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IN-PILE GAS-COOLED FUEL ELEMENT TEST FACILITY

J. Zasler
W. R. Huntley
P. A. Gnadt
T. S. Kress

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J. Zasler W. R. Huntley
P. A. Gnadt T. S. Kress

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ABSTRACT

Design and operating problems of unclad and ceramic gas-cooled reactor fuels in high temperature circulating gas systems will be studied using a test facility now nearing completion at the Oak Ridge Research Reactor. A shielded air-tight cell houses a closed circuit gas system equipped for dealing with fission products circulating in the gas. Experiments can be conducted on fuel element performance and stability, fission product deposition, gas clean up, activity levels, component and system performance and shielding, and decontamination and maintenance of system hardware.

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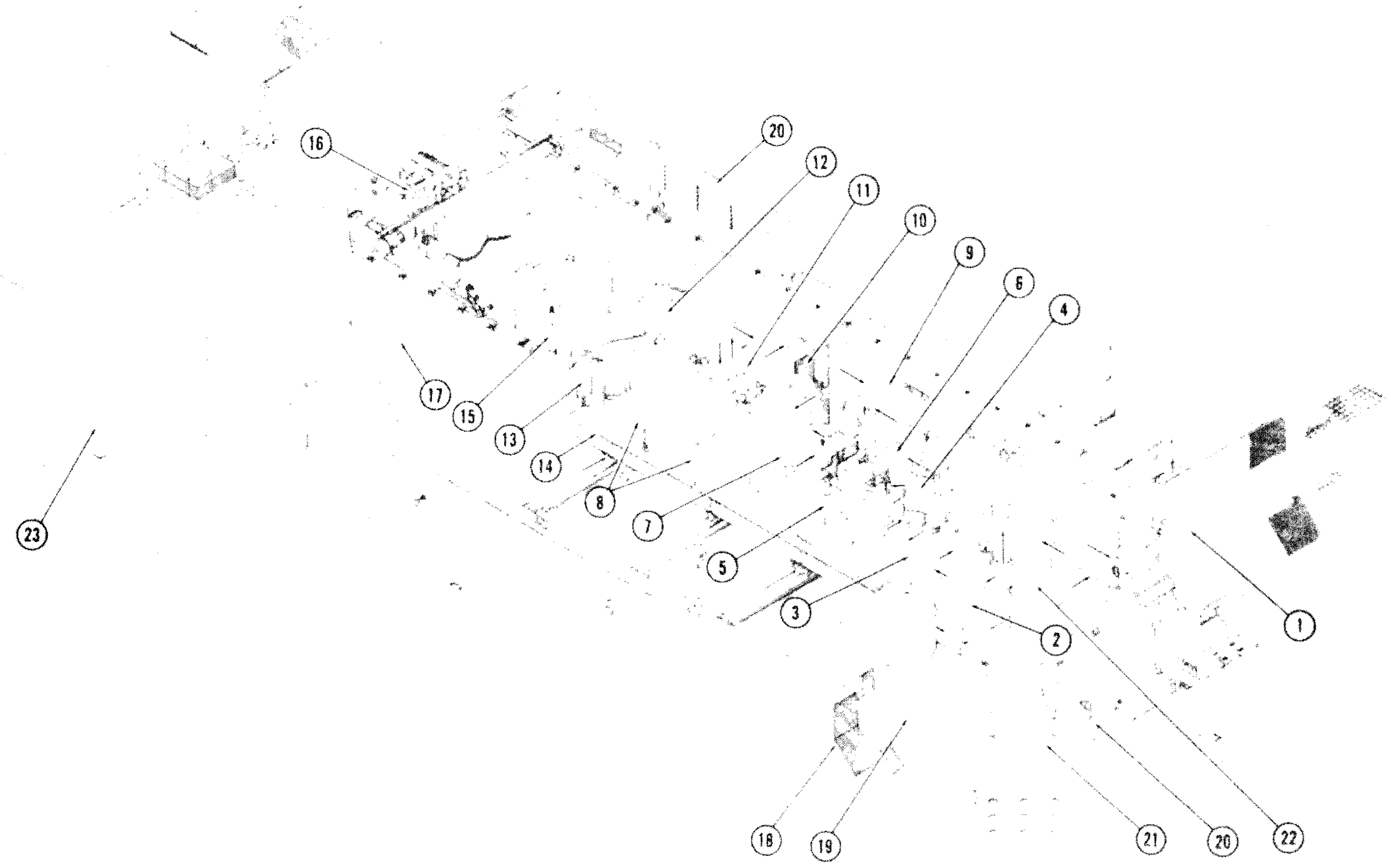

GC-ORR LOOP NO. 2

1. FUEL TEST TUBE
2. HEATER
3. REGENERATER
4. EVAPORATOR BY-PASS VALVE
5. EVAPORATOR
6. CONDENSER
7. FILTER
8. COMPRESSORS
9. SHELL COOLANT STREAM
10. CuO BED
11. SIDE STREAM COOLER
12. SIDE STREAM CARBON TRAP
13. MOLECULAR SIEVE
14. MOVABLE RACK
15. REMOTE MANIPULATOR
16. 5-TON CRANE
17. PERSONNEL ACCESS DOOR
18. EXTERNAL SHIELD DOOR
19. TEST PLUG REMOVAL SLEEVE
20. SPACE COOLERS
21. VIEWING WINDOW
22. MARMON SEAL FLANGE
23. AIR LOCK

Fig. 1. In-Pile Gas-Cooled Fuel Element Test Facility.

IN-PILE GAS-COOLED FUEL ELEMENT TEST FACILITY

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Introduction

The Oak Ridge National Laboratory is participating in the development of gas cooled reactor systems for the Atomic Energy Commission. An important aspect of the development program is to assess the potentials and costs of gas cooled systems designed to achieve higher coolant temperatures through the use of unclad fuel elements.

As part of the program, an in-pile facility has been built at the Laboratory's Oak Ridge Research Reactor to study the problems resulting from the use of unclad fuel elements. In this facility, engineering and design problems of contaminated gas systems will be investigated. Experiments will be conducted on fuel element stability, fission product transport and deposition, fission product clean-up, radiation backgrounds, component shielding, decontamination problems, and maintenance of contaminated system hardware.

While one may anticipate that in the reactor system unclad fuel elements will be designed to retain most of their fission products, the test facility has been designed on the premise that all the fission products available in a fuel element under test may be released. The facility, as shown in Fig. 1, provides double containment for the fission product containing gas and adequate shielding to protect the surrounding work areas in the event of a maximum release. Reasonable access is provided to the various components for examination and possible replacement.

The experimental equipment comprises a re-circulating high temperature gas loop, one section (called the test section) protrudes into a horizontal beam hole of the reactor and contains the fuel specimen to be irradiated. The primary loop components of the facility such as compressors, heat exchangers, filter, piping, etc., are mounted on a platform in a gas tight shielded cell which forms the secondary containment. The platform and therefore the loop and test section is movable horizontally to adjust the fuel position and neutron exposure.

A significant characteristic of the facility is the ability to remove contaminated components readily either for examination or for replacement. A five ton crane and General Mills manipulator, mounted in the cell to provide the capability for remote removal of fuel elements, can be used to assist in the removal of loop components. All components expected to accumulate significant amounts of activity are provided individually with integral shields and buffered, double gasketed flanges (see Fig. 2) to facilitate their removal. Removable plugs in the shields are provided so that shielded radiation monitors can be attached to measure the activity levels associated with any component.

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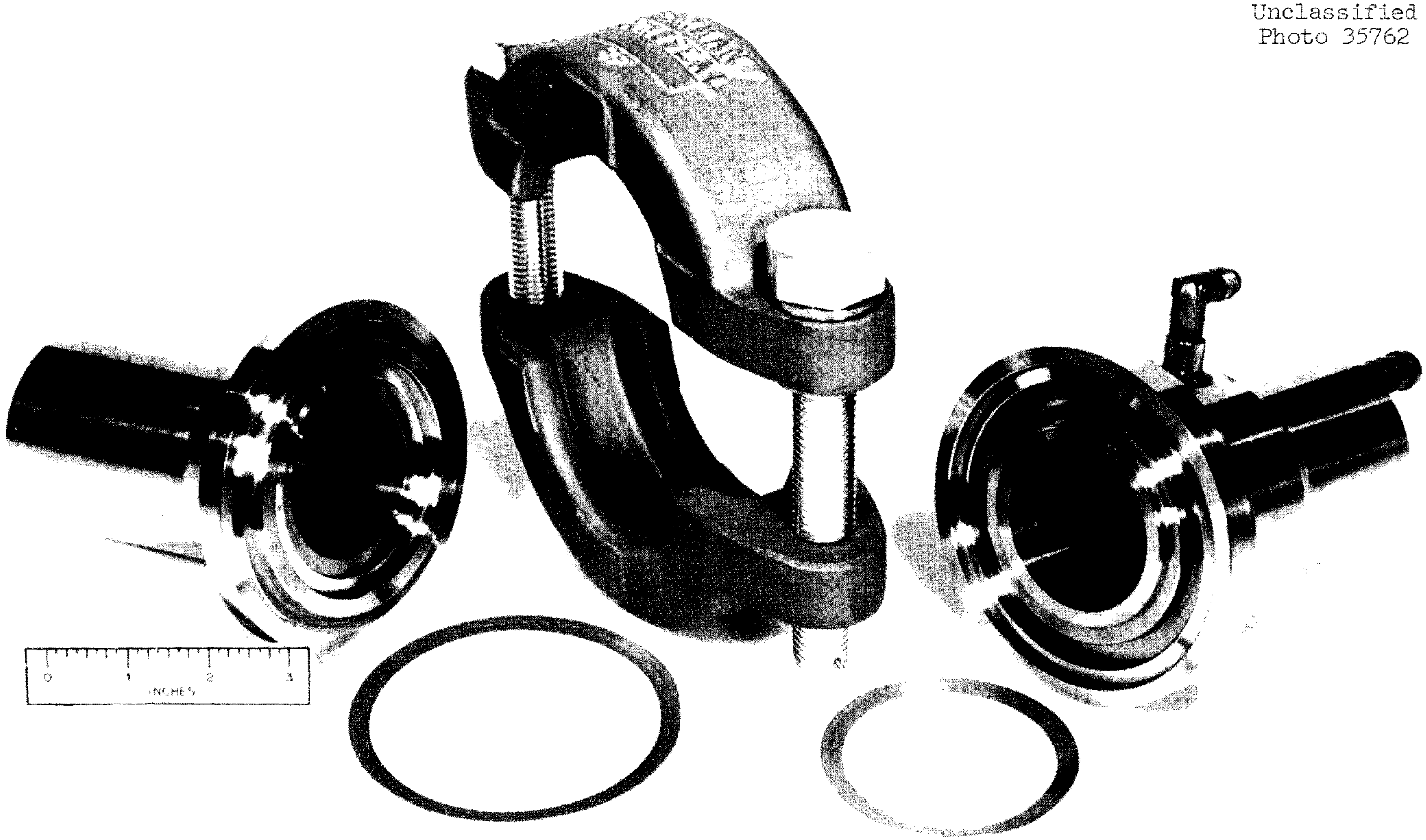

Fig. 2. Buffered Double Gasketed Marmon "Conoseal" Flange.

The flow diagram of the loop is shown in Fig. 3. Part of the helium from the compressors is led directly to the test section to be used to cool parts of the in-pile assembly and to attemperate gas flowing over the fuel element. The remainder enters the cold side of a gas-to-gas regenerative heat exchanger, where it is heated by the hot gas returning from the in-pile section. It then enters an electric heater where the desired test section inlet temperature is attained (1350°F max).

Leaving the heater, the gas enters the in-pile section of the loop and cools the fuel element under test. Within the test section and before entering shielding in the in-pile region, the gas must be cooled to at least 1350°F by mixing with the portion of the 600°F compressor discharge gas which was diverted to provide cooling of the in-pile pressure shell. The attemperated gas from the in-pile section passes through the hot side of the regenerative heat exchanger where it is cooled to 1000°F, through an evaporative cooler which further cools the gas to 600°F, through a full flow absolute filter, and back to the compressors.

A bypass stream of 1.4 lb/hr is drawn from the loop at the compressor discharge, passed through a gas clean-up system designed to remove chemical and radioactive contaminants and returned to the loop upstream of the filter.

Table I presents the main operating conditions and capabilities of the facility.

Description of Loop Components

Compressors. A set of two electrically driven hermetically sealed compressors produce the required gas flow rate. Two sets of compressors have been provided. The set to be used initially consists of two regenerative compressors (ORNL Model HECT-2) operated in parallel. As shown in Fig. 4, the rotating assembly for this type of unit is supported by grease-lubricated ball bearings. The housing which surrounds the bearings and the motor contains passages through which water is circulated for cooling. The compressor volute is bolted to one end of this housing, and the entire assembly is mounted in a pressure vessel. Additional descriptive material for this type of compressor is given in Reference 1.

A second set consisting of two gas-bearing centrifugal compressors (Fig. 5) operated in series will be installed in the test loop at a later date. The rotating assemblies of these compressors are supported on self-acting gas film bearings lubricated by the gas in the test loop. The compressor casing will consist of a volute section and a motor housing section joined to form a pressure vessel. A water jacket surrounding a part of the motor housing is used to cool the motor and bearing compartment, and an auxiliary impeller mounted on the rear end of the compressor shaft circulates a small flow of helium within the casing to remove heat from the bearings and the motor rotor. A further description of these compressors is given in Reference 2. Three of these compressors have been received from Bristol Siddeley Engines, Ltd., Coventry, England.

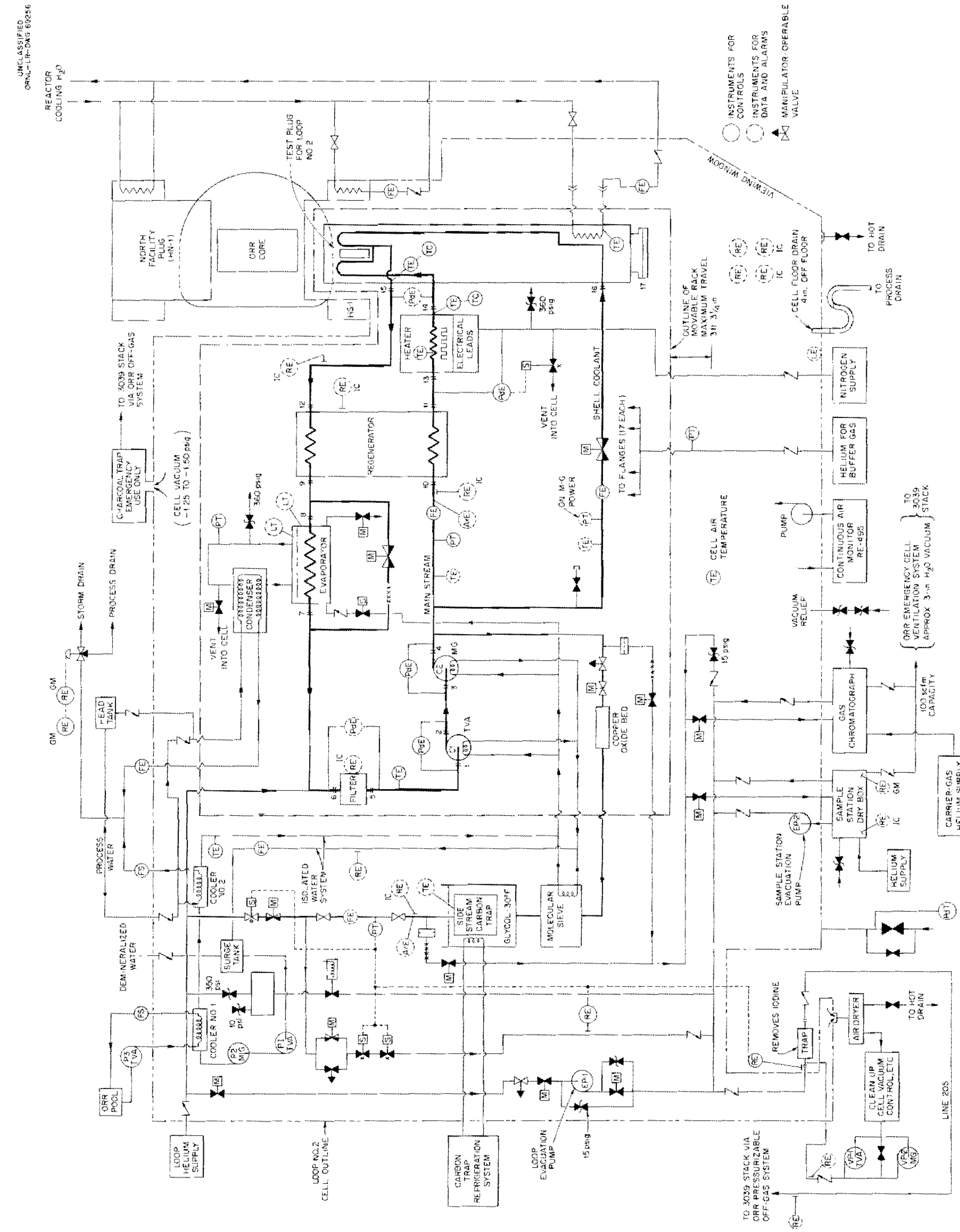

Fig. 3. Composite Flow Diagram.

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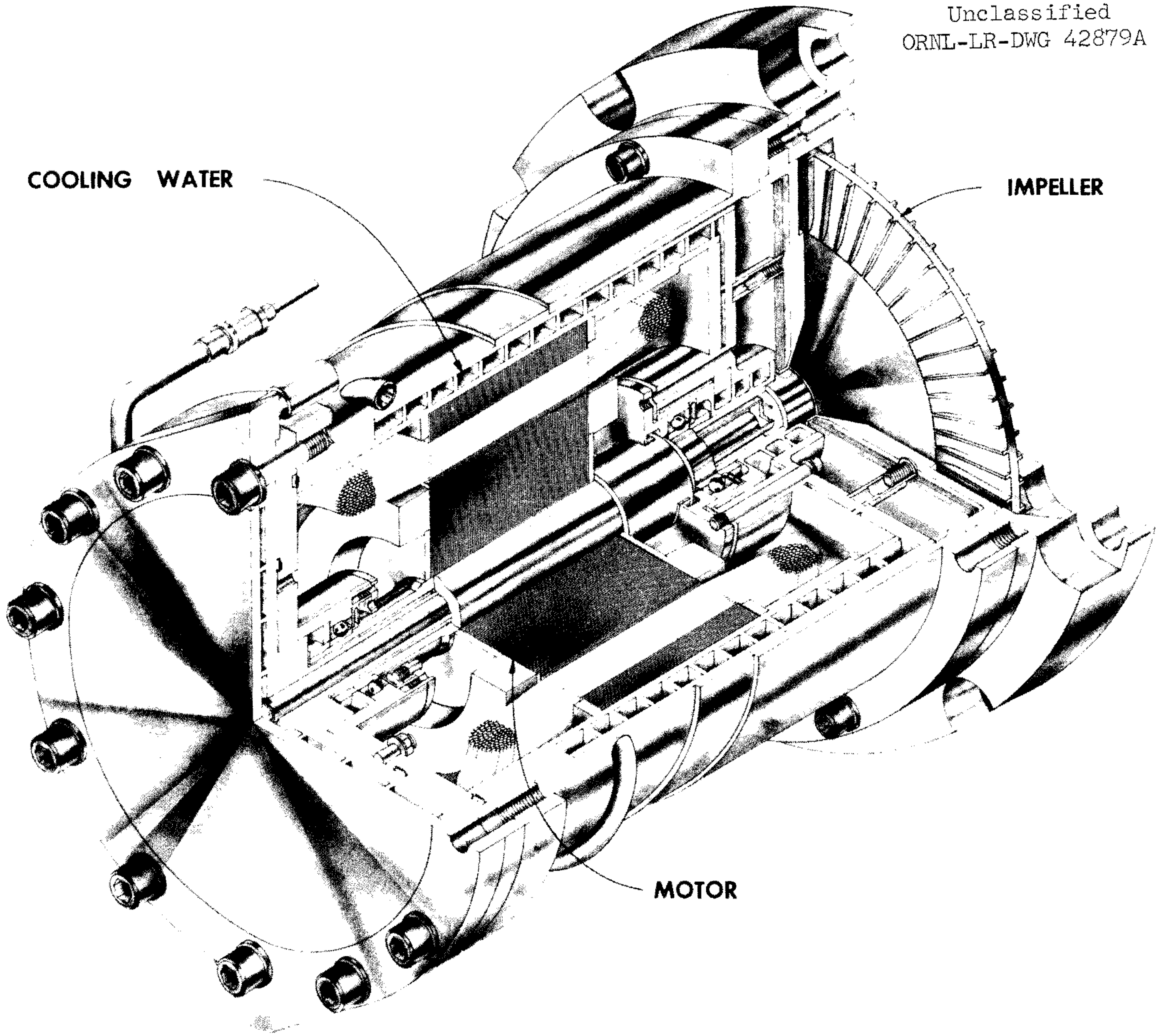

Fig. 4. ORNL Model HECT-2 Grease-Bearing-Helium Compressor.

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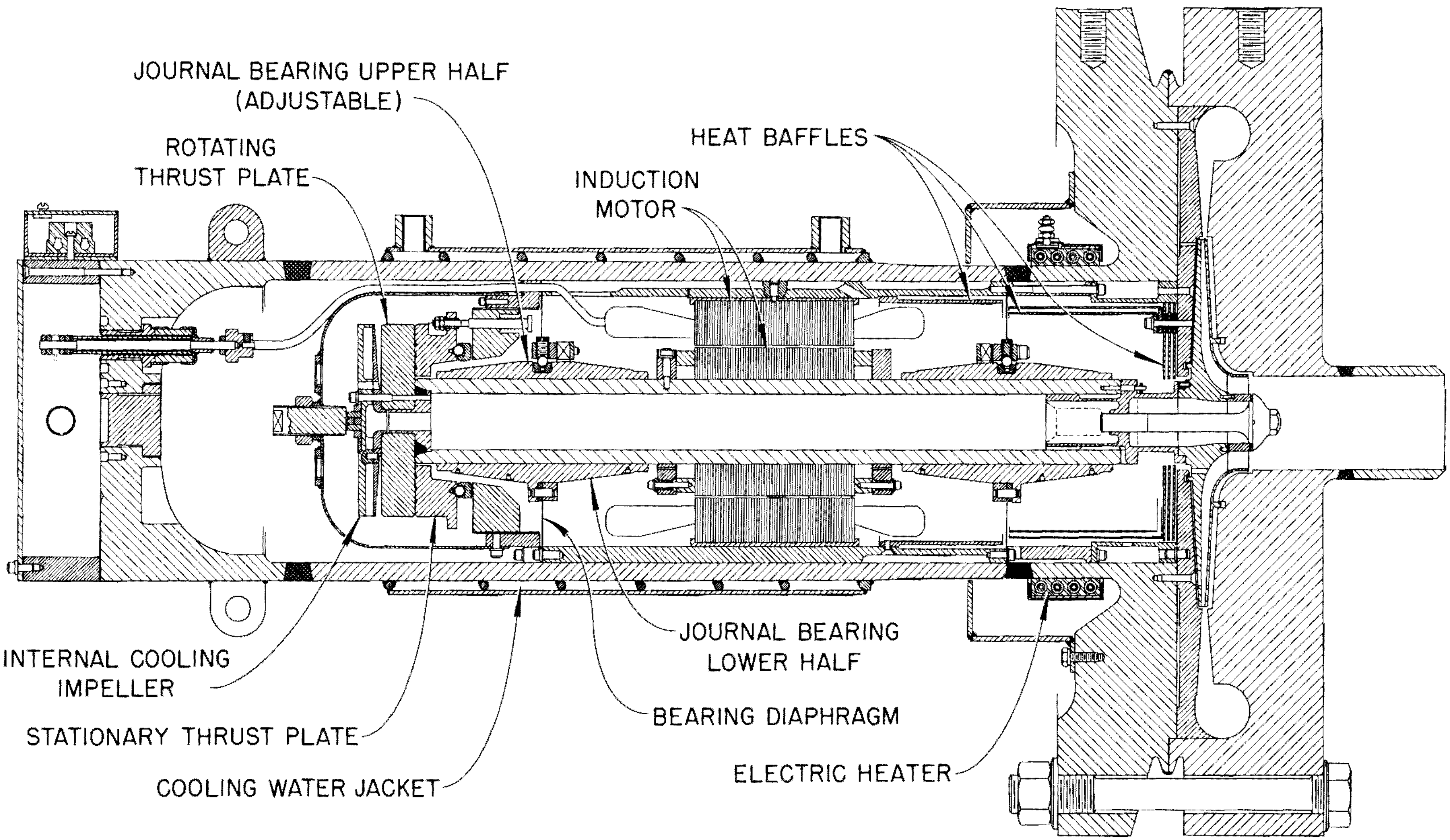

Fig. 5. Bristol Siddeley ORR-2 Compressor.

Table I

GC-ORR Loop 2 Operating Conditions

1.	Maximum Helium Flow Rate	1000 lb/hr
2.	Shell Coolant Flow Rate	180 lb/hr
3.	Element Coolant Flow Rate	820 lb/hr
4.	Side-Stream Purification Flow Rate	1.4 lb/hr (.14% of Item 1)
5.	Total Helium Inventory in Loop	1.7 lb
6.	ΔP Around Loop with 1000 lb/hr He Flow	10 psi
7.	ΔP Available Across Fuel Section	2.3 psi
8.	Design Pressure	360 psig
9.	Operating Pressure	300 psig
10.	Loop Volume	13.4 ft^3
11.	Maximum Helium Temp. at Fuel Inlet	1340°F
12.	Maximum He Temp. at Fuel Outlet	1500°F
13.	Maximum He Temp. after Attemperation	1340°F
14.	Heater Power	80 kw
15.	Cooler Capacity at He Flow = 1000 lb/hr, T_{in} = 860°F	120 kw
16.	Regenerator "Cold-Side" Effectiveness at Total He Flow = 1000 lb/hr	0.74
17.	Thermal Neutron Flux (Maximum)	10^{13} n/cm^2 sec
18.	Axial Flux Ratio (8 inch length)	2 1/2
19.	Estimated Gamma Heating (Maximum at 45 mw of ORR Power)	2.6 w/g-al
20.	Maximum Element Power	60 kw
21.	Fuel Length (Maximum for level neutron flux)	8 inch
22.	Fuel Diameter (Maximum)	2 3/4 inch

Each of these compressor types has certain advantages. Those which use grease-lubricated ball bearings can be started and stopped any desired number of times, whereas those equipped with gas-lubricated bearings may become inoperable if started and stopped more than 200 to 400 times before the bearings are repolished. It is therefore advantageous to use the first type during early loop shakedown operations, when starting and stopping will be relatively frequent. It is necessary, however, to remove the compressors and replace the bearings of the grease-lubricated type every 3500 to 4500 hours. The need for this frequency of bearing maintenance should not be experienced with the gas bearing compressors, provided frequent starts and stops are avoided. Therefore the second set is more suitable for post-shakedown operations. The gas-bearing compressors also have the advantage of eliminating the deposition of traces of grease (0.2 to 0.3 grams or less per 1000 hours of operation) in the inside of the compressor and in the test loop itself.

Heat Transfer Equipment. The design criteria for the heat exchangers evolved from the following desired operating conditions:

(1) A fuel power test capability of 0 to 60 kw.

(2) An upper operating limit of 600°F for the compressor inlet gas temperature.

(3) A maximum helium flow of 1000 lb/hr at 300 psig loop pressure.

(4) Gas temperature as high as 1500°F at the test element.

(5) Gas temperatures no higher than 1350°F entering and leaving the in-pile section.

The components provided to meet these criteria are as follows:

The regenerator receives gas from the coldest region of the main loop and uses it to cool the hotter gas from the test section. This simple energy-economizing function reduces the size and complexity of the remaining heat exchangers. The regenerator (Fig. 6) was designed and manufactured to a performance specification by the Harrison Radiator Division of General Motors. It is a counter-flow heat exchanger of modified shell-and-tube design. The shell is 347H stainless steel, approximately 6 1/2 inches in diameter and 36 inches long. The core consists of nine flattened tubes with corrugated stainless steel clad copper fins on the interior and exterior.

The heat imparted to the gas by the heater and the fuel region is removed through the cooler which lowers the gas temperature to a value acceptable to the compressors. The cooler is a water evaporator heated by the gas. In the evaporator the loop gas passes through U-tubes immersed in demineralized water. The heat from the gas boils the water and the resultant steam moves to the condenser under its own pressure gradient and is condensed on the outside of water cooled tubes. The condensate returns to the evaporator by gravity flow to complete the cycle. The closed steam-water circuit is part of the double containment for the

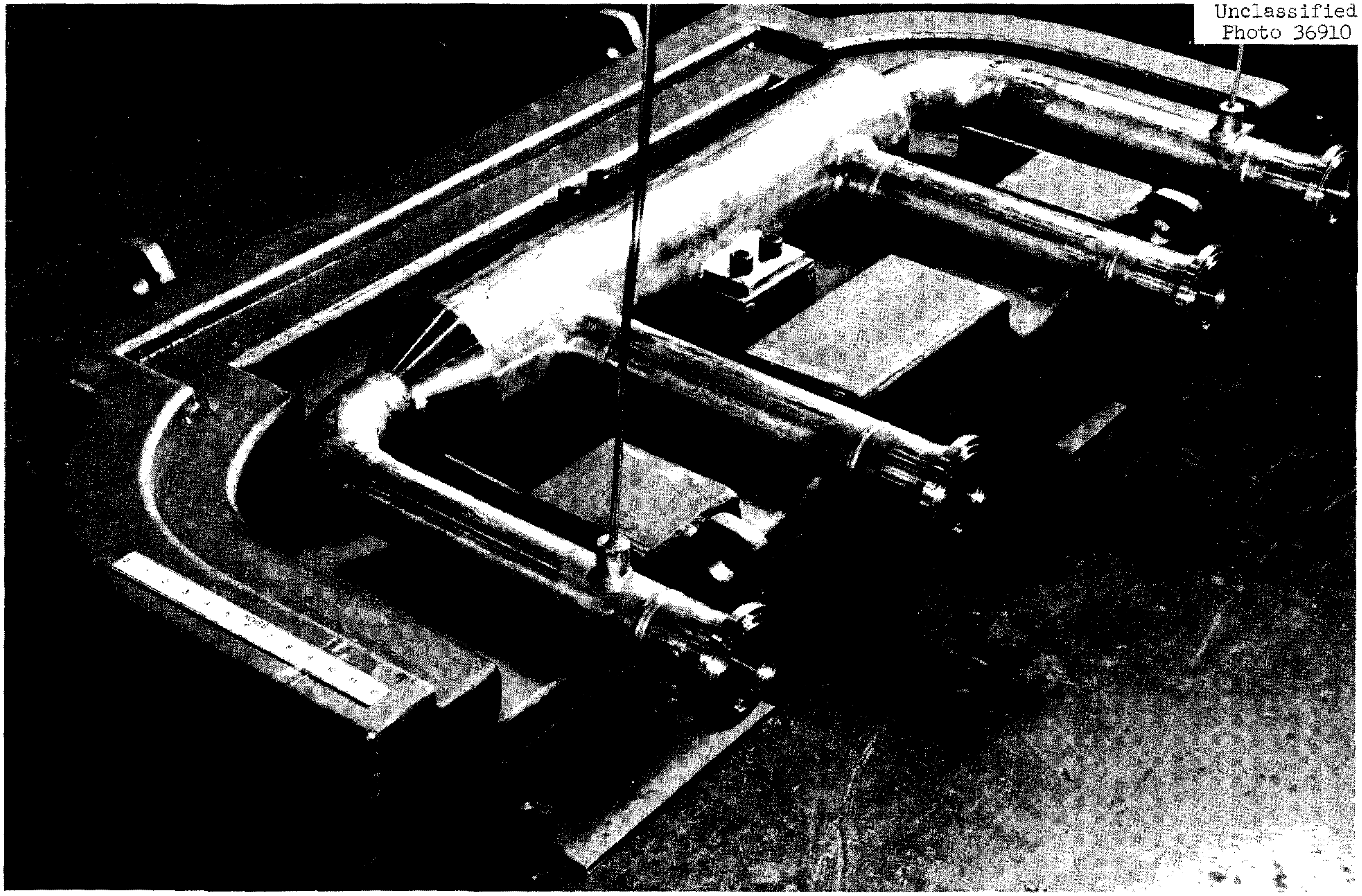

Fig. 6. Regenerator — Shown Before Installing Insulation and Top Half of Shield.

loop gas and also isolates it from condenser cooling water.

A by-pass flow around the evaporator (limited to 50% of flow going through the evaporator) adjusts the cooling rate.

The evaporator is an inconel cylinder 8 1/2 inches in diameter and 26 inches long (Fig. 7). It contains gas inlet and exit chambers at the same end separated by a horizontal baffle. Both ends of seven 3/4-in. diameter inconel U-tubes (3 feet long) are welded into a header which separates the gas inlet and exit chambers from the demineralized water.

The condenser (Fig. 8) is of conventional shell and tube design. The shell is 8-in. schedule 40 pipe (347H stainless steel) which contains 37 tubes (304 stainless steel) each 3/4-in. o.d. and 26 inches long.

After passing through the compressors and being heated in the "cold-side" of the regenerator, the gas is heated to design temperature by an electric heater (Fig. 9), which is a four-pass cross-flow heat exchanger containing 60 electric heating elements in eight staggered rows. These elements are 5/8-in. (nominal) diameter inconel-sheathed cartridges manufactured under the trade name of "Firerods" by the Watlow Electric Manufacturing Company. Each is rated at 4.7 kw giving a maximum installed capacity of 282 kw. Limitations on the electrical circuitry will restrict the power delivered to the heaters to about 80 kw in order to obtain increased heater life.

The heater pressure shell is protected from high temperatures by internal reflective insulation composed of "Hi-luster" stainless steel sheets spaced about 1/8 inch apart to an aggregate thickness of about 1 1/2 inches.

The heating element terminals and leads to them are located in a nitrogen buffered region separated from the main stream by a header to which the cartridges are welded. The individual heaters are connected to form three parallel separately controlled circuits each of which is adjusted by a saturable reactor.

A typical profile of loop temperature levels is given on Fig. 10.

Full Flow Filter. An absolute full flow canned filter (Cambridge Model SI-071) is provided to protect the loop components from potentially harmful particulate matter. Since it will also hold up particulate fission products, and concentrate radioactivity, it is encased in a 6-in. lead shield.

Tests[3] run on two filter units gave measured efficiencies of 97.885% and 99.930% for removal of 0.3 micron particles. The pressure drop is estimated to be 6 inches of water at full flow conditions.

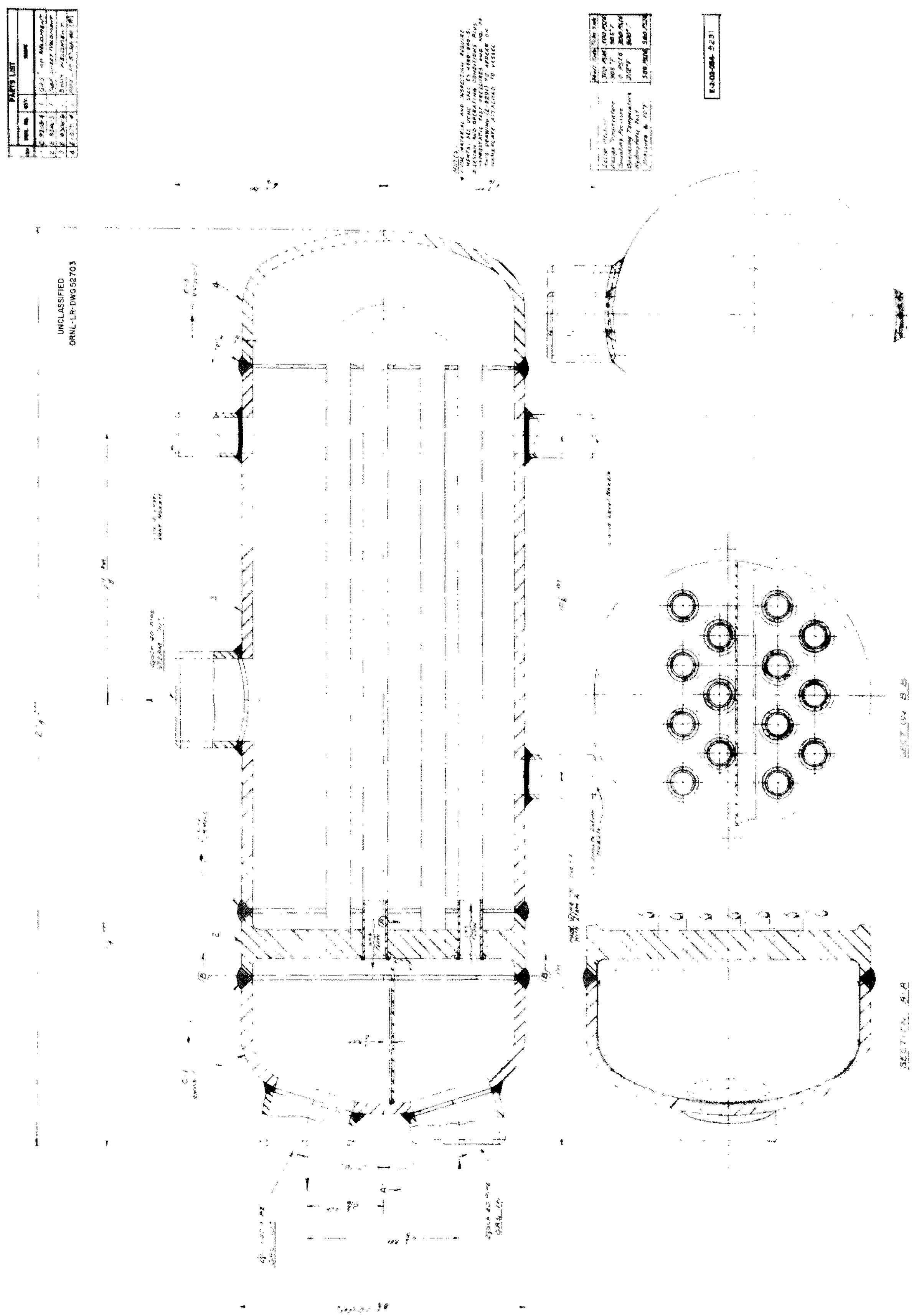

Fig. 7. Evaporator.

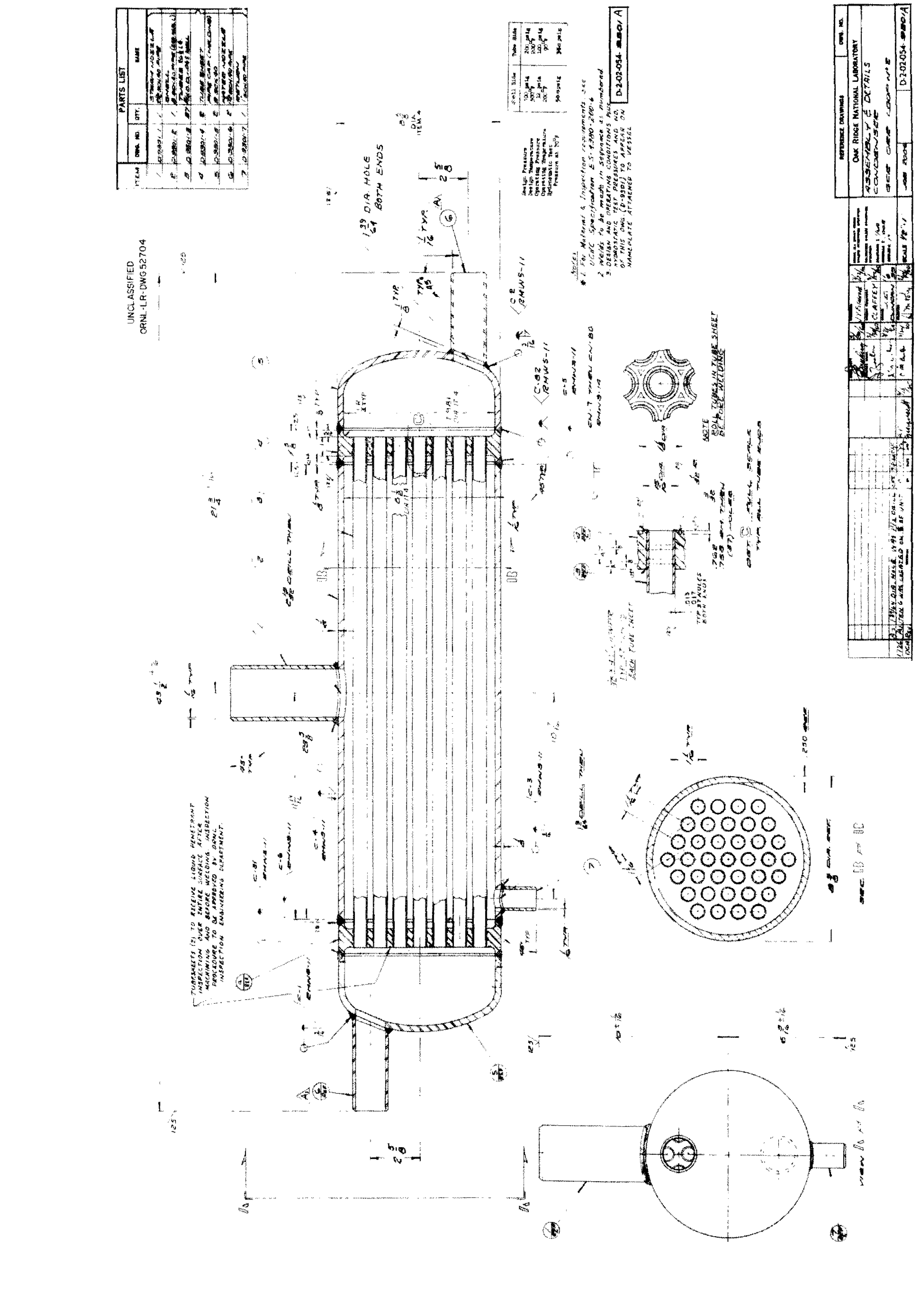

Fig. 8. Condenser.

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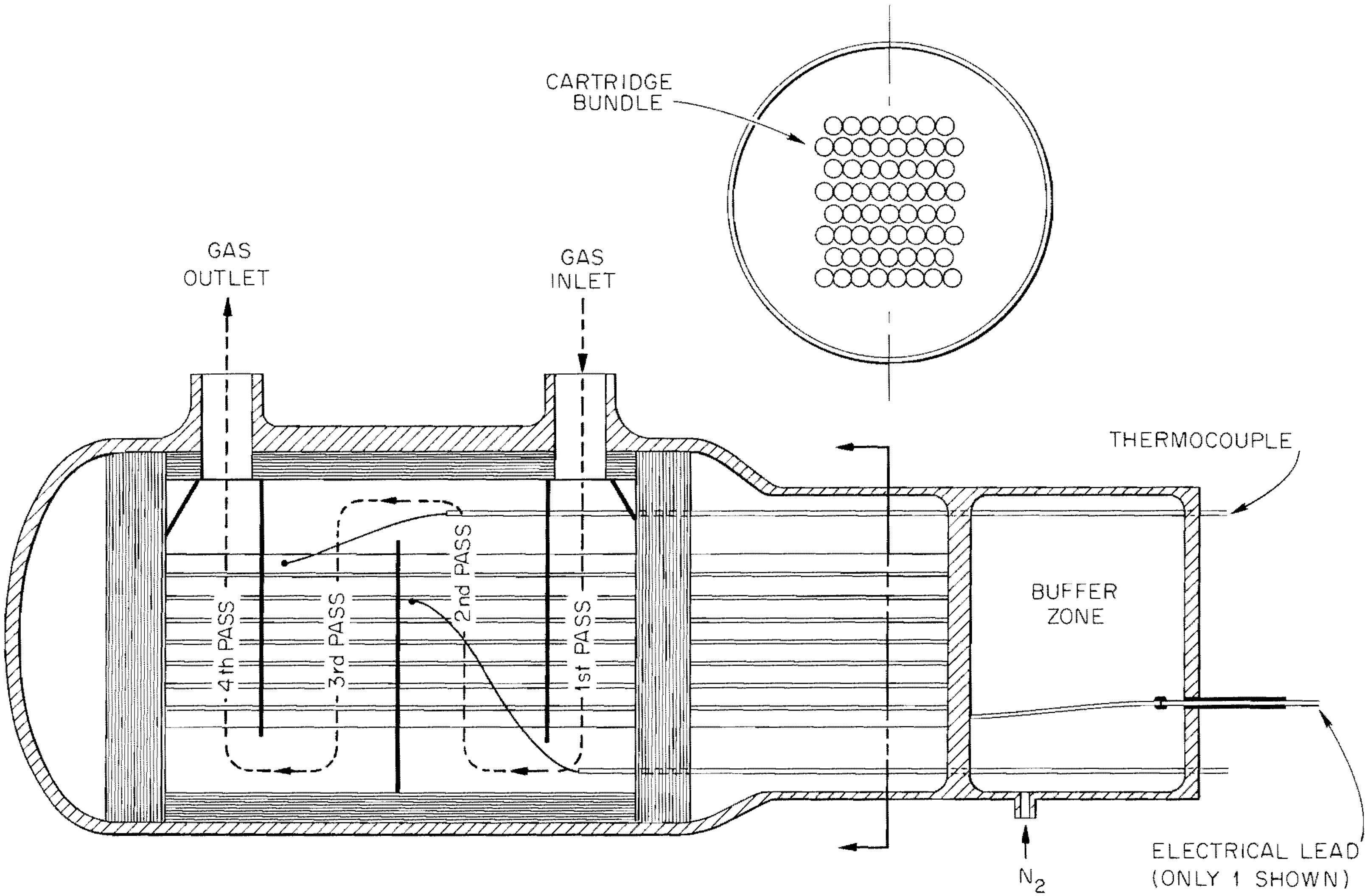

Fig. 9. Electric Heater.

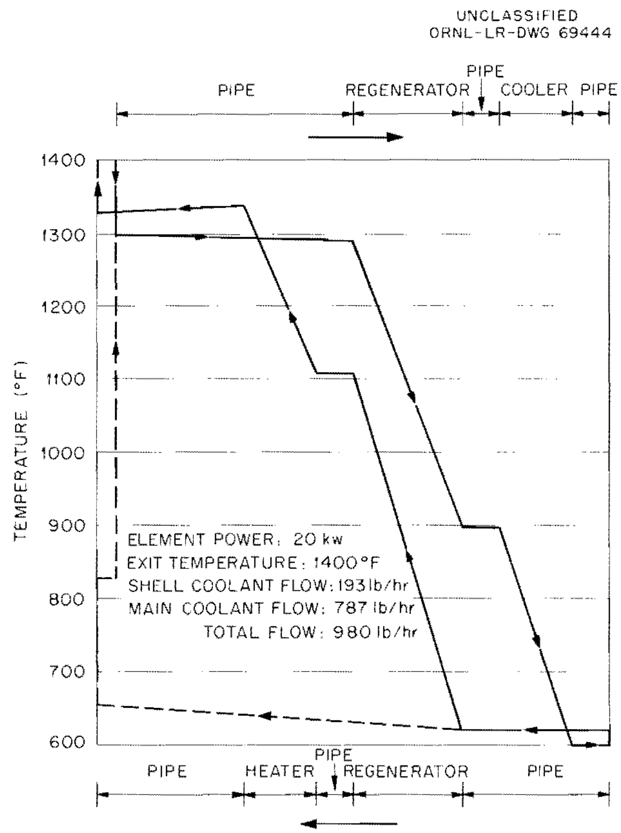

Fig. 10. Typical Temperature Profile.

In-Pile Section. The loop has access to the reactor core through a large beam hole at the south side of the pool. Concentric plugs adapt this hole for use by the in-pile facility.

An 18-in. diameter, pressure piping plug is designed to receive replaceable test sections. It contains the primary helium piping which directs the coolant flow to and from the test element and a specially shaped beryllium insert that thermalizes the fast-neutron flux to minimize attenuation of the thermal-neutron flux along the beam hole. Since it will be attached to the loop piping, the plug moves in and out of the beam hole when the equipment platform in the cell is moved. Internal water cooling circuits remove gamma heat, and forty-one thermocouples within the plug monitor temperatures of the structure and the helium. The plug, partially assembled, is shown in Fig. 11. The plug includes a centrally located 4-in. diameter stepped hole through which the fuel elements may be inserted to a position adjacent to the ORR core face.

The 4-in. diameter stepped tube which supports a fuel specimen horizontally near the core face is sealed to the 18-in. plug with a 5-in. double gasketed Marmon "conoseal" flange. The gas flow is confined to the inner three feet of the tube which can be used for experiment installation, the balance of the tube being a composite shield equivalent to about 4-ft of ferro-phosphorus concrete. The volume available for fuel test specimens is about 3 feet in length by about 2 7/8-in. in diameter. If purge gas flows are part of the element design, a small carbon trap can be installed in the composite shield area within the fuel support tube.

Provision is made for remote removal of the fuel tube and the 18-in. plug into a shielded carrier (Fig. 12). To remove the 18-in. plug, it is necessary to cut the gas pipes joining it to the loop. Since this operation may have to be done when the loop is badly contaminated, a pipe cut and seal die[4] has been developed to be used with a remotely operated portable hydraulic shear. In one operation this die will cut the 1 1/2 schedule 80 pipe and seal the cut ends. Fig. 13 shows samples of pipe cut with this die.

Side Stream Purification System. The side stream purification system removes chemical and radioactive contaminants from the helium during normal operation and during discharge to the disposal stack.

The design is based upon by-passing a flow of 1.4 lb/hr (~2.3 scfm) through a copper oxide bed, molecular sieve, and side stream carbon trap. The rate is about .14% of the flow rate in the main loop. The total loop inventory of helium is about 1.7 lbs.

The insulated and shielded copper oxide bed oxidizes CO and H_2 to CO_2 and H_2O. An electric heater maintains the bed at temperatures up to 700°F.

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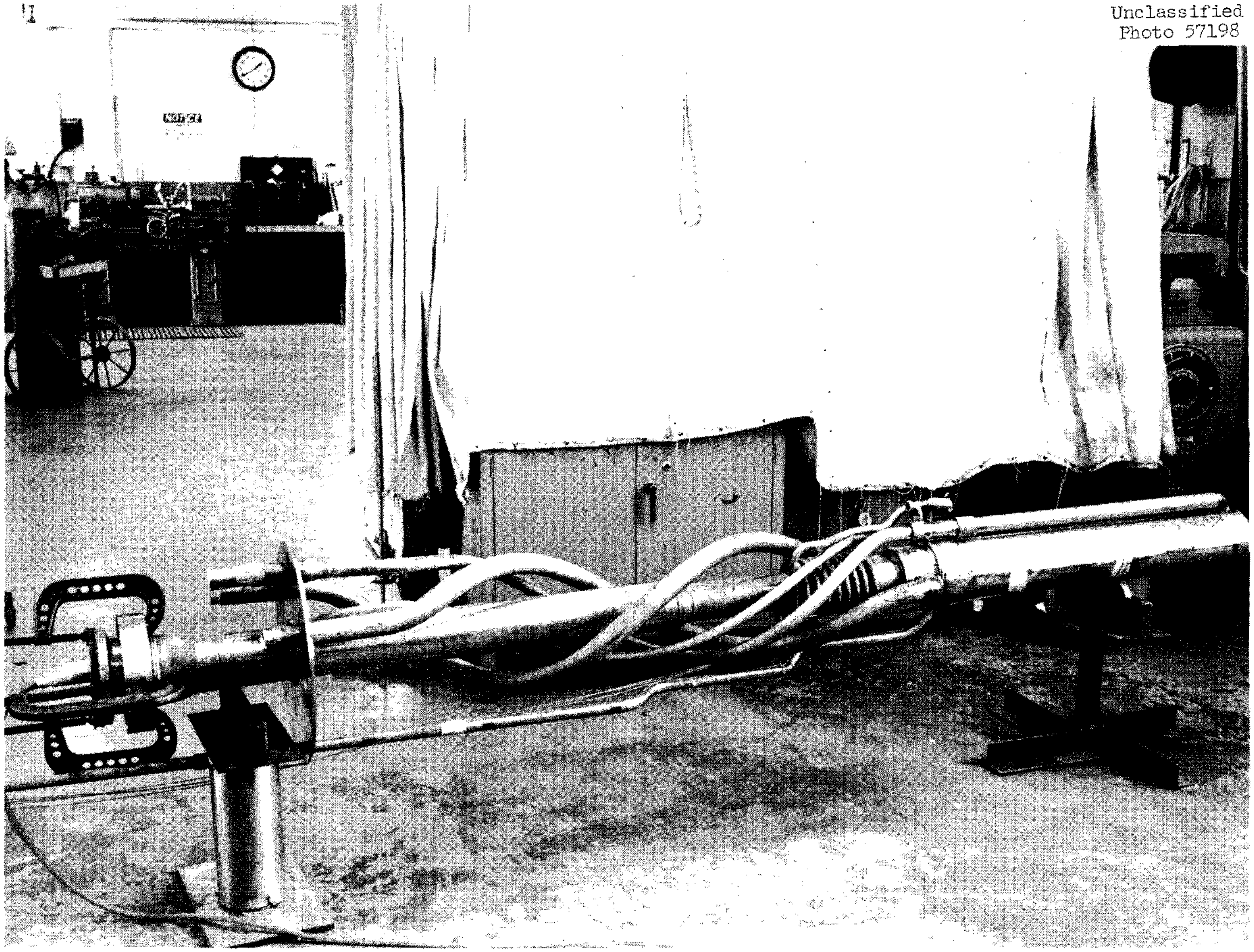

Fig. 11. Partial Assembly of 18-in. Plug.

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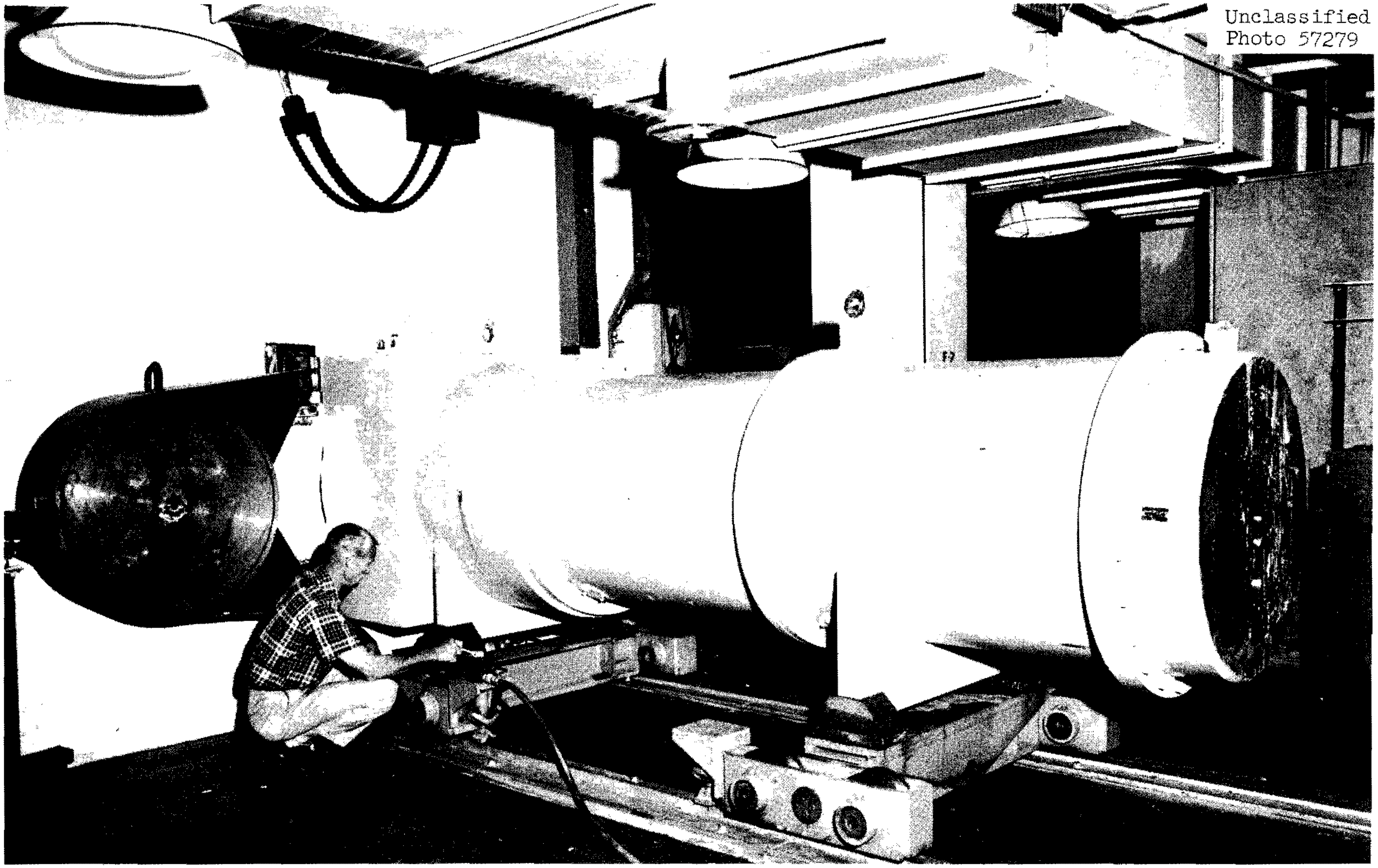

Fig. 12. Shielded Carrier in Position at Experiment Door.

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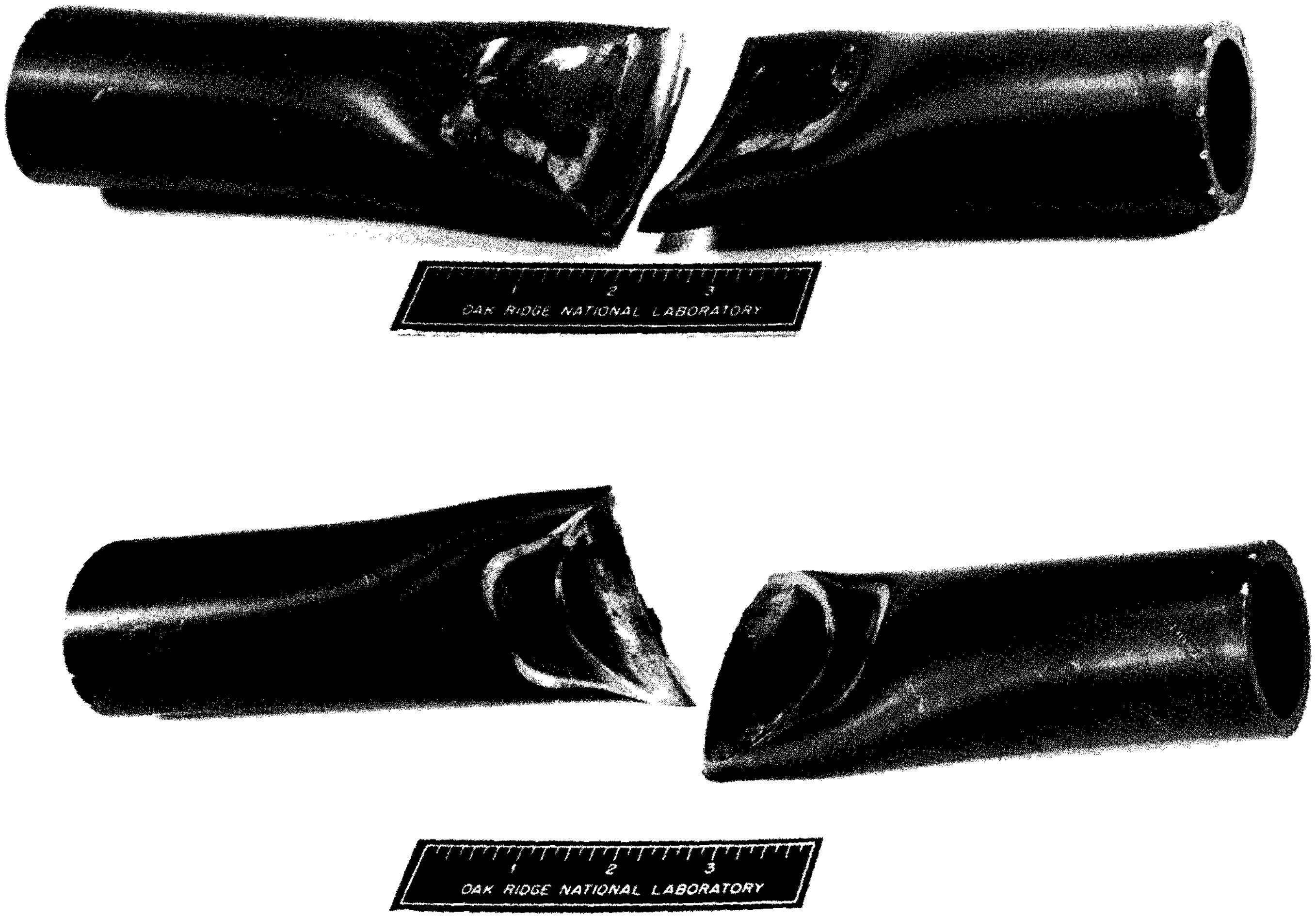

Fig. 13. 1 1/2-in. Schedule 80 347 Stainless Steel Pipe Cut with Pipe Cutting and Sealing Die.

The water cooled molecular sieve removes the CO_2 and H_2O formed in the copper oxide bed. It contains 5 lb of Linde 5A molecular sieve and will operate at 80°F. The unit is shielded and is expected to delay krypton for about 7 1/2 minutes.

The carbon trap reduces activity by adsorbing iodine and by delaying the noble fission gases for several half-lives. It contains 26 lbs of PCB 12-30 activated charcoal and is immersed in a bath of ethylene glycol water solution cooled by R-11 refrigerant to -30°F. Based upon dynamic adsorbtion coefficients of charcoal[5,6], this bed should hold up krypton for about 40 hours (14 half lives for krypton 88 and 9 half lives for krypton 85m). Xenon will be held up about 40 times as long.

The carbon trap is thermally insulated by 4 inches of foamed plastic and shielded with 6-in. of lead.

<u>Gas Sampling System</u>. The sampling system is used to remove samples of the helium coolant for quantitative analysis of long lived noble fission gases and corrosive impurities such as CO, CO_2, H_2O, and CH_4. Two taps for sampling are provided - one from the main loop, and one from the side stream purification system discharge. The flow, pressure and temperature of each sample is controlled by capillary tubing which will reduce the pressure from 300 psig to 15 psig at a flow of 100 std cm^3/min. The heat losses are more than adequate to cool the gas from ~600°F to less than 150°F.

By gamma scanning the main loop sample with a scintillation detector and multi-channel analyzer, it will be possible to measure build-up of activity in the coolant, to determine release rates of fission products by measuring activities at equilibrium, and to observe changes in activity. A "Chroma-matic" Model 112AX gas chromatograph manufactured by Greenbrier Instruments, Inc., is provided to automatically analyze and record the presence of CO, CO_2, H_2, O_2 (and argon), CH_4 and N_2. The analysis cycle can be programmed so that all six components are analyzed at intervals as short as 20 minutes. By analyzing the main loop sample, it will be possible to monitor the quantities of potentially corrosive contaminants in the coolant. By analyzing both samples, it will be possible to measure the effectiveness of the side stream purification system. The chromatograph will also be used to monitor in-leakage from the nitrogen buffered seals on the heater.

<u>The Containment Cell</u>. The loop containment cell is designed as:

1. a secondary containment vessel in the event of primary piping or equipment failure,

2. a biological shield for radiation emanating from fission products and fragments normally circulating in the loop, and

3. a hold up chamber for fission products in the event of a catastrophic accident to the fuel element and primary containment.

The design is such that in the event all the fission products are released from the fuel into the cell through a rupture in the piping, the fission products and radiation fragments will be held within the cell. Radiation levels outside the cell within the ORR Building will be low enough to permit activities to proceed without creating a hazard to personnel.

The containment vessel is a stainless steel lined cell formed by 4 ft thick reinforced barytes concrete walls. It is approximately 11' x 34' x 10' high. A decontamination and cleaning room is located next to the cell.

The cell will be maintained at 1.5 psi below building pressure to insure that all leakages will be into the cell. The cell in-leakage criteria is set at 1% of the cell volume per day (40 ft^3/day) at a pressure differential of 2 psi.

All gas supplies entering the cell are from limited volume tanks so that no more than 10 standard cubic feet of gas can leak into the cell (equivalent to a .04 psi rise in cell pressure) from any supply source.

Pipe and conduit penetrations are seal welded to the liner. Electrical and instrument leads enter the cell through conduits and terminate in junction boxes welded to the liner.

Access to the cell is provided by a gasketed experiment door on the beam hole centerline, a gasketed hatchway with removable concrete blocks in the roof of the cell and a double gasketed marine type door between the decontamination room and the cell. Viewing is through a lead glass shielding window which is seal welded to the liner. The ambient temperature of the cell is maintained at 80°F by two space coolers.

Instrumentation & Control. The facility is instrumented to measure flows, pressures, temperatures, and radiation levels. A view of the main control panel is shown in Fig. 14. The instrumentation is generally of standard design and construction except that the use of pneumatic instruments with their inherent air bleed is precluded by the tight in-leakage requirement of the containment cell. Therefore, all pressure transmitters and valve operators are electric or electronic.

Automatic control of loop temperature is accomplished by controlling the electric heater output using signals from thermocouples downstream of the fuel element. Excessive temperatures, abnormal pressures, loss of cooling water or gas flow automatically initiate safety action. This consists of cutting off heater power and closing the cooler by-pass valve to obtain maximum gas cooling. If the abnormal condition persists and the loop integrity is threatened, a reactor scram or setback is initiated.

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Photo 57283

Fig. 14. Main Instrument Panel.

Experimental Program

Following shakedown tests, the first scheduled experiment will be a low power dual purpose calibrating run. It will determine an axial flux plot and obtain initial deposition data. The test element, shown schematically in Fig. 15, will be a 1.315 inch diameter, 1 inch long cylinder plated on the outside with .002 inches of natural UO_2. Argon will be circulated through the cylinder and its activation measured to obtain the axial flux plot of the experiment hole using the techniques reported by R. M. Carroll[7].

The fission products from the UO_2 coating will circulate in the loop helium and provide initial data on deposition and gas clean-up. Since the amount and type of fission products released to the gas stream can be estimated for this test, the experiment will permit evaluation of the various radiation monitoring and sampling equipment.

The second experiment scheduled for the loop will provide the initial evaluation of full sized, 1.5 inch diameter graphite fuel spheres of the type proposed for the Pebble Bed Reactor Experiment[8]. This experiment will include a controlled temperature fission product deposition tube located just downstream of the fuel element, as shown in Fig. 16.

Although the future test program has not been firmly established, the facility is versatile enough to be used for a variety of engineering experiments including evaluation of components in gas circuits associated with unclad fuel elements. Fuel elements can be tested under varying conditions of flow, temperature, and neutron flux to determine amount and type of fission products released to the gas stream.

It is possible to replace the loop components with alternate designs to evaluate compressors, heat exchangers, valves, instruments, and gas purification equipment. Small by-pass experiments can be connected to capped off pipes provided at high and low pressure points in the loop. These experiments would use the facility as a source of gas containing fission products and could be used to study the effect on deposition of temperature, velocity, and surface finish.

A major contribution of the facility will be the accumulation of operating experience on contaminated gas systems, thus developing background for the design and operation of this class of advanced gas cooled reactors.

Acknowledgements

The development of the In-Pile Gas-Cooled Fuel Element Test Facility described above has been carried out by the Engineering Development Department of the Reactor Division at the Oak Ridge National Laboratory under the sponsorship of the Gas-Cooled Reactor Program. Appropriate phases of the subject have been the responsibility of other sections, in

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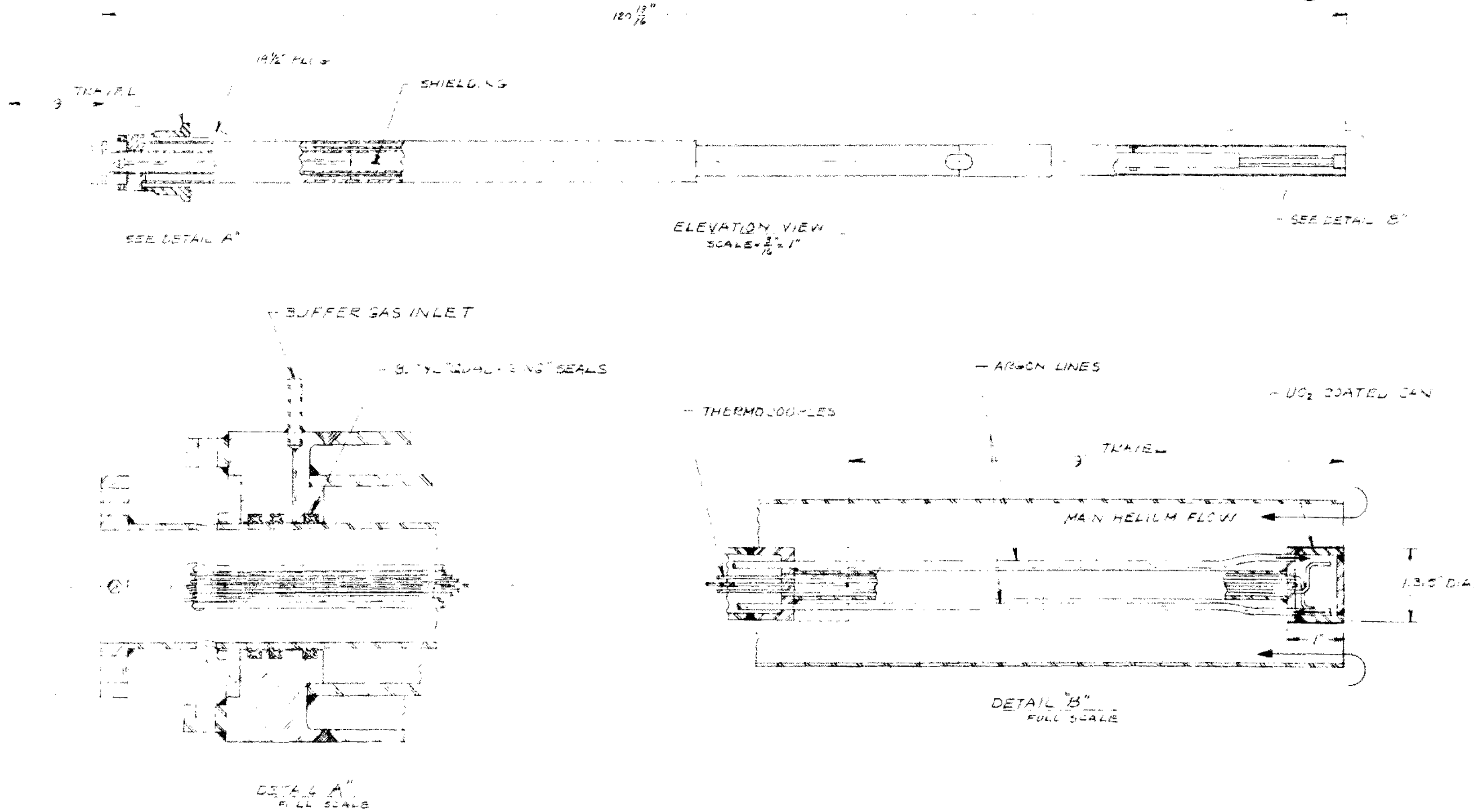

Fig. 15. Low Power Flux Scan Test Section.

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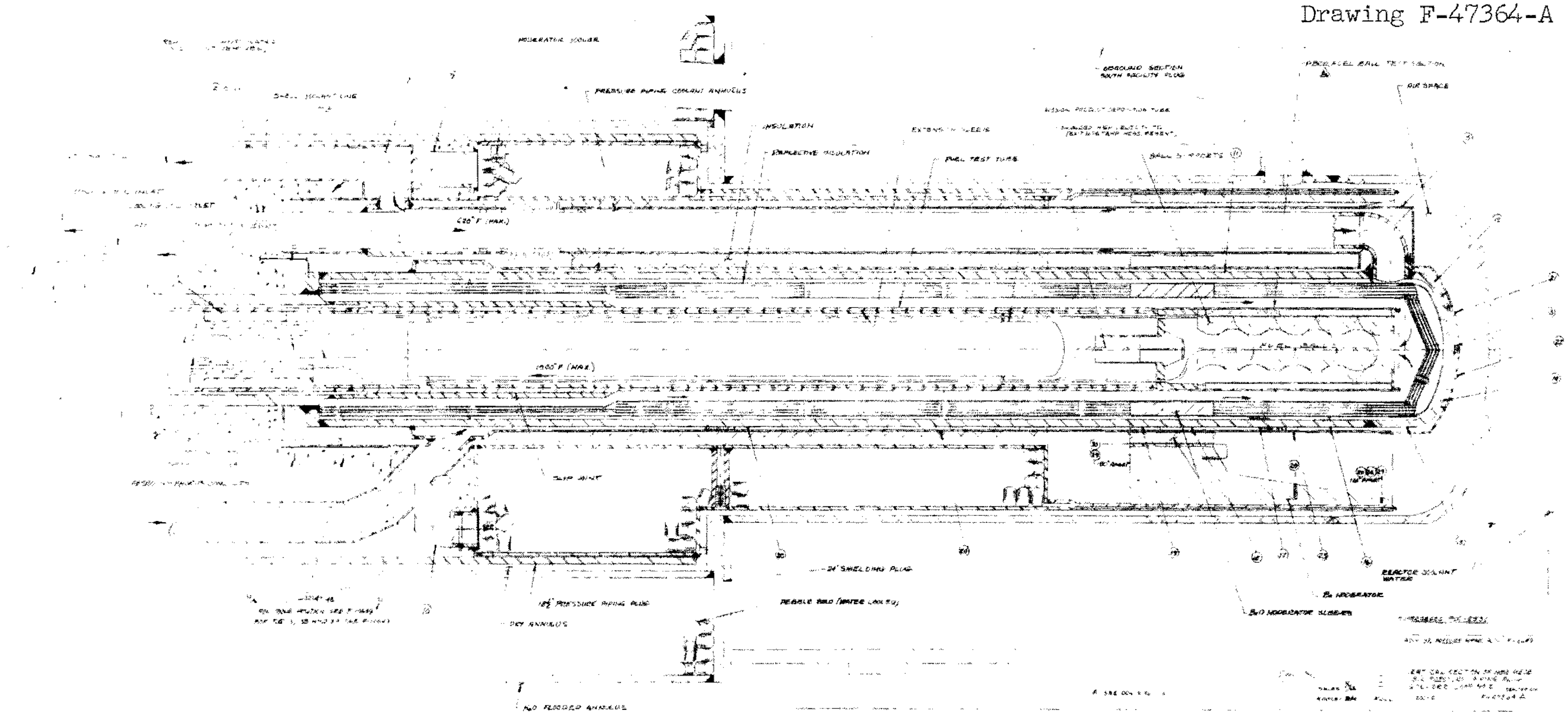

Fig. 16. Test Section for PBRE Fuel Element Test.

particular the Engineering Design, Engineering Services, Reactor Physics, and Irradiation Engineering Departments of the Reactor Division, the Instrument and Control Division, the Engineering and Mechanical Division, and the Reactor Operations Division of the Laboratory.

We regret the impossibility of naming each of the individuals who has contributed directly to the design, installation, and development effort.

The direction and guidance of the project by W. D. Manly and R. A. Charpie, present and past Directors of the Gas-Cooled Reactor Program at the Laboratory, and by D. B. Trauger, Irradiation Engineering, and H. W. Savage, Development Engineering, has been deeply appreciated.

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