173-CD-110-D FOR SPECIFICATIONS.

SAMPLE RESERVOIR & THERMOCOUPLE WELL DET.	014-D
SUPPORT FRAME	015-D
LIQUID N ₂ TRAP	015-D
FEED TANK	015-D
CONDENSATE RECEIVER	008-D
VACUUM STILL & CONDENSER	017-D
FLOWSHEET	012-D
REFERENCE DRAWINGS	NO.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

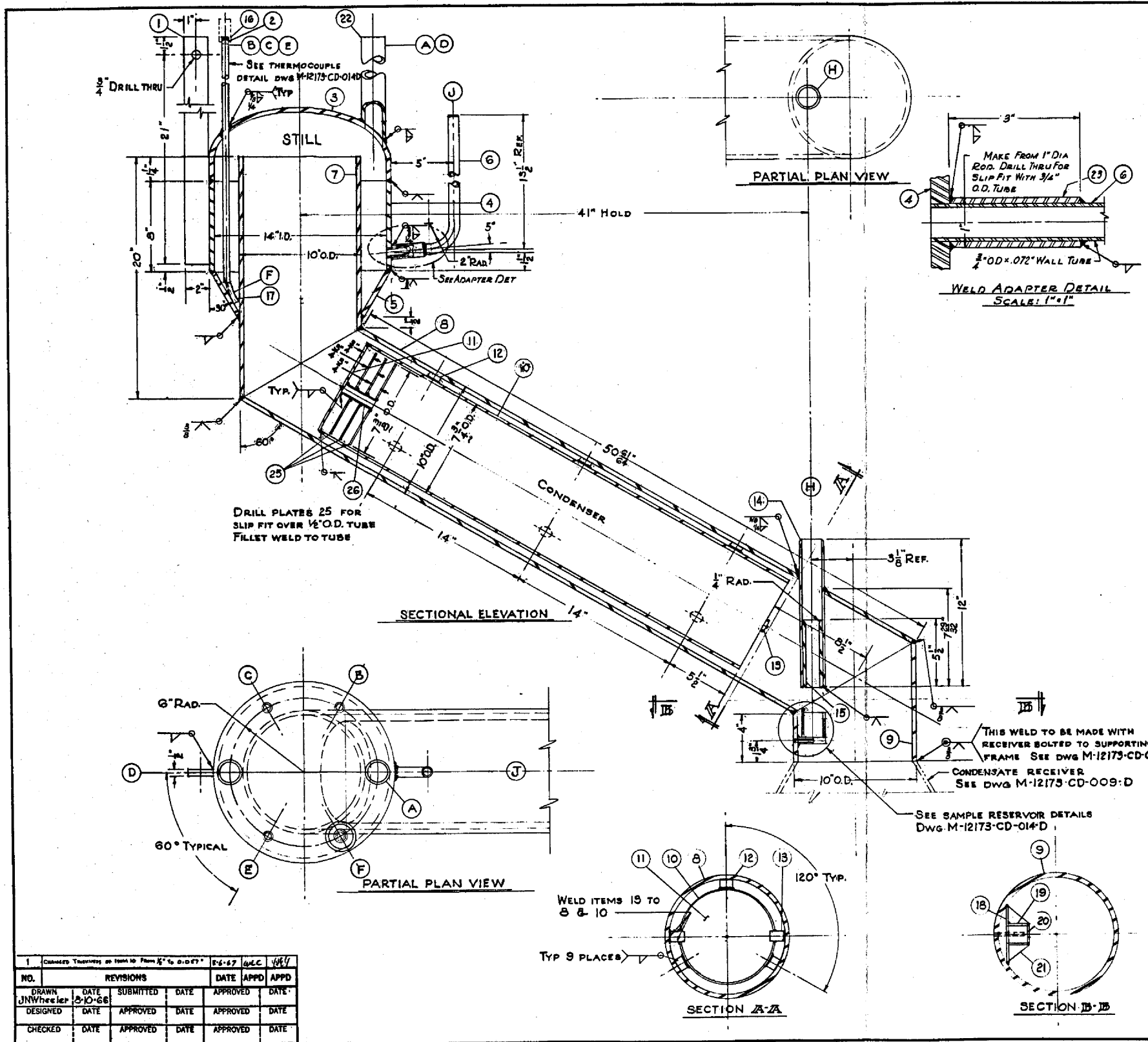
MSRE DISTILLATION EXPERIMENT SLDG. 254
NO. 0-7806

**INSTALLATION OF EQUIPMENT
& PIPING IN SUPPORTING FRAME**

DESIGNED BY: J.M. Wheeler
SUBMITTED: 1/20/67
APPROVED: R.G. ...
M-12173 CD 010 D

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± 1/32"
DECIMALS ± .005"
ANGLES ± 1'
SCALE 1 1/2" = 1'-0"

NO.	REVISIONS		DATE		APPD	APPD
	DATE	SUBMITTED	DATE	APPROVED		
DRAWN	J.M. Wheeler	3-14-66				
DESIGNED						
CHECKED						



PARTS LIST				
ITEM	DWG No.	QTY	DESCRIPTION	MATERIAL
1	THIS DWG	1	STRAP 1/2"x2"x 22 1/2"	HASTELLOY N
2	O14-D	45IN	Rcd 1" O.D.	
3	THIS DWG	1	ELLIPTICAL HEAD 14" I.D. x 3/8" THK (22" O.D. BLANK)	
4		1	SHELL 14 3/4" O.D. x 3/8" WALL x 5"	
5		1	CONE 14 3/4" O.D. LARGE END 10" I.D. SMALL END @ 30° OF 3/8"	
6		1	TUBING 3/4" O.D. x .072 WALL x 20"	
7		1	PIPE 10" O.D. x 3/8" WALL x 20"	
8		1	10" O.D. x 3/8" x 56 3/8"	
9		1	10" O.D. x 3/8" x 9 1/2"	
10		1	7 3/4" O.D. x .057" x 59"	
11		1	PLATE 7 3/4" O.D. x 1/8"	
12		9	Rcd 1" O.D. x 2 1/2"	
13		2	PLATE 1/4" x 1 1/2" x 3/4"	
14		1	PIPE 1 1/2" SCH. 40 x 12"	
15		1	INBERT 1 3/8" O.D. x 1 1/8" I.D. x 5 1/2"	
16		3	COUPLING 1/8" SCH. 40 SCRW'D	INCONEL
17		1	TUBE 1/2" O.D. x .042" WALL x 29 1/2"	HASTELLOY N
18		1	PLATE 1/8" x 4 3/8" x 2 1/2"	
19		2	1/8" x 1 5/8" x 2"	
20		1	1/8" x 1 1/2" x 2"	
21		1	1/2" x 4 5/8" x 2 3/8"	
22		2	PIPE 1 1/2" SCH 40 x 17"	
23		1	Rcd 1" O.D. x 3"	
24	O14-D	3	PIPE 1/8" SCH 40 x 12" LONG 1/8" NPT 1" END	INCONEL
25	THIS DWG	3	PLATE 1/8" x 7 3/8" O.D. (RADIATION SHIELD)	HASTELLOY N
26		1	TUBE 1/2" O.D. x .042" WALL x 2 3/8"	
27	O14-D	1	PIPE 1" SCH 40 x 3 1/4"	
28		1	FLANGE 2 3/8" O.D. x 3/8" PLATE	
29		1		

- GENERAL NOTES**
- ITEMS 4-7-8-9 & 10 TO BE ROLLED FROM PLATE & WELDED FULL PENETRATION. SEE PAR. UG-81, SECT 8, ASME BOILER & PRESS. VESSEL CODE FOR REGO FABRICATION TOLERANCES.
 - WHEN REFERENCE IS MADE TO ANY NATIONALLY ACCEPTED STANDARD REFERENCE OR CODE, THE LATEST REVISION APPLIES. ASME CODE CASE 1270 N & 1275 N.
 - DESIGN CONDITIONS:

DESIGN TEMPERATURE	1000°C
DESIGN PRESSURE	0.5 mm Hg
VESSEL HYDROSTATIC TEST	805 PSIG SEE NOTE-7
VESSEL FREON TEST	10 PSIG
 - MATERIAL SPECS PER MET-RM-2, MET-RM-4, MET-RM-6, MET-RM-B167, MET-RM-B334 & MET-RM-B356
 - FABRICATION:

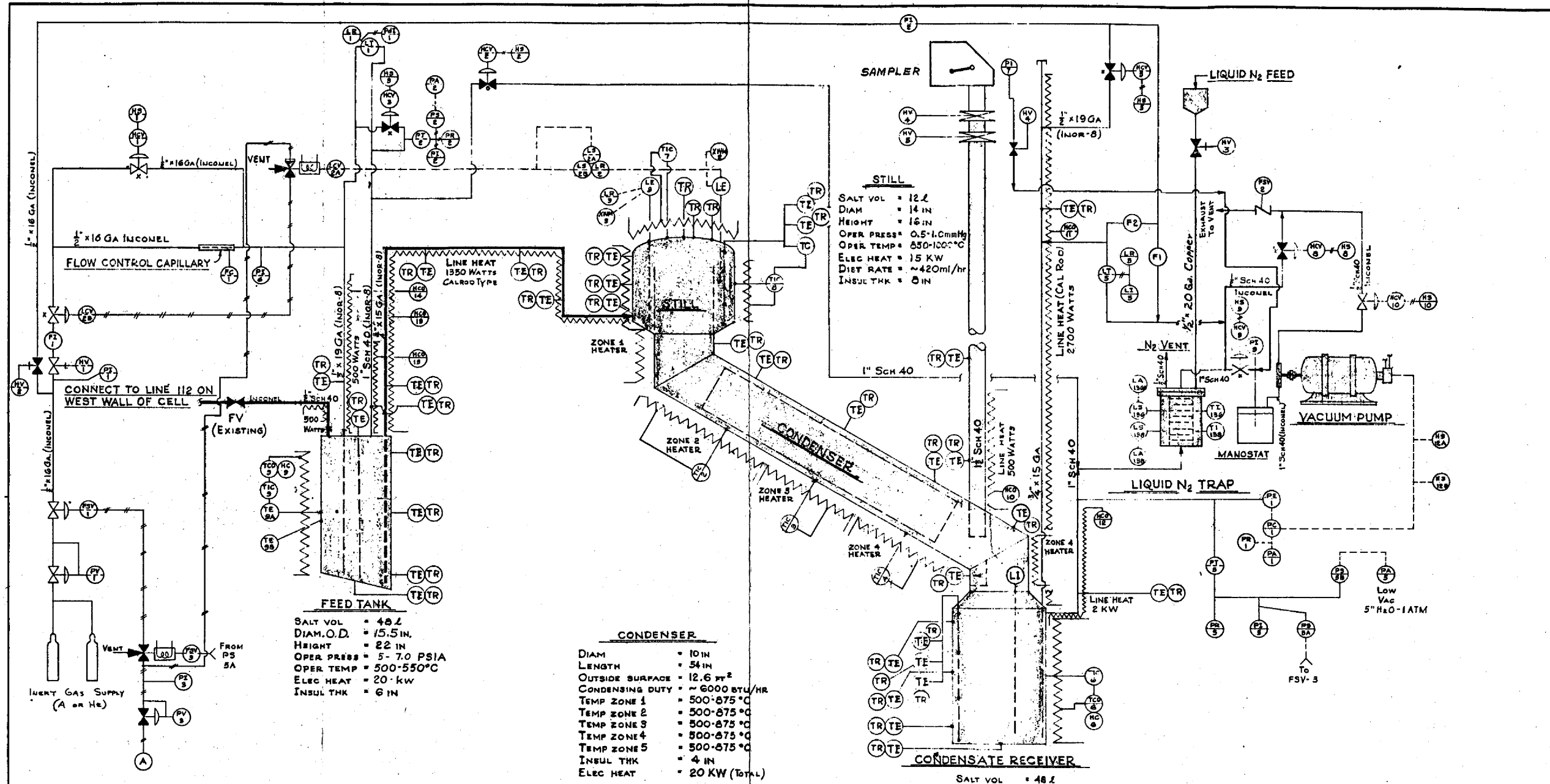
WELDING	ORNL SPECS PS-23, PS-25 & PS-26
INSPECTION	ORNL SPECS MET-WR-200 SCH "B"
 - NO INSPECTION REQUIRED OF WELDS JOINING PART 10 TO PARTS 11, 12, & 13; PART 8 TO PART 13; AND PART 26 TO PARTS 11 & 25
 - AFTER MAKING 805 PSIG HYDROSTATIC TEST ON STILL & CONDENSER ASSEMBLY, ASSEMBLE UNIT WITH CONDENSATE RECEIVER (DWG M-12173-CD-009-D) & MAKE 45 PSIG HYDROSTATIC TEST & 10 PSIG FREON TEST ON COMBINED ASSEMBLY

DETAILS	O14-D
REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:	
FRACTIONS	± 1/32"
DECIMALS	± .005"
ANGLES	± 1°
SCALE	1/4" = 1"

1. CHANGE TO TOLERANCES AS SHOWN FROM 1/4" TO 0.001"						
NO.	DATE	REVISIONS	DATE	APPD	APPD	
DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE	
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE	
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE	

MSRE DISTILLATION EXPERIMENT	
BLDG. 3541 NO. 8-7509	
VACUUM STILL & CONDENSER ASSEMBLY	
SUBMITTED	APPROVED
APPROVED	APPROVED
M-12173 CD 011	D 1



FEED TANK
 SALT VOL = 48 L
 DIAM. O.D. = 15.5 IN
 HEIGHT = 22 IN
 OPER PRESS = 5-7.0 PSIA
 OPER TEMP = 500-550°C
 ELEC HEAT = 20 KW
 INSUL THK = 6 IN

CONDENSER
 DIAM = 10 IN
 LENGTH = 54 IN
 OUTSIDE SURFACE = 12.6 FT²
 CONDENSING DUTY = ~6000 BTU/HR
 TEMP ZONE 1 = 500-875°C
 TEMP ZONE 2 = 500-875°C
 TEMP ZONE 3 = 500-875°C
 TEMP ZONE 4 = 500-875°C
 TEMP ZONE 5 = 500-875°C
 INSUL THK = 4 IN
 ELEC HEAT = 20 KW (Total)

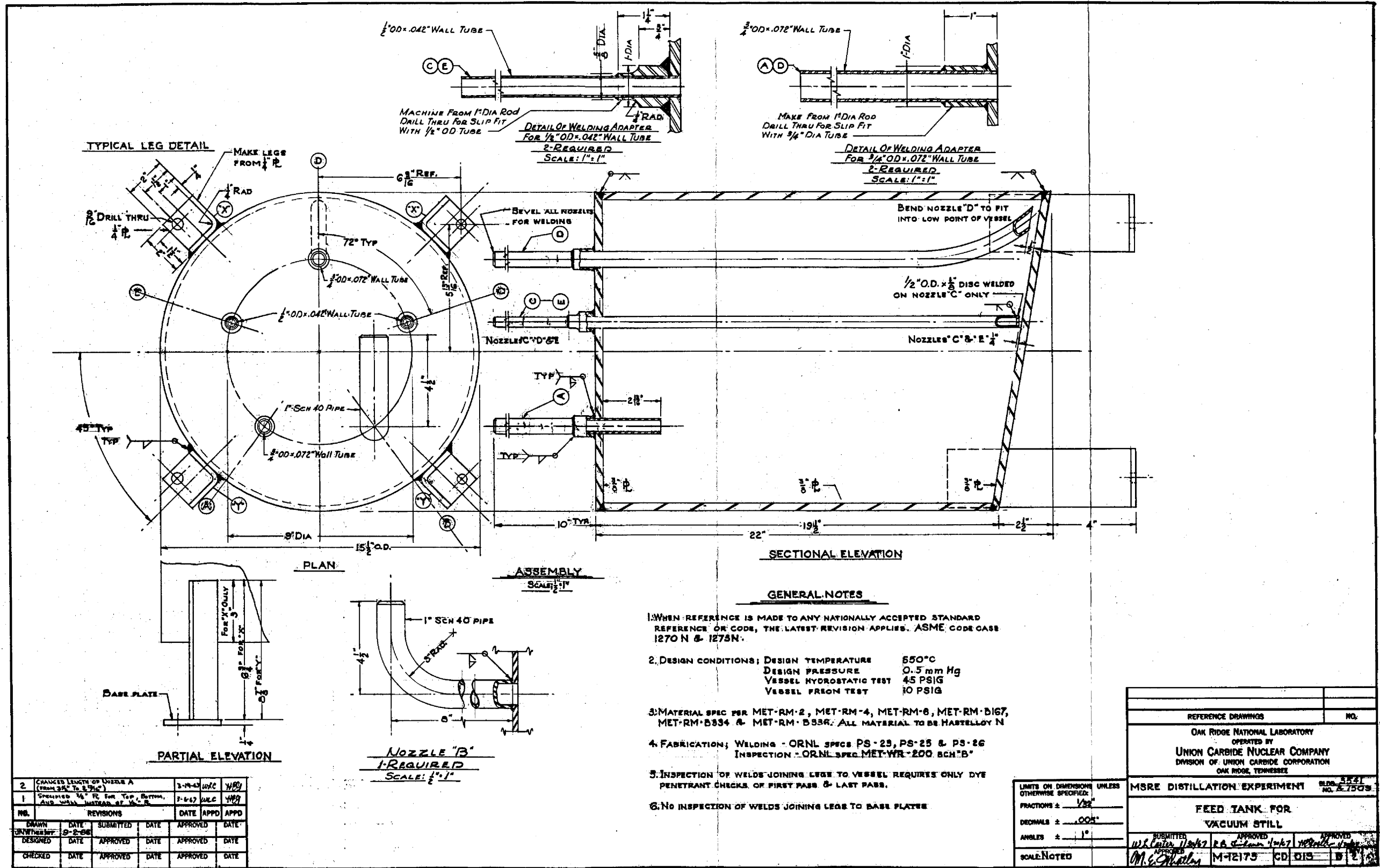
CONDENSATE RECEIVER
 SALT VOL = 48 L
 DIAM. O.D. = 16 IN
 HEIGHT = 16.5 IN
 OPER PRESS = 0.5 mm Hg
 OPER TEMP = 500-550°C
 ELEC HEAT = 20 KW
 INSUL THK = 6 IN

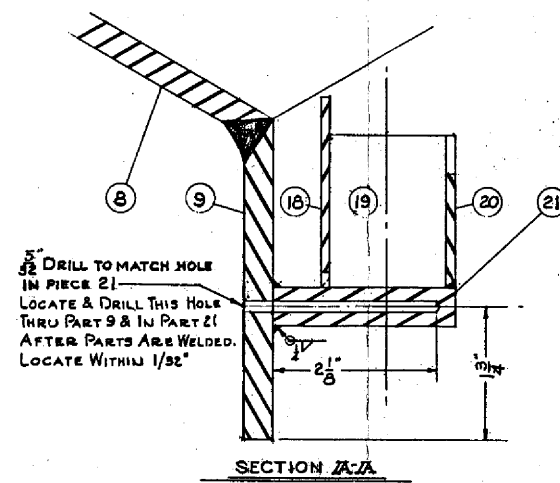
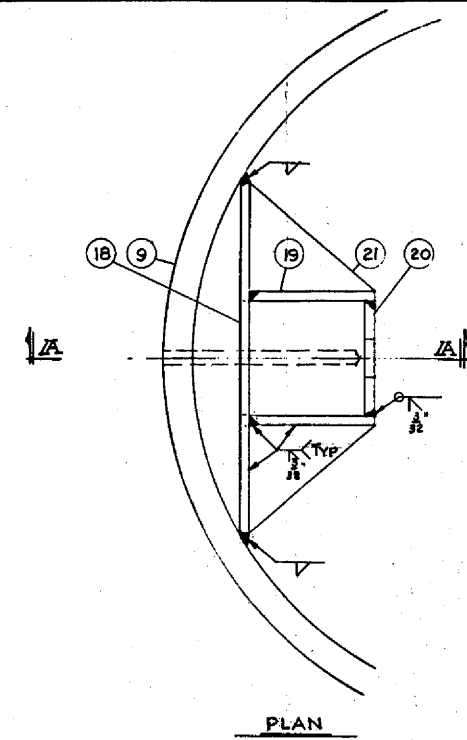
THERMAL INSULATION
 CAREYTEMP 1900 BLOCK TYPE
 K = 0.1 BTU/FT-HR-°F @ 1000°C

2	Changed Line Size on Pressure Diagram	3-6-67	WLC	WLC
1	Changed to Depict Hood Operation Only	2-3-67	WLC	WLC
NO.	REVISIONS	DATE	APPD	APPD
DRAWN	DATE	SUBMITTED	DATE	APPROVED
DESIGNED	DATE	APPROVED	DATE	APPROVED
CHECKED	DATE	APPROVED	DATE	APPROVED

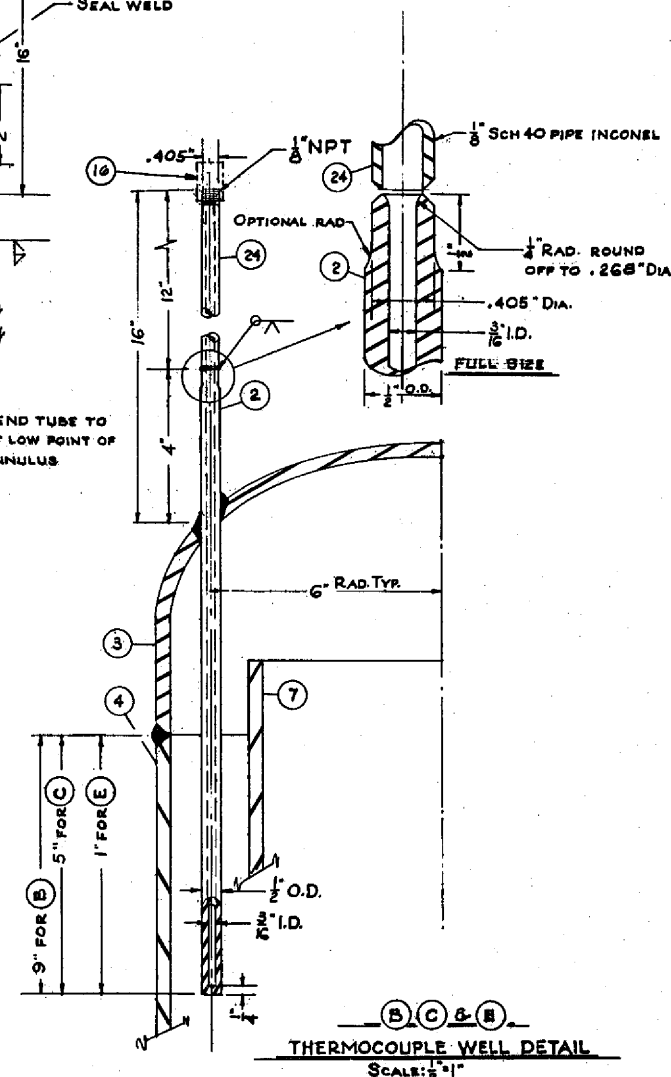
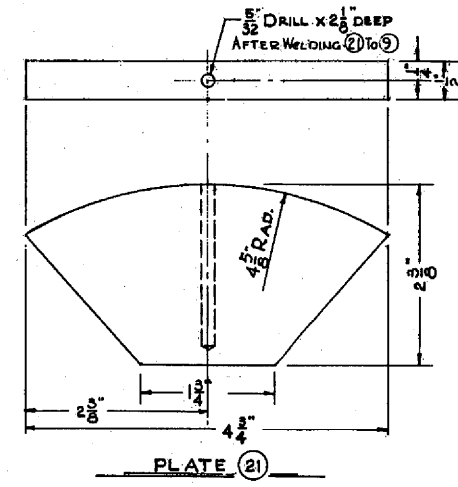
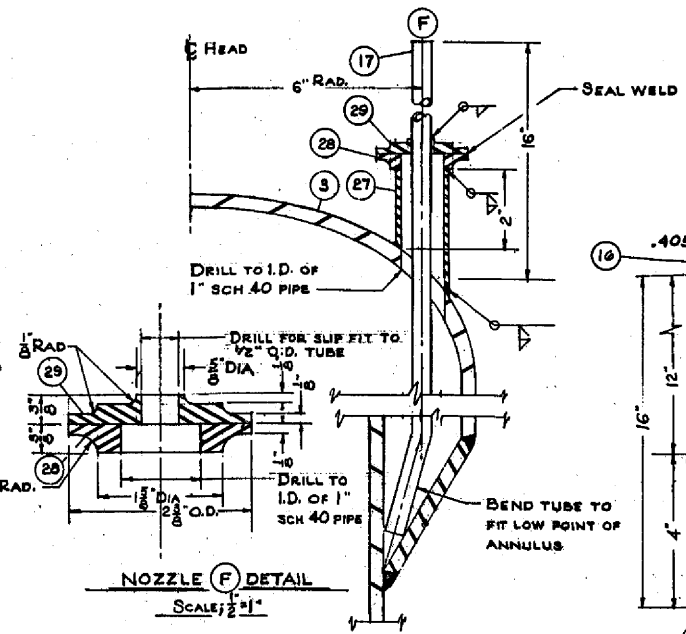
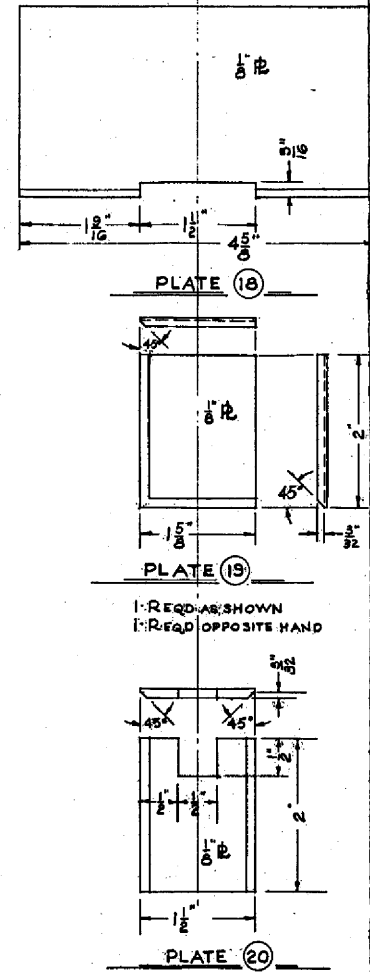
REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MSRE DISTILLATION EXPERIMENT	BLDG. 3541 NO. 750
FLOWSHEET FOR VACUUM DISTILLATION OF MOLTEN SALT REACTOR FUEL (HOOD EXPERIMENT)	
SUBMITTED	APPROVED
W.L. Wheeler 1/20/67	R. B. ... 1/20/67
APPROVED	APPROVED
M. E. ...	W. C. ...
F-12175	CD 012
	D 2

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
 FRACTIONS ±
 DECIMALS ±
 ANGLES ±
 SCALE: NONE





SAMPLE RESERVOIR DETAILS
SCALE: 1"=1"



THERMOCOUPLE WELL DETAIL
SCALE: 1/2"=1"
MACHINE FROM 1" DIA ROD; NO 1/2" DIA
HASTELLOY N ROD AVAILABLE

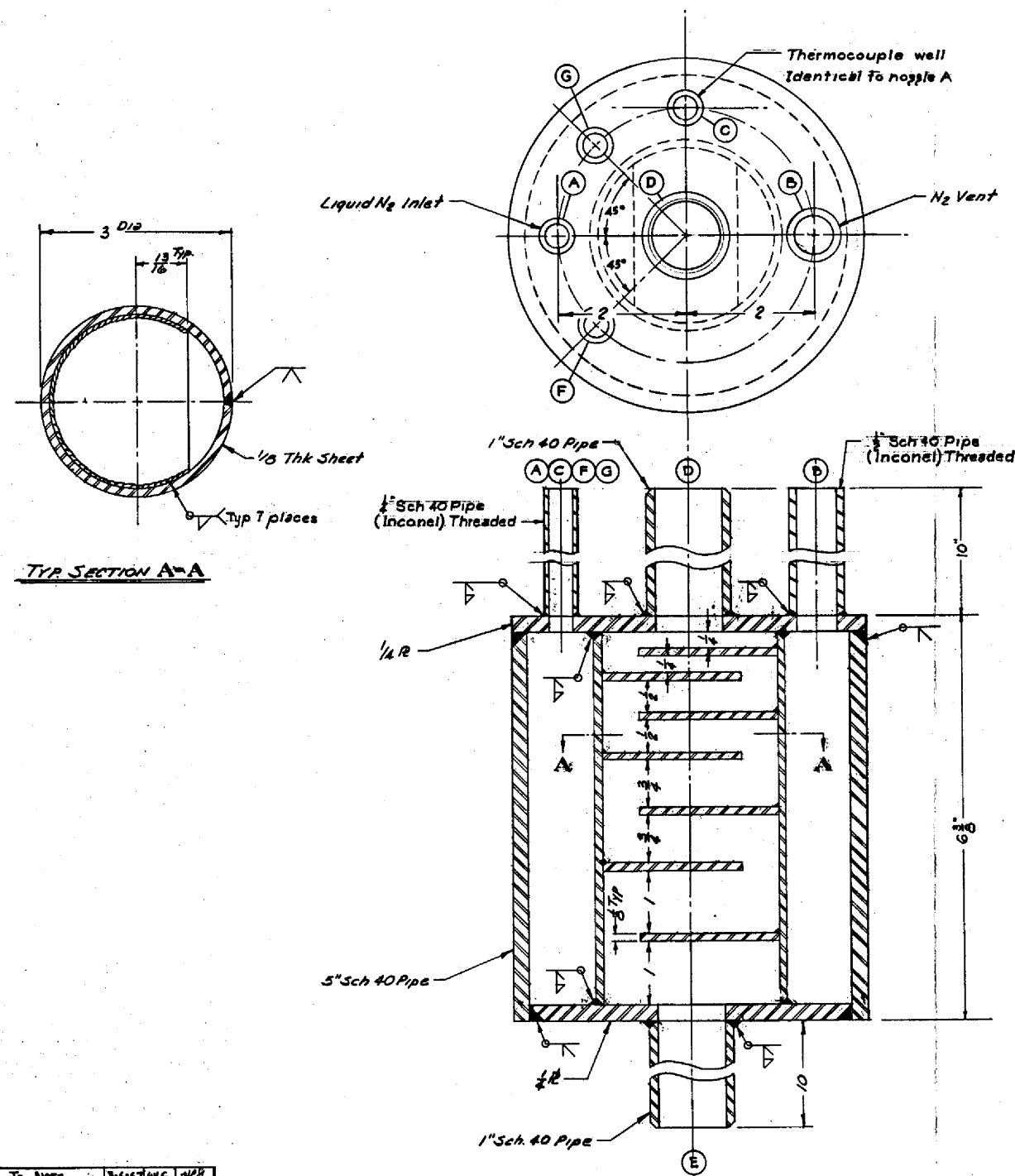
GENERAL NOTES

1. DYE PENETRANT CHECK ONLY REQUIRED OF WELD JOINING PART 21 TO PART 9
2. NO INSPECTION REQUIRED OF WELDS JOINING PART 18 TO PARTS 19 & 21; PART 19 TO PARTS 20 & 21; PART 20 TO PART 21.

NO.	REVISIONS			DATE	APPD	APPD
	DATE	SUBMITTED	DATE			
DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE	
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE	
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE	

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± 1/32
DECIMALS ± .005
ANGLES ± 1°
SCALE NOTED

ASSEMBLY	OIL -D
REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MSRE DISTILLATION EXPERIMENT	DDG 3541 NO. 87609
SAMPLE RESERVOIR AND THERMOCOUPLE WELL DETAILS	
SUBMITTED	APPROVED
W.L. Wheeler 1/30/67	R.B. Anderson 1/30/67
M.E. Whalley	M-12178 CD 014 D

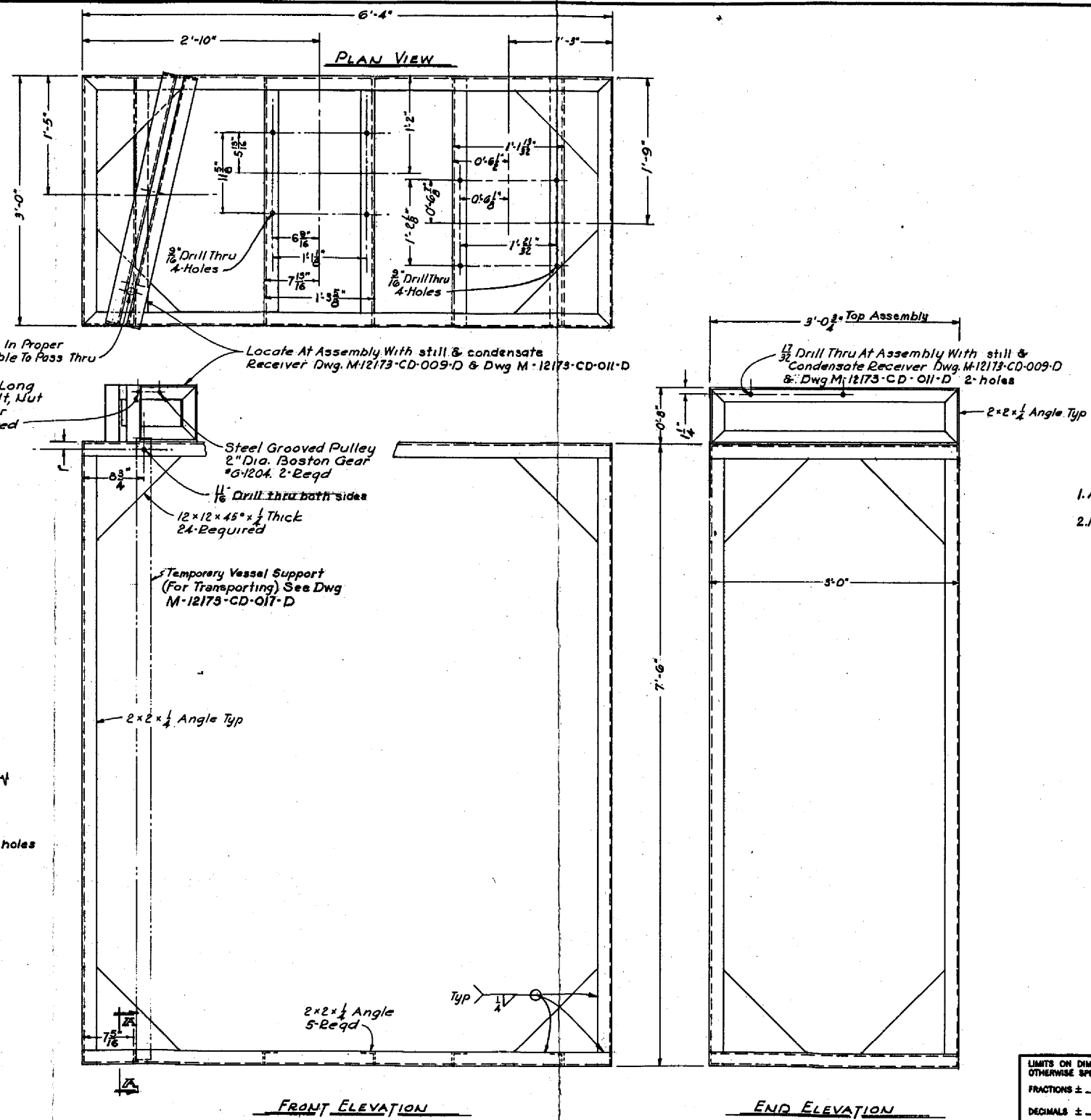


NOTE:
 All Material To Be
 Hastelloy N except as
 noted for nozzles A, D, F, & G

1		As per 'F' & 'G' To Note		3-6-67 MLC		MS	
NO.	DATE	REVISIONS	DATE	APPD	DATE	APPD	DATE
DRAWN	7/14/66						
DESIGNED							
CHECKED							

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
 FRACTIONS ± _____
 DECIMALS ± _____
 ANGLES ± _____
 SCALE: 1" = 1"

REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MSRE DISTILLATION EXPERIMENT BLDG. 3541 NO. 8750B	
LIQUID N ₂ COLD TRAP FOR VACUUM LINE	
SUBMITTED	APPROVED
W. E. Carter 1/20/67	R. B. Stridman 1/20/67
DESIGNED	APPROVED
M. E. Shockey	M-12173 CD 015 D 1



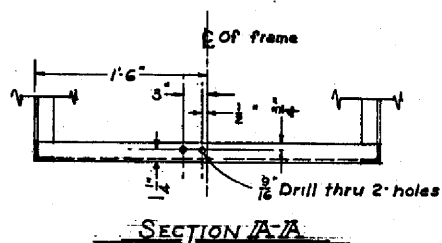
GENERAL NOTES

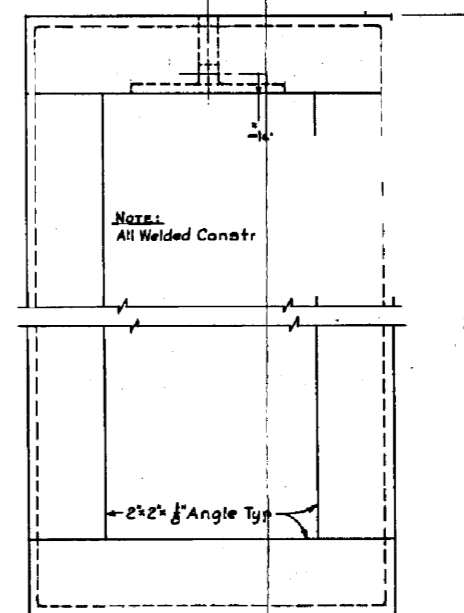
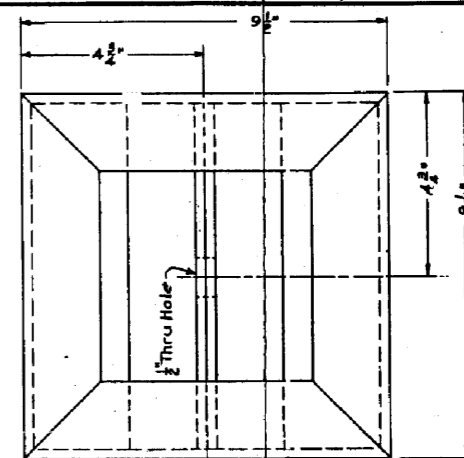
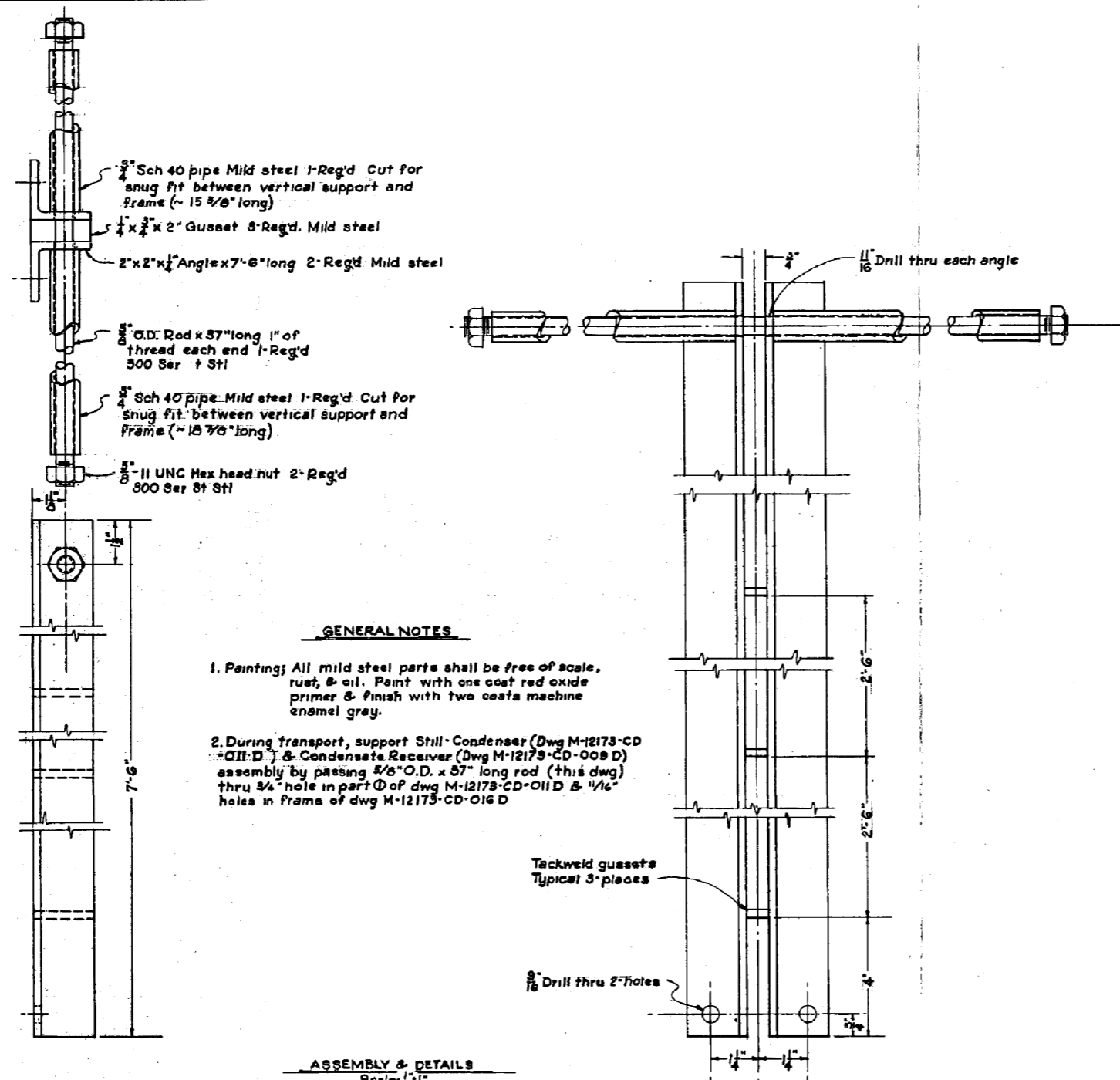
1. All Welded Construction of Mild Steel
2. Painting; All Surfaces Shall Be Free of Scale, Rust & Oil. Paint With One Coat Red Oxide Primer. Finish With Two Coats Machine Enamel Gray

Vessel Support	OIE-D
REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MSRE DISTILLATION EXPERIMENT	BLDG. 5741 NO. 87309
EQUIPMENT SUPPORT FRAME	
SUBMITTED	APPROVED
W. L. Carter	R. B. Anderson
APPROVED	APPROVED
M. J. Phelan	M-12173 CD 010 D

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
 FRACTIONS ± 1/32"
 DECIMALS ± _____
 ANGLES ± _____
 SCALE 1 1/2" = 1'-0"

NO.	REVISIONS		DATE		APPD	APPD
	DATE	SUBMITTED	DATE	APPROVED		
DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE	
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE	
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE	



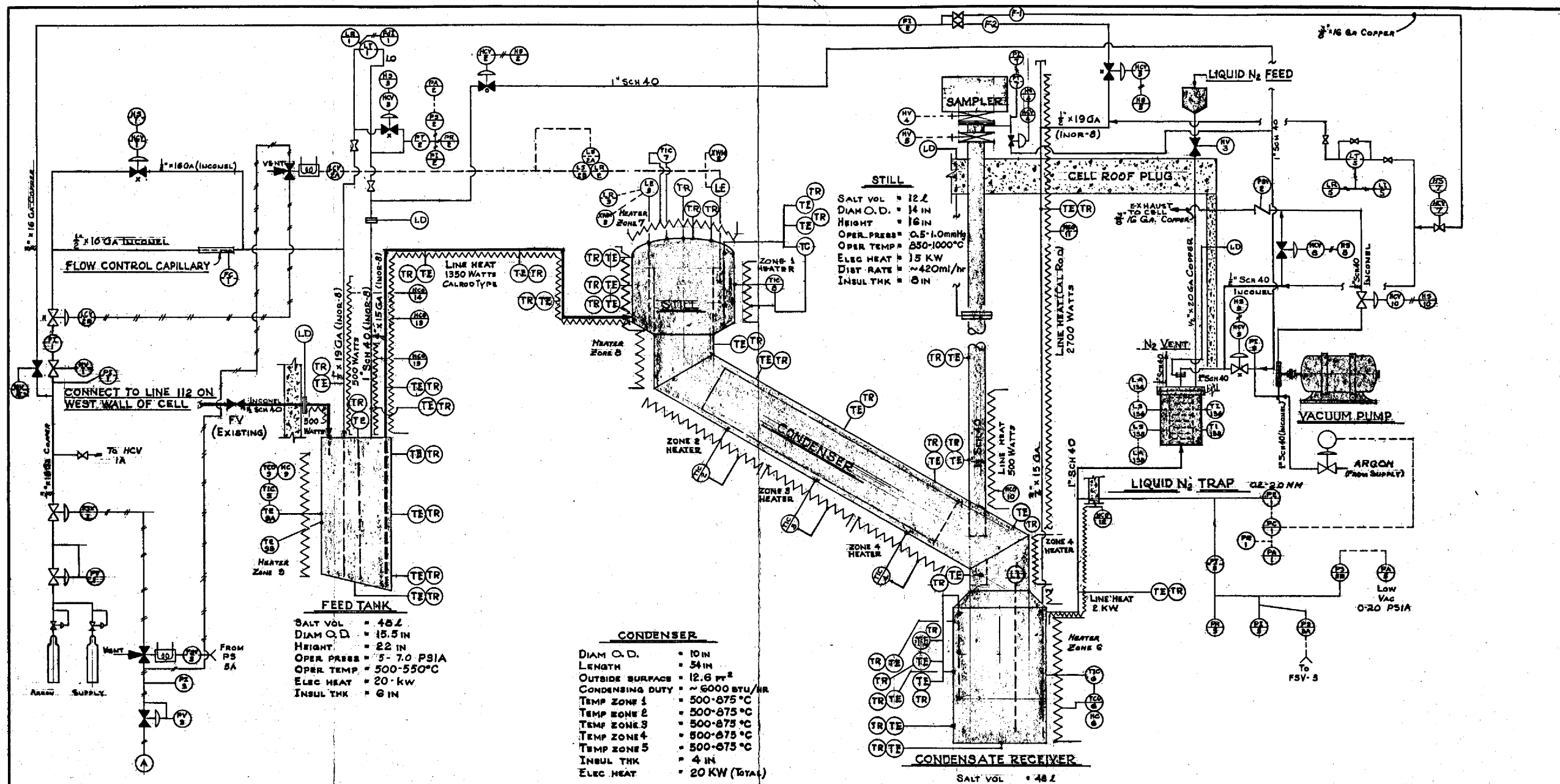


STILL COUNTERWEIGHT
MATERIAL: MILD STEEL

NO.	REVISIONS			DATE	APPD	APPD
	DATE	SUBMITTED	DATE			
DRAWN	DATE			APPROVED		
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE	
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE	

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:	
FRACTIONS \pm	$\frac{1}{32}$
DECIMALS \pm	
ANGLES \pm	
SCALE	$\frac{1}{2}$ " = 1"

SUPPORT FRAME	CD-016-D
REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MSRE DISTILLATION EXPERIMENT	BLDG. 5541, NO. 8-7508
TEMPORARY VESSEL SUPPORT (FOR TRANSPORTING) ASSEMBLY & DETAILS.	
SUBMITTED	APPROVED
APPROVED	M-12173 CD 017 D



STILL
 SALT VOL = 12.2
 DIAM O.D. = 14 IN
 HEIGHT = 16 IN
 OPER. PRESS = 0.5-1.0 mm Hg
 OPER. TEMP = 550-1000°C
 ELEC HEAT = 15 KW
 DIST. RATE = ~420 ml/hr
 INSUL THK = 6 IN

FEED TANK
 SALT VOL = 45 L
 DIAM O.D. = 15.5 IN
 HEIGHT = 22 IN
 OPER. PRESS = 5-7.0 PSIA
 OPER. TEMP = 500-550°C
 ELEC HEAT = 20 KW
 INSUL THK = 6 IN

CONDENSER
 DIAM O.D. = 10 IN
 LENGTH = 54 IN
 OUTSIDE SURFACE = 12.6 sq ft
 CONDENSING DUTY = ~6000 BTU/hr
 TEMP ZONE 1 = 500-875°C
 TEMP ZONE 2 = 500-875°C
 TEMP ZONE 3 = 500-875°C
 TEMP ZONE 4 = 500-875°C
 TEMP ZONE 5 = 500-875°C
 INSUL THK = 4 IN
 ELEC HEAT = 20 KW (Total)

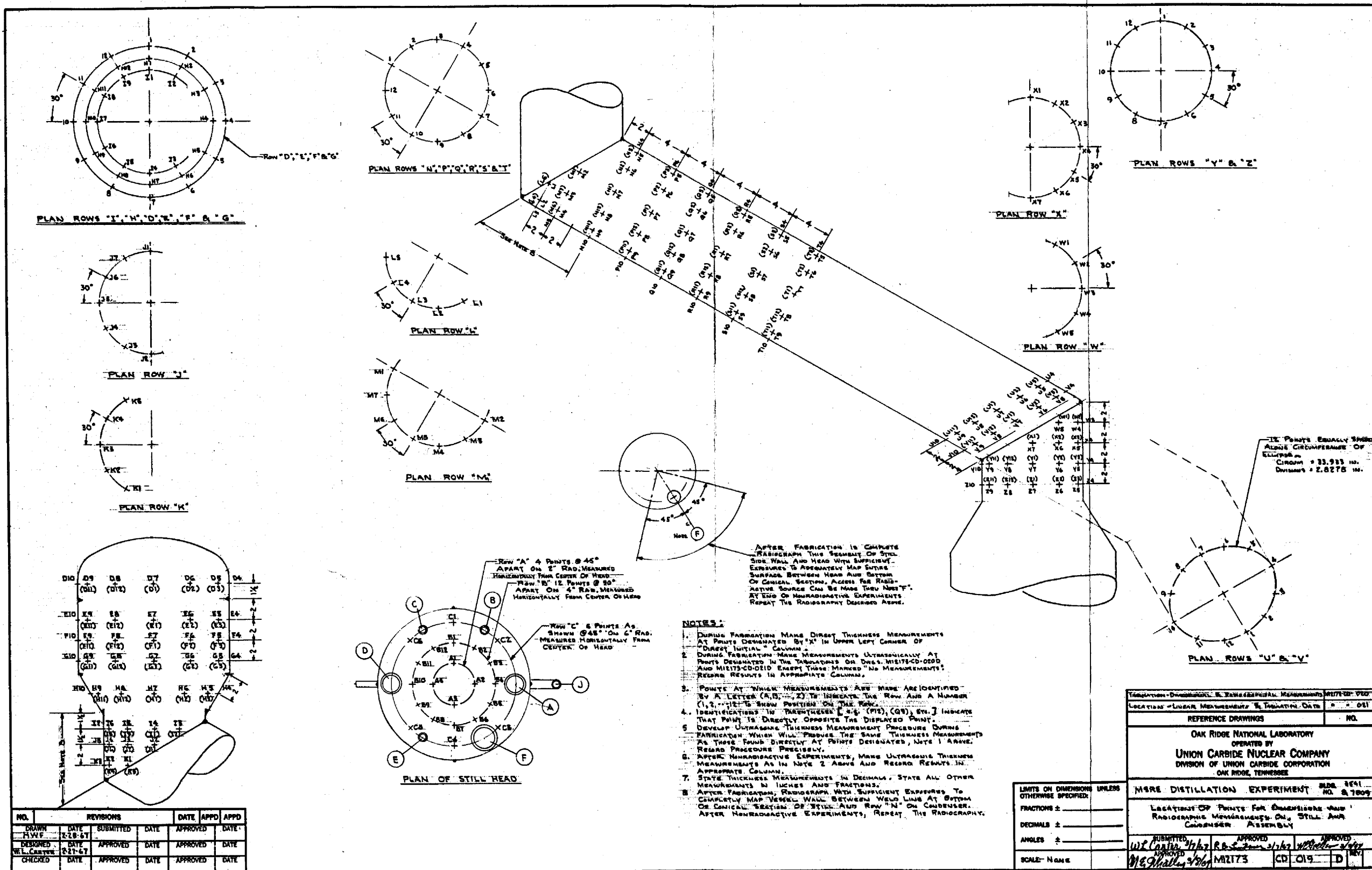
CONDENSATE RECEIVER
 SALT VOL = 48 L
 DIAM O.D. = 16 IN
 HEIGHT = 16.5 IN
 OPER. PRESS = 0.5 mm Hg
 OPER. TEMP = 500-550°C
 ELEC HEAT = 20 KW
 INSUL THK = 6 IN

THERMAL INSULATION
 CARBYTEMP 1900 BLOCK TYPE
 K = 0.1 BTU/FT-HR-°F @ 1000°C

1. APPROX. FROM LINE FOR LEVEL CONTROL					
2. CHANGED LINE SIZE ON RECEIVER DRAWING 3-6-57					
NO.	REVISIONS	DATE	APPD	APPD	

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
 FRACTIONS ±
 DECIMALS ±
 ANGLES ±
 SCALE: NONE

REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MSRE DISTILLATION EXPERIMENT	
BLOK. NO. 4-24-57	
FLOWSHEET FOR VACUUM DISTILLATION OF MSRE FUEL SALT (RADIOACTIVE EXPERIMENT)	
SUBMITTED	APPROVED
W. L. Taylor 4/22/57	R. B. Stewart 4/24/57
W. L. Taylor	W. L. Taylor
F-12175	CD 018



NO.		REVISIONS		DATE		APPD	APPD
DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE		
M.V.F.	2-28-67						
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE		
W.L. CARTER	2-27-67						
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE		

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:	
FRACTIONS ±	
DECIMALS ±	
ANGLES ±	
SCALE: Name	

Location - Linear Measurements & Tabulation Date	DATE
REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MORE DISTILLATION EXPERIMENT NO. 3541 NO. 2 1967	
LOCATION OF POINTS FOR DIMENSIONS AND RADIOGRAPHIC MEASUREMENTS ON STILL AND CONDENSER ASSEMBLY	
SUBMITTED	APPROVED
W.L. Carter	R.B. ...
APPROVED	APPROVED
M.S. ...	M2173
CD 019	D

WALL THICKNESS MEASUREMENTS AND OBSERVATIONS					WALL THICKNESS MEASUREMENTS AND OBSERVATIONS					WALL THICKNESS MEASUREMENTS AND OBSERVATIONS				
LOCATION OF MEASUREMENT	ULTRASONIC			RADIOGRAPHY, OBSERVATIONS, AND REMARKS	LOCATION OF MEASUREMENT	ULTRASONIC			RADIOGRAPHY, OBSERVATIONS, AND REMARKS	LOCATION OF MEASUREMENT	ULTRASONIC			RADIOGRAPHY, OBSERVATIONS, AND REMARKS
	DIRECT INITIAL (Inches)	POST OPERATION (Inches)	DIMENSIONAL CHANGE (Inches)			DIRECT INITIAL (Inches)	POST OPERATION (Inches)	DIMENSIONAL CHANGE (Inches)			DIRECT INITIAL (Inches)	POST OPERATION (Inches)	DIMENSIONAL CHANGE (Inches)	
A1	.383	.378	-.005		G6	.382	.380	-.002		N12	.396	.393	-.003	
A2	.383	.382	-.001		G7	.379	.380	+.001		P1	.397	.394	-.003	
A3	.383	.383	0		G8	.380	.381	+.001		P2	.396	.395	-.001	
A4	.379	.381	+.002		G9	.383	.380	-.003		P3	.396	.396	0	
B1	No MEASUREMENT				G10	.379	.380	+.001		P4	.396	.396	0	
B2					G11	.380	.377	-.003		P5	.397	.396	-.001	
B3					G12	.380	.381	+.001		P6	.396	.397	+.001	
B4					H1	.395	.389	-.006		P7	.397	.395	-.002	
B5	.383				H2	.394	.387	-.007		P8	.395	.392	-.003	
B6	.383	.385	.002		H3	.394	.386	-.008		P9	.392	.392	0	
B7	No MEASUREMENT				H4	.394	.393	-.001		P10	.392	.389	-.003	
B8					H5	.394	.393	-.001		P11	.394	.391	-.003	
B9					H6	.397	.396	-.001		P12	.396	.393	-.003	
B10					H7	.397	.396	-.001		Q1	.397	.396	-.001	
B11					H8	.397	.398	+.001		Q2	.396	.397	+.001	
B12					H9	.400	.399	-.001		Q3	.397	.393	-.004	
C1					H10	.400	.400	0		Q4	.398	.395	-.003	
C2	.382	.384	+.002		H11	.398	.392	-.006		Q5	.398	.397	-.001	
C3	.389	.387	-.002		H12	.394	.388	-.006		Q6	.398	.396	-.002	
C4	.386	.389	+.003		I1	.397	.392	-.005		Q7	.397	.395	-.002	
C5	.390	.387	-.003		I2	.396	.394	-.002		Q8	.396	.395	-.001	
C6	.383	.386	+.003		I3	.398	.398	0		Q9	.396	.394	-.002	
D1	.405	.410	+.005		I4	.398	.396	-.002		Q10	.393	.390	-.003	
D2	.410	.407	-.003		I5	.399	.397	-.002		Q11	.396	.392	-.004	
D3	.415	.416	+.001		I6	.400	.397	-.003		Q12	.397	.395	-.002	
D4	.417	.418	+.001		I7	.400	.397	-.003		R1	.399	.396	-.003	
D5	.418	.422	+.004		I8	.400	.395	-.005		R2	.400	.396	-.004	
D6	.415	.414	-.001		I9	.399	.394	-.005		R3	.398	.396	-.002	
D7	.416	.423	+.007		J1	.397	.393	-.004		R4	.398	.396	-.002	
D8	.420	.426	+.006		J2	.398	.396	-.002		R5	.400	.397	-.003	
D9	.424	.432	+.008		J3	.399	.398	-.001		R6	.398	.397	-.001	
D10	.417	.416	-.001		J4	.399	.398	-.001		R7	.398	.395	-.003	
D11	.406	.406	0		J5	.399	.397	-.002		R8	.397	.394	-.003	
D12	.410	.403	-.007		J6	.399	.395	-.004		R9	.396	.394	-.002	
E1	.382	.383	+.001		J7	.398	.394	-.004		R10	.396	.391	-.005	
E2	.384	.386	+.002		K1	.399	.398	-.001		R11	.396	.391	-.005	
E3	.386	.386	0		K2	.398	.398	0		R12	.397	.394	-.003	
E4	.385	.384	-.001		K3	.399	.397	-.002		S1	.397	.396	-.001	
E5	.384	.384	0		K4	.398	.395	-.003		S2	.398	.396	-.002	
E6	.385	.383	-.002		K5	.397	.395	-.002		S3	.397	.396	-.001	
E7	.382	.382	0		L1	.398	.397	-.001		S4	.397	.396	-.001	
E8	.384	.382	-.002		L2	.396	.395	-.001		S5	.399	.396	-.003	
E9	.380	.383	+.003		L3	.391	.393	+.002		S6	.398	.396	-.002	
E10	.382	.382	0		L4	.396	.392	-.004		S7	.398	.395	-.003	
E11	.380	.387	+.007		L5	.398	.393	-.005		S8	.397	.393	-.004	
E12	.381	.385	+.004		M1	.397	.395	-.002		S9	.395	.393	-.002	
F1	.382	.384	+.002		M2	.395	.398	+.003		S10	.393	.389	-.004	
F2	.383	.384	+.001		M3	.397	.397	0		S11	.396	.393	-.003	
F3	.385	.386	+.001		M4	.395	.395	0		S12	.398	.394	-.004	
F4	.383	.387	+.004		M5	.395	.392	-.003		T1	.400	.399	-.001	
F5	.383	.384	+.001		M6	.396	.393	-.003		T2	.401	.399	-.002	
F6	.382	.381	-.001		M7	.396	.394	-.002						
F7	.380	.383	+.003		N1	.397	.396	-.001						
F8	.382	.382	0		N2	.397	.397	0						
F9	.378	.378	0		N3	.397	.395	-.002						
F10	.377				N4	.398	.396	-.002						
F11	.380	.383	+.003		N5	.398	.396	-.002						
F12	.382	.381	-.001		N6	.398	.397	-.001						
G1	.379	.379	0		N7	.397	.396	-.001						
G2	.383	.383	0		N8	.397	.395	-.002						
G3	.382	.384	+.002		N9	.394	.392	-.002						
G4	.380	.380	0		N10	.394	.391	-.003						
G5	.380	.380	0		N11	.394	.391	-.003						

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

WATER DISTILLATION EXPERIMENT. BLDG. 5641
NO. 57899

TABULATION OF DATA FROM DIMENSIONAL
AND RADIOGRAPHIC MEASUREMENTS OF ENCL
AND CONDENSER ASSEMBLY

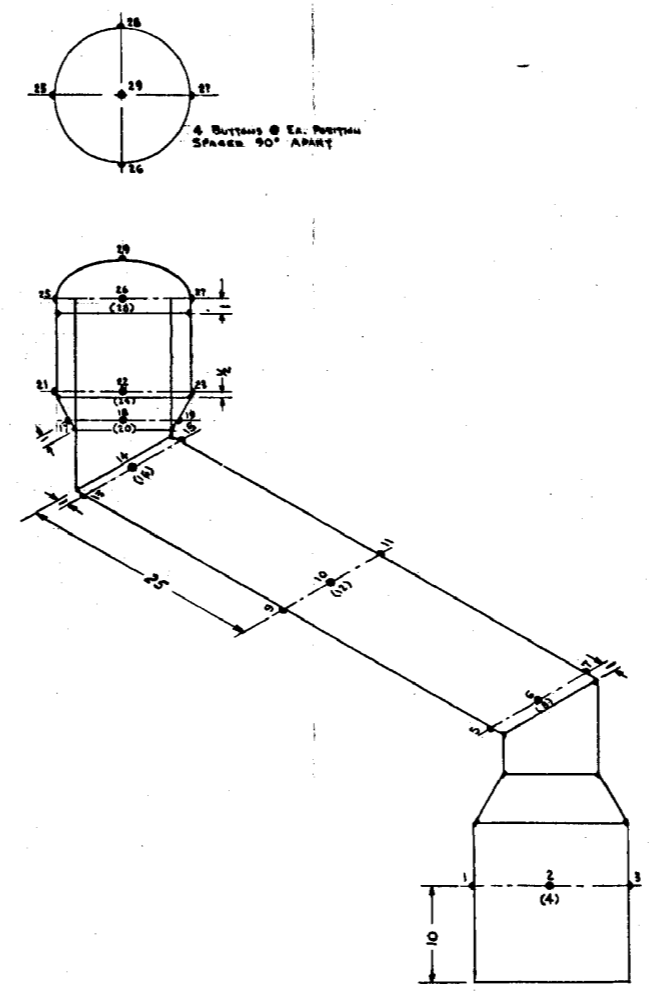
SUBMITTED BY: *W.C. Carter* 3/1/60
APPROVED BY: *R.B. Swann* 4/1/60
DATE: 3/1/60

APPROVED BY: *M. J. ...*
DATE: ...

1. ADDED FINAL DIMENSIONS 1/16 WLC
1. ADDED INITIAL DIMENSIONS 1/16 WLC

CD OZO D

WALL THICKNESS MEASUREMENTS AND OBSERVATIONS					WALL THICKNESS MEASUREMENTS AND OBSERVATIONS					LENGTH AND DIAMETER MEASUREMENTS							
LOCATION OF MEASUREMENT	DIRECT INITIAL (Inches)	ULTRASONIC POST INITIAL (Inches)	ULTRASONIC POST OPERATION (Inches)	DIMENSIONAL CHANGE (Inches)	RADIOGRAPHY, OBSERVATIONS, AND REMARKS	LOCATION OF MEASUREMENT	DIRECT INITIAL (Inches)	ULTRASONIC POST INITIAL (Inches)	ULTRASONIC POST OPERATION (Inches)	DIMENSIONAL CHANGE (Inches)	RADIOGRAPHY, OBSERVATIONS, AND REMARKS	MEASUREMENT FROM POINT	TO POINT	INITIAL AS BUILT LENGTH (Inches)	POST OPERATION LENGTH (Inches)	DIMENSIONAL CHANGE (Inches)	REMARKS
T3		.401	.398	-.003"		Y12	.400	.396	-.004"			1	6	1.035	1.035	0	HORIZONTAL
T4		.400	.397	-.003"		Z1	.396	.397	+.001"			2	6	1.035	1.035	0	VERTICAL
T5		.401	.399	-.002"		Z2	.394	.389	-.005"			3	10	2.070	2.070	0	HORIZONTAL
T6		.401	.398	-.003"		Z3	.395	.397	+.002"			4	10	2.070	2.070	0	VERT.
T7		.400	.397	-.003"		Z4	.394	.394	0			5	14	2.780	2.780	0	HORIZONTAL
T8		.399	.397	-.002"		Z5	.397	.389	-.008"			6	14	2.780	2.780	0	VERT.
T9		.398	.396	-.002"		Z6	.398	.395	-.003"			7	18	3.645	3.645	0	HORIZONTAL
T10		.396	.390	-.006"		Z7	.398	.393	-.005"			8	18	3.645	3.645	0	VERT.
T11		.396	.394	-.002"		Z8	.399	.395	-.004"			9	22	4.510	4.510	0	HORIZONTAL
T12		.399	.396	-.003"		Z9	No MEASUREMENT	.397				10	22	4.510	4.510	0	VERT.
U1	.400	.401	.398	-.003"		Z10	.398	.400	.395	-.005"		11	26	5.375	5.375	0	HORIZONTAL
U2		.401	.398	-.003"		Z11	No MEASUREMENT	.396				12	26	5.375	5.375	0	VERT.
U3		.397	.397	0		Z12	.398	.394	-.004"			13	30	6.240	6.240	0	HORIZONTAL
U4	.397	.396	.393	-.003"								14	30	6.240	6.240	0	VERT.
U5		.394	.388	-.006"								15	34	7.105	7.105	0	HORIZONTAL
U6		.397	.396	-.001"								16	34	7.105	7.105	0	VERT.
U7	.398	.398	.393	-.005"								17	38	7.970	7.970	0	HORIZONTAL
U8		.399	.396	-.003"								18	38	7.970	7.970	0	VERT.
U9		.401	.397	-.004"								19	42	8.835	8.835	0	HORIZONTAL
U10	.400	.401	.395	-.006"								20	42	8.835	8.835	0	VERT.
U11		.401	.399	-.002"								21	46	9.700	9.700	0	HORIZONTAL
U12		.399	.398	-.001"								22	46	9.700	9.700	0	VERT.
U13	.400	.400	.396	-.004"								23	50	10.565	10.565	0	HORIZONTAL
U14		.399	.397	-.002"								24	50	10.565	10.565	0	VERT.
U15	.396	.397	.393	-.004"								25	54	11.430	11.430	0	HORIZONTAL
U16		.398	.397	-.001"								26	54	11.430	11.430	0	VERT.
U17		.399	.396	-.003"								27	58	12.295	12.295	0	HORIZONTAL
U18		.401	.397	-.004"								28	58	12.295	12.295	0	VERT.
U19	.400	.401	.395	-.006"								29	62	13.160	13.160	0	HORIZONTAL
U20		.399	.398	-.001"								30	62	13.160	13.160	0	VERT.
U21		.400	.398	-.002"								31	66	14.025	14.025	0	HORIZONTAL
U22		.401	.398	-.003"								32	66	14.025	14.025	0	VERT.
U23		.397	.394	-.003"								33	70	14.890	14.890	0	HORIZONTAL
U24		.398	.392	-.006"								34	70	14.890	14.890	0	VERT.
U25		.397	.396	-.001"								35	74	15.755	15.755	0	HORIZONTAL
U26		.399	.396	-.003"								36	74	15.755	15.755	0	VERT.
U27	.398	.399	.396	-.003"								37	78	16.620	16.620	0	HORIZONTAL
U28		.400	.396	-.004"								38	78	16.620	16.620	0	VERT.
U29		.400	.397	-.003"								39	82	17.485	17.485	0	HORIZONTAL
U30	.399	.400	.399	-.001"								40	82	17.485	17.485	0	VERT.
U31		.400	.398	-.002"								41	86	18.350	18.350	0	HORIZONTAL
U32		.401	.398	-.003"								42	86	18.350	18.350	0	VERT.
U33		.396	.394	-.002"								43	90	19.215	19.215	0	HORIZONTAL
U34		.398	.392	-.006"								44	90	19.215	19.215	0	VERT.
U35		.397	.397	0								45	94	20.080	20.080	0	HORIZONTAL
U36		.398	.395	-.003"								46	94	20.080	20.080	0	VERT.
U37		.398	.394	-.004"								47	98	20.945	20.945	0	HORIZONTAL
U38		.397	.395	-.002"								48	98	20.945	20.945	0	VERT.
U39		.396	.393	-.003"								49	102	21.810	21.810	0	HORIZONTAL
U40		.396	.397	+.001"								50	102	21.810	21.810	0	VERT.
U41		.398	.394	-.004"								51	106	22.675	22.675	0	HORIZONTAL
U42		.399	.396	-.003"								52	106	22.675	22.675	0	VERT.
U43		.399	.399	0								53	110	23.540	23.540	0	HORIZONTAL
U44	.399	.400	.396	-.004"								54	110	23.540	23.540	0	VERT.
U45		.400	.397	-.003"								55	114	24.405	24.405	0	HORIZONTAL
U46		.399	.392	-.007"								56	114	24.405	24.405	0	VERT.
U47		.398	.395	-.003"								57	118	25.270	25.270	0	HORIZONTAL
U48		.398	.394	-.004"								58	118	25.270	25.270	0	VERT.
U49		.399	.396	-.003"								59	122	26.135	26.135	0	HORIZONTAL
U50		.399	.399	0								60	122	26.135	26.135	0	VERT.
U51	.399	.400	.396	-.004"								61	126	27.000	27.000	0	HORIZONTAL
U52		.400	.397	-.003"								62	126	27.000	27.000	0	VERT.



FILE ENGINE-FEET TO APPROXIMATELY 1/8" DIA. AND CENTER POINT

DETAIL OF BUTTONS

MAKE BUTTONS BY DEPOSITING (WELDING)
HARDBLAY X WELD ROD METAL ON SURFACES.
HAYNES 25 WELD ROD IS AN ACCEPTABLE
SUBSTITUTE.

ADDED INITIAL DIMENSIONS						ADDED FINAL DIMENSIONS					
NO.	DATE	SUBMITTED	DATE	APPROVED	DATE	NO.	DATE	SUBMITTED	DATE	APPROVED	DATE
1	5-23-67					2	5-23-67				
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE	DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE
WEL. CENTER	DATE	APPROVED	DATE	APPROVED	DATE	WEL. CENTER	DATE	APPROVED	DATE	APPROVED	DATE
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE	CHECKED	DATE	APPROVED	DATE	APPROVED	DATE

LOCATION: DIMENSIONAL & RADIOGRAPHY MEASUREMENTS	DATE: 5-23-67
REFERENCE DRAWINGS	NO.
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
MSRE DISTILLATION EXPERIMENT	BLD 2841 NO. 5709
LOCATION OF POINTS FOR LINEAR MEASUREMENTS AND TABULATION OF DATA FOR SPIN-COMPRESSION RECEIVER ASSEMBLY	
APPROVED	APPROVED
W.L. Carter	M.E. 2173
CD	OZI
D	

D-KKC-55179-D One-line Diagram Sheet-5 Motor Control Centers
G3 and G4.

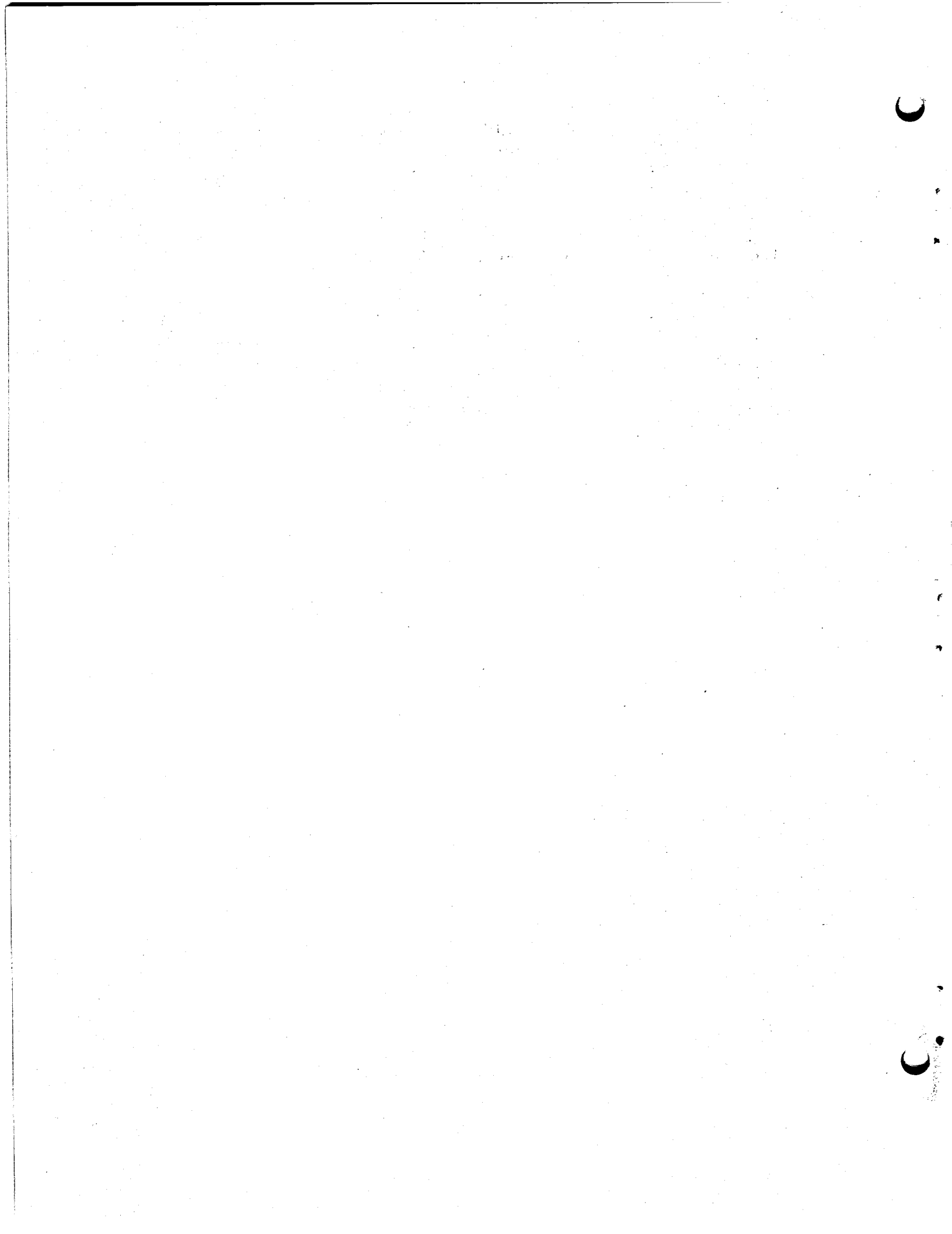
E-FFB-49040	Plan at Elevation 852 Ft-Elevation AA.
49041	Installation of Equipment Between Elevations 831 ft and 852 ft.
49042	Containment Cubicle for Instruments.
49043	Containment Cubicle for Instruments, Piping Details Sheet 1.
49044	Containment Cubicle for Instruments, Piping Details Sheet 2.
49045	Containment Cubicle for Instruments, Piping Details Sheet 3.

The first four drawings in the above list are concerned with modifications to the roof plugs of the spare cell in the MSRE building (Building 7503). These modifications were necessary before distillation of irradiated salt. The remaining six drawings are details of the equipment installation.

Drawings listed below are referenced but are not included in this Appendix. These drawings cover design and installation of instruments. Each drawing bears the principal title MSRE Distillation Experiment with the following numbers and subtitles:

I-12173-QE-001-D	Instrument Application Diagram.
I-12173-QE-002-D	Front of Panel Board Layout.
I-12173-QE-003-D	Rear of Panelboard.
I-12173-QE-004-D	Bill of Materials Panel Construction Nameplate and Annunciator Tag Tabulation.
I-12173-QE-005-D	Panel Cutouts.
I-12173-QE-006-D	Elementary Wiring Diagrams.
I-12173-QE-007-D	Panelboard Wiring Details - Sheet 1 of 2.
I-12173-QE-008-D	Panelboard Wiring Details - Sheet 1 of 2.
I-12173-QE-009-D	Heater Control Schematic.
I-12173-QE-010-D	Relay Box Wiring Diagram.
I-12173-QE-011-D	Load Distribution Panel Wiring and Construction Details.
I-12173-QE-012-D	Pneumatic Tubing Schematics.
I-12173-QE-013-D	Thermocouple Patch Panel Box Details.
I-12173-QE-014-D	Relay Box and Door Details.
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