OAK RIDGE NATIONAL LABORATORY
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UNION CARBIDE CORPORATION
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U.S. ATOMIC ENERGY COMMISSION

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PRELIMINARY DESIGN OF A HYDROGEN-COOLED IN-PILE LOOP FOR THE EGCR

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PREFACE

This report presents the results of a study which established the preliminary design of a hydrogen-cooled loop for the EGCR. During this study, time did not permit a multiple approach to each design problem. Therefore, the design object was to establish feasibility by demonstrating a way to do the job, but not necessarily the best way.

With regard to hazards, a cursory study was conducted to determine which of several possible accidents should be considered the maximum credible loop accident. Two or more unrelated failures were not considered credible. Only the maximum credible loop accident was examined in detail.

During the design study and preparation of this report the authors drew heavily from their own contributions and those of others to an earlier design study of loops for operation in the EGCR with helium or CO_2 as the coolant. The reader is referred to the following document for information concerning this earlier study and for more details concerning many of the hydrogen-cooled loop systems and components which are identical to those in the helium- or CO_2-cooled loops:

ORNL-TM-134 EGCR Experimental Loops Preliminary Design Report

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ABSTRACT

This report covers the preliminary design and hazards evaluation of a hydrogen-cooled in-pile experimental loop for operation in the large double-walled through-tube in the Experimental Gas-Cooled Reactor (EGCR) at Oak Ridge. This loop is designed to permit experimentation with full-scale fuel element configurations up to 8 in. in outside diameter, at inlet gas temperatures in the range 600 to 950°F at 300 psig, and experimental power levels up to 500 kw. The results of a preliminary hazards evaluation indicate that a loop of this type can be safely operated in the EGCR. The hydrogen flammability hazard is controlled by blanketing all hydrogen-filled pipes and components with a sufficient quantity of nonreactive gas, such as helium or carbon dioxide, to produce a noncombustable mixture for all credible hydrogen-release situations.

1. INTRODUCTION

A preliminary design and hazards evaluation has been completed for a hydrogen-cooled experimental loop for operation in the large double-walled through-tube in the EGCR. This loop is designed to permit experimentation at inlet gas temperatures in the range 600 to 950°F at 300 psig and experimental power levels up to 500 kw. Although the loop design limits the test-section mixed-mean outlet gas temperature to 1050°F, higher gas temperatures can be achieved in an experiment by attemperation (bypassing a portion of the loop gas around the experimental section and mixing it with the loop mainstream gas at the outlet end).

A schematic flow diagram of the proposed hydrogen-cooled experimental loop is shown in Fig. 1.1. The compounds through which the mainstream gas normally flows are the in-pile test section (inner tube of a double-walled through-tube) containing the experimental assembly, the mainstream gas cooler, the mainstream gas filter, three compressors in series, and the mainstream gas heater. In addition, there is an auxiliary blower in parallel with the loop compressors.

The function of the mainstream gas cooler is to remove the heat generated by the experimental assembly. The mainstream gas filter is provided to remove any particulate matter in the gas. This should help to concentrate the loop activity in a region where it can be most effectively shielded. The loop compressors provide the positive head required to overcome the loop pressure drop at the required gas flow rate. The mainstream gas heater preheats the loop during startup and heats the loop during operation at zero reactor power or at such times as the experimental assembly does not contain appreciable fissionable material.

The principal auxiliary equipment and services for the loop include a bypass gas-cleanup system for continuous onstream fission-product removal, a gas transfer and storage system for the transfer and storage of loop gas, and an offgas system to take care of processing loop gas for release to the EGCR stack.

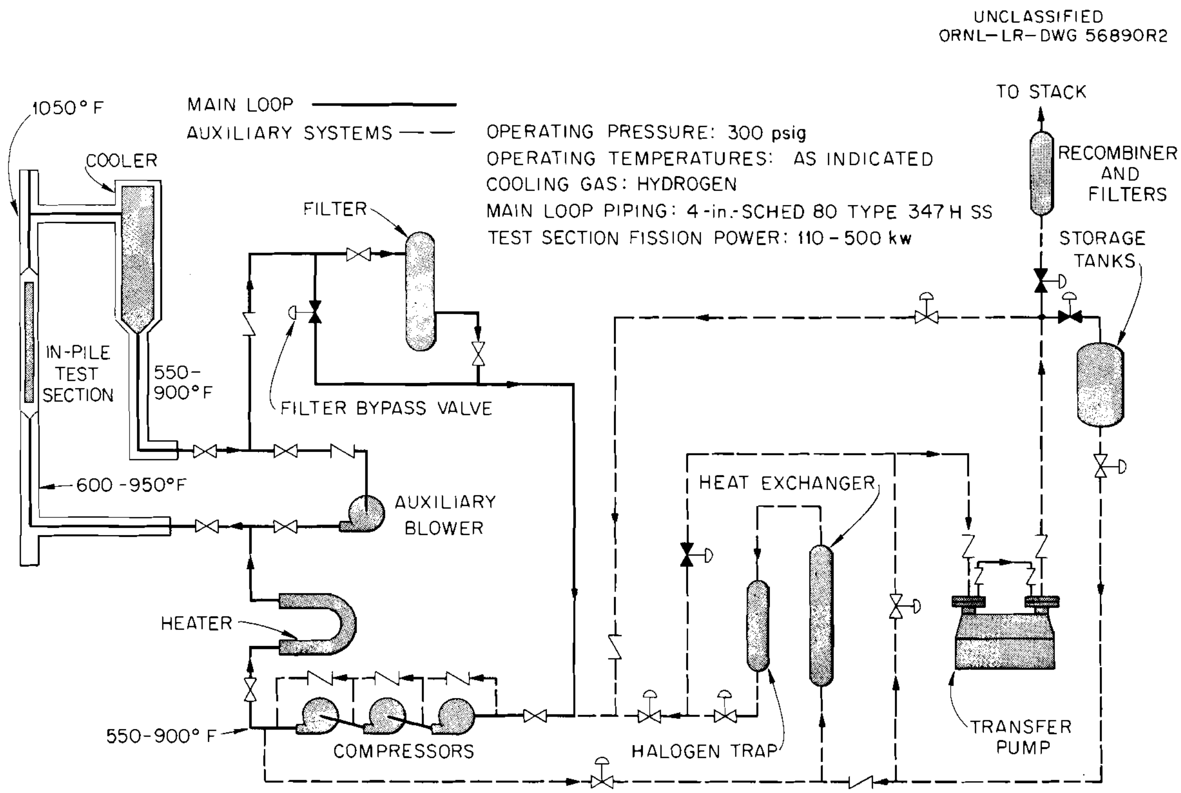

Fig. 1.1. EGCR Hydrogen-Cooled Experimental Loop Flow Diagram.

Other systems required to service the loop include a system for taking gas samples from various parts of the loop; a water system for cooling certain loop components; an electrical system for supplying power to the loop compressors, heater, and other electrical components; a system for supplying hydrogen, helium, and CO_2; a system for distributing the loop gases; and a leak-detection system. With the exception of the mainstream gas cooler, all loop components and equipment that contain loop gas are located in a gastight experimenters' cell.

The results of this preliminary design and hazards evaluation indicate that a hydrogen-cooled loop of this type can be installed and safely operated in the EGCR. In fact, the EGCR is uniquely suitable for this loop because its large through-hole permits the installation of a double-walled through-tube, and its large gastight cell and containment piping arrangement facilitates the blanketing of all hydrogen-filled pipes and components with a sufficient quantity of nonreactive gas to produce a noncombustible mixture for all credible hydrogen-release situations.

1.1. EGCR Loop Accommodations

The EGCR is an experimental gas-cooled reactor being built on the Clinch River about two miles east of the Oak Ridge National Laboratory. It has been designed with space to accommodate up to four gas-cooled experimental loops. Conceptual plan and elevation drawings of the EGCR and its associated experimental accommodations are shown in Figs. 1.2 and 1.3. The reactor is fueled with UO_2 clad in stainless steel; the moderator is graphite; and the cooling gas is helium at a pressure of 315 psia. The reactor is designed to produce approximately 85 Mw of thermal power while operating at a gas inlet temperature of 510°F and an outlet temperature of 1050°F. The reactor thermal power is transferred to water in two boilers to generate superheated steam at 1250 psia and 900°F. This steam is passed through a turbine-generator to produce approximately 25 Mw of electrical power.

The reactor core is a vertical right-circular cylinder made up of 16-in.-square graphite columns that are 19 ft 4 in. high. Vertical circular

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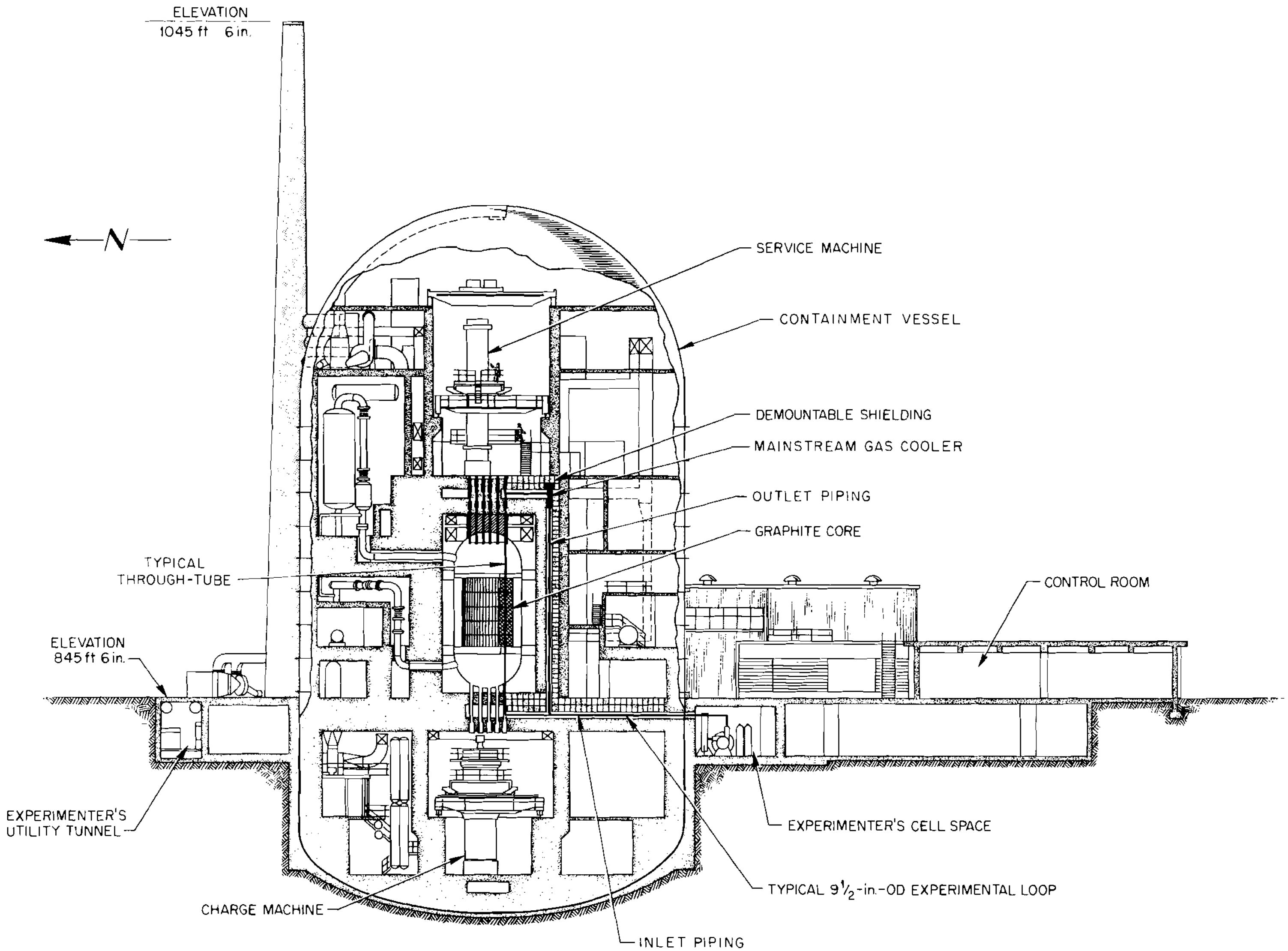

Fig. 1.2. EGCR — Sectional View of Reactor Building.

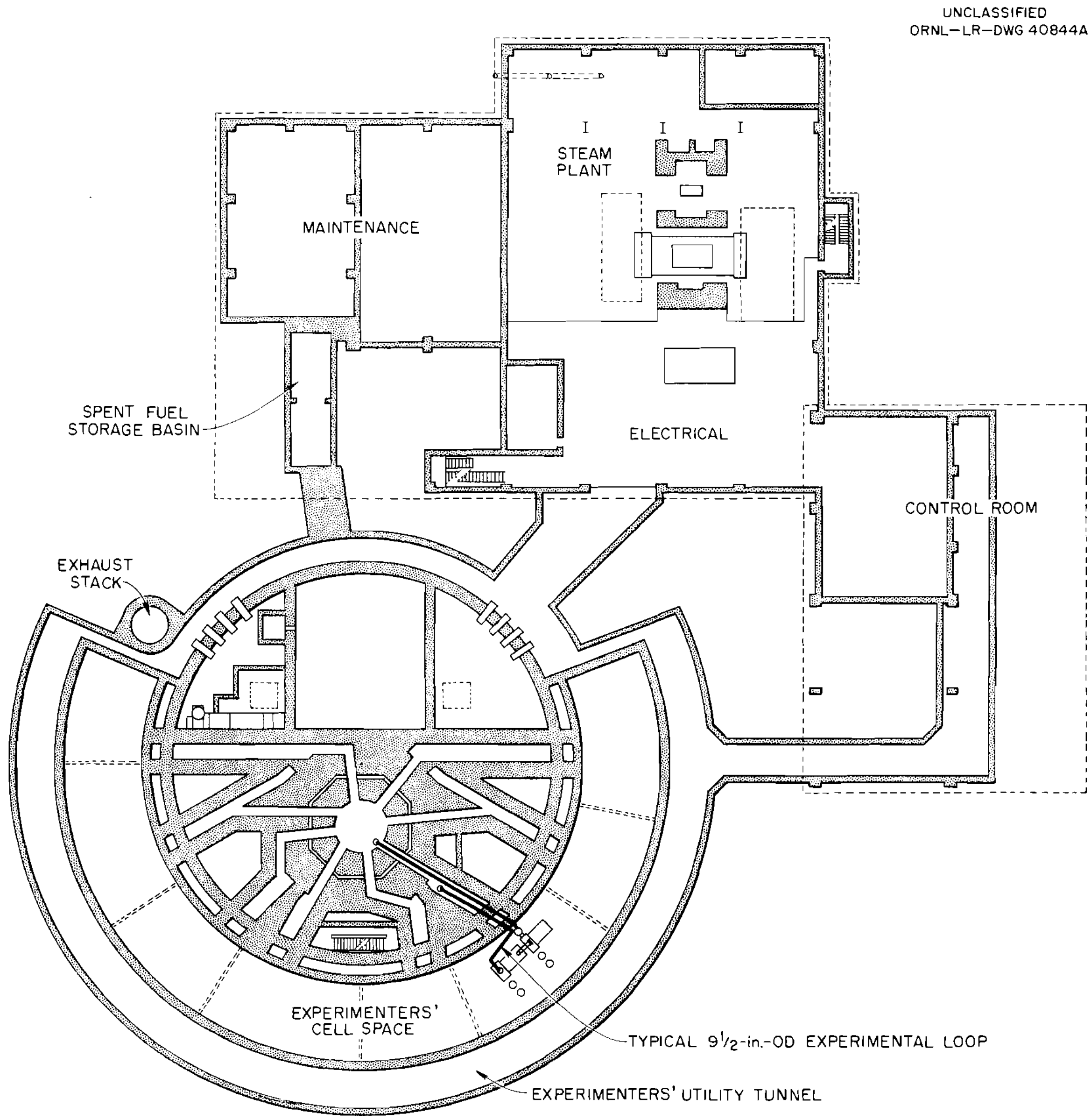

Fig. 1.3. EGCR — Floor Plan of Basement at Elevation 841 ft.

channels through the graphite columns are provided to accommodate the fuel elements, control rods, and experimental loops. The reactor core is housed inside a cylindrical pressure vessel with an inside diameter of 20 ft and an inside height of 46 ft. The reactor containment vessel is a 114-ft-diam cylinder, and the top and bottom are hemispherical. Its over-all height is 216 ft. Access to the containment vessel is through a personnel airlock and an equipment airlock.

The EGCR is designed for fuel charging and discharging while operating at full power. A charge machine, which is located beneath the reactor, will load and unload the reactor fuel elements. A service machine above the reactor will be used to handle the control rods and the loop experimental assemblies.

Eight cells are provided around the periphery of the reactor containment vessel to house loop equipment. Each cell is approximately 24 ft wide, 15 ft deep, and 36 ft long. The cells are located below ground level, with the tops of their roof plugs at ground level. Adjacent cells are separated by removable gastight metal bulkheads that are 18 in. thick and are filled with metal punchings for shielding. The cells have gastight carbon-steel liners. A rupture disk is provided between each cell and the reactor containment vessel to protect the cell against overpressure. Personnel access to each cell is provided by a portable airlock which can be positioned over a special hatchway built into each cell roof. Access to a cell for major maintenance work is provided by removing several roof plugs and cutting out a section of the cell liner. An opening 11 1/2 ft wide and 26 ft long can be obtained in this manner.

Loop piping between the experimenters' cells and the reactor through-tubes runs through pipe chases in the reactor biological shield. The inlet piping to a given through-tube runs horizontally through the lower biological shield. The return piping runs horizontally through the upper biological shield to a vertical pipe chase near the external face of the reactor biological shield. Space is provided in the vertical chase for a loop cooler. From the bottom of the vertical chase the piping runs horizontally to the experimenters' cell.

A utility tunnel is provided next to the experimenters' cells to accommodate various cell services. This tunnel is approximately 12 ft wide, 17 ft deep, and 388 ft long and is situated adjacent to the outer periphery of the experimenters' cells. The top of the utility tunnel roof is at ground level. Personnel access to the tunnel is through corridors from the turbine building and the control building.

A crane bay is provided in the space directly above the experimenters' cells and the utility tunnel. This space is enclosed by corrugated Transite siding and a builtup roof that abuts the reactor containment vessel. The bay is serviced by a 20-ton traveling-bridge crane for removing the cell roof plugs and components from the experimenters' cells.

The experimenters are provided with a control room which is located in the EGCR control building. Two experimental fuel assembly storage holes are provided for storage of irradiated assemblies. These storage holes are located in the reactor biological shield at the west end of the service machine room.

1.2. Hydrogen Containment

The proposed cell for housing the hydrogen-cooled loop would be made up of the first two standard cells adjacent to the EGCR stack. The bulkhead partition between the cells would be removed, and this new cell would be designated cell TL-4. The resulting cell would be 24 ft wide, 15 ft deep, and 72 ft long (approximately 25 000 ft^3). Penetrations are already provided between the cell and the reactor containment vessel for the main loop piping, demineralized-water lines, and the cell rupture disk. The wall between the experimenters' cell and the utility tunnel contains penetrations for the cell ventilation system, the gas supply system, electrical and water lines, etc. The cell is provided with a 4-in. floor drain penetration.

The cell walls are designed with a sufficient thickness of ordinary and heavy-density concrete to reduce the dose rate in all adjacent areas outside the cell to 2.5 mr/hr. Shielding of the adjacent cell is provided by a bulkhead partition.

The cell is equipped with a carbon steel liner to provide leaktight secondary containment. The liner is designed to withstand a maximum internal pressure of 12 psig. A rupture disk that relieves pressure to the reactor containment vessel at 10 to 12 psig is provided to protect the cell against overpressure. The cell liner leakage rate will not exceed 1 vol % in 24 hr at an internal pressure of 12 psig. The cell is cooled by two air-to-water heat exchangers that use service water from the utility tunnel.

External to the experimenters' cell the hydrogen-cooled loop would be doubly contained at all points by a secondary containment system. This system would consist of a secondary containment piping around all primary piping, a secondary containment vessel around the loop cooler, a sealed steam system at the top of the cooler, the outer tees on the top and bottom reactor pressure vessel nozzles, and the outer through-tube of the double-walled through-tube passing through the reactor containment vessel.

1.3. Flammability Limits of Hydrogen in Air[1]

Hydrogen has a wide range of flammability limits in air. The lower limit that yields an upward propagating flame is 4.1% H_2 in air at room temperature and atmospheric pressure. The lower limit at which downward propagation of the flame has been measured is 9.4% H_2 in air at room temperature and atmospheric pressure. The upper flammability limit has been measured as 74.4% H_2 in air at room temperature and atmospheric pressure. For design conditions in industrial operations, it is generally considered wisest to employ the flammability limits of H_2 in air associated with upward propagation of the flame, since these limits are wider than those for horizontal or downward propagation of flame.

The flammability of hydrogen does not present a serious problem so long as detonation does not occur. The hydrogen concentration can, however, reach a point where ignition of a given mixture will produce peak pressures of the order of 12 times the maximum calculated explosion pressure. This is called detonation. The difference between an explosion and a detonation is characterized by the manner in which the combustion

[1]H. F. Coward and G. W. Jones, "Limits of Inflammability of Gases and Vapors", U. S. Bureau of Mines Bulletin 279, 1928, Revised 1930 and 1938.

reaction is propagated through the mixture. An explosion is controlled by the chemical reaction rate and produces a low-pressure subsonic flame front whose movement is governed by heat and mass transfer. A detonation is a shock-propagated phenomenon that produces a stable wave characterized by high pressure, high stability, and a supersonic rate of propagation. The lower and upper detonation limits of hydrogen-air mixtures at room temperature and atmospheric pressure have been measured as 18.3 and 58.9% H_2, respectively. Since these limits are considerably within the limits of flammability, detonation is not a problem if the system is designed to conform to the flammability limits.

There are a number of variables, such as pressure, temperature, humidity, and turbulence that affect the flammability limits. Of these variables, temperature appears to have the greatest effect. If the unburned gas mixture is at a high temperature, less heat has to be supplied from an adjacent layer to ignite it. Thus, the lower flammability limit is decreased by increasing the initial temperature and the upper flammability limit is increased, resulting in a wider range of flammability. Tests made with hydrogen-air mixtures at atmospheric pressure indicate that the lower limit of flammability for downward flame propagation varies linearly with temperature from 9.4% H_2 at 63°F to 6.3% H_2 at 752°F. The upper limit of flammability for the same conditions varies linearly with temperature, increasing from 71.5% H_2 at 63°F to 81.5% H_2 at 752°F.

Initial system pressure has less effect than temperature on the flammability limits of hydrogen-air mixtures unless a high vacuum is maintained. In general, it appears that the limits are at first narrowed by an increase of pressure until approximately 15 to 20 atm is attained; after that the limits are steadily widened at higher pressures. A reduction in the pressure to below 1 atm always narrows the flammability limits. At a suitably low pressure, the upper and lower limits coincide; a further reduction in pressure means that no mixture can propagate flame.

Humidity and turbulence appear to have very small effects on flammability limits. An increase in humidity appears to decrease the lower limit for hydrogen-air mixtures somewhat, and it also decreases the upper limit because of the displacement of oxygen with water vapor. Meager experimental results indicate that turbulence somewhat reduces the lower flammability limits of methane and ethane in air.

1.4. Safe Containment of Hydrogen Gas

There are several ways of preventing the accumulation of an explosive mixture around a hydrogen system. These include the use of adequate ventilation, operation of the system surroundings at a very low pressure, or blanketing the system with a nonreactive atmosphere. Adequate ventilation essentially dilutes any hydrogen leakage which does not burn upon release to below its lower flammability limit. This method is the one usually adopted in industry. However, this method is not acceptable for protecting a potentially radioactive system because an adequate ventilation rate is usually incompatible with the safe confinement of radioactivity. If confinement of a large release is attempted by shutting off all ventilation, the formation of a flammable hydrogen-air mixture is inevitable, thus greatly increasing the hazard. There is also the hazard of a small leak in a high-temperature system burning upon contact with the ventilating air and leading to enlargement of the original leak or damage to adjacent equipment or instruments. The hazards incurred in this case could be significant.

Maintaining the system surroundings at a low pressure is an effective means of explosion control because it eliminates oxygen; however, the problem of building a large containment vessel to operate at any appreciable negative pressure is quite formidable. There is also a problem of heat removal from heat-generating components that must be located within the evacuated region. In many cases the use of standard equipment designs would be ruled out.

Blanketing a potentially radioactive hydrogen system with a nonreactive atmosphere appears to be the most practical way of preventing the accumulation of an explosive mixture. The introduction of a large percentage of nonreactive gas essentially displaces the oxygen surrounding the system and thereby inhibits the hydrogen-oxygen reaction. In addition, the heat capacity and thermal conductivity of the nonreactive gas play important roles in inhibiting the reaction. The addition of a nonreactive gas has the greatest effect on the upper limit of flammability; however, as the nonreactive gas is added to the original air, the flammability limits approach and ultimately coincide, after which the addition of more nonreactive gas assures that no mixture of the air-gas atmosphere plus hydrogen can propagate a flame. Since the effective utilization of a nonreactive gas for explosion control requires a containment system that is sealed off from the surrounding environment, it becomes economically attractive to make the containment system sufficiently strong and tight to serve also as a secondary container for any potential radioactivity release.

The following nonreactive gases were considered for use in a containment atmosphere: helium, nitrogen, and carbon dioxide. A considerable amount of experimental work has been done on determining the flammability of hydrogen in CO_2-air mixtures and nitrogen-air mixtures, as well as the flammability of CO_2-H_2 and N_2-H_2 mixtures in air.[1,2,3,4] Some experimental results are presented in Figs. 1.4 and 1.5. Figure 1.4 shows the variation of hydrogen flammability as a function of the original atmosphere composition. As may be seen, there is a range of original gas compositions over which no flammable mixture can be formed regardless of the amount of hydrogen added to the original gas. Figure 1.5 shows the flammability of hydrogen plus nonreactive gas mixtures in air. In this case there is a range of nonreactive gas-to-hydrogen gas ratios over which no flammable mixture can be formed regardless of the amount of air subsequently added to the mixture. One set of experimental data was found for helium-hydrogen mixtures and is shown in Figs. 1.4 and 1.5 by dashed lines.

Of the three gases investigated, carbon dioxide appears to be the best for a nonreactive containment atmosphere. It requires the smallest percentage of diluent gas added to air to form a containment gas mixture which

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[2]T. H. Pigford, Explosion and Detonation Properties of Mixtures of Hydrogen, Oxygen and Water Vapor, ORNL-1322 (Aug. 14, 1952).

[3]M. C. Zabetakis, Research on the Combustion and Explosion Hazards of Hydrogen-Water Vapor-Air Mixtures, Bureau of Mines, AECU-3327 (Sept. 4, 1956).

[4]B. Lewis and G. Von Elbe, Combustion, Flames and Explosions, Academic Press, Inc., New York, 1951.

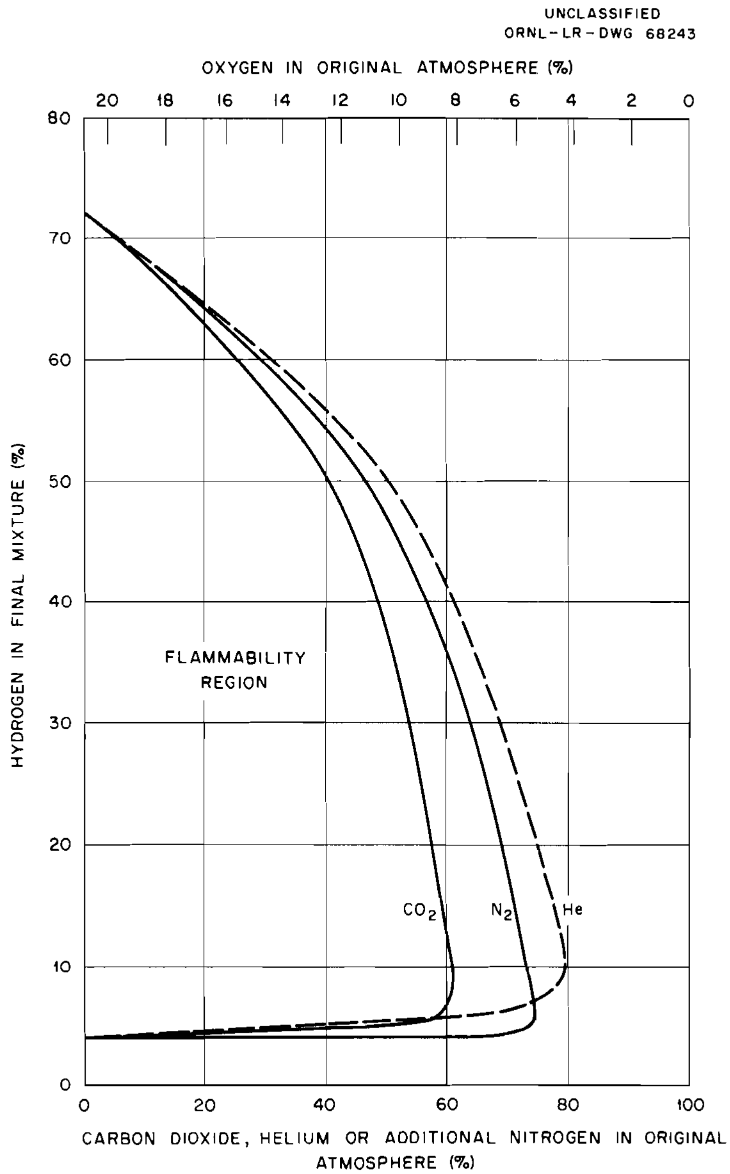

Fig. 1.4. Flammability of Hydrogen Mixed with Various Original Compositions at Atmospheric Pressure.

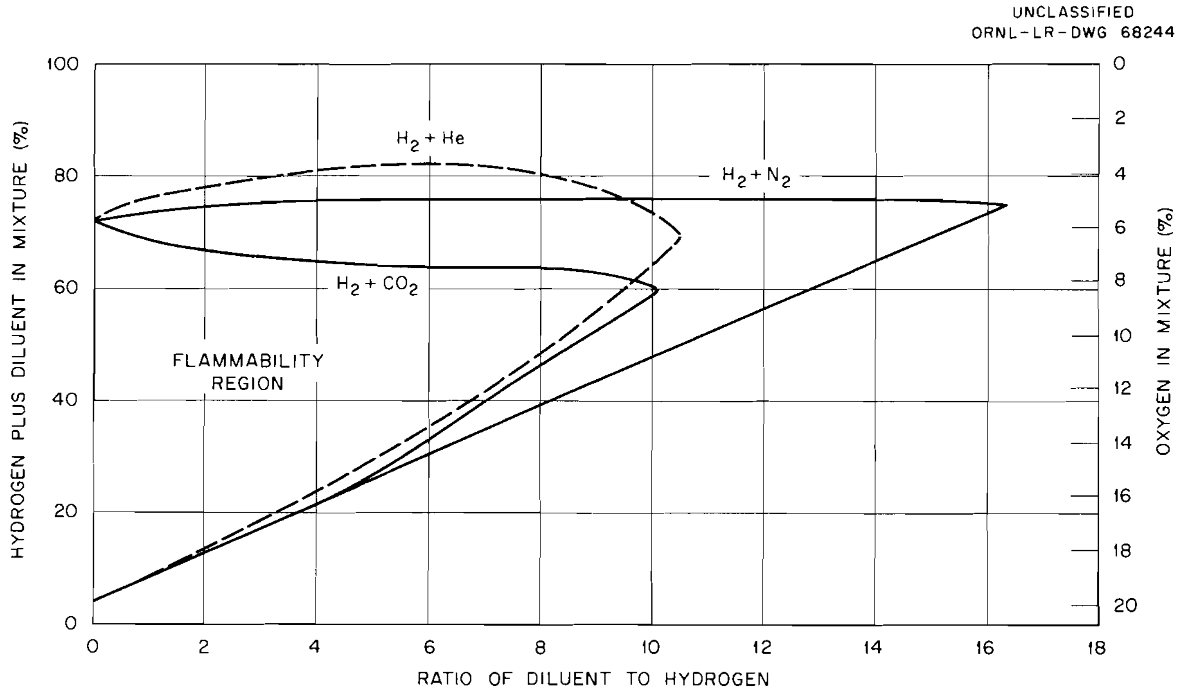

Fig. 1.5. Flammability of Hydrogen Plus Nitrogen, Carbon Dioxide, or Helium Diluent When Mixed with Air.

will inhibit the propagation of flame regardless of the amount of hydrogen added. An air-CO_2 mixture containing over 61% CO_2 cannot be made flammable by any addition of hydrogen. Further, for mixtures of diluent gas plus hydrogen in air, CO_2 has the lowest ratio of diluent gas to hydrogen which can become flammable regardless of the amount of air added to the mixture. If a hydrogen-CO_2 mixture contains over 10.1 times as many carbon dioxide molecules as hydrogen molecules, it will not become flammable regardless of the quantity of air which might be added. This is an important factor in evaluating the potential hazard of a hydrogen-gas release to the containment atmosphere followed by a release to the outside environment. Carbon dioxide is also preferred over the other gases because it is cheaper and easier to handle and store; and, because of its high density, it may be possible to preferentially float air out of the containment region during filling and thereby use less gas to obtain the desired diluent concentration.

1.5. Properties of Hydrogen as a Reactor Coolant

The use of hydrogen as a reactor coolant offers a number of advantages over the gas coolants presently in common use, such as helium and carbon dioxide. These advantages were pointed out previously.[5] Tables 1.1 and 1.2 and Fig. 1.6 present information abstracted from ref. 5. The physical properties of various reactor coolants are given in Table 1.1. The relative heat transfer coefficients were calculated on the basis of the following assumed parameters: constant flow area, equivalent diameter, heat generation, and temperature distribution. The relative pumping power values were calculated on the basis of the heat transport capability of the gas through a given fixed system resistance without reference to the effect of gas composition on the heat transfer coefficients or temperature distribution. The pumping power calculations are illustrated graphically in Fig. 1.6.

In a practical design situation the fuel element surface temperature is fixed by a materials limitation. Therefore, the required heat transfer

[5] The ORNL Gas-Cooled Reactor, ORNL-2500 (April 1958).

Table 1.1. Properties of Gases Suitable for Reactor Cooling

	Hydrogen	Helium	Carbon Dioxide	Nitrogen	Air
Molecular weight	2	4	44	28	29
Thermal conductivity, Btu/hr·ft^2·°F/ft					
At 200°F	0.125	0.097	0.013	0.018	0.018
At 700°F	0.199	0.135	0.028	0.028	0.028
At 1330°F		0.172	0.042	0.037	0.039
Viscosity, centipoises					
At 200°F	0.010	0.023	0.017	0.020	0.021
At 700°F	0.015	0.033	0.028	0.031	0.032
At 1330°F	0.020	0.044	0.041	0.041	0.042
Specific heat, Btu/lb·°F					
At 200°F	3.47	1.24	0.217	0.249	0.241
At 700°F	3.51	1.24	0.262	0.259	0.254
At 1330°F	3.60	1.24	0.295	0.279	0.272
Density at STP, lb/ft^3	0.0052	0.0104	0.114	0.0727	0.0748
Volumetric specific heat at STP, Btu/ft^3·°F	0.0178	0.0129	0.0238	0.0180	0.0179
Relative heat transfer coefficient[a]	1.00	0.84	0.66	0.61	0.61
Relative pumping power[a]	1.0	5.8	5.1	12.8	12.8

[a]For same gas temperature and same power output.

Table 1.2. Pumping Power for Various Gases Relative to that for Hydrogen with the Fuel-Channel Size Adjusted to Give a Constant Heat Transfer Coefficient

Coolant temperature: 450°F inlet, 1000°F outlet
Maximum fuel element temperature: 1200°F
Thermal power level: 700 Mw

Gas	Heat Capacity	Weight Flow	Volume Flow	Head Loss	Pumping Power
Hydrogen	1.0	1.0	1.0	1.0	1.0
Helium	0.357	2.80	1.40	2.07	5.80
Carbon dioxide	0.078	12.9	0.585	0.800	10.4

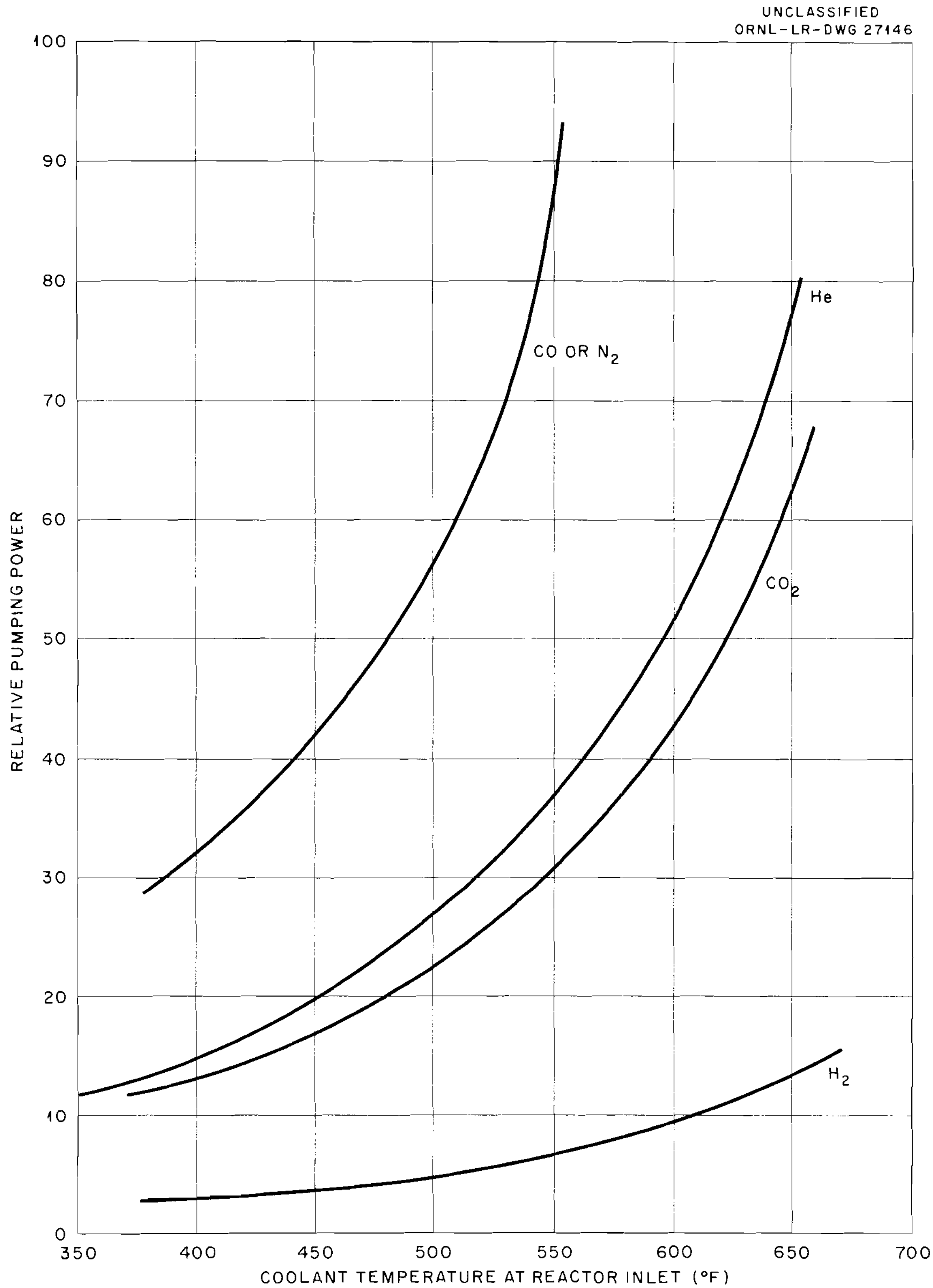

Fig. 1.6. Relative Coolant Pumping Power as a Function of Inlet Temperature.

coefficient for a given power density and gas temperature distribution is automatically fixed. The required heat transfer coefficient is obtained by selecting the proper fuel element free flow area for the rate of coolant gas flow set by the heat transport requirement. Table 1.2 gives a comparison of the relative pumping power for various gases for this more practical case of adjusting the fuel-channel size to give a constant heat transfer coefficient.

In view of the obvious advantages of hydrogen as a reactor coolant, the question arises as to why hydrogen was not selected previously. The primary deterrent appears to be the explosion hazard. Other problems exist, such as the reaction of hydrogen with structural materials (embrittlement), but these problems appear to be much less important than the explosion hazard, and there is much chemical plant experience to draw upon for solutions.

In the chemical industry, hydrogen is handled routinely over a wide range of temperatures and pressures by using adequate ventilation to control the explosion hazard. As pointed out in Section 1.4, however, a potentially radioactive system cannot depend upon this form of explosion control. The use of a nonreactive atmosphere around all hydrogen-containing systems has been shown to be a superior solution to this problem. As long as reactor systems must be placed inside containment vessels for radiological control, the use of a nonreactive atmosphere for explosion control should add little to the cost of the reactor complex. In addition, it will prevent graphite fires, electrical fires, etc., and the water-gas reaction explosions that are serious hazards in the present gas-cooled reactors. The use of a nonreactive atmosphere inside the reactor containment vessel will require that personnel entering the containment vessel carry an oxygen supply with them. This is not an unknown procedure in industry.

The data presented in Section 1.4 are considered adequate evidence to conclude that the explosion hazard in a radiologically contained gas-cooled reactor can be easily and economically controlled. The hydrogen-cooled loop described in the following chapters is designed to test the validity of this conclusion and to provide an important tool for determining answers to key materials and fuel element problems.

2. PRIMARY LOOP COMPONENTS

2.1. Reactor Through-Tube Assembly

In order to fully contain the hydrogen gas during all credible loop accidents, it was considered essential that the loop gas be isolated from the reactor gas by an intermediate containment region. To accomplish this, it was necessary to devise a double-walled through-tube arrangement.

The design of this double-walled reactor through-tube assembly is shown in Figs. 2.1 and 2.2. This design is based on a welded-joint concept. An expansion leg formed by the inlet loop piping was selected as the best method of providing for the relative expansion of the inner through-tube and the reactor pressure vessel. A bellows was required to take up the relative expansion of the outer through-tube and the reactor pressure vessel. The outer through-tube is 9 1/2 in. in outside diameter, and the inner through-tube is a maximum of 8 1/4 in. in outside diameter.

The double-walled through-tube assembly consists of three subassemblies: (1) the two through-tubes, (2) the top nozzle inner and outer tees, and (3) the bottom nozzle inner and outer tees. The top and bottom nozzle outer tees are welded to the reactor pressure vessel. The branches of the inner and outer tees of the top and bottom nozzles are welded to the primary and secondary containment piping, respectively. This connects the primary loop piping to the inner through-tube and the secondary containment piping to the reactor pressure vessel and outer through-tube. The reactor gas is isolated from the secondary containment region by the outer through-tube. A separate line connects to the annulus between the inner and outer through-tubes.

Each through-tube is designed as a replaceable item. Final attachment of the through-tubes to the reactor pressure vessel is performed by remotely welding the tubes to the top and bottom nozzle tees. To replace either tube, the tube-to-tee welds are removed by a remotely operated weld-removal machine.

Installation of the hydrogen-cooled loop will not be completed when the EGCR is scheduled to start operating. However, the top and bottom

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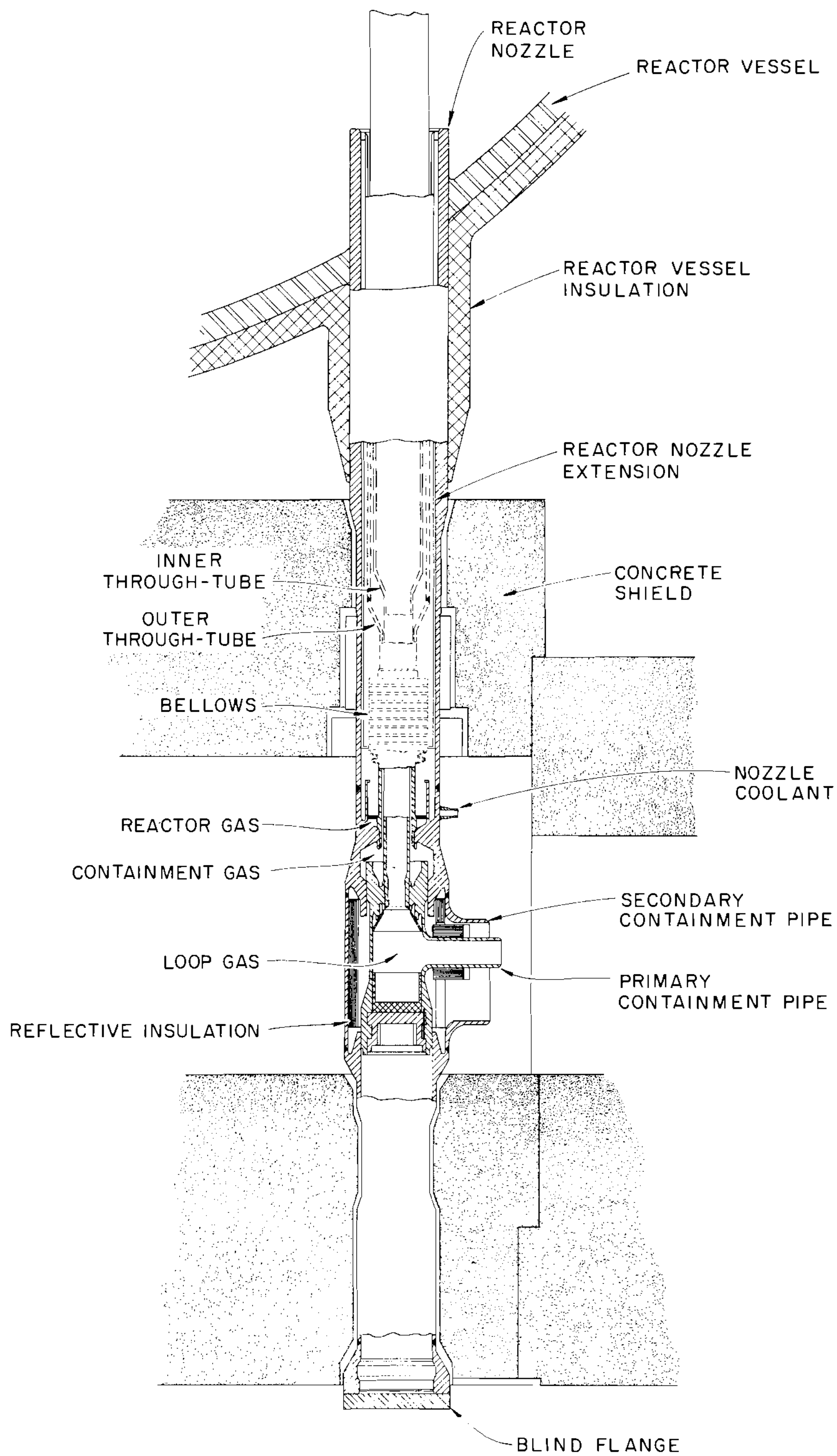

Fig. 2.1. Bottom Nozzle Tee Section for 9 1/2-in.-o.d. Double-Walled Through-Tube.

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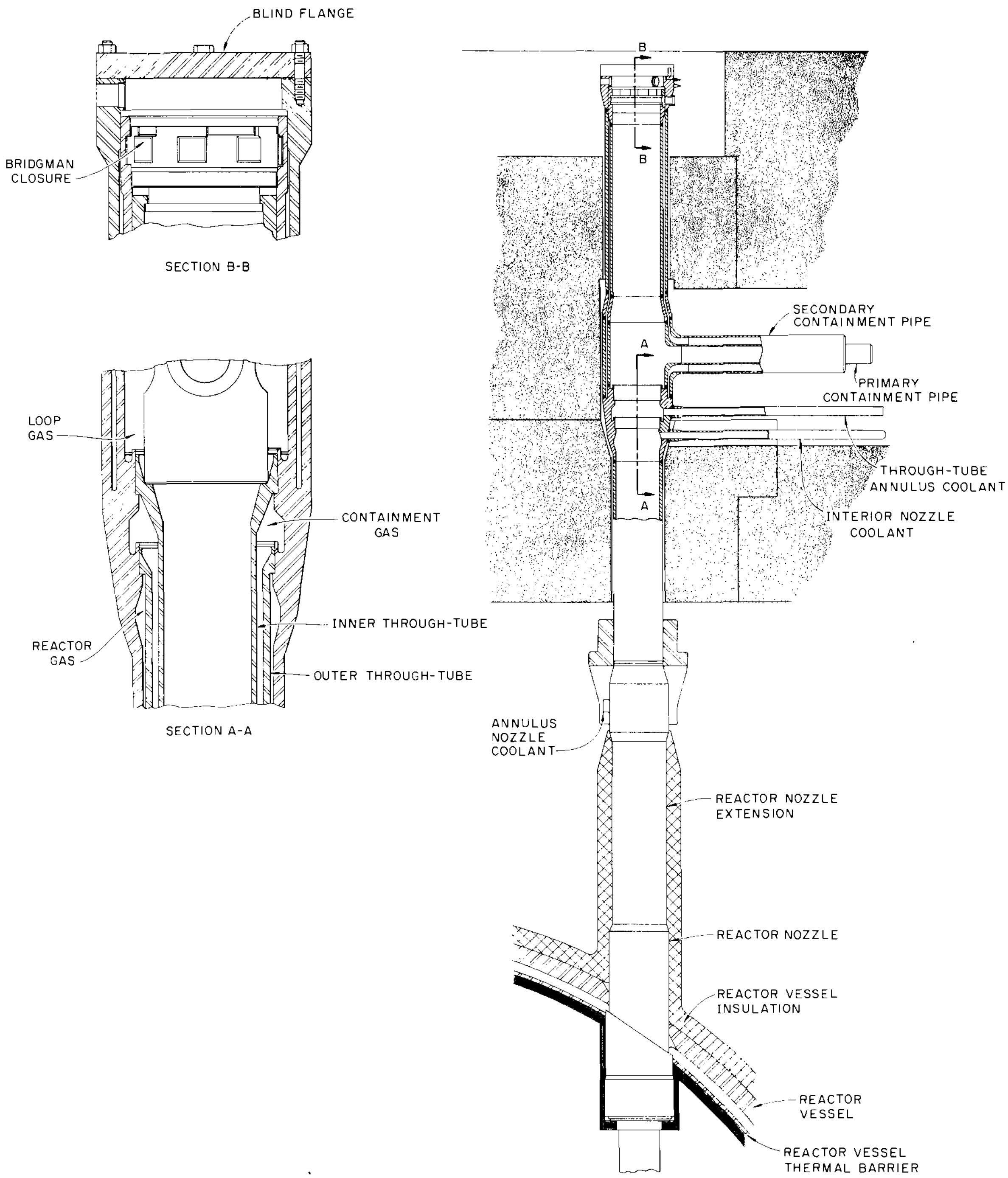

Fig. 2.2. Top Nozzle Tee Section for 9 1/2-in.-o.d. Double-Walled Through-Tube.

nozzle tees will be fabricated and field welded to the reactor pressure vessel and a long section of the primary and secondary containment piping will be attached to the tees. The through-tubes will not be installed.

The bottom nozzle tee assembly for the hydrogen-cooled loop is shown in Fig. 2.1. The primary containment piping is designed for 1100 psia at 975°F. The secondary containment piping is designed for 750 psia at 650°F. Access to the inner tee welded breach plug is obtained by removing the bottom nozzle blind flange, ball-lock closure, and shield plug from the outer tee using the charge machine. The ball-lock closure has an elastomer O-ring that seals the secondary containment gas. This seal is backed up by a double O-ring seal in the blind flange. The entire bottom nozzle tee assembly is welded to the reactor pressure vessel nozzle extension just above the point where the nozzle coolant enters the extension. This weld will be made in the field after the reactor pressure vessel has been erected. This weld must be co-ordinated with the field welding of the charge nozzles to the reactor pressure vessel. It is also necessary to make field welds where the inner and outer tees join the primary loop piping and secondary containment piping, respectively.

The inner and outer through-tubes are each seamless and approximately 64 ft long, with adapters welded to each end to facilitate welding to the top and bottom nozzle tees. The inner through-tube is insulated on the inside with reflective insulation. The outer through-tube is cooled by the nozzle cooling gas and the reactor gas. The inner through-tube is designed for 400-psia internal or 675-psia external pressure at 1075°F. The outer through-tube is designed for 675-psia internal or 350-psia external pressure at 1075°F.

The top nozzle tee assembly for the hydrogen-cooled loop is shown in Fig. 2.2. The primary containment piping is designed for 1100 psia at 975°F. The secondary containment piping is designed for 750 psia at 650°F. The Bridgman closure provides access to the inner through-tube for insertion or removal of experimental assemblies. It also provides a means for attaching and handling the top nozzle shield plug and the experimental stringer. All instrumentation inside the through-tube must pass through the Bridgman closure electrical connector and a secondary containment connector.

Access to the inner through-tube nozzle is obtained by removing the top nozzle blind flange by hand and then removing the Bridgman closure using the service machine. The Bridgman closure uses an elastomer crush-type O-ring seal. This seal is backed by a double O-ring seal in the blind flange.

The top nozzle assembly is field welded to the reactor pressure-vessel nozzle. Each weld is co-ordinated with the field welding of the control rod nozzles and the surveillance nozzles, all of which extend to the service machine floor.

2.2. Experimental Stringer

In order to insert experimental assemblies into the inner through-tube, it is necessary to provide a physical means of support. The experimental stringer serves this purpose. The experimental stringer consists of a Bridgman closure, a shield plug, a support structure for the experimental assembly, insulation, and the instrumentation necessary to obtain useful data. Access to the inner through-tube for insertion or removal of the experimental stringer is through the Bridgman closure, which seals off the upper end of the top nozzle inner tee. The service machine height limits the total length of experimental stringer that can be handled. As a result, only 10.2 ft of the active core length of 14.5 ft in the EGCR can be reached by the experimental stringer. The lower 4.3 ft of active core may be filled with an uninstrumented experimental assembly, but it must be installed and removed from above as a separate unit.

Numerous thermocouples are required to obtain useful data. These thermocouples measure the test section inlet gas temperature, the fuel element surface or central temperature, the test section outlet gas temperature, the attemperated stream outlet gas temperature, and the mixed mean outlet gas temperature.

A measurement of loop gas flow through the experimental assembly is required. For unattemperated experiments, the in-cell loop gas flow is identical to the flow through the experimental assembly. For attemperated experimental assemblies, a venturi is placed downstream of the assembly before the gas streams are remixed. The pressure transmitters for flow determination through the venturi are located between the Bridgman closure and the shield plug. Pneumatic tubes run from the venturi along the experimental stringer to the transmitters.

The inner through-tube is lined with reflective insulation which extends from the top nozzle inner tee to the bottom nozzle inner tee. The insulation required from the top nozzle inner tee to the bottom of the experimental stringer is an integral part of the stringer assembly and is installed and removed with the assembly. Any insulation below the bottom of the stringer is installed separately prior to installation of the stringer. All insulation is of the reflective type.

2.3. Dummy Stringer

The dummy stringer is an experimental stringer with the experimental assembly replaced by a dummy assembly. The dummy stringer will be used for test purposes prior to initial power operation of the loop or after major repairs. The principle use of the dummy stringer will be for testing various components at or near the normal loop operating pressures, temperatures, and flow rates. The dummy stringer will also make it possible to obtain data on total loop pressure drop, check insertion and removal procedures, and determine the effects of differential thermal expansion on instrumentation and tubing.

2.4. Mainstream Gas Cooler

The mainstream gas cooler utilizes an intermediate demineralized water-stream system to transfer the energy generated by the experimental assembly to a service-water heat sink (see Sec. 3.7). The mainstream gas enters the cooler at 1050°F and leaves at temperatures ranging from 550 to 950°F. The mainstream gas cooler is designed to remove all heat generated by the experimental assembly (up to 500 kw), as well as to provide secondary containment of the loop gas. It is designed to have a variable heat-removal rate controlled by the water level in the cooler. This condition is unique compared with conventional evaporative-cooler service requirements. Secondary containment is provided by the intermediate steam system (designed for 1200 psia at 650°F) and the containment vessel that surrounds the loop gas portion of the cooler (designed for 675 psia at 650°F).

The mainstream gas cooler is a re-entrant tube heat exchanger with loop gas flowing over thirteen 1.5-in.-o.d., 6-ft-long tubes containing boiling water. A conceptual design of the unit is shown in Fig. 2.3. Loop gas enters the side of the cooler, flows up around the outside of the shroud tube, enters the annulus between the shroud tube and the boiler tube, and then passes down the annulus, where it is cooled and exhausted to the bottom of the exchanger. Demineralized water condensate enters the cooler near the bottom of the steam chest. Once the condensate reaches a given level above the tube sheet, it enters the downcomer tubes that project through the tube sheet. As shown in Fig. 2.4, the condensate flows down the downcomer (inner) tube to the bottom of the boiler tube. A steam-water mixture forms in the riser (outer) tube and rises into the steam chest. The saturated steam leaves the cooler and is condensed in the loop condenser. The heat transfer rate from the loop gas to the steam system is regulated by controlling the rate of condensate flow to the steam chest, and thereby the water level in the cooler and the number of boiler tubes filled. The downcomer tubes are staggered at various elevations in the steam chest to establish a given heat transfer area for a given water level in the steam chest.

Because of the geometrical arrangement of the boiler tubes, it will be impossible to effectively blow down the steam system. Occasionally, it may be necessary to clean out some of the boiler tubes. This will be done by opening the blind flange at the cooler top, removing the top section of the boiler tube and downcomer tube (which is attached to the top section), and then removing the accumulated sludge in the bottom of the tube.

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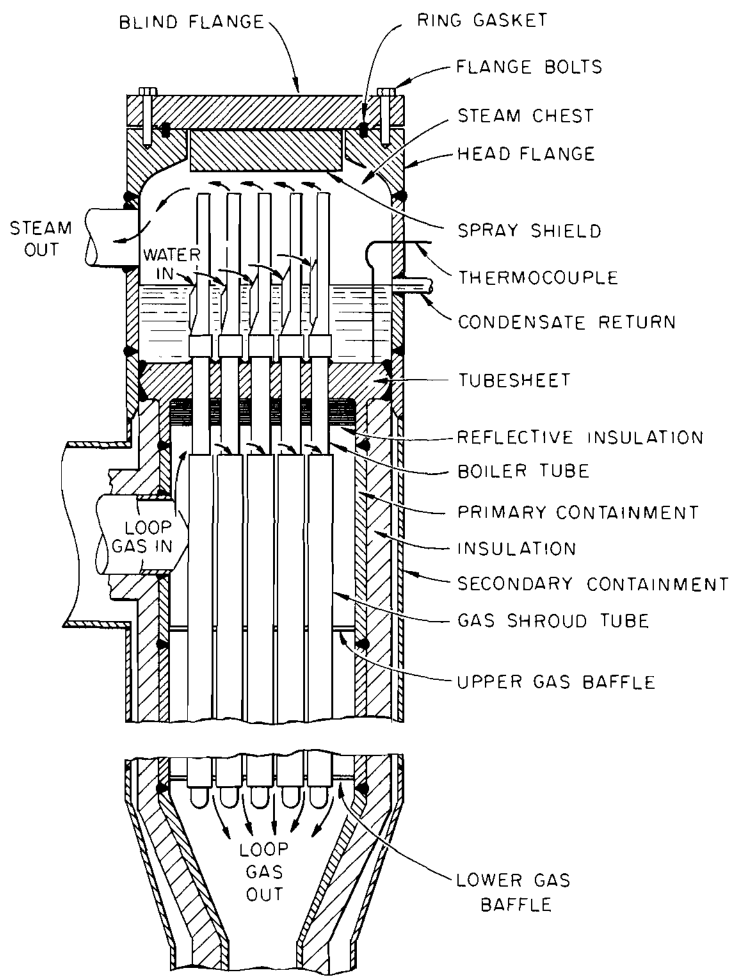

Fig. 2.3. Mainstream Gas Cooler.

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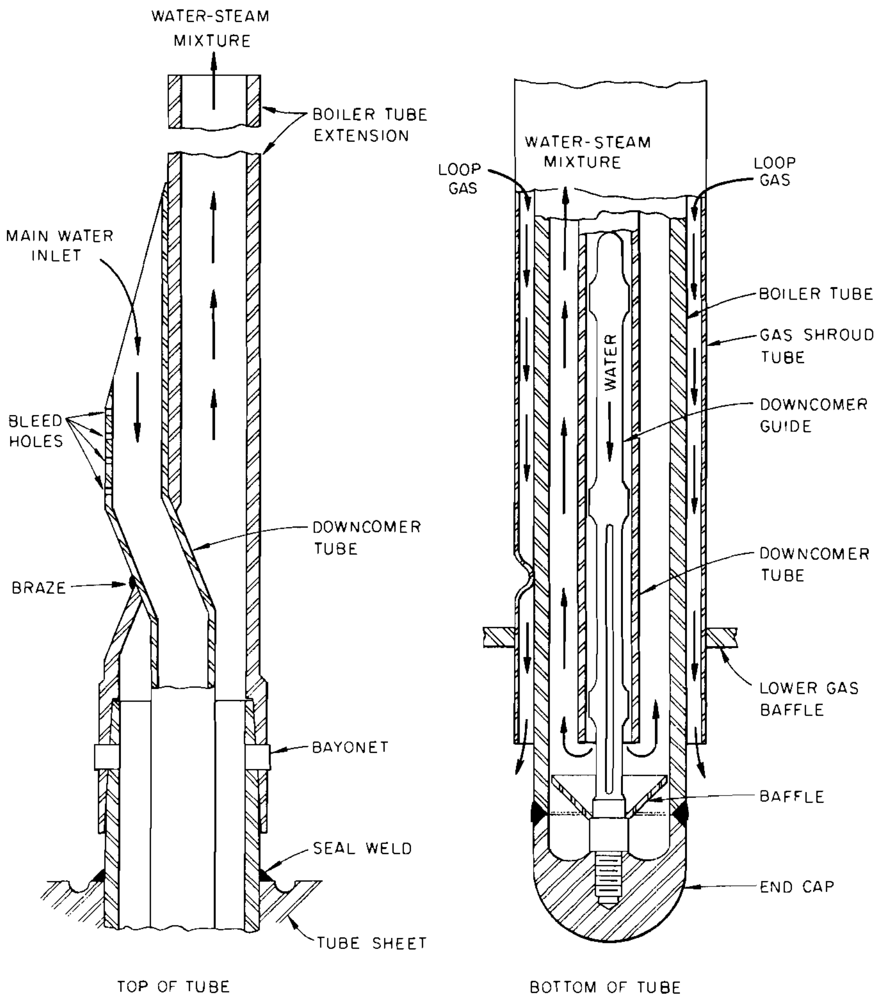

Fig. 2.4. Cooler Tube Details.

2.5. Mainstream Gas Filter

The entire mainstream gas flow passes through a filter system where most of the particulate matter in the circulating gas is removed. This system, shown in Fig. 2.5, consists of a filter vessel, bypass valve and piping, two isolating valves, two disconnect flanges, and associated lead shielding. The filter vessel contains a prefilter, an absolute filter, and a postfilter. The prefilter consists of several layers of stainless steel screen that will stop all particles larger than 140 μ. The absolute filter is made from Fiberfrax plus asbestos fibers and a small amount of binder and has an efficiency of 99.9% for 0.3-μ particles. The postfilter consists of several layers of stainless steel screen that will stop all 330-μ and larger particles. It is provided to stop any large particles if the absolute filter disintegrates. The filter vessel is completely surrounded by a lead shield. When the absolute filter requires replacement, the filter vessel and shield will be carried to a disposal area, where the shield will be removed and decontaminated for reuse. The filter and filter vessel will be disposed of as a unit by burial.

The mainstream gas filter is bypassed by a line containing a motor-operated valve that permits the loop to operate with the filter out of service and provides a relief in case the filter becomes clogged. The instrumentation for this system consists of two differential pressure transmitters (PdT). One transmitter is connected across the filter bypass valve to indicate gross clogging of the filter system. The other transmitter is across the absolute filter. As the pressure drop across the absolute filter approaches its blowout value, this transmitter opens the filter bypass valve an amount sufficient to maintain the pressure drop across the absolute filter at a safe value until it can be replaced.

2.6. Mainstream Gas Heater

The functions of the mainstream gas heater are (1) to preheat the loop to its required preoperating temperature before fission heat is produced in the experimental assembly, (2) to maintain the loop at a

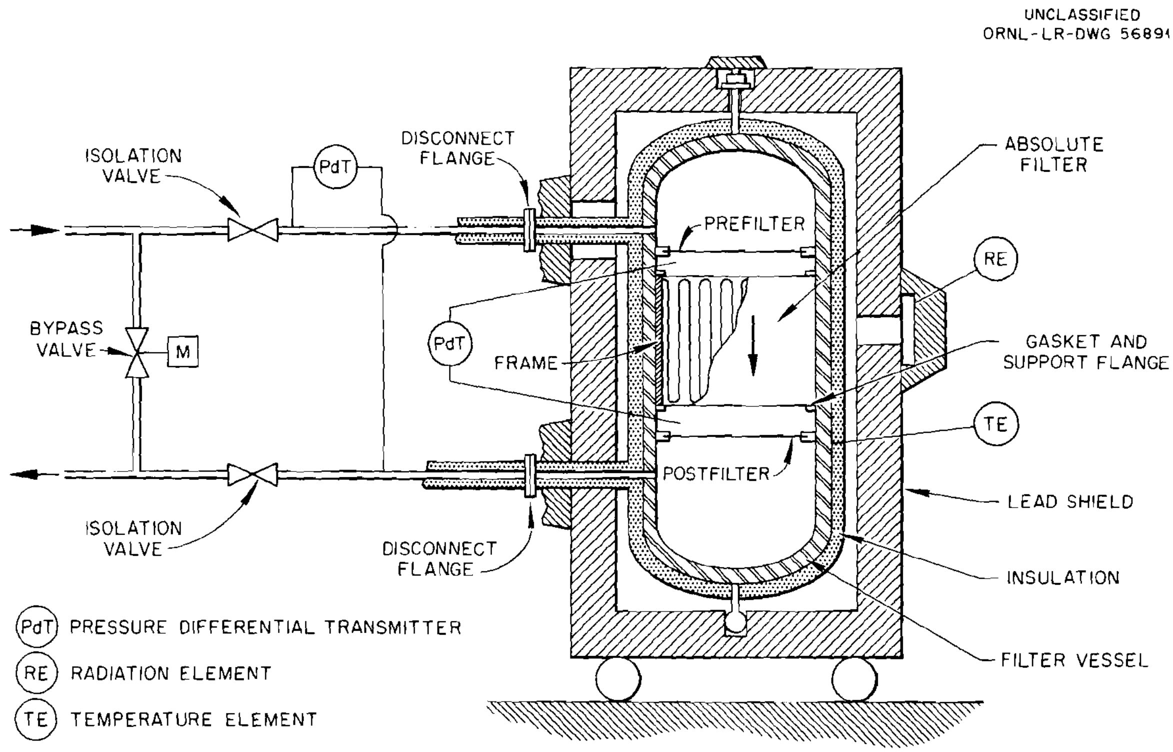

Fig. 2.5. Mainstream Filter.

preset temperature during any experiment for which there is no fission heat source, and (3) to maintain the loop at a desired operating temperature during test runs with the reactor shut down or the experimental assembly removed. The heater is capable of increasing the inlet gas temperature to the test section at least 50°F for all loop operating conditions. A maximum heater power of 65 kw is required.

The mainstream gas heater is an electrically heated U-tube consisting of two 9-ft sections of straight pipe joined at one end by a standard 180°-turn fitting. Heat is produced by passing an electrical current from a high-current transformer directly through the two straight pipe sections of the U-tube. No electrical current passes through the 180° turn or through the weld at each end of the straight pipe sections. The heated pipe is seamless type 347H stainless steel. The high-current transformer is air cooled and has a maximum current capability of 12 000 amp at 6 v.

The entire heater system is protected against overtemperature. Temperatures are sensed in the transformer windings, the bus bars, and at several points along the heated pipe. The primary voltage of the high-current transformer is supplied from a variable-voltage saturable reactor located in the experimenters' crane bay. The entire heater assembly and system, including the high-current transformer, is located inside the experimenters' cell.

2.7. Loop Pressure Drop

The mainstream gas flow path for the hydrogen-cooled loop includes the following components: in-pile test section, pipe and fittings, a mainstream gas cooler, a mainstream gas filter, a mainstream gas heater, and six isolation valves. Total pressure drops have been estimated for hydrogen cooling at 315 psia. For these calculations, the in-pile test section was assumed to be generating 500 kw of combined fission and gamma heat with a gas inlet temperature of 600°F and an outlet temperature of 1050°F. Estimates were also made for the case of reduced power operation (110 kw) with a gas inlet temperature of 950°F based on a constant mass flow rate. In all cases it was assumed that the exit gas from the in-pile section was attemperated to 1050°F.

In-Pile Test Section Pressure Drop

The design criteria for the helium- or CO_2-cooled loops proposed for the EGCR state that "The design pressure drop for the in-pile section of the loop will be determined from the following formula:

$$\frac{W_p}{p} = 0.02 \quad ,$$

where

W_p = pumping power required for in-pile section, kw,

p = total power output of in-pile section, kw."

A study of hydrogen cooling was therefore conducted to evaluate the suitability of the 2% criterion for the hydrogen pressure drop (see Appendix C). A comparison was developed of head loss and pumping power for the case of an experimental fuel element operating at a constant heat flux per unit area of heat transfer surface when cooled by hydrogen or helium. Since the heat rate for the test element was assumed to be fixed because of flux-peaking considerations, the hypothesis of constant heat flux was reduced to that of constant heat transfer surface per unit length.

The basic equation for pumping power through the test fuel element was developed from the requirement for mass flow and the head loss. The head loss was assumed to consist of a friction loss term and a contraction-expansion loss term. The final requirement on the system was heat transport equal to heat transfer. Ratios of the resulting equations were taken for the purpose of comparing gases. As a further simplification, the ratios were taken for the case of constant heat transfer per unit length, constant average fuel surface temperature, constant temperature difference across the test section, and a constant contraction-expansion loss coefficient that was large compared with friction losses. The resulting equations were used to compare the pumping power and head loss for hydrogen (a) compared with helium (h). In comparing the gases, it was assumed that space was available to adjust the free flow area to the required value. The equations used were

$$\frac{A_a}{A_h} = \left(\frac{Pr_h}{Pr_a}\right)^{0.4} \left(\frac{k_a}{k_h}\right)^{0.2} ,$$

$$\frac{h_a}{h_h} = \left(\frac{A_h}{A_a}\right)^2 \frac{(\rho C_p)_h^2}{(\rho C_p)_a^2} ,$$

$$\frac{W_a}{W_h} = \frac{h_a}{h_h} \frac{C_{p,h}}{C_{p,a}} ,$$

where

W = pumping power,

A = free flow area,

h = head loss,

Pr = Prandtl number,

k = thermal conductivity,

ρ = density,

C_p = specific heat.

The results of this helium-based comparison are presented in Table 2.1. All gas characteristics were evaluated at the average gas temperature. This study showed that the pumping power required for the adjusted test fuel element in a hydrogen loop was 14% of that required for the helium loop. Although this theoretical comparison would not apply to all fuel element test designs, it was considered to be a good indication of the trend in pumping power requirements. It appeared from the results of this study that a pumping power allowance of 2% for a hydrogen-cooled experiment was unnecessarily large. Therefore, a more realistic but still quite conservative value of 1% was selected.

Estimated Out-Of-Pile Loop Pressure Drop

Since the out-of-pile portion of the hydrogen-cooled loop is identical in many respects to that portion of a helium- or CO_2-cooled loop, the pressure drop reported previously[1] for a helium-cooled loop was used as a basis for a first approximation of the hydrogen-cooled loop pressure drop. In

[1] EGCR Experimental Loops Preliminary Design Report, ORNL-TM-134 (March 27, 1962).

Table 2.1. Pumping Power and Head Loss Relative to that for Helium for Test Fuel Element with Hydrogen Coolant

Gas	Pressure (psia)	Average Temperature (°F)	Flow Area	Mass Flow	Head Loss	Pump Power
Helium	315	825	1.00	1.00	1.00	1.00
Hydrogen	315	825	1.13	0.36	0.39	0.14
Helium	315	1000	1.00	1.00	1.00	1.00
Hydrogen	315	1000	1.15	0.36	0.38	0.14

order to use the values given for a helium-cooled loop, it was necessary to adjust them for hydrogen gas, mass flow, and loop pipe size. For this adjustment, it was assumed that the pressure drops of all out-of-pile portions of the loop could be represented by the following equation:

$$\Delta P = \frac{K}{\rho} f L_e \frac{W^2}{D_e^5} \quad , \tag{1}$$

where

ΔP = pressure drop, psi,

K = a constant (3.36×10^{-6}),

ρ = average gas density, lb/ft^3,

f = Darcy friction factor,

D_e = equivalent diameter, in.,

L_e = equivalent length, ft,

W = mass flow rate, lb/hr.

It was further assumed that the hydrogen-cooled loop has the same equivalent length and friction factor as the helium-cooled loop but different mass flow rates, gas densities, and equivalent diameters in various portions of the loop. The following comparison equation, based on a helium-cooled (h) reference loop and Eq. 1, was used

$$\Delta P = \Delta P_h \frac{\rho_h}{\rho} \left(\frac{W}{W_h}\right)^2 \left(\frac{D_{e,h}}{D_e}\right)^5 \quad . \tag{2}$$

The equivalent diameter ratio was not applied in those cases where the flow geometry was similar in the helium-cooled and hydrogen-cooled loop designs. The similar portions included the through-tube inlet and outlet regions, the mainstream gas filter, and about one-half of the piping from the reactor to the cooler and from the heater to the reactor. Since the gas-density ratio ρ_h/ρ remained relatively constant over a wide range of temperatures, it was evaluated at the inlet temperature. The data obtained in this study are presented in Table 2.2.

Table 2.2. Comparison of Parameters of Hydrogen- and Helium-Cooled Loops at Gas Inlet Temperatures of 600 and 950°F and a Gas Outlet Temperature of 1050°F

	Helium-Cooled Loop		Hydrogen-Cooled Loop	
	Inlet at 600°F	Inlet at 950°F	Inlet at 600°F	Inlet at 950°F
Gas pressure, psia	500	500	315	315
Gas density ratio, ρ_h/ρ	0.312	0.307	0.312	0.307
Mass flow rate, lb/hr	9190	9190	1090	1090
Equivalent diameter for sched.-80 pipe	5.761	5.761	3.826	3.826
Pressure drop where variable of pipe size, psi	6.45	8.31	2.17	2.76
Pressure drop where not a variable of pipe size, psi	3.55	4.29	0.16	0.18
Total pressure drop in out-of-pile portions of loop, psi	10.0	12.6	2.3	2.9

Estimated Total Loop Pressure Drop

The estimated total pressure drop for the hydrogen-cooled loop is given in Table 2.3.

Table 2.3. Hydrogen-Cooled Loop Estimated Pressure Drop

In-Pile Section Inlet Temperature (°F)	Loop Pressure Drop (psi)		
	In-Pile Section	Out-of-Pile Section	Total
600	4.8	2.3	7.1
950	0.8	2.9	3.7

2.8. Loop Compressors

Three centrifugal gas-bearing compressors[2] connected and operated in series provide the required gas flow through the loop. These compressors are designed to operate with either helium or hydrogen as the loop gas. A compressor of the type being considered is shown in Fig. 2.6. Each compressor contains an electric-motor rotor and an impeller mounted on a common shaft and supported on gas-film bearings, with the bearings lubricated by the gas used in the experimental loop. The compressor pressure vessel consists of the compressor volute and the motor housing. The motor housing is joined to the volute by a bolted and seal-welded flanged joint.

The electric motor and bearing compartment is cooled by conduction to a water-cooled jacket and by forced convection induced by a small centrifugal type of impeller attached to the compressor shaft. This fan circulates the gas in the motor compartment across the water-cooled surfaces. The electric motor leads are insulated and sealed at the motor housing by a ceramic type of insulator, with the final closure seal welded. One additional opening in the pressure vessel is provided for supplying high-pressure gas from an external source for jacking the bearings.

For normal operation, all three compressors are operated to supply the required head and mass flow. In the event one of the three compressors failed, the remaining two would be operated at increased speed

[2]The analysis presented here is based on the use of gas-bearing compressors for the hydrogen-cooled loop. Selection of the optimum type of compressor will require further study.

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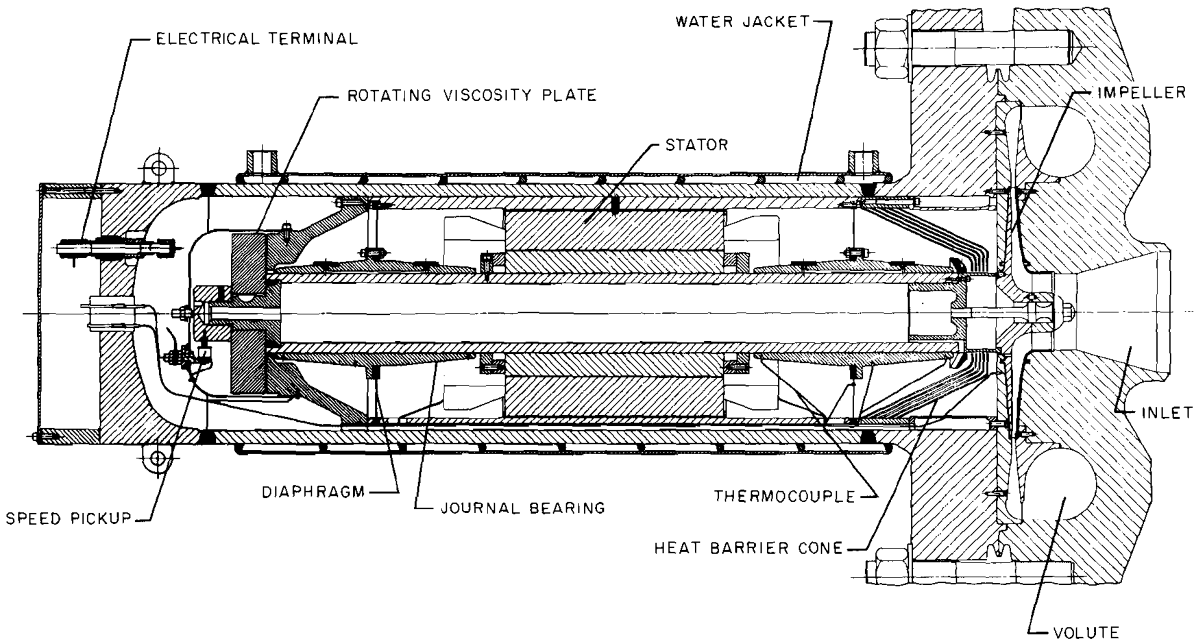

Fig. 2.6. Gas Bearing Compressor Designed by Bristol Siddeley Engines, Ltd., for EGCR In-Pile Loops.

(by increasing the frequency of the variable-speed motor-generator power supply) to provide the original mass flow. A check valve connected in parallel with each compressor is provided to materially reduce the added system resistance of the inoperative compressor. In the event a second compressor failed, the remaining compressor would supply, without surging or stalling, at least 15% of the original loop gas flow for 48 hr.

It is believed that the presence of a thin film of oxide on the bearing surfaces serves as a lubricant to permit starting and stopping the compressor without galling the surfaces. It is possible that in an atmosphere of helium or hydrogen containing less than 10 ppm of contaminants, the oxide layer may be worn away during the initial starting and stopping and that difficulties with galling may be encountered on subsequent starts and stops because the oxide may not reform. As a solution, it is proposed that the rotating element be lifted off the bearings during starting and stopping by supplying loop gas to the bearings from an external source under high pressure. This is known as jacking. Another solution may be to rub molybdenum disulfide into the bearing surfaces to provide a lubricating film; this technique has not received extensive proof testing.

In order to prevent damage to the thrust bearing and possible seizure of the rotating assembly, the rate of change of loop gas pressure should not exceed 4 psi/sec during a loop pressure increase or 7 psi/sec during a pressure decrease. This limitation necessitates the addition of an auxiliary blower in parallel with the loop compressors for use in the event the compressors stop during rapid loop depressurization.

2.9. Auxiliary Blower

The auxiliary blower will substantially contribute to the removal of stored thermal energy and decay heat following rapid depressurization or any other incident which makes all three loop compressors inoperative. The auxiliary blower size was based on consideration of low loop pressure operation. The blower wheel was sized to provide 2% of the normal loop gas mass flow at the lowest anticipated gas pressure (1.9 psig).

Grease-lubricated ball bearings were selected for the auxiliary blower because they appeared to give the greatest assurance of immunity to rapid depressurization, coupled with proven reliability for the short operating periods required. The motor, bearing, and blower housing are water cooled to reduce blower and bearing temperatures. The entire blower assembly is housed in a vessel that is filled with loop gas and pressurized to loop pressure.

The auxiliary blower is installed in a line that is in parallel with the loop compressors. A check valve on the auxiliary blower intake line prevents reverse flow (which would bypass the loop experimental assembly) and yet permits the auxiliary blower to be at loop pressure, on line, and ready for instant use. Another check valve upstream of the mainstream gas filter prevents the auxiliary blower flow from bypassing the loop experimental section via the loop compressors when the latter have failed and the auxiliary blower is operating.

Power is supplied to the auxiliary blower motor from a separate motor-generator set. The coupling between the motor and the generator of this set is a torque limiter that prevents overload of the blower motor if the auxiliary blower starts at high loop pressure.

2.10. Valves

The hydrogen-cooled loop requires eight manually operated, 4-in. (nominal) mainstream isolation valves. One set of valves, called the cell isolation valves, isolates the in-cell portion of the mainstream loop piping from the portion inside the reactor containment vessel. Three other sets of similar valves isolate the loop compressors, auxiliary blower, and mainstream gas filter, respectively. All isolation valves normally operate open.

The cell isolation valves are used to isolate the experimenters' cell when pressurization of the through-tube is desired while the in-cell portion of the loop is depressurized or when decontamination of the in-cell or out-of-cell piping is being performed. The isolation valves on the loop compressors, auxiliary blower, and mainstream gas filter are required to prevent decontaminating solutions from entering these components during decontamination of the in-cell piping.

Other primary loop valves include pressure-relief valves installed on the mainstream loop piping to provide over-pressure protection and the filter bypass valve, which is provided to protect the loop against loss of coolant flow because of a clogged mainstream gas filter. This valve normally operates closed.

The loop requires five mainstream check valves. There is one 4-in. check valve for bypassing each loop compressor. The function of these valves is to bypass the mainstream gas flow around any inoperative compressor. There is a 4-in. check valve on the intake to the auxiliary blower to prevent reverse flow through the auxiliary blower. A 4-in. check valve upstream of the mainstream gas filter prevents reverse flow through the in-cell piping when the auxiliary blower is running.

2.11. Mechanical Joints

Four mechanical pipe joints containing double metallic seals with a buffer zone between the seals are provided in the primary loop piping system. These joints will facilitate the removal and replacement of the loop compressors and the mainstream gas filter. The buffer zone between the metallic seals is held at vacuum by the loop offgas system (see Sec. 3.3). This feature provides positive assurance against leakage of loop gas into the experimenters' cell in the event of seal leakage.

The Conoseal joint manufactured by the Marman Division of the Aeroquip Corporation was selected for this application. Details of the test program leading to the selection of these mechanical joints have been reported.[3] The Conoseal joint utilizes conical stainless steel gaskets installed as shown in Fig. 2.7. This type of sealing applied to a double-sealed gas-buffered joint is shown in Fig. 2.8.

Remote maintenance may be necessary at some time during the useful life of the loop. In view of this possibility, the problem of remote

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[3] J. C. Amos and R. E. MacPherson, Interim Report — Mechanical Joint Evaluation Programs, ORNL CF 60-9-77 (Sept. 26, 1960).

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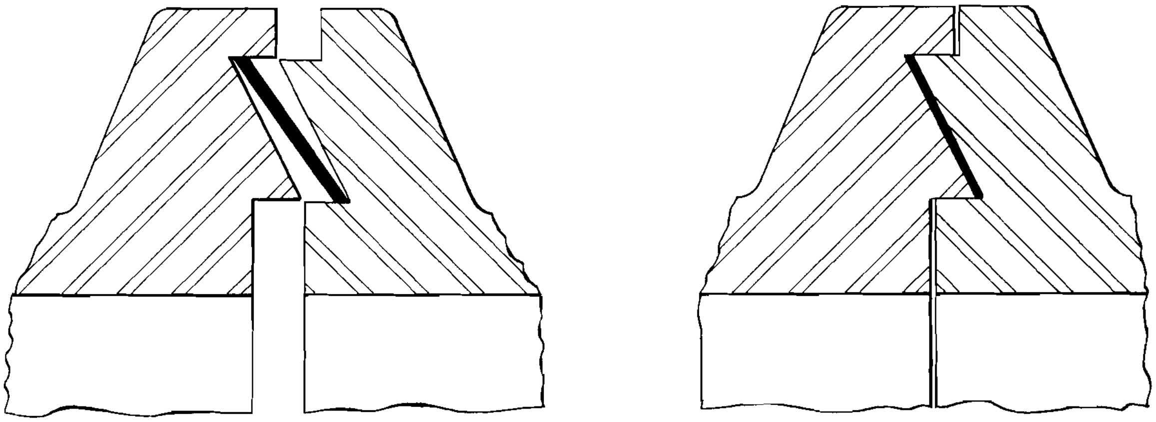

Fig. 2.7. Cross Section of Conoseal Gasket Installed.

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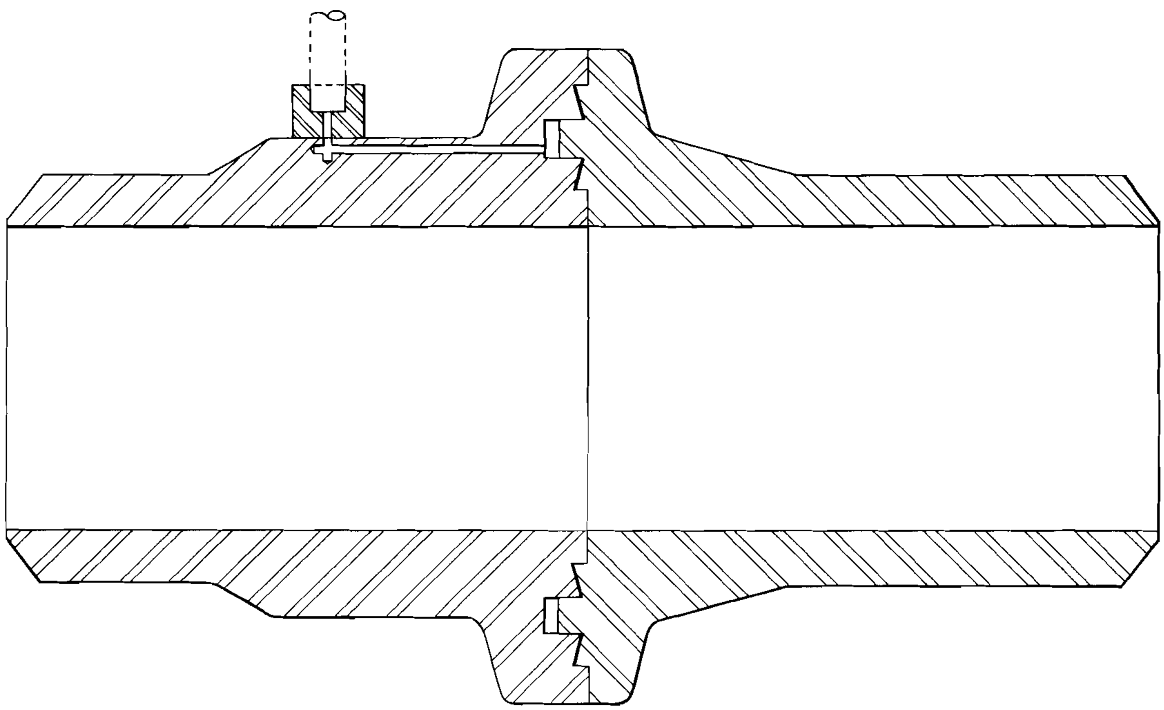

Fig. 2.8. Cross Section of Conoseal Double-Sealed Gas-Buffered Mechanical Joint.

assembly and disassembly of the Conoseal joint has been studied to the extent of designing and operating a remotely controlled bolt runner and manipulating tool.

3. AUXILIARY SYSTEMS AND EQUIPMENT

3.1. Bypass Gas-Cleanup System

The function of the bypass gas-cleanup system is to remove a fraction of those fission products which are released to the loop mainstream gas by the experimental assembly. The bypass gas-cleanup system consists of a gas cooler and a charcoal trap which removes more than 99.9% of the iodine in the bypass stream. The charcoal trap also removes a large fraction of other fission products present in the gas. One of the purposes of the system is to determine what fraction of the mixed fission products in the loop can be removed by the charcoal bed. The system will not remove the noble gas fission products.

The charcoal trap consists of an activated charcoal bed and an absolute filter. The activated charcoal removes the halogens and various other fission products at the lower temperatures obtained by the gas cooler. The absolute filter removes any particulate matter released by the charcoal bed. The nominal flow rate of the bypass gas-cleanup system is 1% of the mainstream gas flow rate.

3.2. Gas Transfer and Storage System

The primary function of the gas transfer and storage system is to remove the mainstream gas from the loop and store it for future use. During normal loop operation the system also provides makeup gas and serves as a containment volume for the loop relief-valve discharge. The essential elements of this system are a transfer pump, gas storage tanks, and associated piping and valves. The gas transfer pump is a positive-displacement pump with two metallic-diaphragm heads. Each pump head is provided with triple diaphragms. A mechanical joint is installed on the inlet and discharge of each pump head to facilitate installation and removal.

The experimenters' cell contains two gas storage tanks connected at top and bottom by a common header. A parasol-type spray nozzle is located inside the top head of each tank for spraying with decontamination solutions.

The top header contains a rupture disk and a pressure-relief valve. The pressure-relief valve is of the balanced-bellows type that permits large variations in the back pressure with little or no change in the relieving pressure and capacity. The bottom header contains a drain valve to permit draining the tanks during decontamination.

In order to remove an experimental assembly from the loop, the hydrogen in the loop must be replaced by helium and cooled to 150°F before it can be permitted to enter the service machine. The hydrogen is replaced by a slow release to the gas storage tanks followed by repressurization with helium in order to lower the hydrogen content in the helium to below the flammability threshold of the mixture in air (see Sec. 1.4). The hydrogen in the gas storage tanks is released to the EGCR stack through the loop offgas system which converts the hydrogen to water vapor.

When loop gas is stored in the gas storage tanks it may be desirable to decontaminate it prior to loop repressurization or prior to discharge to the loop offgas system. The gas transfer and storage system design permits the transfer pump to circulate gas from the gas storage tanks, through the loop bypass gas-cleanup system, and back to the gas storage tanks. Circulation may be continued until a radiation monitor on the top header of the gas storage tanks indicates that the desired radiation level has been reached or that no further decontamination is occurring.

The loop is filled by using gas from the gas storage tanks. The loop and gas storage tank pressures are allowed to equalize and then the gas transfer pump is used to pump the required additional gas from the storage tanks to the loop.

3.3 Loop Offgas System

The function of the loop offgas system is to safely transfer to the ventilation system exhaust header all hazardous gases within the experimenters' cell and loop. They system must remove or dilute radioactive fission products to acceptable levels before release and must provide safe handling procedures for hydrogen gas to circumvent any possibility of a hydrogen explosion or combustion. The system is used during loop blowdown, decontamination, loop evacuation, buffer seal evacuation, sample station operation, cell decontamination, and experimental assembly removal. Since the loop offgas system is one of the key systems in the design of a safe hydrogen-cooled loop, it has received extensive design consideration; it is described in detail in Appendix E to facilitate critical review.

The loop offgas system consists of a charcoal trap, filters, heater, copper oxide bed, condenser, liquid trap, vacuum pump, and shutoff valves. The charcoal bed and filters are used to adsorb radioactive iodine and to filter any radioactive particulate matter that is discharged through the system. A filter, which precedes the charcoal bed, is designed to prevent fouling of the charcoal bed by oil discharged from the vacuum pump. An absolute filter following the charcoal trap is designed to remove at least 99.97% of all particulate matter 0.3 μ or larger in diameter. An electric heater is employed in the offgas system to heat the hydrogen gas to approximately 400°C (752°F) prior to passing it through the CuO bed. A condenser downstream of the CuO bed condenses steam effluent from the bed. The CuO bed oxidizes hydrogen to steam while reducing the CuO to Cu. The CuO bed contains electric heaters to raise the bed temperature to 400°C prior to blowing down the loop. The bed also incorporates a recharging line to permit addition of oxygen for recharging the bed once the loop has been shut down and depressurized. The liquid trap serves two purposes: (1) it is required during decontamination of the loop to trap any liquids entering the loop vent lines, and (2) it serves to collect the condensate from the condenser when recombining hydrogen in the offgas system. The vacuum pump is used to evacuate the loop prior to initial loop filling, to evacuate the chambers between the metallic seals of the mechanical joints, and to evacuate and provide transfer pressures and vacuum for the gas-sampling system.

Provisions have been made for discharging the cell atmosphere through the offgas system in the event it becomes radioactively contaminated. This system consists of an absolute filter, a motor-operated valve, and a check valve. The loop offgas system is isolated by shut-off valves when too much activity is released to the ventilation system exhaust header.

3.4. Gas Supply Systems

The hydrogen-cooled loop requires hydrogen, helium, and CO_2 gas supplies. The helium is used as an alternate loop gas and for purging and filling the out-of-cell containment region and certain loop void spaces which must contain a nonreactive atmosphere. The CO_2 is used to purge and fill the experimenters' cell.

Hydrogen gas is supplied from an open-air bottle station located adjacent to the experimenters' crane-bay enclosure. The gas pressure is reduced at the bottle station before the gas is piped to the experimenters' cell. The pipe line between the bottle station and the experimenters' crane bay is above ground. It is doubly contained at all points inside the experimenters' crane bay and utility tunnel. The containment pipe is charged with high-pressure CO_2 to alleviate the potential hazard of a hydrogen leak in these confined areas.

The helium supply system consists of a bottle trailer, a cooler, and two silica-gel beds. The cooler and silica-gel beds and associated piping are housed in a shed which is a radial extension of the experimenters' crane-bay enclosure. The helium bottle trailer is parked immediately adjacent to the shed. Helium flows from the bottle trailer through the cooler and then through one of two parallel-connected silica-gel beds. The two beds are connected in parallel in order to permit operation of the system during the removal of a bed for silica-gel replacement.

Liquid CO_2 will be transported to the EGCR site by truck. A hose will run from the truck to the fuel connection on a CO_2 bulk-liquid storage tank. This storage tank is housed in the same shed as the helium supply system. It is designed to hold the CO_2 at 0°F. The storage tank includes a vaporizer and a refrigeration unit. Low-pressure steam is used in the vaporizer. An electrical vapor heater is included in the outlet line from the bulk liquid tank to assure that solid and liquid CO_2 do not form when the CO_2 vapor is throttled from high pressure to low pressure while filling the experimenters' cell.

3.5. Gas-Sampling System

The gas-sampling system will be used (1) to obtain information on the release of fission products from fuel materials, (2) to develop techniques for activity level control, including evaluation of the bypass gas-cleanup system and the mainstream gas filters, (3) to obtain information on the decontamination of a contaminated gas system, and (4) to obtain information as to the presence or buildup of other gaseous contaminants that might result from fuel element degassing, corrosion, etc. The gas-sampling system is designed for removing small representative samples of loop gas for subsequent analysis. The gas can be sampled at each of the following points: (1) downstream of the mainstream gas cooler, (2) downstream of the mainstream gas filter, (3) at the outlet of the loop compressors, (4) downstream of the mainstream gas heater, (5) downstream of the bypass gas-cleanup system, and (6) at the outlet of the gas storage tanks. The principle of double containment and atmospheric control of the loop gas is not violated during extraction of a sample.

In addition to the gas-sampling system, the loop is provided with a gas-monitoring system that is capable of continuously withdrawing a small gas stream for on-line analysis and also has radiation monitors at several points along the loop piping. These points include the hot pipe from the reactor, the mainstream gas filter, the mainstream gas cooler, the bypass filter, and the loop compressors.

3.6. Experimental Assembly Removal Cooling System

When removing an experimental assembly from the inner through-tube, cooling must be provided before upward travel of the assembly begins, during upward travel of the assembly into the service machine, and while the assembly is contained in the service machine (both while the service machine is connected to the top nozzle and while it is in motion toward a storage hole, etc.). In order to use the loop gas for assembly removal cooling, it is necessary to add a removal cooling system which provides flow through the experimental stringer at all times and blocks off all significant bypass flow. Before this additional system is brought into play it is necessary to use the normal loop gas flow path for afterheat removal until the afterheat level has fallen to the design capability of the removal cooling system. The normal gas flow path is also used during the first few feet of stringer removal travel because the design of the stringer shield plug prevents flow into the service machine until the shield plug has been lifted a few feet.

It is also necessary to substitute helium for hydrogen in the loop. This is accomplished by depressurizing the loop and refilling it with helium to reduce the hydrogen concentration in the loop to below its flammability level in air. If the secondary containment region is filled with hydrogen because of an out-of-cell piping failure, it will be evacuated through the loop offgas system and filled with helium before the service machine is connected.

The experimental assembly removal cooling system consists of a small blower and a small gas cooler attached to the service machine, plus associated valves and piping. After reactor shutdown and before appreciable upward travel of the experimental stringer, cooling of the stringer is accomplished by forced convection using the loop compressors (or the auxiliary blower if the compressors are inoperative) as the driving force and the mainstream gas cooler as the heat sink. After the experimental stringer shield plug is raised sufficiently to permit loop gas flow through the top nozzle into the service machine, the flow path is from the service machine, through the removal cooling system cooler and blower, through a line extending from the service machine to the experimenters' cell, back through the main loop return piping, upward through the experimental stringer, and into the service machine. With the exception of provisions for supporting the cooler and blower, no changes to the service machine are required. The cooler, blower, and piping are sized to permit removal of a stringer even after complete depressurization of the loop.

3.7. Water Systems

Three types of water systems are required for the hydrogen loop: (1) a demineralized water-steam system for transferring heat from the evaporative cooler to the loop condenser, (2) a demineralized water system for cooling in-cell components, and (3) a service water system for cooling the loop condenser, demineralized water coolers, and cell coolers.

The mainstream gas cooler is an evaporative cooler in which demineralized water boils inside re-entrant tubes (see Sec. 2.4). Steam generated from the demineralized water serves as an intermediate heat transfer fluid between the loop gas and service water. The steam loop is composed of the following components: the evaporative cooler in which heat is transferred from the loop gas to demineralized water and steam, the loop condenser, in which heat is transferred from the steam to service water, and the condensate storage tank which collects the condensate and acts as a reservoir for additional condensate to take care of required variations in the heat-removal capacity of the evaporative cooler. Demineralized water makeup to the steam system is provided by adding water from the demineralized water head tank by means of a small high-pressure feedwater pump. A service water storage tank mounted above the loop condenser provides emergency cooling water to the condenser if the normal service water flow is interrupted. In this event, water from the service water storage tank flows through the condenser, where heat is removed from the steam system by boiling some of the service water. The water steam mixture then flows back into the storage tank, where the steam is separated and vented to the atmosphere via the outlet line, and most of the entrained water is retained in the tank. This cooling system is employed only if all cooling water flow to the loop condenser is lost.

A vent and blowdown system provides pressure relief for the steam system and permits venting of noncondensible gases that might otherwise collect in the system during normal operation. The vent and blowdown system is designed to condense any steam that is vented from the steam system and transfer the noncondensible gases to the EGCR stack. All gases in the system are vented to a blowdown condensing tank, which is simply a tank of water in which the gas inlet line is located below the water surface. The vent and blowdown system is necessary because the loop condenser efficiency is drastically reduced by the presence of noncondensible gases.

Since the steam system of the evaporative cooler forms a part of the secondary containment, its atmosphere must be nonreactive with hydrogen. This requirement is fulfilled by purging and filling the steam system with helium prior to filling the loop with hydrogen. After loop startup the helium is vented through the blowdown system. At any time the loop is shut down without removing its hydrogen, the steam system will be maintained at a positive helium pressure if it cannot hold a vacuum because of inleakage.

The principle function of the demineralized water in-cell cooling system is to cool the three loop compressors. The system is also used to cool the transfer pump, vacuum pump, and cooler in the bypass gas-cleanup system. A separate demineralized water supply line is provided to cool the auxiliary blower. This reduces the probability of a simultaneous loss of cooling water to the loop compressors and the auxiliary blower. All demineralized water used in the cell is dumped into a common open sump tank before being returned. Employing separate discharge lines and an open sump tank prevents any minor gas leakage in a given component from disrupting the flow to the other components and provides positive containment of a large high-pressure leak. Flow valves prevent the sump tank from blowing dry in the event of excessive cell pressure, thus maintaining secondary containment. If a low flow of demineralized cooling water threatens the loop, it is possible to feed service water directly into the demineralized water system.

The service water system supplies cooling water for the loop condenser, demineralized water coolers, cell space coolers, and the compressor motor-generator clutches.

3.8. Electric Power Supply

The construction of an alternate 13.8-kv supply line originating at Y-12 will be necessary. From Y-12, this line will approach the EGCR on a route widely separated from the 13.8-kv line to the EGCR from the ORNL main substation. In this way both lines will not be affected by a single lightning disturbance. The new overhead line will terminate at a point approximately 500 ft from the ORNL line and continue underground to the EGCR site.

At the EGCR it is planned that power for the hydrogen loop will be supplied partly from the EGCR bus, which connects to the ORNL 13.8-kv line, and partly from the new Y-12 line; for instance, of the three motor-generator sets for the loop compressors, one will be supplied by the EGCR bus, one by the new Y-12 line, and a third by a throwover arrangement that can draw power from either source. In this way a power interruption on either source will stop only one of the three motor-generator sets. A similar arrangement is planned for the demineralized water pumps and the instrument and control power.

3.9. Mechanical-Joint Leak-Detection System

The function of the mechanical-joint leak-detection system is to detect excessive leakage of loop gas or cell containment gas through the loop-compressor or filter flange seals. Each of these flanges incorporates a double seal arrangement with a monitoring chamber between the seals (see Sec. 2.11). The leak-detection system draws a vacuum on the monitoring chamber by using the vacuum pump in the loop offgas system. Gas leakage is determined by the rate at which the pressure increases in the monitoring chamber after it is valved off. In practice, all the monitoring chambers are evacuated at once and then isolated by a motor-operated valve. The individual chambers are isolated by check valves. The pressure in each chamber is then monitored by remote pressure indicators.

There are three possible paths for leakage at each joint: (1) from the experimenters' cell into the monitoring chamber, (2) from the loop into the monitoring chamber, and (3) from the loop to the monitoring chamber to the cell atmosphere (a compound leak). For a leak in the outer seal (path 1) the monitoring chamber pressure will slowly rise along a smooth curve with respect to time until it reaches cell pressure. For a leak in the inner seal (path 2), the loop gas will slowly pressurize the monitoring chamber along a smooth curve with respect to time until it reaches loop gas pressure. For simultaneous or sequential leaks through both seals (path 3), the monitoring chamber pressure will slowly increase at varying rates along an irregular curve with respect to time as it approaches loop gas pressure.

4. CONTAINMENT

With the exception of the outdoor supply system, all hydrogen gas is doubly contained with respect to the reactor pressure vessel, the reactor containment vessel, and all other surrounding environments at all times, and the containment region is filled with a nonreactive atmosphere when the loop or any of its auxiliary components contain hydrogen. During loop operation, the secondary containment system consists of the outer through-tube, the loop containment piping, the containment vessel around the evaporative cooler, the intermediate steam system of the evaporative cooler, and the experimenters' cell.

In order to ensure the integrity of the containment system and controlled atmosphere, all piping into and out of the secondary containment region that might serve as a vent to the outside environment contains two automatic valves or check valves in series. This does not include water lines to and from the cell as long as the residual water pressure is greater than 12 psig and they cannot be pressurized to a high pressure by any loop component failure. All gas lines entering the cell contain two check valves in series and all gas exhaust and liquid drain lines leaving the cell contain two automatically controlled valves in series.

When operating the reactor without an experimental assembly in the loop, it is planned to pressurize the out-of-cell containment region with helium to reactor gas pressure in order to prevent excessive through-tube stresses leading to long-term creep and to provide positive secondary containment for the reactor gas. Then major maintenance can be performed in the cell without maintaining cell containment.

4.1. Piping

The mainstream piping for the hydrogen-cooled loop connects the inner through-tube with the various mainstream loop components, including the mainstream gas cooler, filter, heater, loop compressors, and auxiliary blower. In addition to the mainstream piping, there are several auxiliary piping systems. Nearly all the mainstream loop components and auxiliary systems are located inside the experimenters' cell.

The in-cell mainstream piping connects to the out-of-cell mainstream piping at a cell wall penetration located between the experimenters' cell and the reactor containment vessel. The through-tube inlet piping runs horizontally through a bottom biologically shielded chase to the bottom nozzle of the through-tube (see Fig. 4.1). The through-tube outlet piping runs horizontally through a top-shielded chaseway from the through-tube top nozzle to the mainstream gas cooler located at the face of the reactor biological shield. The outlet piping from the cooler runs down a vertical chaseway to a bottom chaseway, where it turns and runs horizontally to the experimenters' cell wall.

The design of the loop piping inside the reactor containment vessel is based on using expansion loops rather than bellows expansion joints to accommodate thermal expansion. Concentric piping is used to provide secondary containment. The bottom nozzle is designed to allow for vertical expansion of the inner through-tube without a bellows expansion joint as required on the outer through-tube (see Sec. 2.1). Type 347H stainless steel is specified for the primary piping, since this material is compatible with hydrogen, has favorable high-temperature properties, is less prone to sigma-phase formation (embrittlement) than other stainless steels, and has favorable welding characteristics.

A closed-loop, forced-convection, air-cooling system is provided to limit the chaseway concrete temperature to 120°F (see Sec 4.2). Both the primary and secondary piping are insulated to reduce heat losses and to reduce the pipe chase cooling load.

A major part of the out-of-cell piping for the hydrogen loop is being installed in the EGCR during construction of the reactor plant. Loop piping within the experimenters' cell will be deferred until loop construction is authorized.

4.2. Pipe-Chase Cooling

The hydrogen-cooled loop piping inside the reactor containment vessel is located in concrete pipe chases. The heat transferred from the loop piping to these chases must be removed by a forced-convection cooling system. A maximum temperature of 120°F is specified to protect the concrete. The

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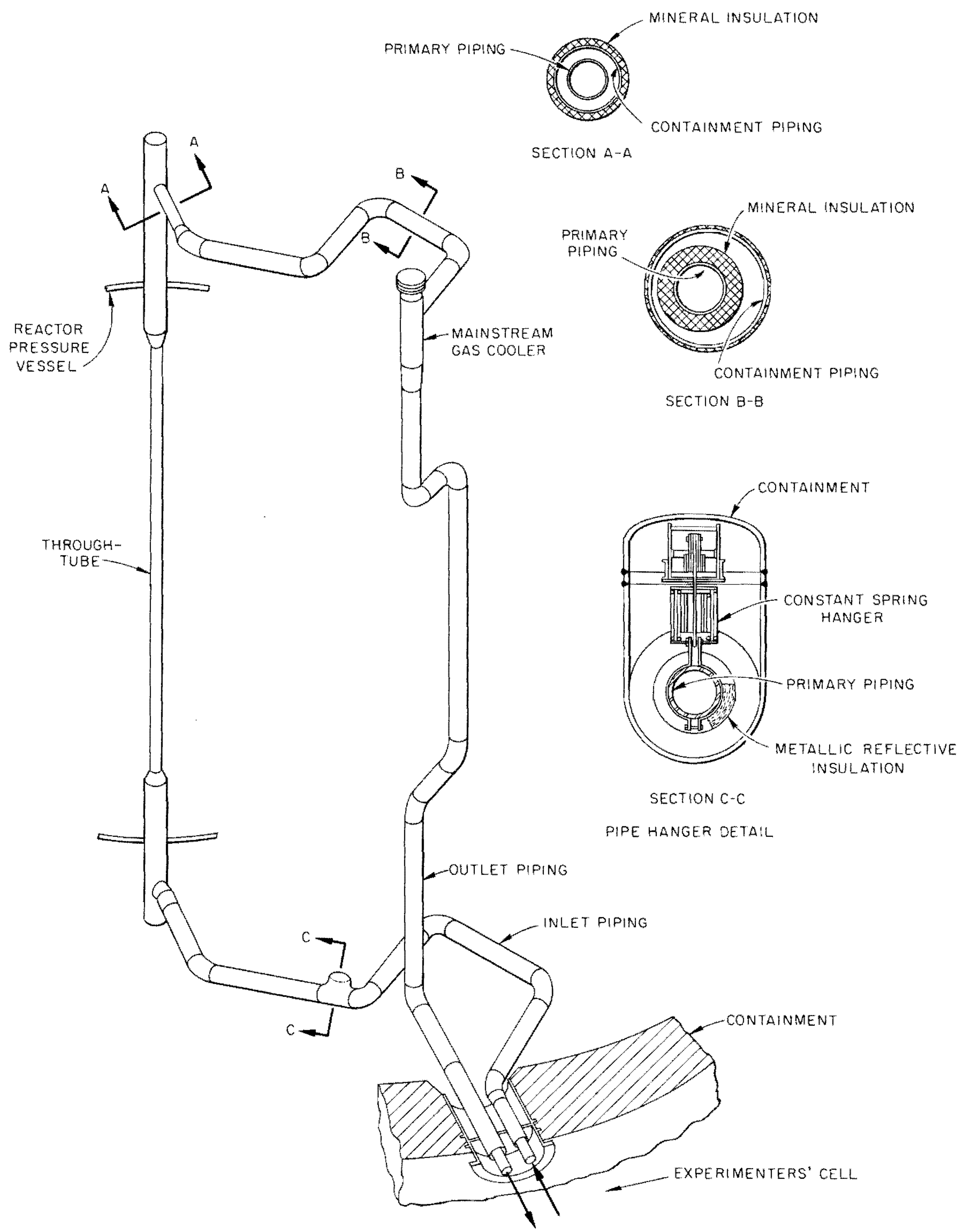

Fig. 4.1. Typical EGCR Experimental Loop Containment Piping.

heat-removal process consists of withdrawing air from the pipe chases, passing it through a water-cooled heat exchanger, and returning it to the pipe chases. A system of ducts distributes the air. Concrete surfaces that receive radiant heat from the piping are blast-cooled with high-velocity air streams.

The pipe-chase cooling units are located outside and adjacent to the reactor biological shield near the ground floor elevation. Each cooling unit consists of a cooling coil, a dust filter, and two blowers. Two blowers are provided as dual protection against overheating the building concrete or the loop containment piping in case of a blower failure.

4.3. Containment Gas Systems

Two containment gases are required for the hydrogen loop: CO_2 for the in-cell containment and helium for the out-of-cell containment regions.

In-Cell Containment Gas

As discussed in Section 1.3, the experimenters' cell air can be diluted with CO_2 until the resulting mixture cannot propagate a flame front regardless of the amount of hydrogen released to the cell. Such an atmosphere is achieved at a CO_2 concentration of approximately 60 vol % in the cell. To provide a factor of safety, the original cell air will be purged with CO_2 until the CO_2 comprises approximately 80% of the cell atmosphere. This will reduce the oxygen content to approximately 4 vol %. If complete mixing of air and CO_2 is assumed during the purge, the rate of change of the air mass in the cell during the process may be expressed as follows:

$$\frac{dm_a}{dt} = \frac{m_a}{V} v \quad , \tag{1}$$

where

m_a = mass of air in cell at time t,

t = time, min,

V = cell volume, ft^3,

v = volumetric CO_2 flow into cell, ft^3/min.

Solving Eq. 1 yields

$$m_a = M_a \, e^{-vt/V} \quad , \tag{2}$$

where M_a is the original mass of air in cell. In order to reduce the air content of the cell atmosphere to 20% ($m_a/M_a = 0.2$) at time t, the quantity of CO_2 required is

$$vt = 1.16 \; V \quad . \tag{3}$$

Thus, for a cell volume of 25 000 ft^3, approximately 2950 lb of CO_2 is required.

During the process of diluting the cell air with CO_2, the original cell air is removed to the exhaust header and EGCR stack through the bypass vent line (see Sec. 4.4) located near the cell ceiling. The CO_2 is added near the cell floor. With this physical arrangement, the CO_2 tends to float the cell air to the ceiling because of the large density difference and thus reduce the amount of CO_2 required to dilute the cell air to the desired concentration in comparison with that calculated for the perfect mixing case. To prevent the possibility of additional air leaking into the cell during loop operation, the cell is pressurized with CO_2 to about 1 psig. This requires an additional 200 lb of CO_2.

After the cell air is sufficiently diluted with CO_2, the cell cooler fans are turned on to ensure continuous thorough mixing of the cell atmosphere. If necessary, additional fans may be added for this purpose. The fans continue operating as long as cell-atmosphere control is required. Thus, any hydrogen leakage into the cell is thoroughly mixed with the cell atmosphere and the mixture remains nonflammable regardless of the amount of hydrogen added.

Within the limits of the amount of hydrogen available in the cell, a cell atmosphere containing 80% CO_2 plus all the hydrogen remains nonflammable regardless of the amount of air subsequently added to the mixture (see Sec. 1.3). The hydrogen loop contains an estimated 68 ft^3 of volume in the primary piping. It is necessary to store approximately one cold loop volume of hydrogen gas in the cell (7.1 lb or 1290 scf). Since the cell volume is approximately 25 000 ft^3 and contains 20 000 scf of CO_2, the ratio of CO_2 to hydrogen following a complete release of all the stored gas (not considered credible) is 15.5. A ratio greater than 10:1 is sufficient to make the resulting mixture nonflammable regardless of the amount of air subsequently added. As a result, if the hydrogen release is followed by cell depressurization into the reactor containment vessel through the cell rupture disk, the gas mixture from the cell cannot form a flammable mixture with any combination of air in the reactor containment vessel.

The CO_2 required for diluting the cell air is supplied from a CO_2 storage tank located in the experimenters' crane bay (see Sec. 3.4). It is stored at 300 psig and 0°F. The CO_2 is taken from the tank through a block valve and a pressure-reducing valve that throttles it to approximately 6 psig and −80°F. The gas then passes through a heater where its temperature is raised to approximately 50°F. Next, the gas flows to a reducing station in the experimenters' utility tunnel where its pressure is reduced from 6 psig to approximately 1.0 psig. This arrangement assures a positive CO_2 overpressure in the cell at all times. During initial filling, the last pressure-reducing valve is bypassed to speed up the filling process. A motor-operated valve plus a check valve in series are attached to the CO_2 line inside the experimenters' cell to provide secondary containment of the cell atmosphere and protect the cell from overpressurization due to a malfunctioning of the CO_2 supply system. The motor-operated valve closes when the cell vent valves close.

Out-of-Cell Containment Gas

The out-of-cell containment region consists of the outer through-tube and nozzle tees, the secondary containment piping, and the secondary containment vessel around the evaporator cooler. This region is divided into two parts by a gas-tight barrier built into the reactor pressure vessel top nozzle. As a result, the portion of the containment piping around the through-tube inlet piping has a net containment volume of about 89 ft^3. The portion around the through-tube outlet piping has a volume of about 148 ft^3. The two parts of the system are joined by a 1 1/2-in. (nominal) pipe containing an orifice plate. The containment system is pressurized with helium to at least 100 psi above the loop pressure at all times. Its nominal gas operating conditions are 400 psig at 500°F. The higher containment gas pressure eliminates the possibility of a primary pipe failure generating missiles which could penetrate the secondary containment pipe.

The helium supply for the out-of-cell containment region is drawn from the helium supply system for the loop (see Sec. 3.4). It enters the experimenters' cell from the helium-reducing station in the experimenters' utility tunnel. A control valve plus two check valves in series are provided to ensure secondary containment of the cell. A rupture disk venting into the experimenters' cell provides overpressure protection. Adjustment of the containment pressure or removal of the containment gas is accomplished through a let-down valve which leads to the loop offgas system. The system is evacuated by the vacuum pump in the loop offgas system prior to filling with helium.

4.4. Cell Ventilation

The experimenters' cell can be ventilated any time extensive in-cell maintenance is required but only after all hydrogen gas has been removed through the loop offgas system or diluted to the point where it does not present a flammability hazard. In addition, any radioactivity-contaminated gases present in the cell must be removed before ventilation starts. The experimenters' cell ventilation system is an induced-draft system. Air is brought into the cell from the experimenters' utility tunnel through a manually operated 6-in. butterfly valve located inside the cell. Air leaving the cell passes through a similar in-cell 6-in. valve into a common exhaust header located along the ceiling of the utility tunnel. The inlet to the exhaust valve is located near the cell floor while the line from the inlet valve is located near the ceiling. This arrangement facilitates the removal of CO_2. Before reaching the EGCR stack, the exhaust header splits and the flow passes through one of two parallel lines, each containing an absolute filter (99.95% efficiency at 0.3 μ) and an induced-draft fan which discharges to the stack. One fan is operating while the other is held in standby condition. Each fan and filter combination has a pair of isolation valves to facilitate filter replacement.

During loop operation, the experimenters' cell must be sealed to contain its nonreactive atmosphere at a slightly positive pressure. A 1-in. vent line has been provided that bypasses the closed exhaust valve. This line permits venting excess cell pressure as long as the radiation level and hydrogen concentration of the gas creating the overpressure is within the limits set by the total allowable radioactive effluent from the EGCR stack and the limits of containment-gas flammability in air. The vent line contains two motor-operated valves in series to seal off the cell if the activity or hydrogen concentration in the exhaust gas exceeds the allowable limits. Closure of the vent valves activates a number of interlocks which prevent further gas addition to the experimenters' cell. In addition to the two motor-operated vent valves, the bypass line contains a check valve to prevent air from backflowing into the cell when the vent valves are open. This valve is spring loaded so that it will not open unless there is a positive pressure inside the cell.

4.5. Cell Temperature and Humidity Control

The allowable cell temperature is limited by the electrical and electronic equipment in the cell. The life and operation of this equipment may be seriously impaired if the cell temperature exceeds 120°F, even for relatively short periods of time. The principal heat sources in the cell are heat losses from the transfer pump, in-cell piping, high current buses, and heater transformer.

The cell cooling system includes two water-cooled forced-convection heat exchangers, each of which is connected to an independent blower power supply. The coolers are arranged and sized so that either unit will provide cooling throughout the cell if the other unit should fail. The blower motors are totally enclosed units and are capable of operation in CO_2 at pressures up to 26 psia. The service-water supply and return lines for the coolers lead into the experimenters' utility tunnel. Since it is doubtful that the cell coolers will have sufficient dehumidifying capacity, a small refrigeration-type dehumidifier is provided in the experimenters' cell to control the humidity. This unit discharges to the cell floor drain.

5. INSTRUMENTATION

In order to minimize unnecessary reactor power reductions or scrams as a result of loop instrument failures, the power reduction signals from the hydrogen loop will originate in coincidence-redundance type systems whereby two out of three signals from a given variable must indicate that an unsafe condition exists before the reactor power can be reduced by an automatic motor-driven rod insertion or a scram. Three independent power supplies will be provided for the safety circuits. Critical valving and other equipment will be duplicated, operated continuously, and connected to separate power supplies. Independent instrumentation and controls will be provided for each piece of critical equipment. To avoid violation of the controlled atmosphere in the cell, electrical instrument signal transmission will be used instead of pneumatic transmission.

Any of the following conditions may lead to a reactor shutdown:

1. a high mixed-mean gas temperature at the test section outlet (alternate — high fuel-element-cladding temperature),
2. high or low loop pressure,
3. low pressure in the service-water supply system at the mainstream gas cooler condenser elevation,
4. low volume flow rate of the loop gas,
5. low through-tube nozzle-cooling flow rate in any circuit,
6. low demineralized-water head-tank level,
7. high demineralized-water temperature (in head tank),
8. high cell water level,
9. high cell temperature,
10. low demineralized-water flow from auxiliary blower,
11. change in containment gas pressure or constitution,
12. failure to switch over loop compressor,
13. experimental assembly rupture (fission break),
14. loss of either the Y-12 or EGCR power supplies at the main switchgear, and
15. main dc power supply failure.

The mainstream instrumentation proposed for the hydrogen-cooled loop is shown in Fig. 5.1. The required measurements may be grouped into four basic categories: temperature, pressure, flow, and radiation.

5.1. Temperature Measurements

An attemperated experiment requires the following temperature measurements: experimental section inlet (TE-1) and outlet (TE-5 and -6) gas temperatures, attemperator stream outlet temperature (TE-2), mixed-mean outlet gas temperature (TE-8), temperature rise across experimental section (T_dE-7), and experimental assembly surface (TE-3) and central (TE-4) temperatures. Attemperator stream and experimental assembly outlet temperatures are not required for an unattemperated experimental assembly.

Thermocouple wells for future use (TE-9) are located in the outlet piping leading from the top nozzle. The top nozzle temperature (TE-10) is also measured to assure that adequate top nozzle cooling is maintained. The evaporative cooler tube sheet temperature (TE-11) is monitored for the purpose of detecting the absence of water on the tube sheet. Loop temperature control is achieved by controlling condensate flow to the evaporative cooler by temperature measurements obtained from three thermocouples (TE-12) located downstream of the cooler. The mainstream gas filter has one thermocouple (TE-13), which is located between the thermal insulation and lead shield enclosing the filter to provide high-temperature indication. Compressor inlet (TE-14) and compressor outlet temperatures (TE-15 and -16) are for operation information and mass flow computation. They are measured with sheath thermocouples welded into the pipe. Temperature measurements are made at several points on the mainstream gas heater pipe walls (TE-17) and on the heater lugs (TE-18) to provide overtemperature indications.

5.2. Pressure Measurements

Static pressure measurements are made at the experimental section outlet (PT-1) (attemperated experiments only), mainstream gas cooler outlet (PT-3), loop compressor outlets (PT-4), and near the experimental section inlet (PT-5). Differential pressures are measured across the

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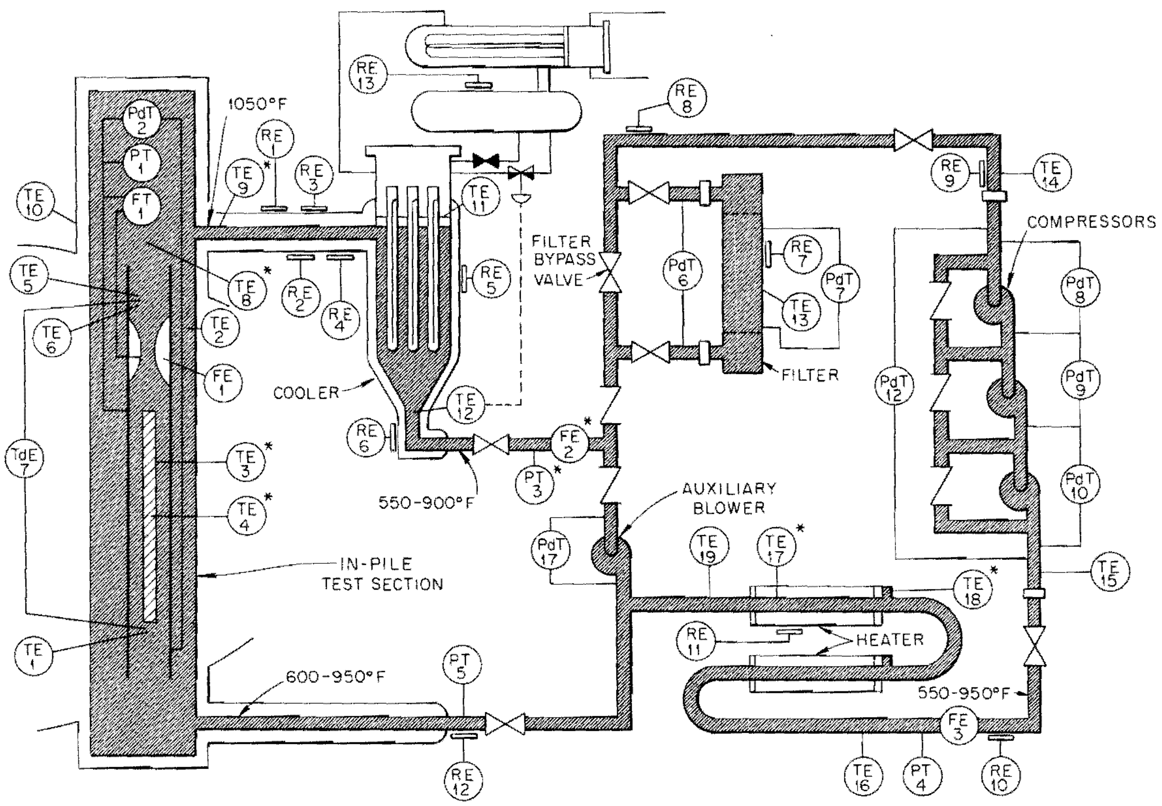


*DENOTES THAT MULTIPLE SENSORS ARE USED IN ACTUAL MEASUREMENT. SHOWN AS SINGLE SENSOR FOR SIMPLICITY.

OPERATING PRESSURE: 315 psia
OPERATING TEMPERATURES: AS INDICATED

(TE) TEMPERATURE ELEMENT
(FE) FLOW ELEMENT
(RE) RADIATION ELEMENT
(PT) PRESSURE TRANSMITTER
(FT) FLOW TRANSMITTER
(PdT) DIFFERENTIAL PRESSURE TRANSMITTER
(TdE) DIFFERENTIAL TEMPERATURE ELEMENT

Fig. 5.1. Mainstream Instrumentation Schematic Diagram.

experimental section (P_dT-2), the mainstream gas filter (P_dT-6), the absolute filter portion of the mainstream gas filter (P_dT-7), each of the loop compressors (P_dT-8, 9, and 10), the auxiliary blower (P_dT-11), and across the group of loop compressors (P_dT-12).

5.3. Flow Measurements

Flow is measured at three points in the loop if an attemperated experiment is being performed. Venturi flow elements are used for all flow measurements. The experimental section outlet volume flow measurement (FE-1) is not required for an unattemperated experiment because the mass flow is the same in the experimental section as in the loop proper. The main flow-measuring device (FE-2) is installed in a line downstream of the mainstream gas cooler. The compressor outlet volume flow (FE-3) is measured primarily to detect failure of the check valves for the auxiliary blower.

5.4. Radiation Measurements

Radiation element RE-1 is a delayed-neutron monitor used to detect a release of fissionable material from the experimental assembly to the loop gas. Radiation elements RE-2, 3, and 4 are used to measure the total gamma activity in a known section of outlet loop piping. Gamma activity and fission-product deposition in the cooler are measured by radiation element RE-5. Radiation element RE-6 is used in conjunction with radiation element RE-4 to check the amount of activity deposition in the mainstream gas cooler. Gamma activity in the mainstream gas filter is monitored by radiation element RE-7. Radiation element RE-8 is used in conjunction with radiation element RE-6 to determine the effectiveness of the mainstream gas filter. Radiation elements RE-9 and 10 are for monitoring the gamma activity in a known length of primary loop piping attached to the inlet and outlet of the loop compressors. Radiation element RE-11 monitors the loop piping which passes through the mainstream gas heater. The loop gas activity downstream of the loop heater and at the experiment inlet is monitored by radiation element RE-12. Radiation element RE-13 monitors the condensate storage tank for the evaporative cooler.

6. SPECIAL OPERATIONS

6.1. Experimental Assembly Handling

The operations involved in handling a hydrogen-cooled loop experimental assembly can be grouped into three phases: preirradiation, irradiation, and postirradiation. The preirradiation phase includes assembly of the experimental equipment, shipment to the EGCR, final nonnuclear testing and inspection, and positioning for loading into the loop. The irradiation phase includes actual loading into the loop, operation at power, temporary removal from the loop, storage in the experimental assembly storage holes, reinsertion into the loop, and final removal from the loop. The postirradiation phase includes prolonged storage in the storage facility, separation of the experimental assembly from the support structure, loading of the experimental assembly into a carrier, transportation of the carrier to a hot cell, removal of the experimental assembly from the carrier and insertion into a hot cell, and hot cell disassembly of the experimental assembly.

The principle piece of equipment for handling experimental assemblies is the EGCR service machine. This machine is designed to install experimental assemblies in the inner through-tube, remove them, and transport them to and from the reactor and the experimental assembly storage holes, or transport them to a carrier or the spent-fuel transfer mechanism. The service machine is also designed to handle open core experimental equipment, control rods, shield plugs, and other special equipment which can be inserted into any of the reactor top nozzles. Cooling of the experimental assembly during removal from the loop and during storage in the service machine is achieved by means of a blower and cooler mounted on the service machine carrier (see Sec. 3.6).

The principal facilities for the storage of irradiated experimental assemblies are the two special storage holes located in the service machine room. Each storage hole facility consists of a primary pressure vessel with a cooling water jacket, the necessary equipment for supplying and controlling its helium atmosphere and cooling water, and the required ventilation and evacuation system. The experimental assemblies in the storage hole facility are cooled by natural convection of pressurized helium upward through the assemblies and along the water-cooled wall of the primary vessel.

A carrier is provided for shipment of assemblies to a processing or examination facility. The carrier is designed to accommodate the 13-ft-long in-core portion of a loop experimental assembly after it has been separated from its support stringer. The carrier is a fully sealed pressure vessel containing a helium gas atmosphere. Decay heat is removed by natural convection and radiation to the carrier vessel wall. The carrier vessel is cooled by natural convection in a sealed system that circulates water through a jacket in the vessel wall and out through finned tubes extending through the carrier shield into the ambient atmosphere. At the top of the carrier vessel is a shear or cut-off tool for separating the loop experiment from its support structure. Once the fuel is in the carrier and the carrier is sealed, no utilities are needed.

The spent-fuel transfer mechanism is the means by which an experimental assembly in the service machine can be transferred to the fuel storage basin in the reactor service building. The experimental assembly is inserted into the transfer tube of the mechanism by the service machine. All portions of the experimental assembly except the shield plug and Bridgman closure are separated from the support stringer by a shear attached to the mechanism and are transferred to the fuel storage basin.

6.2. Decontamination

The hydrogen-cooled loop is provided with a decontamination system capable of removing fission-product contamination from the inner surfaces of most of the primary loop piping and components. This system is required for reducing radiation in the experimenters' cell and around the mainstream gas cooler and certain other components prior to performing direct maintenance. Decontamination of the inner through-tube is required so that shielding of the through-tube welding and machining equipment may be reduced.

The equipment required to perform these functions includes a solution makeup unit located in the experimenters' crane bay, piping and valving for transferring solutions from the makeup unit to the loop piping, and a special shield plug for insertion in the through-tube by the service machine. The decontamination solution will be 4% sodium oxalate and 3% hydrogen peroxide in water. Ammonium oxalate is currently being tested and will replace sodium oxalate in the solution unless serious detrimental properties are revealed.

6.3. Cell Washdown

A portable spray unit is provided for cell washdown. This unit mixes cold water and steam to obtain a high-velocity hot liquid at temperatures ranging from 175 to 205°F and at jet pressures of 100 to 600 psig. Detergents and other solvents may be added to the spray as required.

The jet pump for the spray unit is installed in the experimenters' crane bay. It requires river water and a 90-lb steam supply. To decontaminate the cell, a multijet sprayer head is installed in an access port in the cell roof. Complete cell washdown is provided by the jets spinning about a horizontal axis while at the same time turning about a vertical axis. After the cell is washed down and the solution drained through the cell floor drain, decontamination is completed by manually washing down those areas or equipment not accessible to the sprayer.

6.4. Through-Tube Replacement

The hydrogen-cooled loop inner and outer through-tubes are containment components designed to isolate the loop gas from the reactor gas by an intermediate containment region. Inside the EGCR core, both through-tubes will be subjected to severe gamma and neutron irradiation. Since the physical properties of the tubes may undergo detrimental changes as a result of this exposure, both through-tubes are designed as replaceable items. When either tube is replaced, the welds which attach it to the top and bottom tees are removed by a remotely operated weld-cutting machine. After replacement of the through-tube, new welds are made by a remotely operated welding machine. These welds provide the seal between the loop gas and the containment gas for the inner through-tube case, and between the containment gas and reactor gas for the outer through-tube case.

The through-tube welding machine includes all components required to make the initial through-tube welds and the remote rewelds required each time either through-tube is replaced. It is designed to operate from a control board located on the machine.

The through-tube weld-cutting machine is a machine especially designed to insert and withdraw the breach plug and the breach adapter from the bottom nozzle inner tee and to perform all weld removal and other operations necessary to remove either through-tube. After completion of weld removal, the through-tube is pulled from the reactor into a shielded cask equipped with a cutting tool. The tube is cut into short pieces and stored in the cask for removal to a burial ground.

7. MAXIMUM CREDIBLE LOOP ACCIDENT

The maximum credible loop accident for the hydrogen-cooled loop will result from sudden in-cell depressurization of the loop piping when the experimental assembly has a large amount of stored thermal energy and consists of fuel pins or plates which are clad and supported with steel. A sudden, large break in the in-cell piping will cause the loop gas pressure to rapidly decrease to about 1.9 psig as the hydrogen gas leaves the loop and mixes with the air-CO_2 containment gas in the experimenters' cell. The cell vent valves will automatically close if they are open at the time; the reactor will be scrammed; the mainstream gas cooler will automatically go to full cooling; and the auxiliary blower will be turned on. It is assumed that the loop compressors will stop because of severe thrust-bearing damage caused by the rapid rate of loop gas depressurization (see Sec. 2.8). The auxiliary blower will not be damaged because it utilizes grease bearings instead of gas bearings (see Sec. 2.9).

Because the loop is depressurized, the mass flow of gas produced by the auxiliary blower alone will be very small compared with the mass flow existing prior to depressurization. An auxiliary blower of practical physical size can maintain only about 2% of the normal mass flow following depressurization. It should be pointed out that the auxiliary blower is incorporated into the loop to reduce the severity of several lesser but more probable loop accidents. It is not practical to size it to reduce, to any great extent, the initial severity of the maximum credible loop accident. It can be sized to adequately take care of the decay heat a minute or two after shutdown, but not the initial decay heat load and the removal of stored energy from the experiment.

The large amount of stored energy already in the experimental assembly and the addition of more energy by the decay heat will cause the temperature of the experimental assembly, including its steel cladding and supports, to rise rapidly. The only heat-removal mechanism will be forced convection by the auxiliary blower and the thermal capacity of the immediate surroundings. Radiation to the nonfueled portions of the assembly and subsequently to the inner through-tube will be effective only to the extent of the heat capacity of these components. The inner through-tube will not be cooled appreciably by radiation and conduction to the outer through-tube and thence to the reactor gas.

The rapid rise of the steel cladding temperature can be described in another manner. The fuel in the experimental assembly (UO_2, for example) is normally at a much higher temperature than the steel cladding. A large amount of thermal energy is therefore stored in the fuel. Immediately after depressurization, the rate of heat removal from the cladding is greatly reduced; therefore, the cladding temperature will increase quickly.

If the cladding reaches its melting point, the fuel will be released and will fall to the bottom of the inner through-tube, where it may lodge in the lower neck of the tube or collect in the dead end of the bottom nozzle inner tee. That portion which lodges in the lower neck may be adequately cooled by the auxiliary blower, but the portion which collects in the dead end will rapidly overheat. The dead end of the tee is lined with a graphite cup, but it will not offer appreciable protection in this case. The amount of heat transfer surface is small and the heat transfer coefficient is very poor. As a result, the decay heat from the fuel collected in the tee will increase the temperature of the dead end to its melting point.

At the instant of burn-through in the dead end of the tee, the pressurized helium containment gas will be released through the penetration and cool the immediate surroundings, thus preventing a propagation of the burning. In the same manner, any other point of burn-through will be cooled by the containment gas at the point of greatest need and maximum effectiveness. As noted in section 4.3, the containment gas system is filled with helium at 400 psig and 500°F during loop operation. The total containment volume of 237 ft^3 is divided into two portions. The part surrounding the lower tee and inlet piping contains 89 ft^3. The portion surrounding the upper tee and outlet piping contains 148 ft^3. The two parts are joined by a 1 1/2-in. (nominal) line containing an orifice plate. When the lower containment gas is released through the bottom inner tee, the flow of gas from the upper to lower containment region is restricted sufficiently to spread the containment gas depressurization over several minutes. In this way it is possible to assure cooling of one or more burn-through points during the initial 1 to 2 min during which the auxiliary blower is unable to cope with the situation. As an additional feature, the return loop piping has a secondarily contained check valve which prevents the containment gas from back-flowing into the experimenters' cell. All containment gas which flows through a burn-through must also flow up through the loop experimental section and thus help to remove the decay heat and stored energy in those parts of the experimental assembly which remain in-pile. The addition of containment gas to loop gas in the cell will increase the cell pressure to 5.8 psig. All gas released will be fully contained by the experimenters' cell liner. Within 1 to 2 min, the auxiliary blower will be able to remove the decay heat.

If the auxiliary blower should fail to start within this time, the decay heat generation following the loop and containment gas depressurization will be removed by conduction and radiation to surfaces which are cooled by reactor gas or other means. All surfaces enclosing the secondary containment region are cooled by some external means. For example, the outer through-tube is cooled by reactor gas and nozzle cooling gas, the bottom outer tee by an air blast flow over its outside surfaces, and the secondary containment pipe by the pipe-chase cooling system. All these systems can be adjusted or modified to yield the cooling rate specified by a detailed study of the maximum credible loop accident. In addition, most of the secondary containment vessels have very large heat capacities that will take care of thermal transients.

A detailed simulator study of the transient which will occur during the first minute after loop depressurization may reveal better schemes for utilizing the large volume of pressurized gas available in the containment region. It may prove to be more efficient to start the injection of containment gas into the bottom inner tee as soon as the loop depressurization occurs and thereby prevent meltdown. The study may show that this scheme can provide adequate heat-removal capacity until the auxiliary blower can take over. This system could be made very reliable by using a rupture disk set to a predetermined pressure differential between the loop and containment gas. Other means are available if this should still prove inadequate, and it is felt that the effects of the maximum credible loop accident can be held to modest proportions, with no danger of explosion or radioactivity release.

APPENDICES

Date of Issue: Nov. 4, 1960
Revised: Oct. 1, 1961

APPENDIX A. EGCR EXPERIMENTAL LOOP CRITERIA

Subject: Hydrogen Loop Design Criteria*

1. General Description

In-Pile Piping

The hydrogen loop through-tube will be located inside a modified version of one of the large reactor through-tubes (TL-4) presently being designed for the EGCR. It will be sized to suit the requirements of possible test fuel assemblies and the unique requirements of hydrogen containment. The loop through-tube will be shop fabricated, tested, and installed inside the large reactor through-tube in one continuous section. It will be so constructed that it can be replaced by removing it from the core in 20-ft sections into existing shielded casks. The large through-tube will be replaceable in the same manner as the other large reactor through-tubes.

Containment

The hydrogen loop will be totally enclosed by a separate containment pipe at all points outside of the experimenters' cell. A modified version of the large reactor through-tube will provide this containment within the reactor pressure vessel. External to the reactor pressure vessel, the hydrogen loop will be enclosed by a secondary containment pipe similar to the other large experimental loops. This containment pipe will extend as a continuation of the reactor through-tube from the reactor vessel to the experimenters' cell. This entire loop containment system will be designed as a sealed system filled with a suitable inert gas and capable of

*These criteria scope the conceptual process design of an experimental loop intended for installation in the EGCR at a future date. Their use in detailed design will be limited to those areas where provisions for the loop must be made during reactor construction. Approval of these criteria indicates acceptance in principle and to the extent necessary to make these provisions.

containing the loop or reactor pressure at the highest operating temperature.

Out-of-Pile Piping

The loop and containment piping to the experimenters' cell will run horizontally through an existing pipe chase in the upper biological shield of the reactor to the external face of the shield. Existing space is provided along the external vertical face of the biological shield for the loop cooler and a vertical run of the loop and containment pipe to the experimenters' cell elevation. The return loop and containment pipe will pass through an existing pipe chase in the lower biological shield to the lower pressure vessel nozzle. The containment pipe will be sufficiently insulated or cooled so that the temperature of the surrounding concrete will not exceed 120°F during normal operating conditions.

Thermocouple leads and other electrical wiring from the experiment will penetrate a removable plug assembly located between the loop through-tube and reactor through-tube regions, and will be routed through the top nozzle tee section in a manner similar to the other large experimental loops. The intermediate region will be blanketed by the loop containment gas.

Experimenters Cell

An existing experimenters' cell (TL4) will be provided for the hydrogen loop outside and adjacent to the containment vessel. An existing trench adjacent to the cell will provide space for the utilities. Existing shielding outside the cell area should be sufficient to reduce the activity level during normal operations to tolerance in the area above the experimental cells, inside EGCR containment vessel, and inside the utility trench. The existing cell is lined with steel sheets welded together to minimize gas leakage to the atmosphere. The cell will be designed to withstand an internal pressure of 12 psig. The maximum allowable leakage from the cell will be 1% of the cell volume per 24 hr when pressurized to 12 psig. The cell will contain a suitable inert gas at a slightly positive pressure.

To facilitate maintenance, the cell will be provided with a ventilation system capable of delivering filtered outside air to the cell at the rate of 220 cfm. The air will be exhausted through filters to the EGCR stack. An existing isolation valve system will seal the cell during periods of atmosphere control in the cell. A cell cooler will be provided to remove the heat lost from the system or delivered during various emergency conditions so as to maintain an ambient temperature not to exceed 100°F. Access to the cell during operation will not be permitted. An existing equipment hatch in the cell roof and a personnel airlock will be used only when the loop is not in operation and inert atmosphere control is not required. Spray nozzles will be provided in the cell for washing down the cell walls and flooding of the cell, if necessary. A warm waste drain with appropriate shut off valves will be provided. No air lines or other potential sources of oxygen will be permitted.

Control Room

The monitor and control instruments for the hydrogen loop will be grouped together into a single control panel in the experimenters' control room. Pneumatic controls, even with inert gases, will not be permitted between the loop and the control room.

2. Operation Parameters

In-Pile Section

For normal operation, the hydrogen gas will enter the in-pile section at 600°F (bulk mean temperature) and leave the in-pile section at 1050°F (bulk mean gas temperature). Sufficient coolant flow will be provided to remove 500 kw (fission plus gamma heat) from the loop. It will be possible to raise the inlet bulk mean gas temperature to a maximum of 950°F at proportionally reduced power output from the experimental element. The operating pressure will be 315 psia. In order to utilize the developed technology of the present centrifugal gas-bearing type compressors, it will be necessary to determine the design pressure drop for the in-pile section of the loop from the following formula:

$$\frac{W_p}{p} = 0.01$$

where

W_p = pumping power required for in-pile section

p = total power output of the in-pile section

The hydrogen loop will be capable of operating with heterogeneous or homogeneous samples.

The practical limits for heat rates from either type of element will be 100 kw/ft (average) and 150 kw/ft (maximum). Test fuel elements requiring exit gas temperatures in excess of 1050°F will be provided by the experimenter with an integral arrangement for attemperation of the gas to the outlet temperature limit. The facility design will provide the attemperated mass flow necessary to meet the test conditions.

Heater

An electrical heater will be provided in the inlet line to the loop through tube. It will be capable of raising the inlet gas temperature to the in-pile test section a maximum of 50°F for all normal operating conditions.

Cooler

A gas-to-water evaporator-type heat exchanger will be provided in the outlet line from the loop through-tube to lower the coolant temperature from 1050°F to near the desired inlet temperature to the in-pile test section. This heat exchanger will be located in existing space along the vertical external face of the biological shield. The condenser for the loop cooler will be located directly above the cooler and will be cooled by river water. The cooler will be totally enclosed by the loop containment gas system. The condenser will be purged with an inert gas and evacuated before going into operation.

Loop Compressors

Three centrifugal, gas bearing, canned-rotor-type compressors connected in series will be used to circulate the gas through the loop. Sufficient capacity will be available in the set of compressors that the failure of any single unit will not require a loop shutdown. The failure of two units will require a reactor scram.

Design Temperatures and Pressures

Design temperatures and pressures for all piping and components will be specified at a later date.

Auxiliary Blower

A centrifugal gas blower will be placed in parallel with the loop compressors to remove afterheat in the event of the loop depressurization and compressor failure. Sufficient flow capacity will be provided by this blower to remove the test fuel element afterheat at atmospheric pressure. This blower will be designed to take power from either one of the two independent power supplies available to the loop.

Coolants

The loop will be designed for hydrogen gas coolant. Provisions will be made to use helium gas for testing and pre-operational checkouts over a limited operating range.

Control

Low loop gas flow, high loop gas temperature at outlet of in-pile section, and low loop gas pressure will annunciate in the control room and automatically take corrective action. The reactor will subsequently scram if the actions do not correct the fault.

3. Loop Compressor Failure

In the event of failure of any one loop compressor, design flow will be maintained by the remaining compressors by increasing their speed. In case of a complete power failure of both independent power supplies to the compressors, it will be necessary to scram the reactor if it is not already shut down. The loop design will provide for sufficient natural convection to remove the afterheat if the loop does not depressurize.

4. Contamination

Liquid Waste

Two forms of liquid waste will be created in the hydrogen loop facility; (1) warm waste from washdown of the cell area, and (2) hot waste from decontamination of the loop. Each will be collected in separate waste tanks located underground outside of the cell area.

Gaseous Waste

Three potential sources of contaminated gas will be present in the loop facility: (1) inert gas removed from the cell, (2) inert gas removed from the loop containment system, and (3) gas removed from or used for purging the loop. The cell and loop containment gas will be discharged through high efficiency filters directly to a special gas disposal system. The loop gas will be purged by means of a transfer pump to a decay tank located within the cell and capable of accepting about one and one-half loop volumes at reduced pressure. Valving will be so arranged that the gas in the decay tank can be returned to the loop by means of a pressurizing pump, or bled through a filter system to the special gas disposal system.

Solid Waste

A bypass stream around the loop compressors will be used to reduce the equilibrium activity in the loop. This cleanup system will produce a solid waste. A second source will be the mainstream filter. These wastes will be removed during schedule shutdowns of the reactor.

5. Gas Sampling

A gas sampling station will be provided so that small samples of gas can be extracted from the loop for analysis during operation. The sample station will include a means for circulating the gas through the sample bottles in order to obtain a representative sample. Special care will be taken in the design of the sampling system to reduce the explosion hazard associated with the removal technique.

6. Gas Supply

Gas Headers

The initial and make-up hydrogen gas supply will be provided as a part of the loop facility. It will be located in an outside area far removed from the experimenters' cell and reactor facilities. The connecting line to the experimenters' cell will be located in a controlled-atmosphere chase. No hydrogen gas bottles will be permitted inside the cell.

7. Support Facilities

Crane

A 20-ton crane will be located above the cell area for removing the roof slabs, compressors, heat exchanger, filters, and filter beds from the cell area.

Maintenance Area

It is proposed that the existing Butler building at the EGCR site be used as a general storage area for parts storage. The final continuity check and inspection of the experimental element in the hydrogen loop will be made inside the containment vessel.

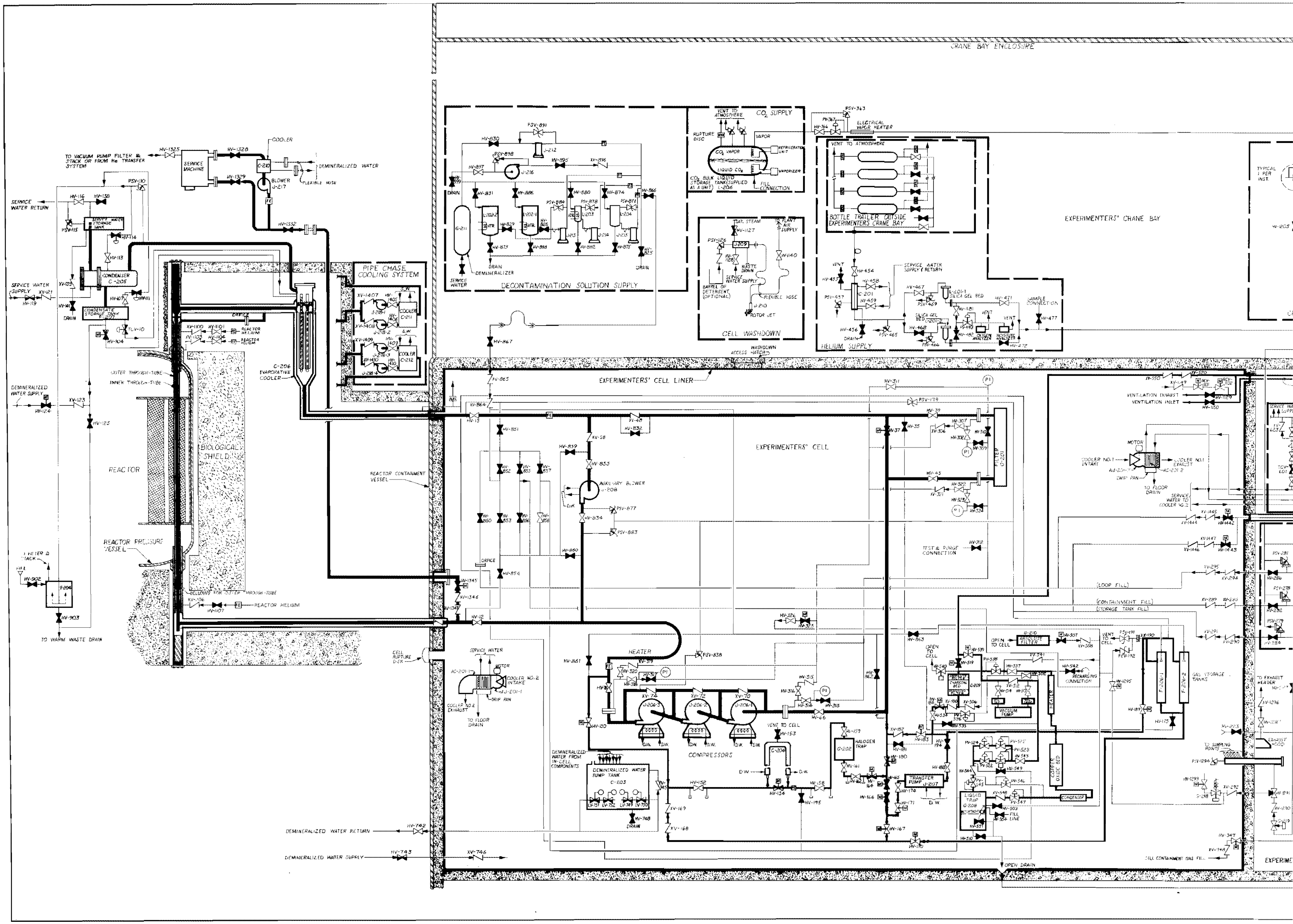
Compressor Generators

The variable frequency motor-generator supply for the loop compressors will be located external and adjacent to the cell area at ground level.

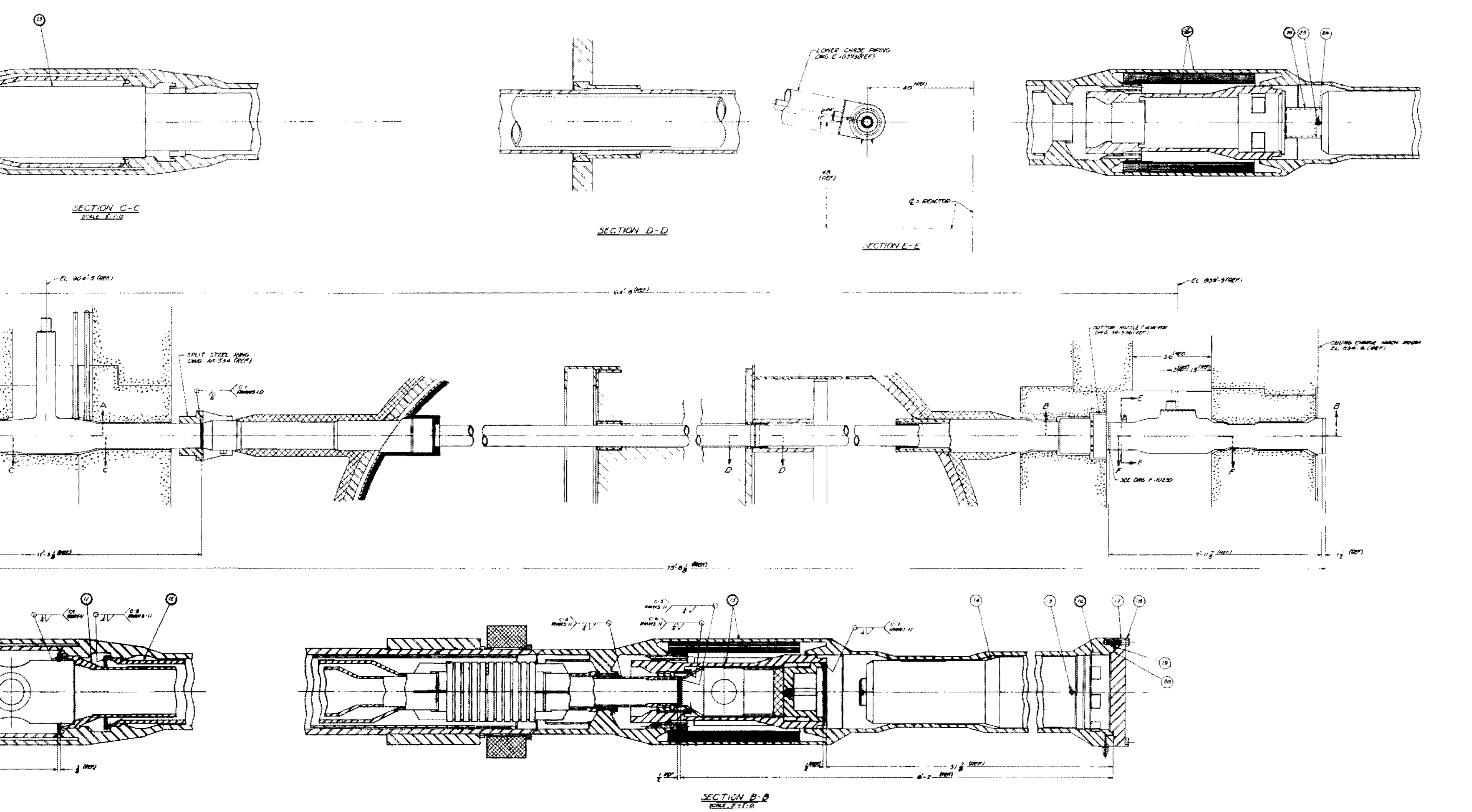
APPENDIX B

PRELIMINARY DESIGN DRAWINGS

Subject	Drawing No.
Composite Flowsheet of Hydrogen-Cooled EGCR Experimental Loop	F-RD-10983
Through-Tube Assembly	F-RD-10286
Top Nozzle Tee Section Assembly	F-RD-10208-B
Bottom Nozzle Tee Section Assembly	F-RD-10250-C
Inlet Piping Plan	E-RD-10171
Outlet Piping Plan	E-RD-10341
Outlet Piping Elevation	E-RD-10342



CRANE BAY ENCLOSURE
DECONTAMINATION SOLUTION SUPPLY
CO2 SUPPLY
CELL WASHDOWN
HELIUM SUPPLY
BOTTLE TRAILER OUTSIDE EXPERIMENTERS' CRANE BAY
EXPERIMENTERS' CRANE BAY
PIPE CHASE COOLING SYSTEM
EXPERIMENTERS' CELL LINER
EXPERIMENTERS' CELL
REACTOR
BIOLOGICAL SHIELD
REACTOR PRESSURE VESSEL
REACTOR CONTAINMENT VESSEL
OUTER THROUGH-TUBE
INNER THROUGH-TUBE
REACTOR HELIUM
C-206 EVAPORATIVE COOLER
CONDENSER C-205
CONDENSATE STORAGE TANK
SERVICE WATER RETURN
SERVICE WATER SUPPLY
DEMINERALIZED WATER SUPPLY
TO VACUUM PUMP FILTER & STACK OR FROM He TRANSFER SYSTEM
SERVICE MACHINE
COOLER
DEMINERALIZED WATER
FLEXIBLE HOSE
TO WARM WASTE DRAIN
AUXILIARY BLOWER J-208
HEATER
COMPRESSORS
DEMINERALIZED WATER PUMP TANK C-203
DEMINERALIZED WATER RETURN
DEMINERALIZED WATER SUPPLY
HALOGEN TRAP
TRANSFER PUMP
LIQUID TRAP
VACUUM PUMP
CONDENSER
GAS STORAGE TANKS
TEST & PURGE CONNECTION
(LOOP FILL)
(CONTAINMENT FILL)
(STORAGE TANK FILL)
OPEN DRAIN
CELL CONTAINMENT GAS FILL
VENTILATION EXHAUST
VENTILATION INLET
COOLER NO. 1 INTAKE
COOLER NO. 1 EXHAUST
COOLER NO. 2 INTAKE
TO FLOOR DRAIN
CELL RUPTURE DISK



PARTS LIST			
ITEM	DWG NO	QTY	NAME
1	F-10286-1	1	[illegible]
2	F-10286-2	1	[illegible]
3	F-10286-3	16	[illegible]
4	F-10286-4	16	[illegible]
5	E-10466-1	1	TOP BLIND FLANGE
6	E-10266	1	TOP BREAKAWAY CLOSURE
7	F-10286-7	1	[illegible]
8		1	CLAMP
9	E-10288	1	TOP SHIELD PLUG
10	F-10230	1	TOP NOZZLE TEE SECT.
11		1	[illegible] THRU TUBE SUB-ASM
12		1	[illegible] THRU TUBE SUB-ASM
13	F-10230	1	BOTTOM NOZZLE TEE SECT.
14	F-10288	1	BOTTOM SHIELD PLUG
15	F-10286-15	1	[illegible]
16	E-10466	1	[illegible] SUB-ASM
17	E-10466-2	1	BOTTOM BLIND FLANGE
18	F-10286-18	16	[illegible]
19	F-10286-19	1	[illegible]
20	F-10286-20	1	[illegible]
21	F-10286-21	4	[illegible]
22	F-10286-22	4	[illegible] CONNECTOR
23	E-10406	1	TEMPORARY TOP SHIELD PLUG
24	E-10466-3	1	TEMPORARY TEE SUPPORT
25	E-10466-13	1	CONNECTING PIN
25	F-10286-25	1	COTTER PIN [illegible]

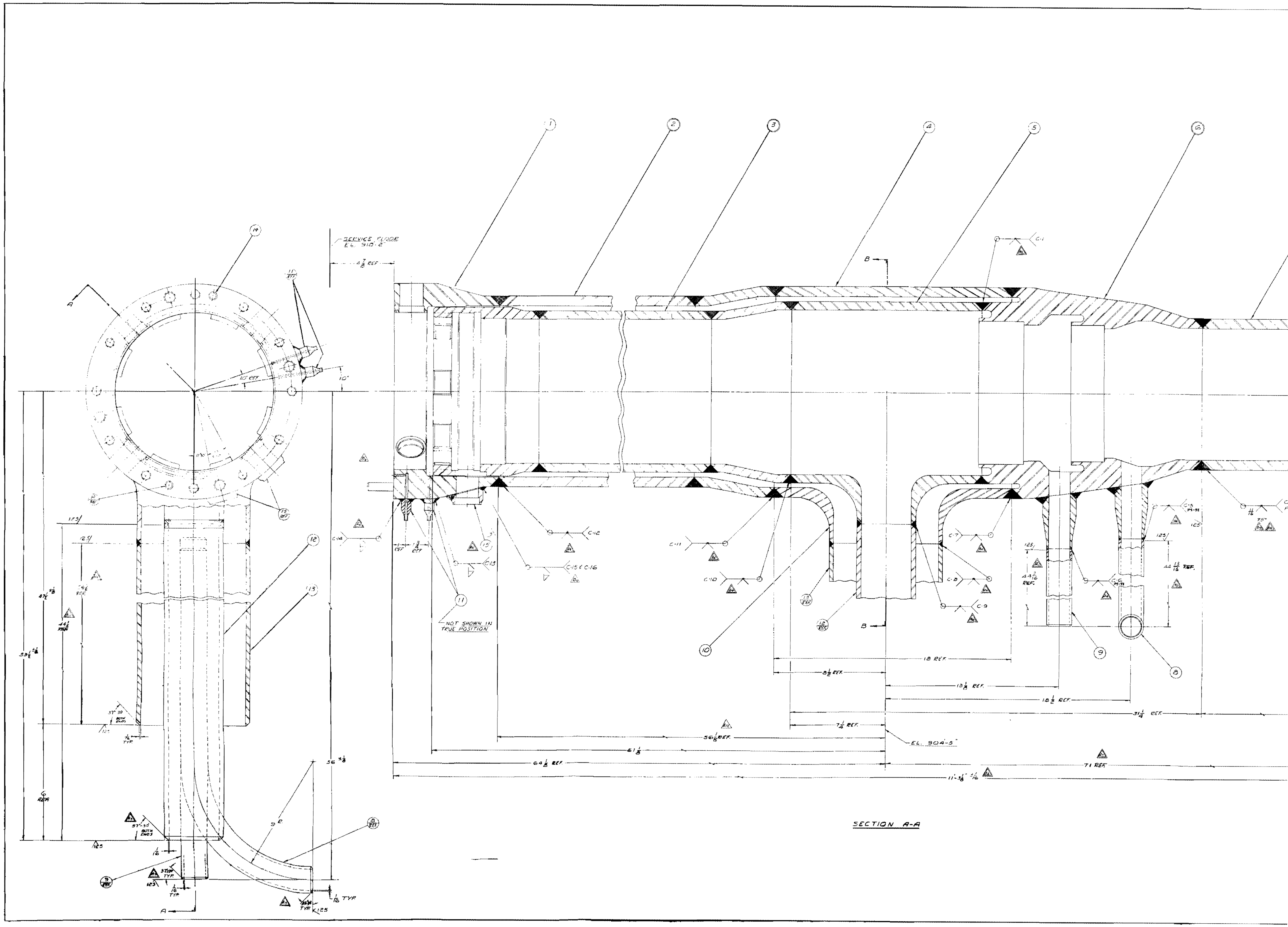
REFERENCE DRAWINGS	DWG NO
UPPER CHASE PIPING TL-4	E-10393
LOWER CHASE PIPING TL-4	E-10394
BIOLOGICAL SHIELD PENETRATIONS	E-10314
BILL OF MATERIAL	BM-10286

Oak Ridge National Laboratory

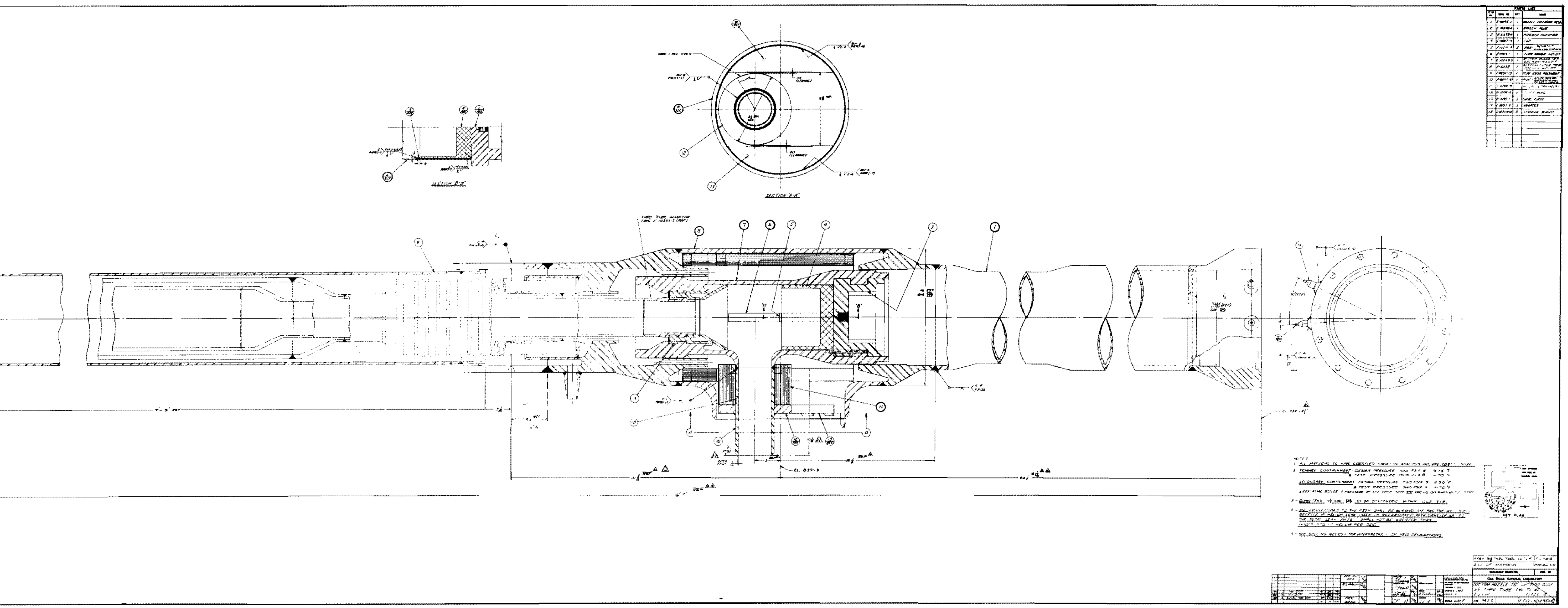
ASSEMBLY
9 1/2" THRU TUBE No. TL-4
EGCR TITLE II

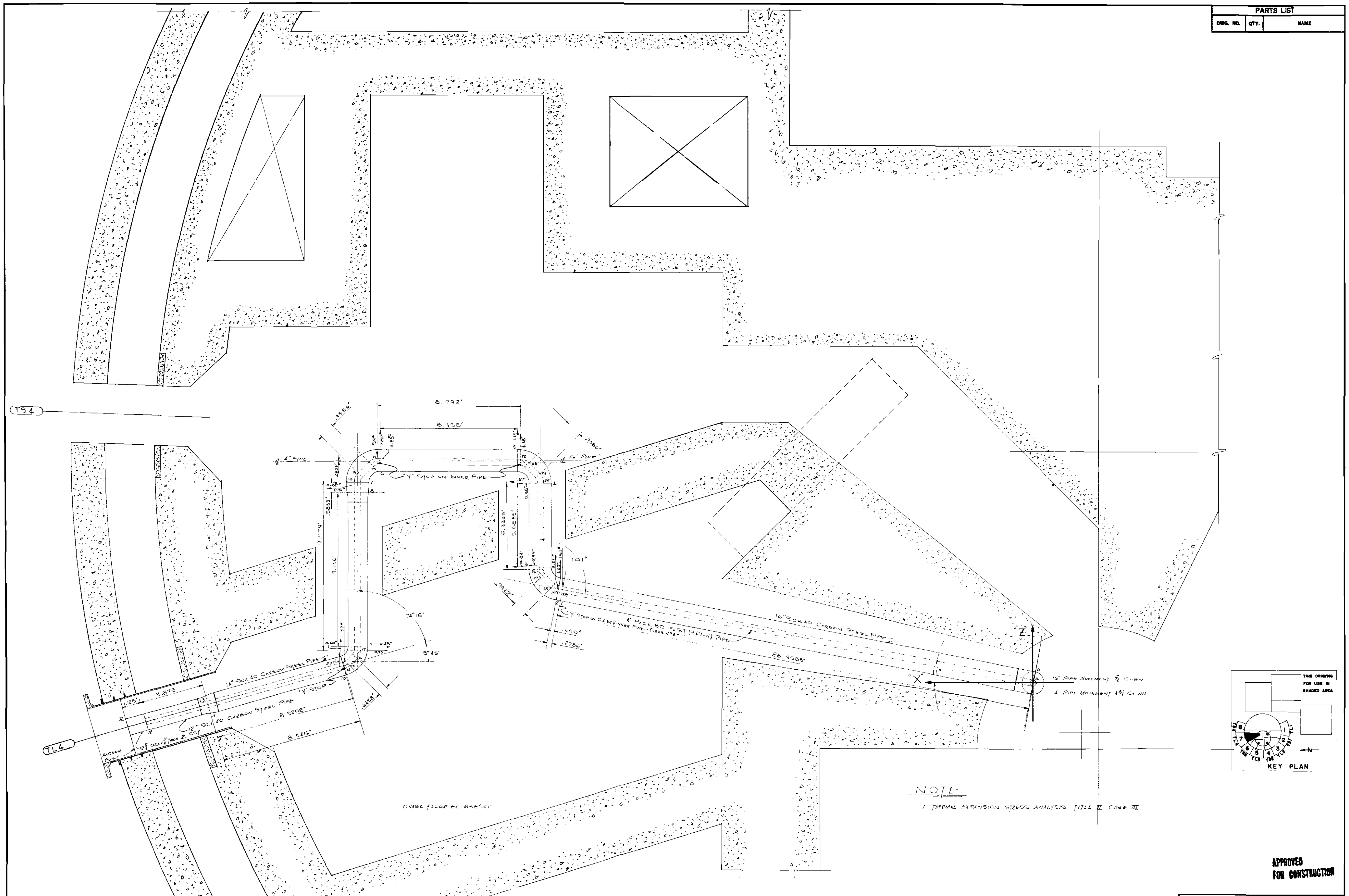
SCALE AS NOTED

F-RD-10286


SERVICE FLOOR
EL. 910'-2"
NOT SHOWN IN TRUE POSITION
EL. 904'-5"
18 REF.
8 1/2 REF.
13 1/8 REF.
18 1/2 REF.
31 1/4 REF.
7 1/4 REF.
56 1/8 REF.
61 1/8
64 1/8 REF.
71 REF.
10° REF.
B
A

SECTION A-A


PARTS LIST
NOZZLE EXTENSION
BREECH PLUG
BREECH ADAPTOR
CAP
FLOW GUIDE WELDT
FLOW GUIDE WELDMENT
GAGE PLATE
ADAPTER
SPACER BAND
SECTION "A-A"
SECTION "B-B"
THRU TUBE ADAPTOR
EL. 839-3
NOTES:
1. ALL MATERIAL TO HAVE CERTIFIED CHEMICAL ANALYSIS AND MFG CERT
2. PRIMARY CONTAINMENT - DESIGN PRESSURE 1100 PSI @ 975 °F
TEST PRESSURE 1900 PSI @ 70 °F
SECONDARY CONTAINMENT DESIGN PRESSURE 750 PSI @ 250 °F
TEST PRESSURE 940 PSI @ 70 °F
ASME BOILER & PRESSURE VESSEL CODE SECT III
3 - DIAMETERS AND TO BE CONCENTRIC WITHIN
4 - ALL CONNECTIONS TO THE ASSY SHALL BE BLANKED OFF AND THE ASSY SHALL RECEIVE A HELIUM LEAK CHECK IN ACCORDANCE WITH THE TOTAL LEAK RATE SHALL NOT BE GREATER THAN STD CC HELIUM PER SEC.
5 - SEE SPEC NO. FOR INTERPRETATION OF WELD DESIGNATIONS.
KEY PLAN
BILL OF MATERIAL
REFERENCE DRAWINGS
OAK RIDGE NATIONAL LABORATORY
BOTTOM NOZZLE TEE SECTION ASSY
THRU TUBE
FULL HALF
E-10250-C

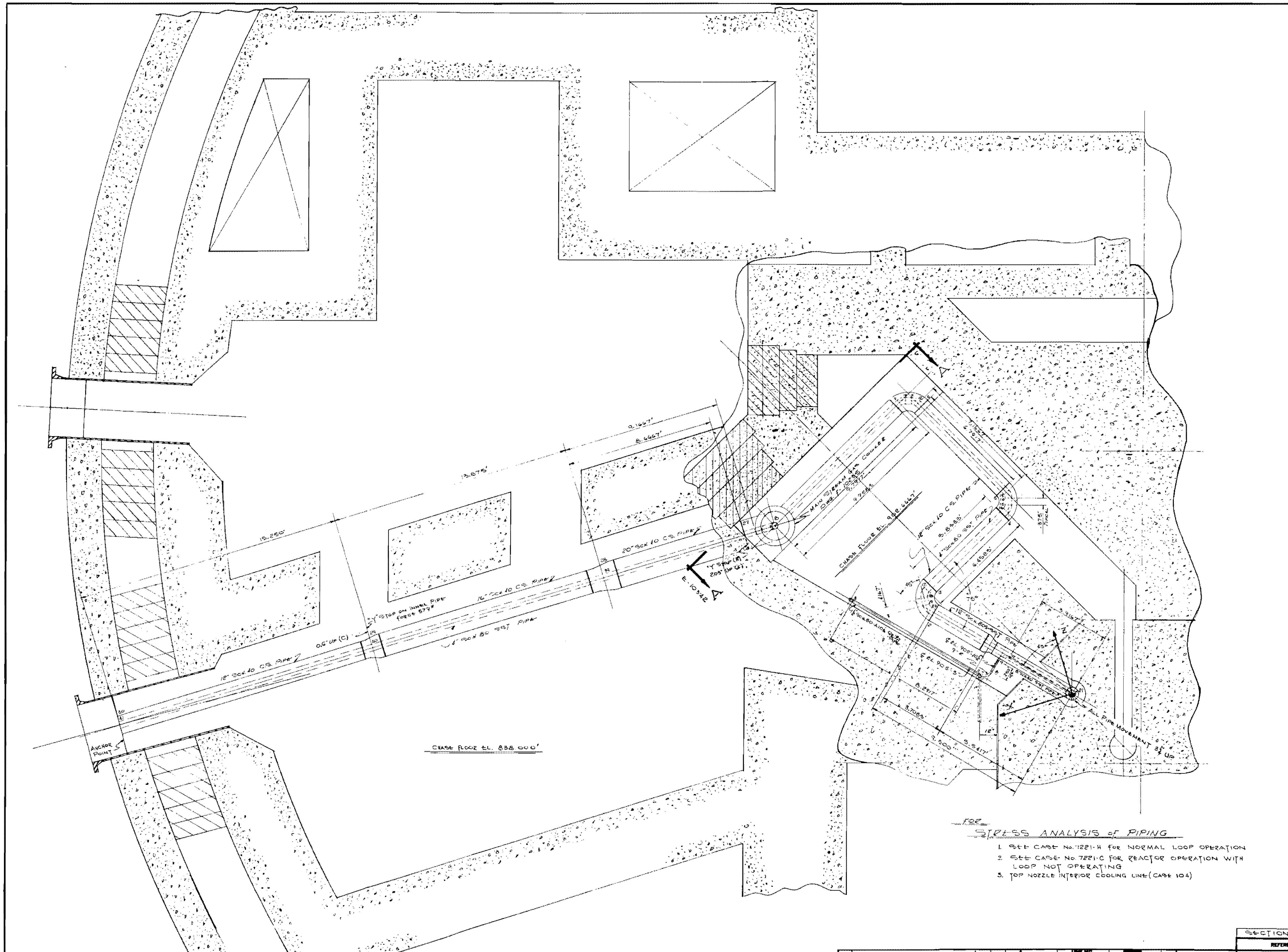


REFERENCE DRAWINGS		DWG. NO.
OAK RIDGE NATIONAL LABORATORY		
STRESS ANALYSIS of TL4 INLET PIPING PLAN		
E.G.C.R. MAIN STREAM LOOP PIPING		
JOB A-4.3	TITLE II	E-RD-10171

Chmielewski 4/4/61; E.C. Miller 4-19; G.D. Whitman 4-20; AEC L.H. Jackson 5/5/61
DESIGN ENGINEER T.W. Pickel 4/6/61; DRAWN Hobey Thomas 4/4/61; CHECKED W.A. Bush 4/6/61

BREAK ALL SHARP EDGES UNLESS OTHERWISE SPECIFIED.
TOLERANCE UNLESS OTHERWISE SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SCALE 1/2" = 1.000'

REVISION | BY | DATE | APP.



FOR STRESS ANALYSIS of PIPING

1. SEE CASE No. 7221-H FOR NORMAL LOOP OPERATION
2. SEE CASE No. 7221-C FOR REACTOR OPERATION WITH LOOP NOT OPERATING
3. TOP NOZZLE INTERIOR COOLING LINE (CASE 104)

APPROVED FOR CONSTRUCTION

REFERENCE DRAWINGS	DWG. NO.
SECTION A-A - LOOP TL4	E-RD-10342

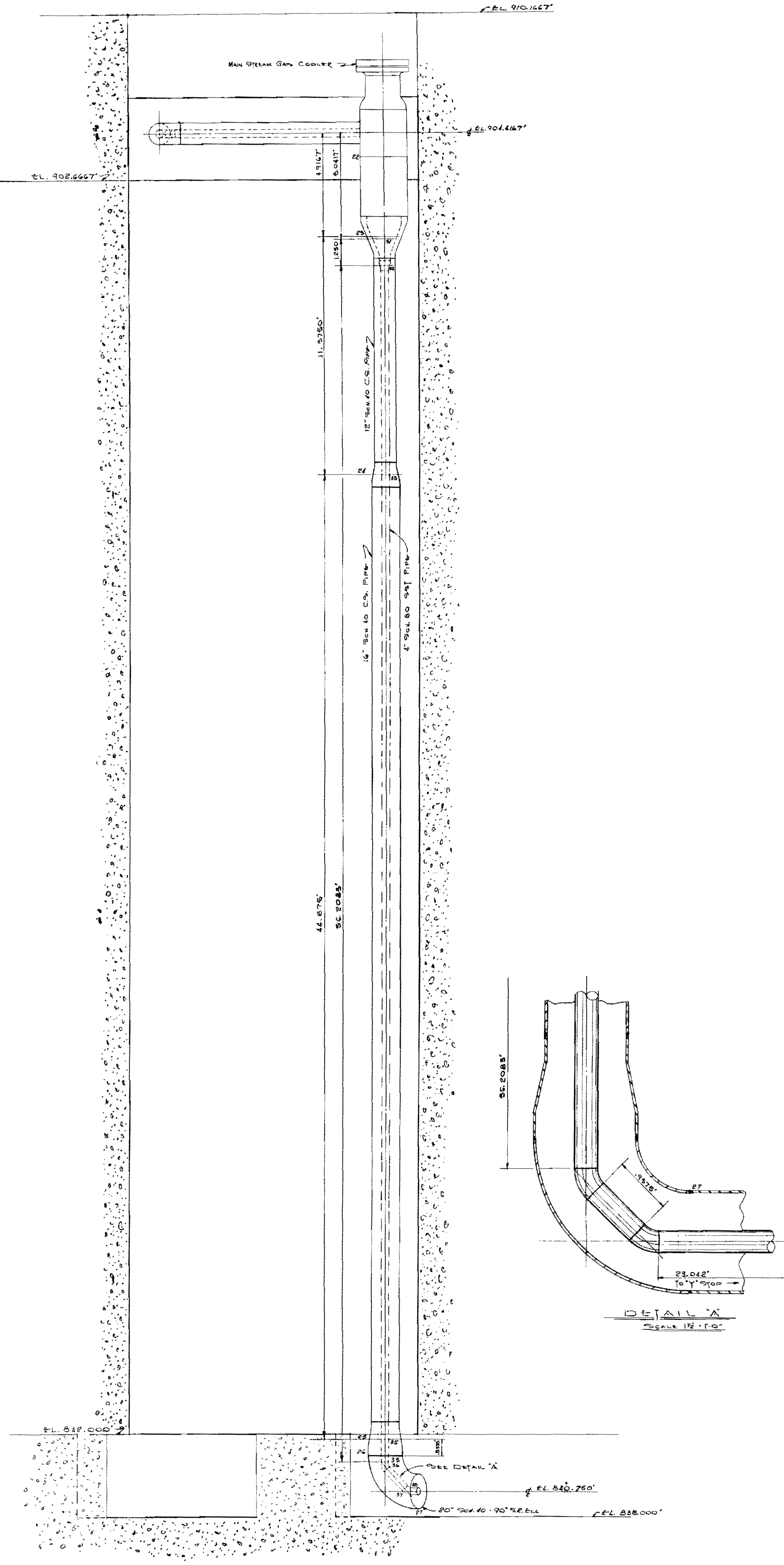
OAK RIDGE NATIONAL LABORATORY

STRESS ANALYSIS of TL4 OUTLET PIPING PLAN

EGCR MAIN STREAM LOOP PIPING

E.C. Miller 4-19 · G.D. Whitman 4-20 · L.H. Jackson · T.W. Pickel · W.A. Bush

SCALE 1/4" = 1.000' · JOB A-4.1 · TITLE II · E-RD-10341



SECTION A-A
SCALE ½"-1.000'

APPROVED FOR CONSTRUCTION

REFERENCE DRAWINGS	DWG. NO.
OUTLET PIPING PLAN	E-20-10341

OAK RIDGE NATIONAL LABORATORY

STRESS ANALYSIS of TL4 OUTLET PIPING - SECTION A-A
E.G.C.R. MAIN STREAM LOOP PIPING

SCALE ½"-1.000' | JOB A 42 | TITLE II | E-20-10342

C.D. WHITMAN 4-20 · E.C. MILLER 4-19 · L.V. JACKSON 5/9/61 · T.W. ROXBE 4/4/61 · BOBBY THOMPSON 4/4/61 · W.A. BUSH 5/9/61

APPENDIX C. EXAMINATION OF IN-PILE SECTION DESIGN CRITERIA FOR HYDROGEN

1. Nomenclature

Fuel Element

A	Free flow area, ft^2
C	Wetted perimeter, ft
D	Equivalent diameter, ft
F	Fission heat per unit length, kw/ft
f	Friction factor
h	Film coefficient, $Btu/hr \cdot ft^2 \cdot {}^\circ F$
H	Head loss, ft
K	Entrance and exit loss coefficient
L	Length, ft
ΔP	Pressure drop, psi
p	Total fission heat, kw
S	Heat transfer surface, ft^2
t_s	Average surface temperature, °F

Cooling Fluid

C_p	Specific heat, $Btu/lb \cdot {}^\circ F$
g	Gravitational constant, 32 ft/sec^2
k	Thermal conductivity, $Btu/hr \cdot ft \cdot {}^\circ F$
M	Mass flow rate, lb/hr
P	Absolute pressure, psi
t_1	Inlet temperature, °F
t_2	Outlet temperature, °F
t_a	Average temperature, °F
V	Average velocity, ft/hr
W_p	Pumping work, kw
μ	Viscosity, $lb/ft \cdot hr$
ρ	Density, lb/ft^3

2. Procedure

The design pressure drop for the in-pile section of the loop was determined from the following formula:

$$\frac{W_p}{p} = 0.02 \quad . \tag{1}$$

The conservation of heat energy within the system was assumed to be satisfied by the following set of equations:

$$p = FL = \frac{hS(t_s - t_a)}{3413} = \frac{MC_p(t_2 - t_1)}{3413} \quad , \tag{2*}$$

where

$$h = 0.023 \, \frac{k}{D} \left(\frac{\rho DV}{\mu}\right)^{0.8} \left(\frac{\mu C_p}{k}\right)^{0.4} \quad . \tag{3*}$$

The pressure drop across the fuel element due to the mass flow rate required by (2) was assumed to be:

$$\Delta P = \frac{\rho}{(3600)^2} \left(\frac{fL}{D} + K\right) \frac{V^2}{2g} \quad , \tag{4*}$$

where K represents the velocity head losses due to entrance and exit conditions in the fuel element. The equivalent diameter in (3) and (4) was assumed to take the form

$$D = \frac{4A}{C} \quad . \tag{5}$$

---

*All gas constants evaluated at $t_a = \dfrac{t_1 + t_2}{2}$.

The following equation was used for velocity determinations:

$$V = \frac{M}{\rho A} \quad . \tag{6}$$

The simultaneous solution of (2) yielded:

$$\frac{S^{0.8}C^{0.2}}{A} = 292 \left(\frac{FL}{S}\right)^{0.2} \frac{(t_2 - t_1)^{0.8}}{(t_s - t_a)} \left(\frac{\mu C_p}{k}\right)^{0.4} \frac{1}{k^{0.2}} \quad . \tag{7}$$

This equation describes the basic geometric requirement for heat transfer to equal heat transport for any fuel element system and cooling fluid; the geometric quantity $SC^{0.2}/A$ and the mass flow rate are fully defined by the selection of power level, operating temperatures and pressure, and the cooling fluid.

The pressure drop in the fuel element due to the required mass flow rate was

$$\Delta P = 0.014 \frac{S^2}{A^2} \left(\frac{fLC}{4A} + K\right) \left(\frac{FL}{S}\right)^2 \left(\frac{1}{\rho C_p^2}\right) \frac{1}{(t_2 - t_1)^2} \quad . \tag{8}$$

The determination of pressure drop for any combination of geometric, power, and gas constants required simultaneous solution of (7) and (8).

The hydrogen loop design conditions were examined with the aid of (7) and (8) in the following form and the physical properties listed in Table C.1:

$$\frac{S^{0.8}C^{0.2}}{A} = G_1 \frac{\left(\frac{FL}{S}\right)^{0.2}}{(t_s - t_a)} \quad , \tag{9}$$

$$\Delta P = G_2 \left(\frac{fLC}{4A} + K\right) \left(\frac{FL}{S}\right)^2 \left(\frac{S}{A}\right)^2 \quad , \tag{10}$$

$$G_1 = 292(t_2 - t_1)^{0.8} \left(\frac{\mu C_p}{k}\right)^{0.4} \frac{1}{k^{0.2}} \quad , \qquad (11)$$

$$G_2 = 0.014 \left(\frac{1}{\rho C_p^2}\right) \frac{1}{(t_2 - t_1)^2} \quad . \qquad (12)$$

The G values obtained are presented in Table C.2.

Table C.1. Physical Properties of Hydrogen and Helium at 315 psia

Physical Property	Hydrogen		Helium	
	At 825°F	At 1000°F	At 825°F	At 1000°F
k, Btu/hr·ft·°F	0.211	0.237	0.154	0.167
ρ, lb/ft^3	0.046	0.041	0.091	0.081
μ, lb/ft·hr	0.0388	0.0422	0.091	0.099
C_p, Btu/lb·°F	3.48	3.48	1.241	1.241
$\mu C_p/k$	0.640	0.620	0.733	0.736
μC_p^2	0.556	0.495	0.140	0.124

Table C.2. G Values for Loop Design Conditions

Pressure (psia)	t_1	t_2	Parameter	Hydrogen	Helium
315	600	1050	G_1	4.43×10^4	5.00×10^4
			G_2	1.24×10^{-7}	4.93×10^{-7}
315	950	1050	G_1	1.28×10^4	1.48×10^4
			G_2	2.83×10^{-6}	11.25×10^{-6}

A direct comparison of pressure drop and the ratio $S^{0.8}C^{0.2}/A$ for cooling gases a and b at a given operating point was made by comparing the respective G values indicated by the following equations:

$$\left(\frac{S^{0.8}C^{0.2}}{A}\right)_a = \frac{G_{1a}}{G_{1b}} \frac{\left(\frac{FL}{S}\right)_a^{0.2}}{\left(\frac{FL}{S}\right)_b^{0.2}} \frac{\left(t_s - t_a\right)_b}{\left(t_s - t_a\right)_a} \left(\frac{S^{0.8}C^{0.2}}{A}\right)_b \quad , \tag{13}$$

$$\Delta P_a = \frac{G_{2a}}{G_{2b}} \frac{\left(\frac{fLC}{4A} + K\right)_a}{\left(\frac{fLC}{4A} + K\right)_b} \frac{\left(\frac{FL}{S}\right)_a^2}{\left(\frac{FL}{S}\right)_b^2} \frac{\left(\frac{S}{A}\right)_a^2}{\left(\frac{S}{A}\right)_b^2} \Delta P_b \quad . \tag{14}$$

A study of the original design criteria, as stated by (1), was performed to determine its applicability to hydrogen cooled systems by applying the following defining equation, in which pumping power is the work required per unit time to move a given mass per unit time against a given restricting force:

$$W_p = \frac{MH}{2.66 \times 10^6} = \frac{M \, \Delta P}{2.66 \times 10^6} \quad . \tag{15}$$

Equations (2) and (15) were then combined to give:

$$\begin{aligned} W_p &= 1.28 \times 10^{-3} \frac{FL}{C_p(t_2 - t_1)} H \\ &= 1.28 \times 10^{-3} \frac{FL}{C_p(t_2 - t_1)} \frac{\Delta P}{\rho} \quad . \end{aligned} \tag{16}$$

In order to select a reasonable basis for designating a value for W_p for various gases, the following argument was considered. Equation (16) showed the pumping power required for a given fuel element with a fixed power output and a set temperature-pressure environment to be directly proportional to the pressure drop in the fuel element and inversely proportional to (ρC_p) for the given gas. It was therefore proposed that an arbitrary value for W_p be assigned only for a specific gas (h = helium) in a given temperature-pressure environment, and that, in the absence of a detailed pressure drop study of other gases in the same environment, the value of W_p for some other gas (a) should be adjusted to the standard created for gas (h) by the following equation:

$$(W_p)_a = (W_p)_h \frac{P_a}{P_h} \frac{(\rho C_p)_h}{(\rho C_p)_a} = (W_p)_h \frac{H_a}{H_h} \frac{(C_p)_h}{(C_p)_a} \quad . \tag{17}$$

In order to facilitate the simultaneous solution of (13) and (14), the heat transfer coefficient was held constant, thus holding S constant for a given fuel surface temperature. The ratio $C^{0.2}/A$ was used to adjust the flow geometry for each gas. (This assumed space was available to make the required channel adjustment.) The variation of $C^{0.2}$ was negligible compared with the change in A. In all cases K was assumed large compared with fLC/4A. The following simplified equations resulted:

$$A_a = \left(\frac{G_{1h}}{G_{1a}}\right) A_h \ , \tag{18}$$

$$\Delta P_a = \left(\frac{G_{2a}}{G_{2h}}\right) \left(\frac{A_h}{A_a}\right)^2 \Delta P_h \ , \tag{19}$$

$$H_a = \left(\frac{G_{2a}}{G_{2h}}\right) \left(\frac{\rho_h}{\rho_a}\right) \left(\frac{A_h}{A_a}\right)^2 H_h \quad . \tag{20}$$

APPENDIX D. PHYSICAL PROPERTIES OF HYDROGEN

Contents

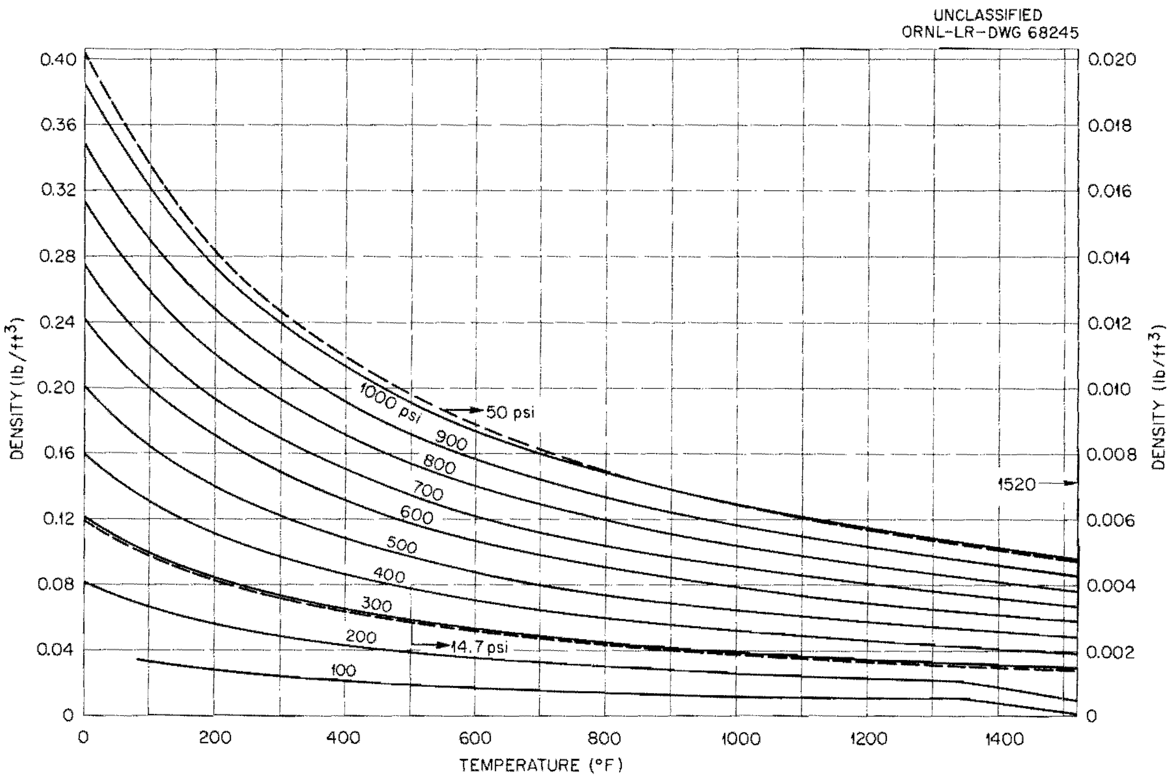


Fig. D.1. Hydrogen Density as a Function of Temperature and Pressure.

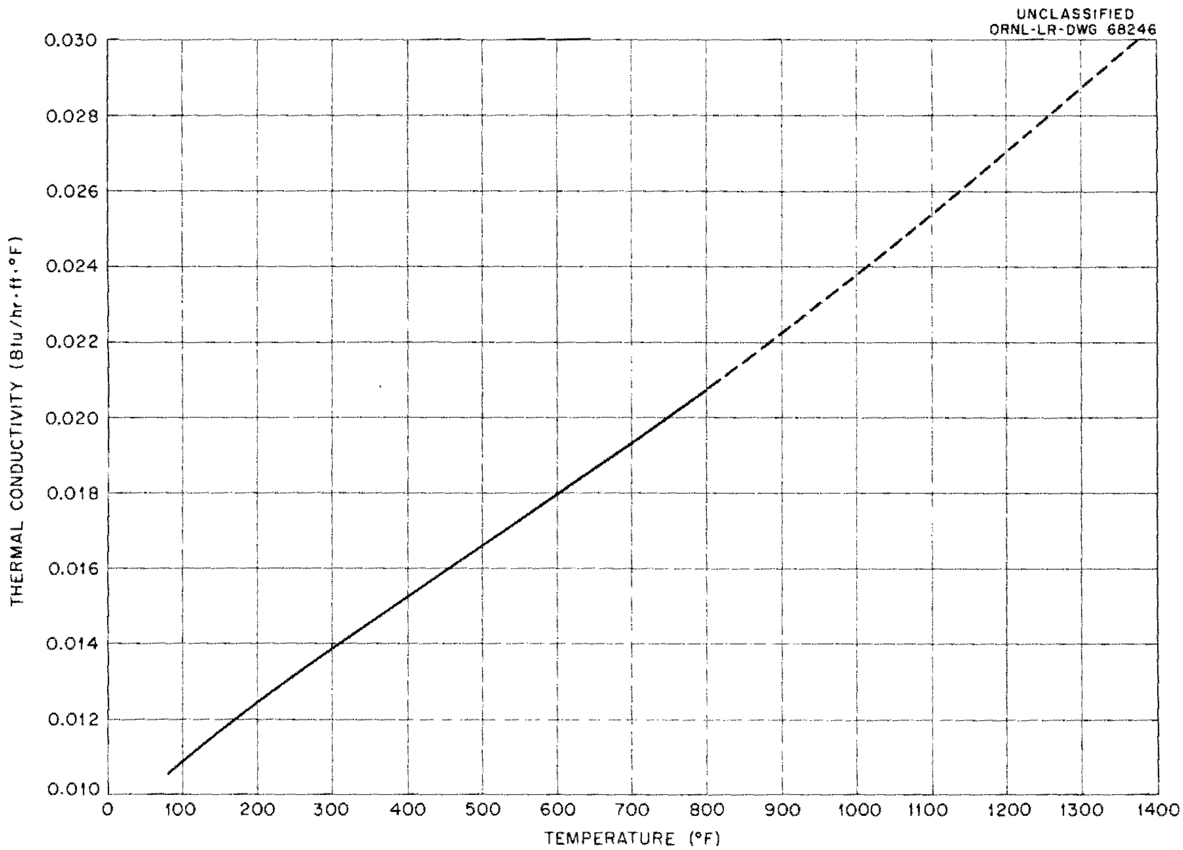


Fig. D.2. Thermal Conductivity of Hydrogen at Atmospheric Pressure. Taken from "Thermal Properties of Gases," National Bureau of Standards Document NBS-564.

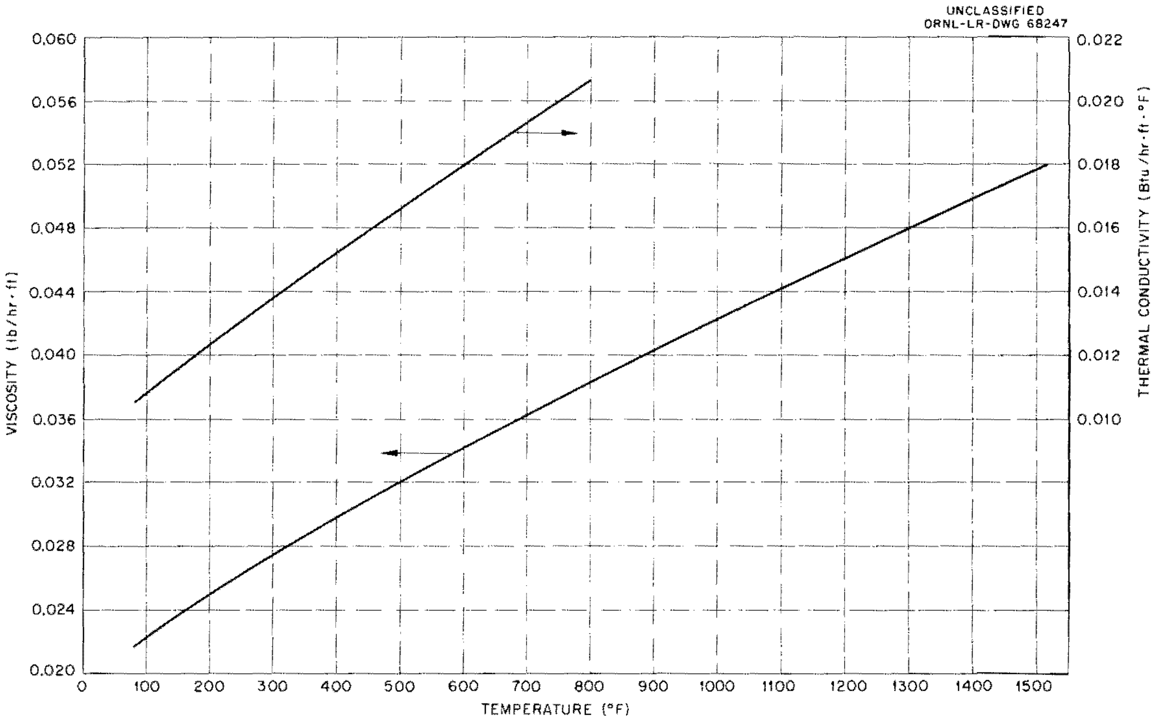


Fig. D.3. Thermal Conductivity and Viscosity of Hydrogen at Atmospheric Pressure. Taken from "Thermal Properties of Gases," National Bureau of Standards Document NBS-564.

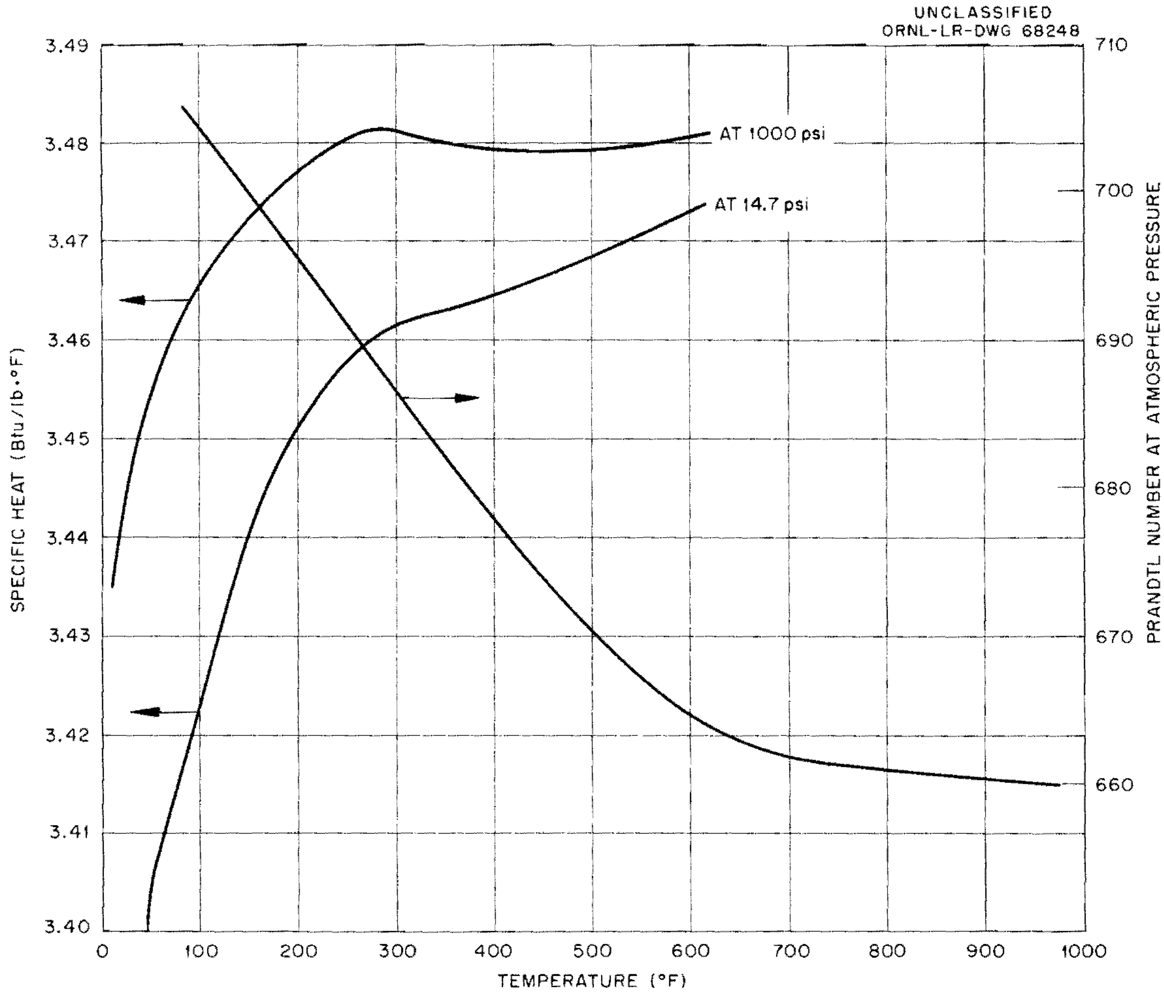


Fig. D.4. Specific Heat and Prandtl Number of Hydrogen. Taken from "Thermal Properties of Gases," National Bureau of Standards Document NBS-564.

APPENDIX E. LOOP OFFGAS SYSTEM DESIGN

1. Component Description

Charcoal Trap

The charcoal trap consists of a roughing filter, a charcoal bed, and an absolute filter contained in one pressure vessel. The absolute filter has a minimum efficiency of 99.97% for 0.3-μ particles and is suitable for operation up to 250°F in a high-humidity atmosphere. The pressure vessel is designed for 500 psig at 250°F.

Heater

The heater is used to raise the temperature of the incoming gas to 400°C before entering the CuO bed. This unit is composed of a pipe wrapped with electrical resistance wire with proper overtemperature protection.

CuO Bed

The CuO bed[1] consists of a pressure vessel packed with porous pellets of CuO, 1/8 in. in diameter and 1/8 in. long. The pellets are packed in the bed and sintered to obtain a specific gravity of approximately 3.0. In order to oxidize at least 99% of the hydrogen in the bed, approximately 1.25 times the stoichiometric amount of CuO is required. To provide a margin of safety, at least 1.5 times the stoichiometric quantity of CuO is used. For the 4 lb of hydrogen contained in the loop, this corresponds to approximately 240 lb of CuO or a bed volume of 1.28 ft^3. Since a high hydrogen velocity through the bed is desirable, the bed should have a minimum length-to-diameter ratio of 3. A pressure vessel composed of a 16-in.-long piece of 4-in. sched.-80 pipe was selected for the bed. This vessel is designed to hold 500 psig at 1000°F.

The CuO bed and the gas being processed must be kept at a temperature of 400 to 600°C to assure complete oxidation; therefore, the bed is equipped with electrical heaters to preheat the system prior to passing hydrogen

[1]Information on CuO Beds was obtained from C. D. Scott of ORNL, who has conducted many experiments with these beds.

through it. Since the reduction of CuO is an exothermic reaction, little additional heat is required once the reaction has started. The reaction takes place over a narrow band in the bed starting at the inlet end and propagating through it as the CuO is reduced. The effluent steam is released to a condenser at essentially the temperature of the bed.

The CuO bed can be recharged. Experimental beds that have been cycled as many as four times have been recharged to 75% of full CuO capacity in a 24-hr period. Recharging is accomplished by passing an oxidizing atmosphere through the bed or simply by pressurizing the bed with such an atmosphere, although the latter method takes longer. The recharging procedure is initiated with air and completed with pure oxygen. The air prevents excessive temperatures from developing in the bed initially because of the exothermic reaction. As in the case of the reduction reaction, the bed is maintained at 400 to 600°C during the recharging operation. Recharging cannot be performed when cell atmosphere control is required.

Condenser

The condenser located downstream of the CuO bed condenses the steam effluent from the bed and cools the noncondensible gases. The heat is transferred to service water flowing through the shell side of the unit.

Liquid Trap

The liquid trap collects any moisture entrained in the loop offgas. If the liquid in the trap exceeds a certain level, an automatically controlled drain valve (V-29) will open and drain some of the fluid to the experimenters' cell drain. A manually-operated valve (V-30) is located at the low point in the trap to permit drainage of the entire tank. A fill line, containing a manually operated valve (V-28) is also provided on the trap in the event additional water is desired for dilution purposes. The tank is designed to contain 500 psig at 250°F.

Vacuum Pump

The vacuum pump is a standard vacuum pump with a free air capacity of not less than 50 scfm. It is capable of producing a 0.01-mm-Hg vacuum.

The pump lubricant is a radiation-resistant fluid. The suction side of the pump contains a trap to prevent back diffusion of the pump lubricant into the loop, while the discharge side contains a separator to prevent loss of lubricant. Cooling water is supplied to the pump at 0.5 gpm and 50 psig.

Air Filter

Air entering the loop offgas system from the experimenters' cell passes through an absolute filter. The minimum efficiency of this filter is 99.97% for 0.3-μ particles. A prefilter is used to remove the gross particulate matter. Both filters are suitable for operation in a high-humidity atmosphere at temperatures up to 250°F.

2. System Operation

The offgas system is designed to safely discharge contaminated gas to the EGCR stack via the ventilation system exhaust header. Prior to loop filling the system is used for loop evacuation. When the loop is operating at power, the system is used to operate the sampling-station equipment, to evacuate the mechanical-joint monitoring chambers, to remove some of the cell atmosphere, and occasionally to discharge gas from the gas storage tanks. Following reactor shutdown, the system is used to blowdown the loop. It is also used during decontamination of the loop.

Loop Evacuation

Prior to filling the loop with clean gas, the entire loop must be evacuated to remove all gaseous contaminants. To facilitate this operation, a manually-operated valve (V-35), which is locked and tagged in the closed position during loop operation, is opened to permit the loop to be evacuated through a 2-in. line instead of the 1/2-in. line containing valve V-1. Loop evacuation is performed with valve V-25 open and valves V-40 and V-17 closed and requires a minimum of 1 hr.

Sample Removal and Mechanical-Joint Evacuation

At various times during loop operation, it will be necessary to remove a sample of loop gas with the sampling system or to evacuate the chamber between the seals of the mechanical joints (see Sec. 2.11). Both these operations involve evacuation of the individual systems. The mechanical-seal system evacuation is accomplished through motor-operated valve V-38 and block valve V-39, and sampling-station evacuation is obtained through motor-operated valve V-37. Since a very small quantity of loop gas is involved in these operations compared with the volume of the system being evacuated and the volume of the experimenters' cell, it is planned that the gas will be passed through the charcoal trap and exhausted to the cell atmosphere with no attempt made to oxidize the hydrogen.

The gas from either system passes through a check valve (V-24) and a block valve (V-5) to the heater, CuO bed, and condenser. The heater and CuO bed are not at temperature. From the condenser, the gas flows to the vacuum pump through valves V-31, V-9, V-14, and the reducing station. The vacuum pump exhausts the gas through check valve V-42, the charcoal trap, and valve V-40 into the experimenters' cell. Shutoff valves V-25 and V-17 are both closed during this operation.

If the activity level in the cell is high, it may not be desirable to dump additional gas into the cell. In this event, the heater and CuO bed will be heated to oxidize any hydrogen in the offgas. The exhaust from the vacuum pump will then be transferred to the ventilation system exhaust header via the charcoal bed and a shutoff valve (V-25). Valve V-40 will be closed.

Cell Evacuation

Should the activity level of the cell atmosphere leaving the cell vent line during a venting operation exceed a given level, the cell vent valves close automatically. Since a subsequent addition of gas might force shutdown of the loop due to high cell pressure, provisions have been made to remove the cell overpressure through the loop offgas system. The cell atmosphere is drawn through an absolute filter, a motor-operated valve (V-22), and a check valve (V-21) into a common header with the sampling-station and mechanical-seal evacuation lines. From this header, the gas follows the same path as for the other two systems, except that the gas is exhausted to the ventilation system exhaust header through a shutoff valve (V-25) instead of into the experimenters' cell. If the cell pressure is not too high, the cell atmosphere can be "cleaned up" by circulating it through the offgas system and exhausting it back to the cell through valve V-40.

Loop Blowdown

Loop blowdown or depressurization (controlled discharge of all gas from the mainstream loop piping and auxiliary systems) is the operation that releases the largest amount of activity to the ventilation system exhaust header, and it also releases the largest amount of hydrogen to the loop offgas system. The valving arrangement shown in Fig. E.1 is positioned for a loop blowdown.

During loop depressurization, the loop gas is transferred to the gas storage tanks from where it is fed to the offgas system. The gas from the storage tanks is fed to the offgas system through a manually-operated block valve (V-1), a motor-operated valve (V-2), and a check valve (V-3) to the charcoal trap. From the charcoal trap, the gas passes through a back-pressure regulator (V-4) and a manually-operated block valve (V-5) to the heater. In the heater, it is heated to approximately 400°C (752°F) prior to entering the CuO bed where the hydrogen is oxidized to steam. The effluent of the CuO bed then passes through a condenser where the steam is condensed and the noncondensible gas cooled. The condensate-gas mixture then passes to the liquid trap through a back-pressure regulator (V-6) and a check valve (V-7).

The condensate is separated in the liquid trap, and the noncondensible gases pass through a back-pressure regulator (V-8) and a check valve (V-9) to a pressure-reducing station containing four pressure-regulating valves (V-10 through V-13 in two parallel branches, each containing two valves in series). The reducing station reduces the exit gas pressure to 15 psia to prevent overpressurization of the vacuum pump. The gas then passes through a manually operated block valve (V-14) to the vacuum pump or to a bypass check valve (V-20). The gas then flows or is pumped through a motor-operated shutoff valve (V-17) and two check valves in series (V-18

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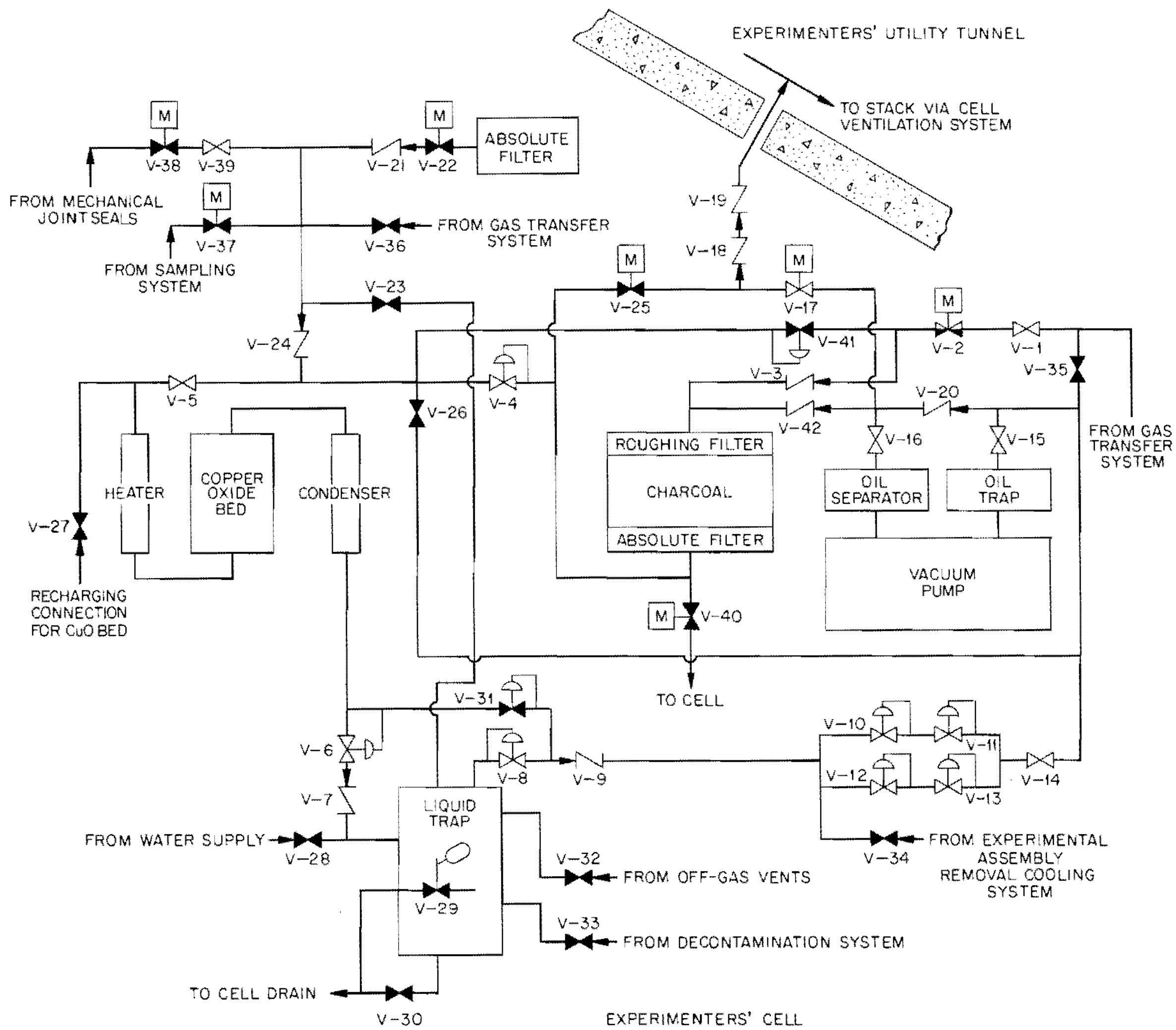

Fig. E.1. Hydrogen Loop Offgas System.

and V-19) to the ventilation system exhaust header in the experimenters' utility tunnel.

This process continues until the loop pressure reaches 20 psia. At this point, the back-pressure regulating valves V-4, V-6, and V-8 close. The vacuum pump decreases the pressure until, at 14 psia, shutoff valve V-17 closes and shutoff valve V-25 opens. When the system pressure reaches 12 psia, pressure-regulating valves V-31 and V-41 open. These valving operations isolate the liquid trap from the system and prevent the pump from drawing a vacuum on the charcoal trap. Under this valving arrangement, the loop gas flows through valves V-1, V-2, V-41, and V-5 to the heater, CuO bed, and condenser. It then flows through valves V-31, V-9, etc., to the ventilation system exhaust header.

By having two flow systems, most of the loop gas is filtered and passed over activated charcoal before it flows through the balance of the system. This considerably reduces the fission-product deposition and contamination of the other loop offgas components.

Decontamination Gas Removal

Decontamination of the loop (see Sec. 6.2) will be accompanied by the evolution of gases. These gases, principally decomposition products of the decontamination reagents and water vapor, are removed from the loop piping by the loop offgas system. During this process, valves V-32, V-33, V-23, V-26, and V-25 are opened and valve V-5 is closed. Any liquid and water vapor entering the lines is collected in the liquid trap. After the decontamination process has been completed, the resulting solution in the liquid trap can be drained to the warm waste system via valve V-30 and the cell drain.

To facilitate draining liquids from the loop components, the loop offgas sytem contains a "breather" which admits air to the loop via a vent line. This "breather" is the same system as that used to exhaust the cell atmosphere through the offgas system during loop operation. A check valve (V-21) prevents backflow of gases into the experimental loop, and the absolute filter prevents any particulate matter from entering or leaving the system.

3. Interlocks

To prevent misoperation of the loop offgas system, a number of electrical permissive interlocks are installed on the motor-driven valves. Valves V-17, V-25, and V-40 are interlocked so that no valve can be opened unless the other two are fully closed. Valves V-17 and V-2 are interlocked so that it is impossible to open valve V-17 until valve V-2 is fully opened. In addition, valve V-17 automatically closes when the pressure at valve V-2 drops to 14 psia. Another interlock on valve V-2 prevents opening of this valve unless the heater and CuO bed are at operating temperature. A radiation monitor located on the ventilation system exhaust header next to the cell warns of excessive radiation levels in the experimenters' utility tunnel. Should the radiation level in the utility tunnel exceed some maximum limit, the monitor will close shutoff valves V-17 or V-25 and the supply valve V-2 if it is open. These interlocks are designed to prevent inadvertent release of either highly contaminated gas or flammable hydrogen to the ventilation system exhaust header.

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