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THE ATR HIGH TEMPERATURE HELIUM LOOP MODEL DESCRIPTION AND CAPABILITIES

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By

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THE ATR HIGH TEMPERATURE HELIUM LOOP MODEL DESCRIPTION AND CAPABILITIES

P. M. Jackson and R. J. Evans

INTRODUCTION

This report describes construction features, current application, and potential future applications of a high temperature, high purity, helium gas loop in operation at Pacific Northwest Laboratory (PNL). The loop is an approximate one-tenth scale model of a high temperature materials-testing helium gas loop under construction at the Advanced Test Reactor (ATR), Idaho Falls.

Originally the model loop was built to evaluate material problems and various design parameters of the ATR Gas Loop. Currently, the model loop is being used as a pilot operation for the ATR Gas Loop and as an out-of-reactor control in evaluation of specimen assemblies to be irradiated in the ATR Gas Loop.

In fulfilling its original objective the model gas loop operated successfully for approximately 700 hr at various heater outlet temperature up to 2100 °F. When the designs of the ATR Loop were taken beyond the conceptual stage, it became apparent that the tenth-scale gas loop was no longer an adequate model. Since the ATR loop contains features that were significant departures from its model and from commercial practice, it was necessary to incorporate the new features into the "model" loop. This task has been completed and the loop has to date undergone an additional 4000 hr of operation.

SUMMARY

The model loop is a high purity gas system with the potential for recirculating 500 lb/hr helium gas at 300 psi pressure and a maximum temperature of 2100 °F.

Loop circulation is provided by a two stage hermetically sealed gas bearing compressor, and a desired flow rate can be automatically or manually controlled. A heater with concentric nichrome and molybdenum tubular elements provides outlet gas temperatures to 2100 °F. Two test sections are incorporated to permit evaluation of components and specimens; one is oriented vertically the other horizontally. An attemperator device is included to limit the outlet gas temperatures within desired conditions. Complete instrumentation is incorporated to maintain safe operating conditions with shutdown devices for abnormal conditions. Gas clean-up equipment was installed to maintain the loop atmosphere at less than one part per million of contaminating gasses.

Future application of this system would include such uses as:

- Survey tests on gas reactor components
- Transport phenomena studies
- Magneto hydrodynamic phenomena
- And Heat Transfer studies of fluidized beds.

DISCUSSION

The model loop (Figure 1) is a closed system that recirculates high temperature, high purity helium gas. The helium gas flows from the compressor through the flow orifices and flow control valves to the shell side of the regenerative heat exchanger where this gas is heated. The preheated gas flows to the main heater where the temperature is raised to a maximum of 2100 °F. The horizontal test section is located immediately downstream of the heater and about 5 feet upstream of the vertical test section. After passing both test sections, the gas enters the tube side of the regenerative heat exchanger and is cooled. Further gas cooling is provided by an air to gas heat exchanger which limits the gas temperature to a 640 °F maximum before it re-enters the compressor.

An attemperator system injects the cooler gas from the compressor into the outlet side of the vertical test section, when necessary, to precool the hot gas before it enters the regenerative heat exchanger. Remote instrumentation is provided to safely operate the system.

MAJOR COMPONENTS

Eight major components of the model gas loop are as follows:

- Compressor
- Orifices and Flow Control Valving
- Regenerative Heat Exchanger
- Heater
- Horizontal and Vertical Test Sections
- Air to Gas Heat Exchanger
- Attemperator
- Instrumentation

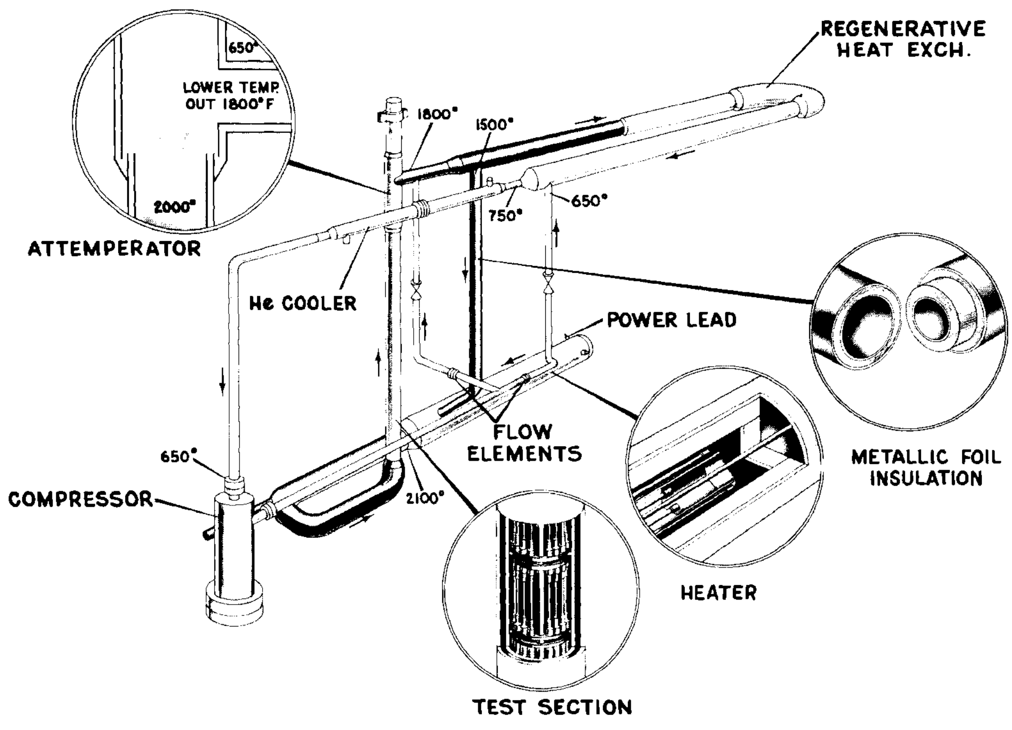

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FIGURE 1. High Temperature Gas Loop

Gas Compressor

The gas in the loop is circulated by a hermetically sealed, vertical two-stage, centrifugal, gas-bearing compressor driven by a synchronous motor. The compressor output is varied by regulating the rotor speed from 5000 to 24,000 rpm. Speed of the compressor rotor is controlled through a motor generator set which varies the frequency from 60 to 400 cycles. Water cooling of the compressor prevents overheating at gas inlet temperatures up to 640 °F maximum. The compressor characteristics are illustrated in Figure 2. These curves can be used to predict the amount of pressure drop available at any flow and compressor speed. The vertical curve on the graph was obtained by decreasing the compressor speed with the flow control valve fully open.

In reference to Figure 2, if a 300 lb/hr flow rate is desired, a specimen train with a maximum pressure drop of 1300 ft helium (27.5 in. H_2O at 100 °F, 150 psig) could be utilized by operating the compressor at a speed of 20,000 rpm.

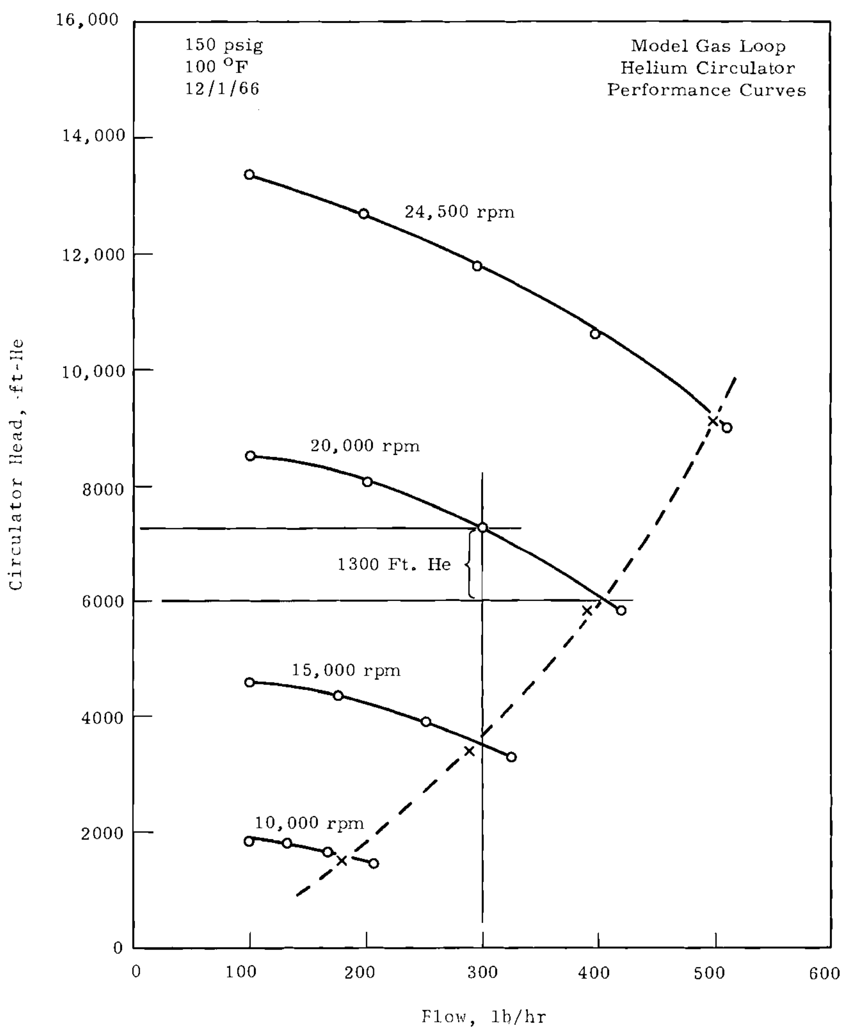

FIGURE 2. Gas Compressor Characteristics

Orifices and Flow Control Valving

Flow control of the primary and attemperator circuits is maintained automatically or manually. The valves are pneumatically operated from their control instrumentation through the signal from the flow indicating orifices. Once set, the flow will remain constant unless the system temperature or pressure is changed.

Regenerative Heat Exchanger

The Regenerative Heat Exchanger, a tube-in-shell type unit, cools the gas flowing from the test section to the compressor by heating the return gas from the compressor to the heater. The unit is a counter flow design—the gas is cooled on its passage through the central tubes while the return gas flowing through the shell is simultaneously heated. The Heat Exchanger is of the "U" type to reduce the problems associated with thermal expansion.

Heater

The original system heater has recently been replaced by a new design substantially more prototypic of that required for the ATR Loop. Although briefly described here, the new heater was reported in detail in 1966.(1)

The newly installed heater (Figure 3) is a two-stage concentric type unit in which the gas passes through tubular heating elements. The first or low temperature stage consists of twelve 51-in. lengths of nichrome tubing 0.640 OD x 0.062 wall thickness connected in series with a single phase 60 kW power

1. R. J. Evans. A Two Stage 2100 °F Helium Gas Heater for the ATR Model Gas Loop, BNWL-328, Pacific Northwest Laboratory, Richland, Washington, November, 1966.

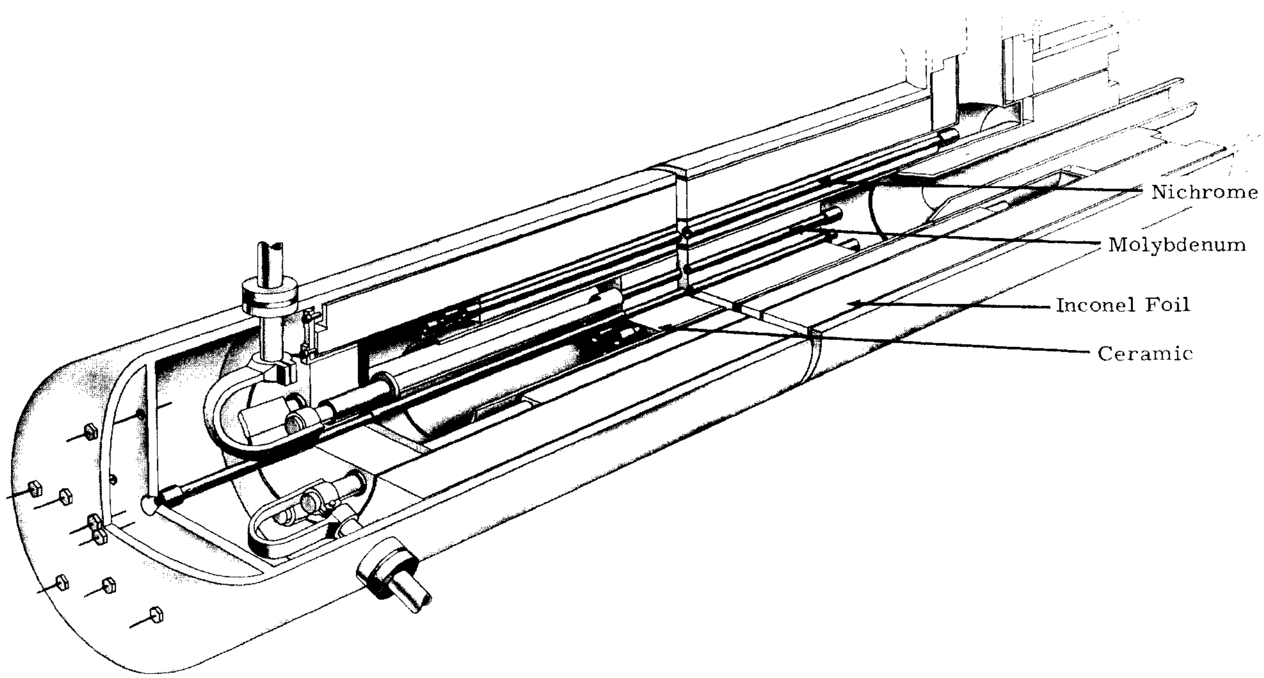

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FIGURE 3. High Temperature Gas Loop Heater

supply. The second or high temperature stage, which is similarly connected to another single phase 60 kW electrical supply, utilizes six 39-1/2 in. lengths of molybdenum tubing 0.635 in. OD x 0.045 in. wall thickness. These tubular elements are continuously supported within discs of high purity aluminum oxide. The second stage is located coaxially within the first stage, thus the gas flow emerging from the first stage is reversed before entering the second stage. Bypass flow is prevented by a liner between stages. Gas enters a nozzle through the side of the cylindrical shell and exits axially through the same end. The electrical and instrumentation penetrations are through the opposite end.

Test Sections

There are two test zones in the model loop where material specimens can be placed for evaluation (Figure 4). One test section is oriented horizontally, and the other vertically.

Horizontal Test Section

The horizontal test section is located immediately downstream of the heater; thus, the maximum test temperatures are obtained in this zone. The test zone is 66 in. long and 4 in. in diameter. Access and instrumentation penetrations are through a 4 in. Graylock fitting on the downstream end of the horizontal test section. Test temperatures within this test section will vary about 175° from a maximum of 2100 °F at the heater outlet, with a gas flow rate of 400 lb/hr.

Vertical Test Section

The vertical test section is located about 5 ft downstream of the horizontal test section; therefore, the test temperatures are somewhat lower. At a 2100 °F heater outlet temperature with a 400 lb/hr flow rate, the test section inlet temperature is about 1875 °F, and the outlet 250 °F less. The vertical test chamber is 48 in. long with a 2 in. diam. A reduction of the internal insulation thickness can provide an alternate 4 in. diam near the upper zone. Entry is made through a 4 in. axial port similar to that for the horizontal section, and the gas flow past the test specimens in the vertical test section is upward, as it is in the ATR gas loop test section.

Air-to-Gas Heat Exchanger

To limit the gas entering the compressor to a maximum of 640 °F, the air to gas heat exchanger further cools the gas leaving the regenerative heat exchanger. Maintaining the circulator inlet temperature near the 640 °F limit minimizes the loop heat losses. Originally, the heat exchanger was water cooled; however, changing to air cooling has resulted in a system providing an easily adjustable moderate cooldown.

Attemperator

The attemperator is a device where the hot gas is cooled by mixing it with cooler gas. In the ATR gas loop system, the gas will be hottest when it flows through the in-reactor test section. The containment piping temperatures, produced by this hot gas, would exceed

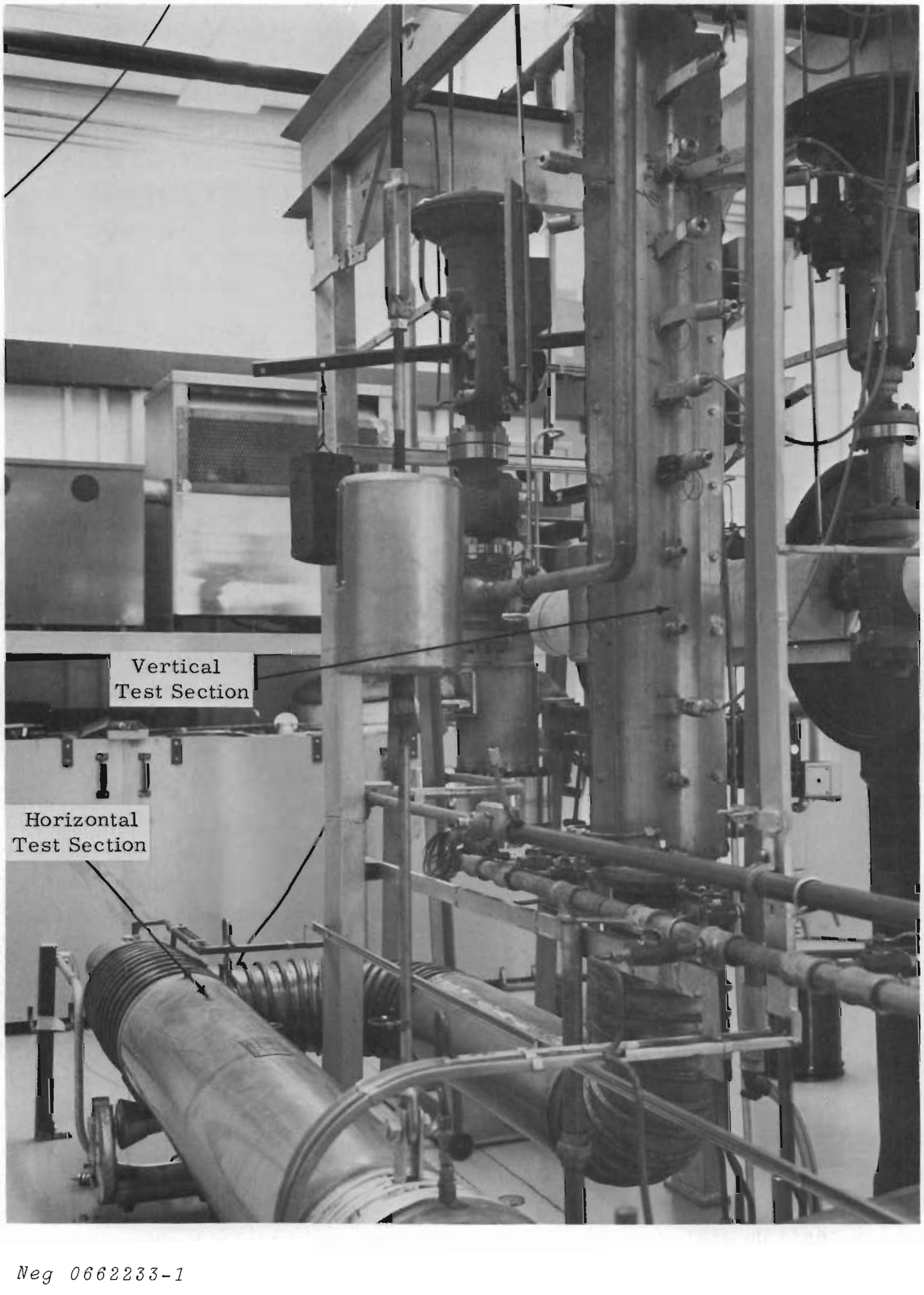

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FIGURE 4. Horizontal and Vertical Test Sections

safe operational limits if the gas were not precooled by an attemperator system. This type of system was installed on the model loop to evaluate the design parameters. A bypass flow of cool gas from the model loop compressor is used to mix with the hot gasses exiting from the vertical test section. To date, the attemperator system has not been required for operation of the model loop; however, it has performed satisfactorily during evaluation tests.

Instrumentation

The instrument panel (Figure 5) contains the necessary instrumentation to allow a manual control of the loop system. Although several of the individual systems (i.e., flow-temperature-pressure) have automatic steady state operational capability, a completely automatic system has not been established. An enunciator system is provided to warn the operator of abnormal conditions, and if such conditions continue, safety shutdown circuitry is available to shut down either individual components or the total loop system.

Data collection is primarily manual; however, selected data is recorded continuously. Figure 6 shows the positions of the thermocouples currently in use. Additional thermocouples can be readily

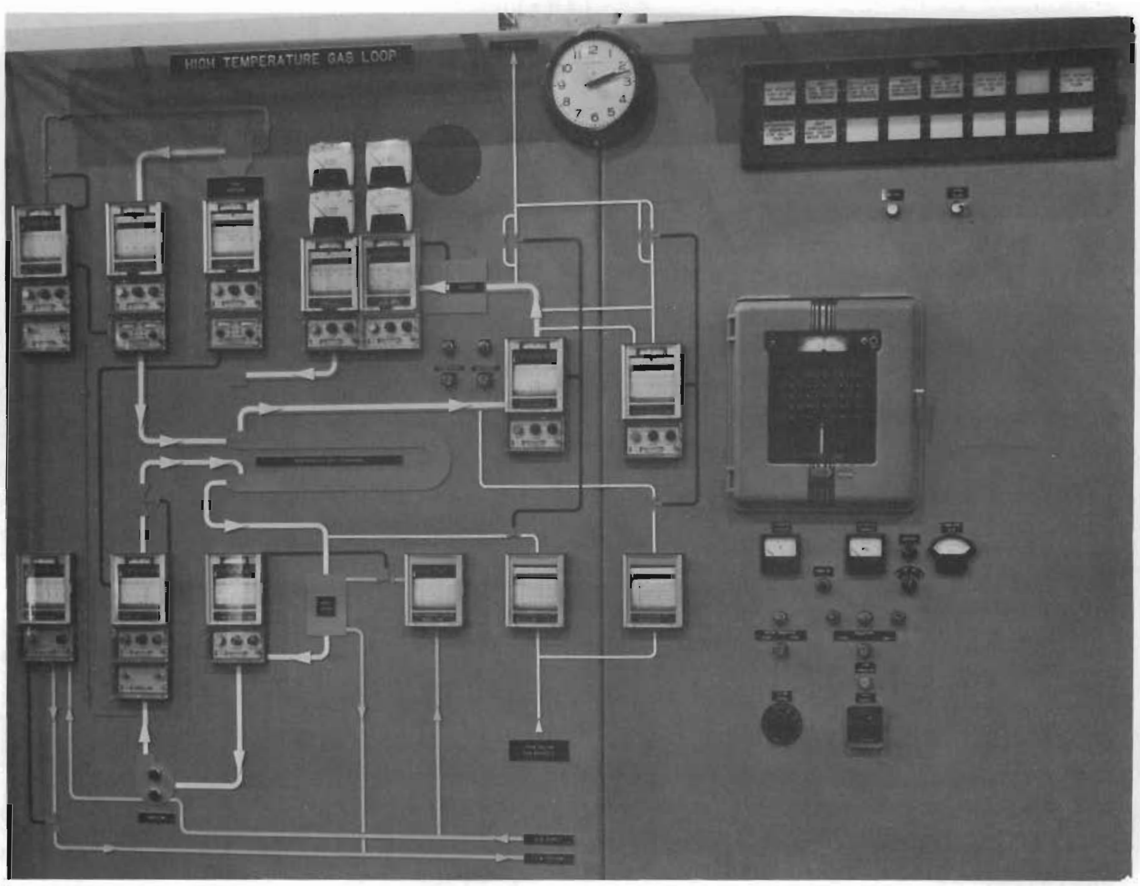

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FIGURE 5. Instrument Panel

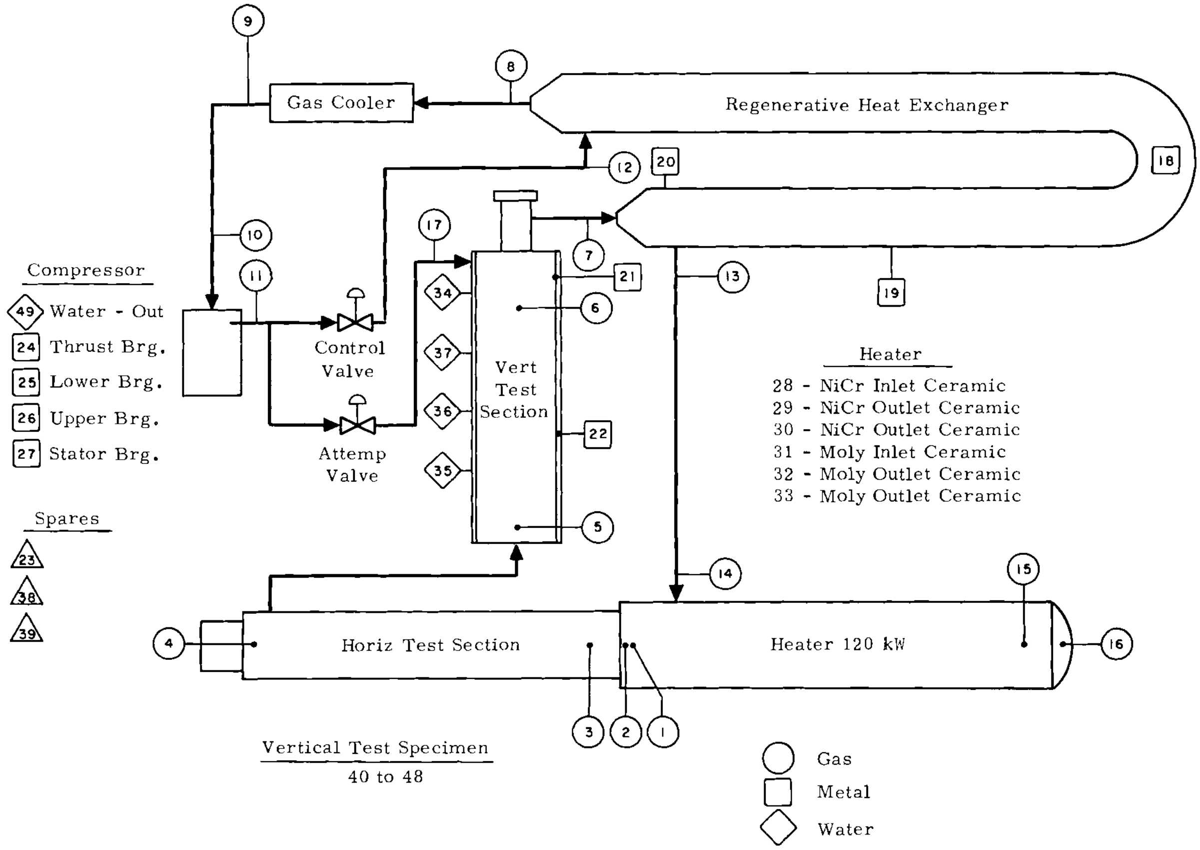

FIGURE 6. Thermocouple Locations

installed through existing penetrations in either test sections, and indicating and/or recording instruments are available for the readout of all thermocouples.

Differential pressure measurements are currently being taken across the compressor, heater, and test sections.

AUXILIARY SYSTEMS

In addition to the eight major components of the gas loop, there are three systems—gas purification, bypass cleanup, and gas monitoring—which are used for preparing, maintaining, and monitoring the helium gas purity.

Gas Purification System

To properly evaluate the effects of high temperatures on material properties specimens, it is necessary to maintain the specimens within a high purity inert gas atmosphere. Since its total impurities can be as high as 50 ppm, commercially available Grade A helium does not meet the purity requirements for this testing. Therefore, a helium purification system was developed to provide the high quality gas needed for the model loop operation.

The purification system (Figure 7) is capable of generating ultra-high purity helium gas with less than 1 ppm total impurities including water from either commercial Grade A helium or from less pure gas stored within a balloon. The balloon is used to store spent gas from the loop and/or other experiments being conducted within the

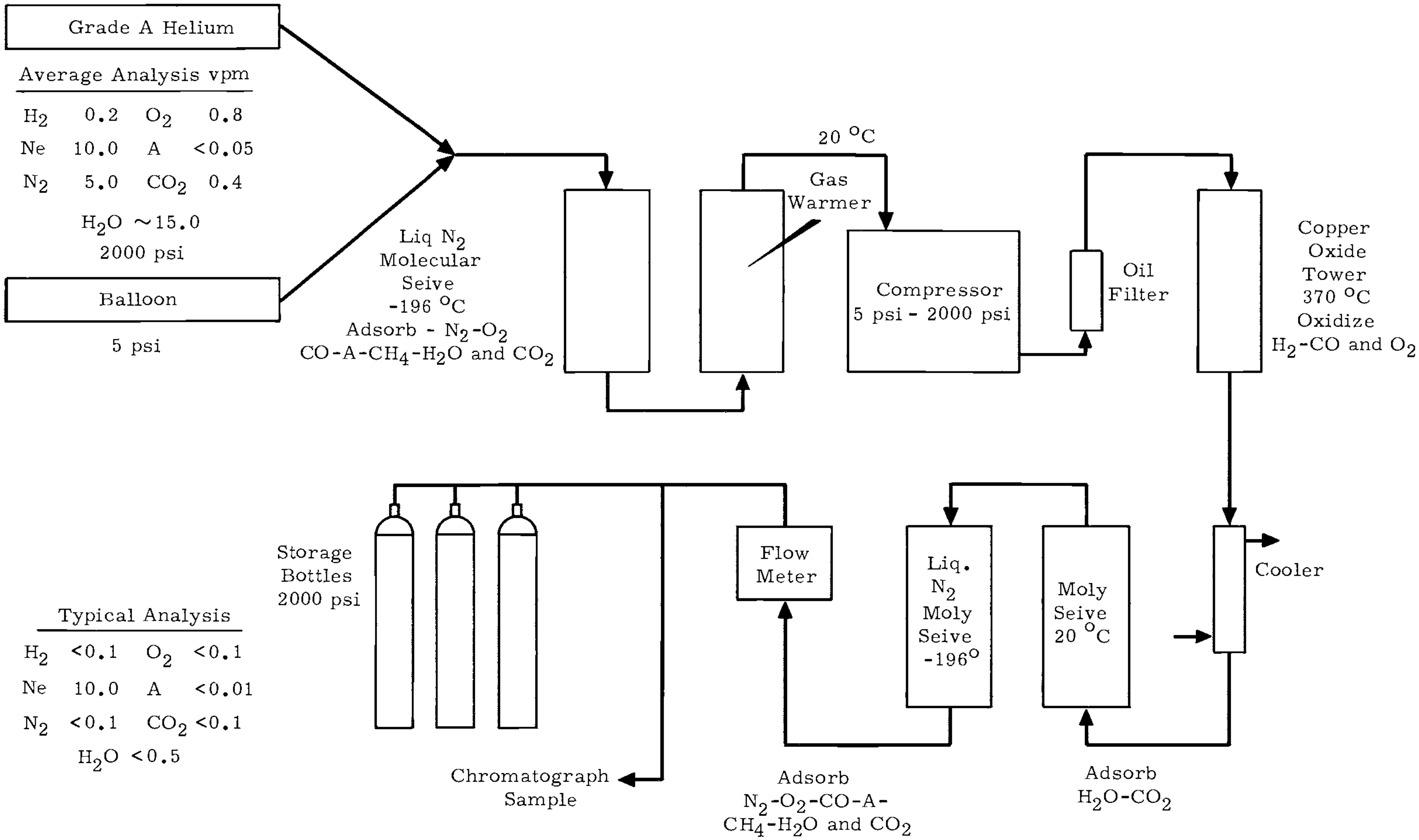

FIGURE 7. Helium Purification System

building. A high pressure gas compressor circulates the contaminated gas through a series of towers containing copper oxide and molecular sieves. These materials absorb the impurities, thus a pure gas is produced.

Bypass Cleanup System

Although high purity helium gas is initially charged into the system, during high temperature loop operation this gas will pick up contaminants caused by outgassing and leakage inflow. A bypass cleanup system (Figures 8 and 9) has been installed to maintain the gas quality at a high level during system operation. A small gas flow from the circulator outlet is directed through the cleanup system and returned to the circulator inlet where it mixes with the main loop flow. This system operates similarly to the gas purification system. The cleanup system is provided with dual molecular seive towers; this system allows a change to regenerated towers when the gas analysis indicates the quality is decreasing. The alternate towers can be regenerated without an interruption in loop operation.

Gas Monitoring System

The ultimate success of a test program conducted with a closed gas loop system depends upon the ability to know the quality of the recirculating gas within the system. A highly refined semiautomatic gas chromatograph[2] has been developed at PNL, and this unit (Figure 10) was selected for use on the model gas loop. The gas purity is routinely monitored by this chromatograph which is capable of detecting individual impurities to less than one volume part per million. Presently, impurity levels of the following contaminants are determined: oxygen, hydrogen, nitrogen, methane, and carbon monoxide. In addition, an electrolytic moisture monitor is used to determine the levels of water vapor.

SYSTEM CONSTRUCTION

The model loop has been fabricated from a considerable array of materials. Originally, the system employed a double containment arrangement where the cooler shroud piping was pressurized to relieve the stresses on the inner and much hotter primary piping. That system has since been replaced with 300 series stainless steel containment piping with internal metal foil insulation which makes double containment unnecessary. All portions of the loop between the regenerative heat exchanger and the vertical test sections are now insulated with metal foil insulation and have water cooling jackets or tubes on the outer surface. This insulation is composed of 2 mil thick inconel foil sheets with a corrugated pattern to provide greater strength and a minimum contact area. The foil sheets are concentrically wound on a liner fabricated of superalloy materials (Haynes 25-Hastelloy X). A 300 series stainless steel outer liner is pinned through the foil sheets to the inner liner and provides a structurally sound uniformly thick insulation. The sections (Figure 11) are fitted to each other with labyrinth type joints which permit adequate space for thermal expansion without allowing a direct path for gas flow

2. *D. W. Shannon, "Chromatographic Analysis of Helium Containing Trace Impurities", BNWL-12, Nov. 1964.*

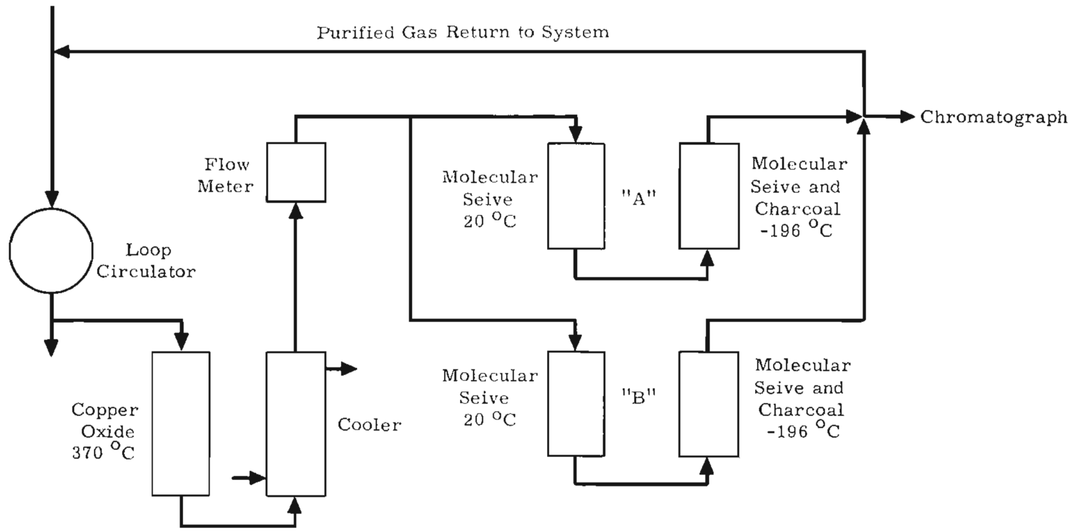

FIGURE 8. By-Pass Clean-Up System

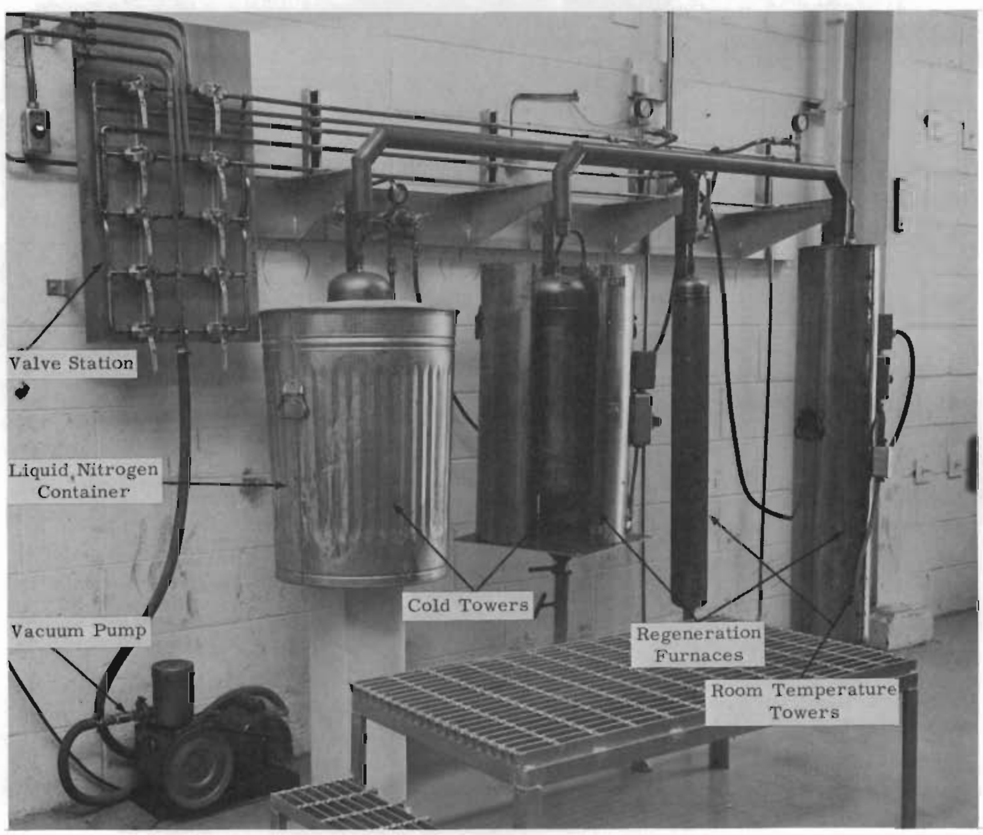

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FIGURE 9. By-Pass Clean-Up System

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FIGURE 10. Chromatograph

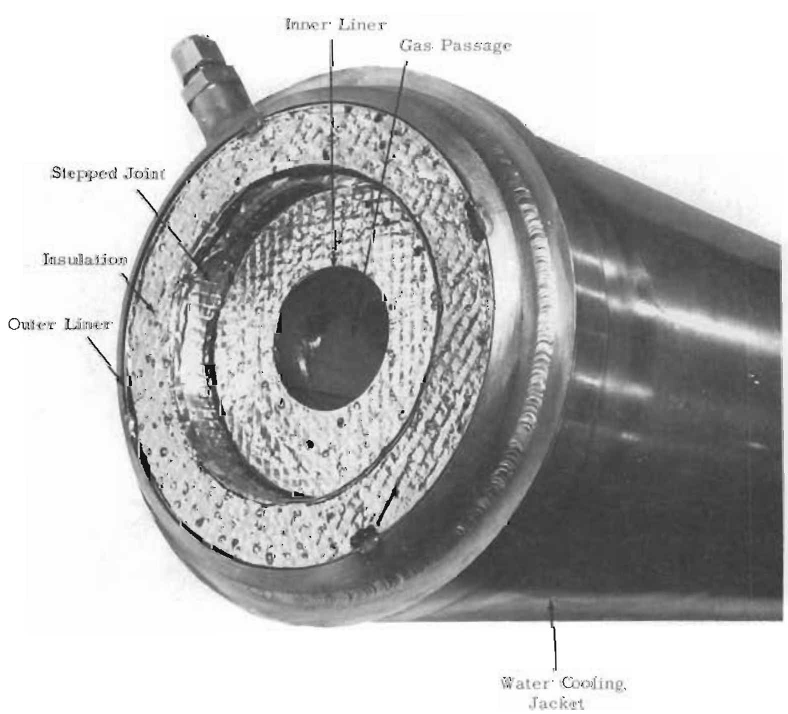

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FIGURE 11. Typical Pipe Section

or thermal radiation to the outer containment member. The water jackets and/or cooling tubes, fixed to the outer containment piping, provide system integrity by keeping the containment surface cool and, thus, within allowable stress values. Bleed ports have been installed on all cooling jackets to prevent hot spots from steam vapor buildup. The model loop piping (Figure 12) is supported by conventional pipe hangers and rollers from a structural steel framework to reduce the effects of temperature stresses caused by thermal expansion and contraction. To provide maximum safety for operating personnel, the loop is located in a separate room adjacent to the instrumentation and auxiliary systems.

CURRENT APPLICATION

Initially, the model loop was used as a design aid and development tool for construction of the ATR Gas Loop. Now, it evaluates components or test samples exposed to the high temperature gasses within the horizontal and vertical test sections. To date, one test assembly has undergone approximately 2000 hr of exposure within the horizontal test section; a second test assembly (Figure 13), 750 hr exposure within the vertical test section.

The model loop is being used as the gas source for evaluating a gas chromatograph prior to its transfer to the ATR loop at Idaho Falls. This chromatograph, designed and developed at PNL and fabricated in a vendor plant, has been returned to PNL for evaluation. This system (Figure 10) is automatically operated, has the same capabilities as described for the model loop chromatograph; but, in addition, has the capability of measuring total impurities.

POTENTIAL APPLICATIONS

The uniqueness of the gas loop facility, ease of component replacement, excellent operating characteristics, and general versatility combine to make the model loop valuable for other Research and Development applications. Some potential uses would be as follows:

- Survey Tests on very high temperature gas reactor components such as insulation control valves, heat exchangers, linear activators, gas compressors, and blowers.
- Tests under prototypical conditions on small components for very high temperature gas reactors. Instrumentation, thermocouples, sonic resonance thermometers, and analytical probes are examples.
- Transport phenomena studies.
- Magnetohydrodynamic phenomena studies.
- Heat transfer studies involving high temperature fluidized beds.

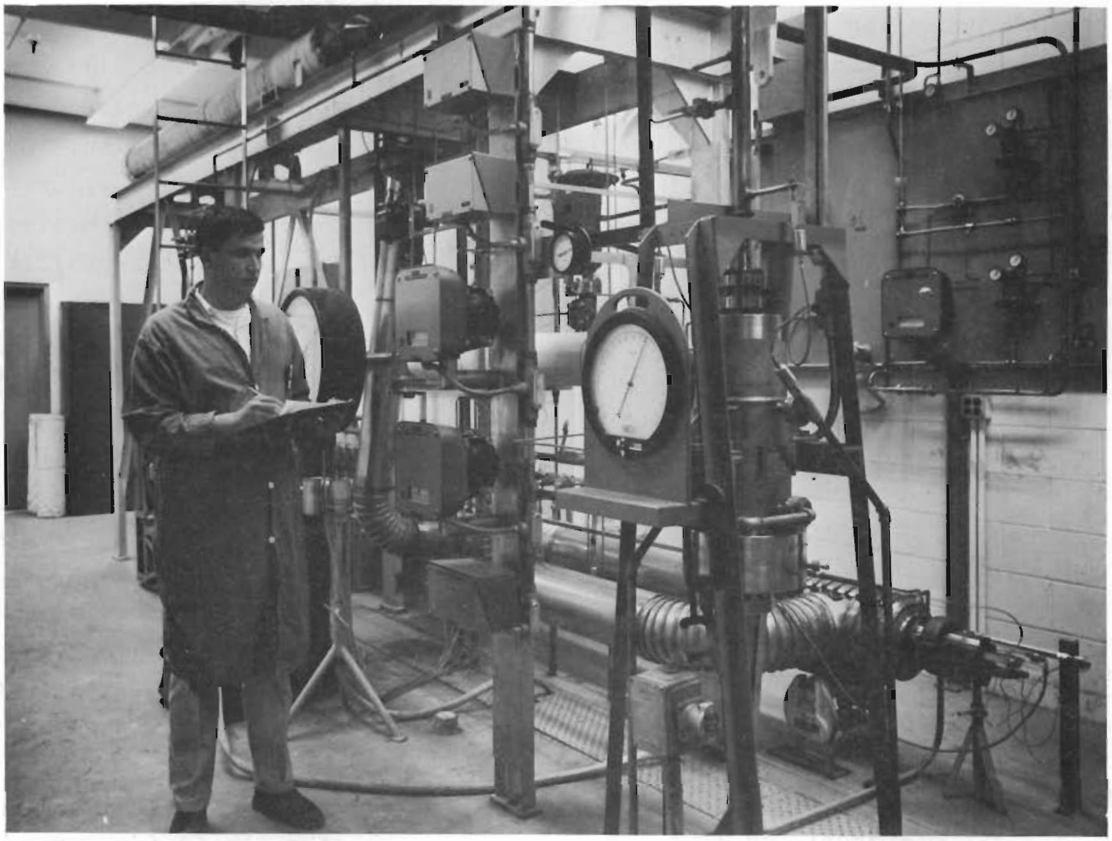

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FIGURE 12. Model Loop Piping

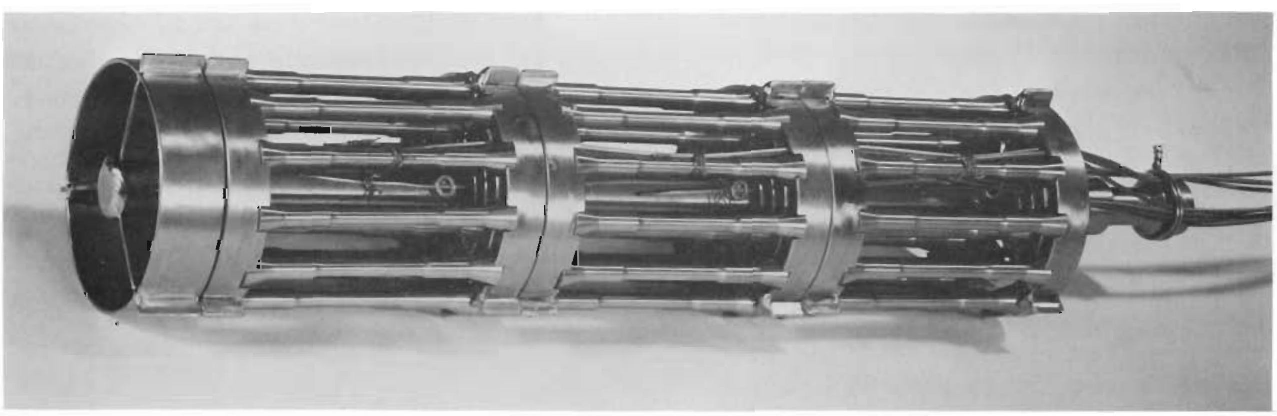

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FIGURE 13. Test Assembly

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