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THE BMI-16 RECIRCULATING GAS LOOP
INSTALLED AT THE ETR

by

Joseph V. Baum
Gerald A. Francis

Aided in work by

Harold M. Epstein
Sherwood L. Fawcett
Donald W. Frink
Earle O. Fromm
Donald L. Keller
George E. Manning
Albert M. Rockwood
Donald E. Roop
John A. Smith
Wallace J. Stevens
Michael U. Widman
Marvin L. Yeager

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BATTELLE MEMORIAL INSTITUTE
505 King Avenue
Columbus 1, Ohio

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THE BMI-16 RECIRCULATING GAS LOOP INSTALLED AT THE ETR

Joseph V. Baum and Gerald A. Francis

A developmental program was conducted to provide an in-pile loop facility for use in evaluating gas-cooled-reactor fuel subassemblies. The program included the design, construction, and installation of a recirculating gas loop which is located in a 6 by 6-in. facility in the aluminum reflector of the ETR.

The loop system was designed to recirculate the primary nitrogen coolant at flow rates up to 0.9 lb per sec and pressures up to 200 psia. It will accept fuel subassemblies up to 36 in. in length and 2.26 in. in diameter with specimen power generation up to 150 kw. The maximum coolant temperature at the specimen outlet is set at 1500 F.

The loop system includes the in-reactor section, the machinery, the control system, and the specimen-handling apparatus.

Salient features of the re-entrant system include an aluminum pressure wall in the in-reactor section, static gas insulation between the reactor coolant and the circulating loop gas, and a controllable rate of heat exchange between the specimen inlet- and specimen outlet-gas channels in sections of concentric counterflow piping. The three blowers in the system feature grease-lubricated bearings and water cooling.

The complete system was tested out of pile and is now installed in the ETR.

INTRODUCTION

An in-pile recirculating gas loop was constructed for use in materials evaluations associated with the Army Gas-Cooled Reactor System Program. The high-temperature loop system is designated BMI-16 and is installed in the ETR. Plans call for initial use of the loop in support of the GCRE program which is being performed by Aerojet General Nucleonics.

The in-reactor loop provides an environment which simulates as nearly as possible, the conditions which were expected to exist in the reactor which was yet to be developed. The loop provides coolant flow and temperature conditions at the specimen which are virtually independent of the test-reactor operating conditions. The loop permits the evaluation of a fuel subassembly operating at reference reactor conditions without the program cost and risk which would be associated with the operation of a full reactor experiment.

The loop is designed for both materials and engineering research. Data from both the operation and postirradiation examination of a test specimen are important to an over-all reactor program. The operational data can yield information on temperature

profiles, heat transfer, and the effects of varying coolant flows and specimen inlet-gas temperatures and pressures. Reactor-related parameters which can also be studied include instrumentation, diffusion of gaseous fission products, effect of irradiation on coolant chemistry, effectiveness of filter system, plate-out of fission products in the system, and fuel-handling methods.

Important information which can be obtained by postirradiation examination of a test specimen includes the dimensional stability of the specimen, the corrosion and erosion characteristics, the total fuel burnup, and the combined effects of radiation damage and vibration on the specimen materials.

Any of the items normally revealed in the postirradiation examination can become manifest during the period of loop operation. In fact, one of the purposes of a loop is to permit manifestation of system nuclear and mechanical problems without generating problems of the magnitude which would be encountered in the operation of a full reactor core at reference conditions. To this end an in-reactor loop is an important tool in nearly all reactor development programs.

During the gas-cooled-reactor materials program being performed by the Army Reactors Branch of the AEC, the need for loop evaluation of full-size fuel subassemblies was recognized. A loop reported in BMI-1290 was designed, constructed, installed, and operated at the Battelle Research Reactor. Soon after construction of the BRR loop was initiated, the design of the BMI-16 loop for the ETR was started. The BMI-16 design was specified for the testing of advanced fuel specimens. Near the middle of the program direct sponsorship of the research was transferred from the Army Reactors Branch of the AEC to Aerojet General Nucleonics.

GENERAL DESCRIPTION OF THE LOOP FACILITY

In the BMI-16 loop a gas coolant is continuously recirculated past a fuel element located in the aluminum-reflector area of the ETR. Figure 1 is a layout of the over-all loop system. Inside the reactor vessel a vertical section extends from a point just above the grid plate in Reflector Positions B12, B13, C12, and C13 to a point 1 in. below the main reactor flange. The coolant gas enters and leaves the vertical leg at a tee located above the top SW (southwest) in-shield pipe flange. The loop piping leaves the reactor vessel through the SW in-shield pipe, makes a 90-deg bend in the sub-pile room and extends through the sub-pile-room nozzle, SU-7, into the BMI-16 cubicle. Means are provided for taking thermocouple and instrument pressure lines out from the reactor vessel through the angular nozzle, 8A-6.

The machinery and equipment necessary for circulating, cooling, heating, and regulating the gas flow is located in the BMI-16 cubicle, or machinery room, on the basement floor of the ETR building. The system control console is located near the southeast corner of the console floor. Electrical panels, junction boxes, pressure transmitters, and similar equipment are located near the machinery room in the basement. The fuel-element differential-pressure transmitter is located on the outside of the reactor wall just below the main floor and is accessible from the console floor.

FIGURE 1. SCHEMATIC LAYOUT OF BMI-16 LOOP INSTALLATION

Figure 2 is a schematic diagram of the loop and shows the major operating components as well as the gas-flow path through the system. The gas coolant is recirculated continuously through the loop. Starting at the bottom of the fuel subassembly or specimen, the gas flows upward through the element where heat is transferred from the specimen to the gas. The gas leaves the top of the specimen and continues upward through the center passage of a concentric pipe arrangement. The outlet gas is cooled by a transfer of heat through the innermost pipe wall to an adjacent annulus containing inlet gas. The outlet gas continues through the center passage of the concentric piping to the machinery room. The gas then enters a filter where any particulate matter is removed from the gas stream. Upon leaving the filter the gas enters one of two water-cooled heat exchangers provided in the system. Either heat exchanger can be selected for use at the control console. The gas is cooled in the heat exchanger and then enters the blower inlet header.

Centrifugal blowers receive the cool gas from the inlet header and pump it on to the outlet header. Three blowers are provided to circulate the coolant gas. The loop is operated with one blower. The second and third blowers are maintained in a standby condition for emergency use.

The electric heater is used to provide control of the temperature of the gas entering the diverter valve. The diverter valve divides the flow between two concentric annular passages surrounding the specimen outlet-gas passage. One annulus is adjacent to the hot outlet gas. The other annulus is surrounded by a cooling water jacket. The diverter valve is used to proportion the gas flow between the two annuli and thus controls, in part, the amount of heat exchange between the inlet gas and the outlet gas in the concentric piping. The two streams of entering gas are reunited at a point approximately 6 ft below the top SW in-shield pipe flange where the concentric piping enters the reactor vessel. As the gas continues through the inlet annulus, it receives heat from the outlet gas and loses heat to the reactor coolant until it reaches the bottom of the fuel element where the recycle begins.

DESIGN REQUIREMENTS

In the design of an in-pile loop facility, consideration must be given to both the requirements and limitations which are peculiar to the test reactor in which the facility is to be operated, and the requirements which are dictated by the purposes for which the loop is to be used.

A survey of the fuel-element-design studies under consideration led to the following design specifications for the loop operating conditions:

Coolant	Nitrogen gas plus additives
Gas pressure	200 psia
Gas-flow rate	0.9 lb per sec, maximum
Differential pressure across sample	10 psi

FIGURE 2. GAS-FLOW SCHEMATIC OF BMI-16 LOOP

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Gas temperature

Inlet to specimen	900 F
Outlet from specimen	1500 F

Maximum specimen dimensions

Round element	2.26-in. diameter by 36 in. long
Square element	1.6 in. square by 36 in. long

Maximum specimen power generation	150 kw
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The loop design is based on operation with clad specimens and the assumption that testing will stop in the event that coolant-gas activity exceeds a preselected value.

For design purposes the gamma heating of the piping surrounding the element was assumed to be 4 w per g. The midplane thermal-neutron flux in the vicinity of the fuel element was taken to be 1.23×10^{14} n/(cm²)(sec). The resulting calculated loop temperatures and heat transfer at design conditions are shown by Figure 3 and Figure 4, respectively.

DEVELOPMENT OF THE DESIGN CONCEPT

The design concept was influenced primarily by the restrictions and limitations imposed on it by the reactor facility in which the loop would be installed. Because the ETR is of the closed pressure-vessel type and because of the large number of other experiments using the reactor facilities, it was recognized that the installation of the in-reactor section of the loop must be as straightforward and simple as possible. This required that the in-pile section be permanently installed in a fixed location and that the number of points of entry into the pressurized vessel be held to a minimum. Early design calculations also indicated that some form of insulation would be required around the coolant-gas passages to reduce the transfer of heat from the gas to the reactor water.

Consideration of these factors led to the selection of a three-tube concentric pipe arrangement for the in-reactor section. By this arrangement it was possible to take both the cool gas flowing toward the element, and the hot gas flowing from the element, through the reactor wall at one point. Also, by making the gas passages concentric, one insulating barrier could be used for both passages. Further calculations indicated that a static gas chamber around the concentric piping should be sufficient to hold the heat losses to an acceptable value.

The center tube was selected to carry the hot gas from the sample. By flowing the cool inlet gas through the annular space adjacent to the center tube, the transfer of heat to the gas in the outside static chamber was held to a minimum. Because of the construction of the reactor facility it was necessary to continue the concentric tubing down through the concrete shield surrounding the reactor vessel and into the sub-pile room before the inlet and outlet passages could be separated. Having progressed to this point

FIGURE 3. LOOP TEMPERATURES AT DESIGN CONDITIONS

FIGURE 4. LOOP HEAT TRANSFER AT DESIGN CONDITIONS

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it was expedient to continue the concentric piping on into the machinery room. Further calculations indicated that too much regeneration might be obtained with this arrangement and that it might be difficult to supply enough gas to the sample at the proper temperature to handle the desired maximum power generation.

Early design calculations also indicated that some cooling of the pressure wall in the concrete-shield area would be required. Consequently, a design was evolved which would provide means for controlling the amount of regeneration in the loop system and at the same time providing cooling for the loop pressure wall and the concrete shielding. This was accomplished by providing two inlet-gas channels and an outer water cooling jacket in the concentric piping between the top of the concrete shield and the machinery room. Because a static gas chamber was not needed with this arrangement, it was necessary to add only one pipe to the system.

The static gas chamber, consisting of the outer annulus, was blocked off at a point just above the concrete shield. This annular space thus became available for use as the second inlet-gas passage. The two inlet-gas channels were also made common at this point. A fourth pipe was then added to provide a cooling jacket around the three-tube arrangement. Thus, gas flowing toward the element in the inner channel is heated by the hot gas from the element while the gas flowing in the outer channel is cooled by the water jacket. By controlling the proportions of gas flow between the two channels, the amount of heat transfer between the inlet and outlet gas can be controlled. This in turn controls the temperature of the gas entering the sample. A remotely operated valve in the automatic control system is used to proportion the flow between the two channels.

Early in the design program it was realized that if it were necessary to operate the loop with fuel elements of limited power generation it might be impossible to develop reference temperatures at the fuel subassembly. Consequently, an electrical preheater was incorporated into the over-all design to provide additional heat whenever required. A heater capable of supplying up to 50 kw of electrical energy was provided for this purpose.

The heat-exchanger design was based on the maximum specimen power generation anticipated. Two heat exchangers, either of which is capable of handling maximum power generation, were incorporated into the system to insure uninterrupted operation. Because of the fixed position of the test section with respect to the reactor core the blower system was designed to insure adequate flow under all conceivable circumstances. To this end, multiple facilities were made available. A fully automatic control system was evolved to start a spare blower instantly following the failure of the operating unit.

Safety considerations and the need for adequate experimental measurements required that the loop system be well instrumented for the measurement of gas flow, pressure, and temperature and that suitable controls be provided to assure stability of these conditions. Safety circuits were designed to assure the safety of the fuel specimen, the loop, and the reactor. Instrumentation and control components and circuits were selected to provide maximum protection in the event of a failure of a component or the loss of operating facilities. Operational aids were included on the control panel to assist the operator. A visual and aural warning system was provided to advise of a malfunction or an off-normal condition.

A suitable radiation-activity monitoring system was included in the design to continuously provide information relative to the activity levels existing in the loop system and the machinery cubicle. A filter was included in the system to remove particulate matter entrained in the gas stream.

These criteria are quite general in nature and are applicable in varying degrees to any loop system and test-reactor installation. However, they are mentioned here because they had a direct bearing on the design of this loop system.

THE PRIMARY SYSTEM

The primary system consists of the test section, filter, heat exchangers, blowers, preheater, interconnecting piping, valves, and the miscellaneous devices necessary to provide a closed loop. Each item was designed or selected solely on the basis of the over-all requirements of the system.

Loop Piping

Because conditions are not constant throughout the loop, design parameters for the loop piping were considered separately for the following areas:

- (1) In reactor
- (2) In-shield pipe
- (3) Sub-pile room
- (4) Machinery room

The loop piping was designed to meet the ASME Unfired Pressure Vessel Code as a minimum standard in all parts of the loop.

In Reactor

This section contains the fuel subassembly or specimen. Consequently, certain parts of this subassembly operate at the highest temperatures encountered in the loop.

Having selected a three-tube concentric pipe arrangement for the in-reactor piping, further design study showed that the entire assembly could be contained within a 5-in. -diameter pipe. It was also found that sufficient flow area, to and from the sample, would be provided by using a 3-in. -OD, 0.083-in. -wall tube, concentrically located inside a 4-in. , Schedule 5, stainless steel pipe.

Type 347 stainless steel was chosen for the inner tubes because of its generally desirable characteristics which include resistance to corrosion, particularly after welding. With the static gas in the outer annulus at loop pressure, the outer tube becomes the pressure wall. This proved to be a significant design problem. Calculations indicated that combined thermal and pressure stresses made stainless steel unsuitable because of code restrictions. Because of the excellent heat-transfer characteristics of aluminum, 5-in.-diameter, Schedule 40, Type 6061-T6 aluminum-alloy pipe was selected for the outer tube. The selection keeps the entire loop-piping design within the ASME Unfired Pressure Vessel Code. The low neutron-attenuation factor of aluminum was also recognized.

The test section is shown in Figure 5.

Caps were welded to the bottom of the 5-in.-aluminum pipe and to the 3-in. stainless steel pipe to form the static gas chamber. A guide ring was provided near the bottom of the 3-in. pipe to properly position the lower end of the fuel specimen. A second guide ring was welded to the end of the 3-in. pipe which contains the hot gas as it leaves the element. Between the two guide rings the fuel-element sheath serves as the inner wall of the inlet gas passage. The upper guide also serves as a seal between the inlet and outlet gas.

The heat energy received by the pressure wall as a result of radiation and conduction from the fuel-element enclosure was calculated to be 1900 Btu per hr per ft of pipe. In addition, it was expected that gamma heating of the pressure wall in this area would be 31,900 Btu per hr per ft of pipe. Assuming the reactor water to be at 110 F, this would result in a temperature difference of less than 5 F across the pressure wall. Similar calculations indicated that above the fuel-specimen area the heat loss from the system to the reactor water would be 1140 Btu per hr per ft of pipe. The thermal stress in this area, therefore, would be much less than that in the test section and much below the design limit.

The allowable internal pressure, according to ASA B31.1, Section 1, Paragraph 122, for the pressure wall is 440 psig. The allowable external pressure is 210 psig, according to the ASME Code for Unfired Pressure Vessels, Section VIII, 1956.

With the loop operating at the design power of 150 kw, the total heat generation in the 3-ft-long fuel-element area was calculated to be 682,400 Btu per hr, including gamma heating. The heat dissipation to the reactor water in this area was expected to be 110,600 Btu per hr. The heat carried away by the loop gas, therefore, should be approximately 571,800 Btu per hr. This is equivalent to a temperature rise of 692 F for a nitrogen flow rate of 3170 lb per hr (0.88 lb per sec).

Six iron-constantan thermocouples, sheathed in Type 347 stainless steel, were attached to the inside surface of the outer tube to measure the temperature of the pressure wall in the fuel-element area. The thermocouples were mounted in blocks welded to the pressure wall and were mounted in pairs, diametrically opposed, on a radial line extending from the center of the reactor core. Couples were located at the top, center, and bottom of the fuel-element area to provide a temperature profile of this area.

FIGURE 5. LONGITUDINAL SECTION THROUGH TEST SECTION

All welding of the aluminum pressure wall was performed by the Heliarc process using Type 4043 aluminum-alloy filler rod. Weld joints were prepared according to Section VIII, ASA B31.1-1955 and the welds were made by ASME certified welders. The inner stainless steel tubes were provided with slip joints to allow for the differences in thermal expansion that would occur and to provide adequate seals against gas flow from the inlet channel to the outlet channel.

To provide neutron shielding the inlet- and outlet-gas channels were fitted with helical sections of Type 316 stainless steel. Each helix was made up of 5-in. sections of material and, starting at a point 24 in. above the fuel element, extended upward for a distance of 110 in. This arrangement provided radiation shielding equivalent to 35 in. of solid stainless steel. With the stainless steel sections extending upward for this distance they are also effective in providing shielding for the secondary reflected radiation that may enter the in-pile tube above the core area. Radiation propagation in the static chamber was attenuated by means of alternately spaced segments of pipe.

A tee section and horizontal run were designed into the in-pile tube to permit connection of the vertical leg to the in-shield pipe section of the loop system. Additional stainless steel sections and a lead-filled plug were used above the tee section to provide additional radiation shielding. The upper end of the vertical leg was terminated with a flanged cap to permit access to the test-section area for the insertion and removal of specimens. The top cap was sealed by the use of three O-rings. Means were provided just below the top cap for taking thermocouples and instrument pressure lines out through the side of the reactor vessel. Exit was made through the 8A-6 angular nozzle into a pressure-tight connection box which was designed for this installation.

The horizontal branch of the tee section was terminated at a flange for ease of assembly with the in-shield section of the loop piping. Slip joints and a bellows were included in the design of the horizontal section to allow for unequal expansion of the concentric pipes.

In Shield

Although the type of construction used in the in-reactor leg of the loop piping was generally suitable for the in-shield pipe section, problems peculiar to this area required a slightly modified approach. In general, the concentric arrangement was continued down through the reactor in-shield pipe and concrete-shield area into the sub-pile room. The static chamber was terminated just above the concrete shield. An additional pipe was also added to the concentric arrangement at this point to provide a cooling water jacket. Because high temperatures in the pressure wall presented no serious problems in the design of this section, Type 317 stainless steel was used throughout.

The in-shield section starts at the flanged connection with the in-reactor section. The three-tube concentric arrangement was continued from this point, and by means of a 90-deg bend, was directed downward through the reactor in-shield tube. Starting at the flange, 5-in., Schedule 40 stainless steel pipe was used for the pressure wall. Just above the point where the in-shield piping enters the concrete shielding surrounding the reactor, a 6-in., Schedule 10 stainless steel pipe was added to the concentric arrangement to provide the water jacket. This tube was terminated just inside the sub-pile room.

Provision for supplying cooling water to the jacket was made through a short length of 1-in. stainless steel tubing which is connected to a similar water jacket on the sub-pile-room section of the loop piping. The cooling water flows up through the water jacket to cool the pressure wall and the concrete shielding. Five 3/8-in. tubes, running the length of the jacket, carry the water back down to a collector ring at the bottom. The water leaves the jacket at this point and is piped back to the source. A tube filled with static water was placed on each side of the outlet tubes to minimize the transfer of heat back to the inlet water. A thermocouple, attached to the jacket wall, was provided to measure the jacket temperature.

Because of the anticipated difficulty in precise positioning of the in-pile tube in the reactor vessel, a slip joint was included in the horizontal leg of the in-shield piping to provide an over-all variation of 2 in. in the length of this section. When the in-pile tube was properly located, its position was fixed by making a field weld at this point.

The slip joint was made by reducing the wall thickness of the two mating sections. Although a decrease in allowable working pressures resulted, an adequate margin of safety was maintained. The minimum wall thickness for the outside sleeve is 0.140 in. whereas that for the inner sleeve is 0.130 in. The allowable external pressure on this section of the piping is 185 psig based on an allowable stress of 16,000 psi, assuming no stiffening rings, according to Section VIII of the ASME Unfired Pressure Vessel Code. This is a conservative rating because the maximum unsupported length of pipe with the reduced wall thickness is limited to 2 in. The allowable internal pressure is 815 psig according to ASA B31.1-1955. All other pressure-wall piping in this assembly conforms to ASTM-A312-55T and ASA-B36.19. The allowable external pressure is 480 psig and the allowable internal pressure is 1900 psig. The heat loss through the pipes in this area was calculated to be 911 Btu per ft. The temperature drop across the stainless steel pressure wall is of the order of 1.57 F.

Below the reactor in-shield pipe flange the loop pressure wall is not immersed in the reactor water. The temperature of the pressure wall in this area is of the order of 310 F. The expected temperature drop across the wall was found to be about 0.93 F. The heat loss through the piping was calculated to be 535 Btu/(hr)(ft). The allowable internal pressure, according to ASA B31.1, is 1330 psig. This is well within safe limits. The inner pipes were equipped with slip joints to provide for unequal expansion in the concentric tubing.

Sub-Pile Room

To conform to the space allocation at the reactor site it was necessary to turn the concentric piping 90 deg in the sub-pile room to enter the cubicle area or machinery room. The turn was accomplished by means of a special elbow consisting of three concentric tubes. The concentric piping was then routed horizontally across part of the sub-pile room and through the sub-pile-room nozzle, SU-7, into the BMI-16 machinery cubicle.

The type of construction used for this section was identical to that used for the in-shield section except for the flanging arrangement provided at the machinery-room end. Two inlet-gas passages were provided around the central gas-return passage. All this was then enclosed in a fourth concentric tube which provided a water jacket for the assembly. Type 347 stainless steel was used throughout. The inner pipes were

equipped with slip joints to allow for unequal expansion in the different pipes. The water jacket was connected directly with the jacket on the in-shield section as previously stated. Means were provided for the cooling water to enter the concentric piping at a flange just inside the machinery room. The water then leaves the horizontal jacket just short of the elbow in the sub-pile room and enters the vertical jacket just above the elbow. The water jacket was equipped with a thermocouple for temperature measurement. The gas passages were terminated at flanges for connection to the machinery-room piping.

The allowable temperature rise of the cooling water was limited to 30 F. The total heat-removal capacity of the combined water jackets was calculated to be of the order of 111,600 Btu per hr. This requires a water-flow rate of 7.5 gpm. The pressure drop through the 3/8-in. return tubes in the vertical jacket was found to be 3.8 psi.

Machinery Room

The design of the machinery-room piping was generally more straightforward than that of the other sections and, with a few exceptions, was not complicated by intricate thermal-stress problems. Figure 6 is a photograph of the machinery cubicle taken from the access door.

Type 347 stainless steel was selected for the gas piping because of its corrosion resistance even though high temperatures were not a factor in all areas of the machinery-room piping. This was done partly because it was felt that standardization would lessen the cost of fabrication. Type 304L stainless steel was selected for the coolant-water piping because of the low temperatures involved in the secondary cooling system and because of the further saving in fabrication costs achieved by the use of this material. Flanged joints were used to facilitate the removal and replacement of individual components.

Octagonal-ring-joint seals were used at connecting points in the gas system because of their successful use in high-pressure and gas-transmission systems. Ring-joint slip-on flanges were used between the machinery-room piping and the concentric piping to assist in obtaining satisfactory alignment in this area by field welding the flanges during the installation at the reactor site. The maximum, nonshock, service-pressure rating for the flanges is 355 psi at 1000 F. Raised-face, slip-on-type flanges with composition seals were selected for the cooling-water system because of the lower temperatures existing in these lines. All flanges in the water lines are Type 304L stainless steel and are rated for 300-psi service.

It was found that in most cases, 2-in. piping would suffice for the gas system and that, except for the lines between the concentric piping and the heat exchangers, insulation would not be required. Exceptions to this general condition are discussed individually in following sections of this report.

Calculations based on the heat-removal capacities required, dictated the selection of 2-in. pipe for the main water-supply lines, 1-1/2-in. pipe for the heat-exchanger water-supply system, and 1-in. pipe for the sub-pile room and in-shield water-jacket system.

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FIGURE 6. MACHINERY CUBICLE AT THE ETR

Heat-Exchanger Inlet. Upon entering the machinery room, the hot gas from the in-pile section of the loop flows through the particle filter and thence to the heat-exchanger inlet header. Because of the high temperatures expected in this region, it was decided that some means must be provided to minimize heat losses from the system gas to the air in the machinery room. Consequently, the 2-in. pipes on both sides of the filter were enclosed concentrically in 3-1/2-in. diameter pipes to provide a static gas chamber around the sections of pipe containing the hot gas. Cooling water jackets consisting of 5/16-in. stainless steel tubing were wound in a spiral around each of the 3-1/2-in. pipe sections. The stainless steel tubing was silver soldered to the 3-1/2-in. pipes to obtain good heat-transfer characteristics. The cooling jackets, in addition to minimizing the transfer of heat to the machinery room, were used to reduce the linear expansion of the pipes.

According to ASA B31.1 the allowable working pressure for the 2-in. pipe is 980 psi at 1000 F. For the 3-1/2-in. pipe the allowable working pressure is 860 psi at 200 F and 620 psi at 1000 F. Therefore, these sections of piping are well within the allowable limits even if the cooling water should be removed from the 3-1/2-in. sections. The maximum temperature rise permitted in the cooling water was 30 F. The amount of heat which will be transferred to the cooling water was calculated to be 831 Btu per hr per ft of pipe length. The total length of the pipe covered by the water jacket is approximately 15 ft. Consequently, the water flow required to meet these conditions is less than 2 gpm.

Blower Inlet Piping. Design of the piping between the heat exchangers and the blowers was straightforward. The outlets from the heat exchangers were combined by means of a conventional tee joint. A short distance downstream from this point the bypass gas from the blowers was united with that from the heat exchangers. At this point the pipe size was increased to 3 in. in diameter to handle the combined flow. The 3-in. pipe was also used for the inlet header to the blowers. Since the flow area for a 3-in. pipe is more than twice that for a 2-in. pipe, the gas velocity in this area is not excessive.

From the inlet header the gas flow is distributed to the blowers through automatic shutoff valves. To facilitate alignment of the blowers with the inlet header and to compensate for thermal expansions in the blower inlet piping, semiflexible connectors were used between the automatic valves and the inlet flanges on the blower housings. The connectors are capable of $\pm 1/8$ -in. lateral deflection and 1/8-in. compression.

Blower Outlet Header. Design conditions for the outlet header were similar to those for the inlet header. The outlet gas from the blowers was routed through flexible connectors and then through the automatic valves. In the header assembly, 3-in. pipe was used for those passages which might receive the output from two blowers. A portion of the gas leaving the outlet header could be diverted back to the inlet header through a manual bypass valve.

Heater Inlet Piping. The gas from the outlet header flows to the electric heater. The system-gas-flow orifice assembly was located in this section of the piping. This area was selected because of the relatively constant temperatures expected over a wide range of operating conditions. Freedom from turbulence was another factor in the selection. At the recommendation of the orifice manufacturer, 3-in. pipe was used to accommodate the orifice assembly.

Heater Outlet Piping. The design of this portion of the piping was straightforward. A manual flow-control valve was located downstream of the heater. Two-inch pipe was used in this section.

Diverter-Valve Outlet Piping. Two pipe assemblies were required to connect the diverter valve to the inlet flanges of the concentric piping. Two-inch pipe was used for this purpose. Ring-joint 300-lb slip-on flanges were used to connect these lines to the concentric piping to facilitate alignment.

Gas-Supply Line. To connect the loop system to the makeup-gas supply a 1/2-in. stainless steel pipe was run from a high-pressure manifold to the automatic gas-supply valve. Downstream of the supply valve the pipe size was increased to 1 in. in diameter because of the lower pressure at this point. The 1-in. line was connected to the loop system by means of a tee joint on the blower outlet-header assembly. These small lines are adequate because of the low flow rate required in this area.

Gas-Vent Line. Means for venting excessive loop pressure were provided by connecting a 1-in. stainless steel pipe to a tee joint in the blower inlet-header assembly. This pipe was run to the automatic loop-gas-exhaust valve. As a safeguard a bypass line, equipped with a rupture disk and an overload-relief valve, was run around the exhaust valve.

Cooling-Water Inlet-Header Assembly. Calculations of the total cooling water required for the loop system resulted in the selection of 2-in. pipe for the supply and return lines. The supply line was connected to a header of 2-in. pipe. A tee joint was provided in the header to divide the flow between the heat exchangers and the water jackets on the concentric piping. It was found that 1-1/2-in. pipe would suffice for the heat-exchanger supply line; whereas, 1-in. pipe would handle the water requirements of the cooling jackets. A flow-control valve was inserted in the 1-in. line for regulating the water flow to the cooling jackets.

Heat-Exchanger Inlet-Water and Outlet-Water Headers. A tee joint was provided in the 1-1/2-in. line to provide water flow to either heat exchanger. Manually controlled shutoff valves were inserted in the 1-1/2-in. lines just downstream of the tee. A similar arrangement was provided at the outlet of each heat exchanger. As at the inlet, 1-1/2-in. pipe was used between the heat exchangers and the shutoff valves. Downstream of the shutoff valves the individual lines were combined into one 1-1/2-in. pipe. A stub with a hand valve was welded to each assembly to permit drainage of the heat exchangers if necessary. Downstream of the tee joint the pipe size was increased to 2 in. in diameter to permit the insertion of an orifice flange assembly to measure the water flow through the heat exchangers. Downstream from the orifice assembly the size of the piping was reduced to 1-1/2 in. in diameter before connecting to a remotely operated manual flow-control valve.

Downstream of the flow-control valve the water from the heat exchangers is united with that from the water jackets on the concentric tubing. At this point the size of the piping was increased to 2 in. in diameter for connection to the service return line. One-inch pipe was used for the return line from the water jackets. A 1-in. orifice assembly was inserted in this line to measure the water flow through the cooling jackets.

Blowers

The purpose of the blowers is to continuously circulate the primary gas coolant through the loop system. A study of operating conditions at the reactor site indicated that the blower system must be essentially failproof to insure adequate flow under any condition of operation and to minimize reactor downtime. This concept greatly influenced the design of the individual blowers as well as the development of the over-all blower system. To obtain high reliability for the operating system, the system was designed to include three blowers, with each blower capable of maintaining the required gas-flow rate. Blower controls were included to provide automatic switching from one blower to another in the event of low flow or high bearing temperature for the operating blower. Within the space limitations of the reactor facility, the blowers were arranged to provide easy accessibility for maintenance and replacement.

Design Parameters

Because of the operating conditions stipulated for the loop system, the blower design was based on the following parameters:

Inlet pressure	200 psia
Inlet-gas temperature	200 F maximum
Blower pressure ratio	1.10
Gas-flow rate	0.9 lb per sec

In addition, it was recognized that a steady flow would be required and that the entire blower should be included in the sealed high-pressure system to eliminate rotary shaft seals and the associated leakage. Relatively high flow in combination with a low pressure ratio was desirable and it was essential to keep the gas system free from oil. Although these conditions might be obtained in several ways, single-stage high-speed centrifugal blowers appeared to be best suited to this application.

Calculations indicated that a centrifugal blower with an impeller 12-1/8 in. in diameter rotating at 10,000 rpm would satisfy the design parameters. On the basis of 35 per cent compression efficiency and 85 per cent mechanical efficiency, the required drive horsepower was calculated to be 19.3. Motors of 25 hp were selected to drive the blowers. Because of the relatively low temperatures expected at the blower inlet, it was possible to use grease-lubricated bearings for the high-speed impeller shaft. Thus, contamination of the system gas by an oil lubricant and the need for a rotary shaft seal were avoided. A manual lubrication system was incorporated in the over-all blower design scheme to permit relubrication of the blower bearings. Instrumentation was provided to measure and record the temperature of each bearing on the high-speed impeller shaft.

Component Design

The impeller design was similar to one used in an earlier blower which has been operated successfully at the BRR. The shape of the impeller and the configuration of the blades were changed slightly to obtain greater strength, to provide better dynamic balance, and to simplify machining. Type 430 stainless steel was selected for the impeller on the basis of strength and machinability. The latter characteristic was considered important. The impeller was machined from a forging 12-1/2 in. in diameter by 4 in. thick.

Torque was transmitted from a high-carbon-steel drive shaft by means of two round pins. The impeller was secured to the drive shaft by means of a second shaft, located concentrically within the drive shaft. This method of attaching the impeller to the drive shaft was selected in order to keep the face of the impeller clean and thus minimize turbulence and provide improved flow characteristics through the blower. Grease-lubricated, angular-contact, super-precision ball bearings were used. Two pairs of bearings were used to distribute the load.

The impeller housing consists of two parts machined from Type 430 stainless steel forgings. Here again, the selection of materials was made on the basis of machinability and high mechanical strength. The volute was designed to increase linearly in cross section from 1/16 to 1-1/8 in.². This straightforward design was adopted to simplify the machining of the housing components. A diffuser stage was connected to the outlet of the volute. Holes were drilled through the impeller to equalize the pressures on each side of the impeller and thus reduce the thrust loading on the bearings.

A 25-hp, 440-v, three-phase, 60-cycle, 3530-rpm motor with a toothed timing-belt transmission was selected for the blower drive. This arrangement was selected in preference to a direct-drive, high-speed motor system, on the basis of simplicity and lower cost. Direct-drive arrangements would have required power-converter units to supply 180-cycle alternating current for 10,000-rpm motors, and a variable-frequency output would have been required to change speed. The belt drive between the motor and the impeller shaft was selected in preference to a gear train on the basis of lower cost and the elimination of the need for lubrication. Motors were procured which were equipped with Class B insulation.

The transmission cover was made from an aluminum casting impregnated with a polyester resin. Aluminum was chosen for this purpose to save weight in an area where great mechanical strength was not considered necessary. The casting was designed in accordance with the ASME Unfired Pressure Vessel Code for use at 200-psig pressure at 300 F. The motor housing was fabricated from a short section of 18-in.-diameter tube to which a flanged and dished head was welded. Both parts were constructed of low-carbon steel and were designed to comply with the ASME Unfired Pressure Vessel Code for an operating pressure of 200 psig.

Rotating pressure seals were not needed since the blower-drive-assembly housing was vented to the circulating gas in the loop. Compression-type seals were used for the thermocouples and the electric power lines. The seals were made of neoprene rubber. Special fittings were designed for taking the cooling-water lines in and out of the blower housing. Double O-ring-type seals were used in all other areas. The thermocouples were located in the bearing housing and were arranged so that one thermocouple was in contact with the outer race of each bearing.

Testing

One blower was fabricated in accordance with the above specifications. The unit was run approximately 4 hr at intermittently increased speeds to channel the grease in the high-speed bearings prior to balancing the impeller. The impeller was then dynamically balanced at a speed of 2200 rpm. Figure 7 shows an impeller-shaft assembly mounted in the balancing equipment. The blower was then run several hours at 10,000 rpm to collect performance data. It was found that both the maximum flow and the pressure rise developed across the unit were considerably in excess of the design values. Consequently, the impeller speed was reduced to approximately 8500 rpm to establish the desired operating characteristics. Typical blower-performance data are shown in Figure 8. Performance data taken during this period indicated that at the reduced speed, both the maximum flow and the pressure rise were above the design values. During these tests, it was also learned that more cooling would be required to hold the blower temperatures within acceptable limits. The cooling system of the original unit was revised to provide the needed cooling. Three additional units were then fabricated. Each unit was balanced and tested under conditions similar to those applied to the original unit. Figure 9 shows one of the blowers installed in the loop at the ETR.

Preheater

The preheater is a once-through device with a number of V-shaped nickel-chromium heating elements arranged in a "star" pattern within a stainless steel pipe which serves as the pressure wall. Approximately 2 in. of low-density insulating material was used around the heater to minimize the heat losses to the surrounding atmosphere. The unit was designed to supply up to 50 kw of electrical heat to the specimen inlet gas. However, it is expected that during normal operation, the heater will be operated at a level of approximately 13 kw. The heater was designed to operate on 220-v, three-phase power. The completed unit is shown by Figure 10.

Filter

The filter was designed to have a minimum efficiency of 99.5 per cent for 0.3- μ particles at a design flow rate of 0.9 lb per sec of nitrogen gas. To hold the pressure drop across the filter within acceptable limits, it was designed with a cross-sectional flow area of about 100 in.². The filter element was made of Fiberfrax material. The pressure wall was constructed with Type 347 stainless steel and was designed to meet the ASME Unfired Pressure Vessel Code for a working pressure of 200 psi at 1000 F. The filter case is 24 in. long by 12 in. in diameter and is equipped with 2-in., ring-joint-type flanges.

Heat Exchangers

The purpose of the heat exchangers is to remove from the gas a portion of the heat imparted to it by the fuel specimen and the preheater. Although two heat exchangers are provided, either heat exchanger is capable of removing 180 kw.

N55134

FIGURE 7. IMPELLER ASSEMBLY BEING BALANCED

FIGURE 8. TYPICAL BLOWER-PERFORMANCE DATA

A-33262

FIGURE 9. BLOWER INSTALLED IN THE LOOP

FIGURE 10. PREHEATER

N55439

Design Requirements

The design of the heat exchangers was based on the following initial requirements:

Gas	Prepurified nitrogen plus additives
Gas-flow rate	0.88 lb per sec
Gas pressure	200 psia
Gas-inlet temperature	1000 F
Gas-outlet temperature	150 F
Gas pressure drop	0.5 psi
Coolant	High-pressure demineralized water
Coolant inlet temperature	130 F
Coolant outlet temperature	170 F
Coolant pressure drop	Not to exceed 50 psi.

Construction

The heat exchangers were constructed of Type 347 stainless steel and were welded and stressed in accordance with the ASME code for 200-psi service. A three-tube concentric arrangement, with a single annular gas passage sandwiched between two coolant-water passages, was selected to hold the gas pressure drop across the heat exchanger within the specified limit. Each heat exchanger was folded back upon itself, in a double-loop arrangement, to reduce the over-all length. Figure 11 shows one of the units ready for shipment to the reactor site.

To avoid high bending stresses from being developed as a result of the unequal temperatures in the two legs of the U-construction, the hot leg was prestressed so that the bending stresses in the U would be negligible at operating temperatures. Calculations for the maximum stresses encountered in each tube show that a maximum stress of 3,740 psi occurs in the outside pipe during normal operation. The allowable stress for this pipe is 16,000 psi. Maximum stresses of 8,200 and 7,130 psi occur in the middle and center pipe, respectively, when a loss in water pressure is experienced. These tubes have an allowable stress of 14,450 psi.

Because of the heat losses occurring between the test section and the heat exchangers, the heat removal required of the heat exchangers is considerably less than the design value.

FIGURE 11. HEAT EXCHANGER

N55434

Associated Components

Two methods were available for bringing the thermocouples and instrument pressure lines located in the test-section area to the outside of the reactor vessel. One method would route these facilities through the concentric tubing into the machinery room. The second method would require taking these lines out of the reactor vessel independently of the loop piping. Because it would be extremely difficult to provide means for feeding the leads from thermocouples on a test element out through the concentric tubing, an independent route was provided for all the instrument lines associated with the fuel-element test area. This required the following additional facilities which are peculiar to the installation in the ETR.

Instrument Lead

The instrument lead provides a sealed passage through the reactor vessel wall for the thermocouples and the fuel-element differential-pressure taps located in the in-reactor leg of the loop. Although this passage is separated from the circulating gas in the loop, it is at loop pressure. The instrument lead starts at the upper portion of the in-reactor leg of the loop piping immediately below the top cap and passes through the reactor wall at the 8A6 angular-nozzle flange.

The lead was designed in two sections. The part connected to the in-reactor leg was made from 1-1/2-in. , Type 6D61-T6 aluminum pipe to permit welding to the in-reactor leg. This section was terminated in a welding neck flange of the same material. The other part was made from 1-in. , Type 304L stainless steel pipe with a matching stainless steel flange. O-ring grooves were machined in the stainless steel flange for sealing. The 1-in. pipe was taken out through the angular-nozzle flange and terminated inside a junction box mounted on the flange.

Junction Box

The junction-box assembly provides the seals necessary for taking the instrument lead from the pressurized reactor vessel and for taking the thermocouples and pressure tubes from the pressurized loop to the atmosphere. The junction-box assembly is attached to the outside of the 8A6 angular-nozzle flange.

A modified blind flange was bolted to the angular-nozzle flange to contain the pressurized reactor water. The instrument lead was taken out through a packing-nut-type seal incorporated in the blind flange. The instrument lead was then taken into a pressure chamber through a similar seal. Conax fittings were used to take the thermocouples and pressure tubes from the pressure chamber to the atmosphere.

The pressure chamber was made from a short length of 5-in. steel pipe. One end was sealed by welding to a steel block which was drilled and tapped for the instrument lead seal. The other end was terminated with a welded flange. Two O-ring grooves were machined in this flange to provide a seal. A blind flange was bolted to the welded flange to contain the loop pressure. The pressure chamber was mounted to the blind flange attached to the angular nozzle. The entire assembly was covered with a 12-gage steel hood.

AUXILIARY SYSTEMS

Operation of the primary system is dependent upon several secondary systems such as a make-up gas system, a coolant-water system, and an electrical system. The piping for the coolant-water system was discussed along with the primary-system piping. The electrical system will be discussed in connection with the instrumentation and controls. Part of the make-up gas system also belongs in this category.

The common method of handling gases is by means of portable high-pressure tanks, or bottles. The bottle pressure, therefore, provides a simple means for supplying make-up gas to the loop. To insure an adequate gas supply and uninterrupted operation, a manifold system was selected. Facilities were provided for connecting four bottles to the manifold. To avoid bottle pressure in the manifold, a pressure-regulating valve was connected to the output of each bottle. By means of the regulators the manifold pressure is maintained at an intermediate value. Two bottles are used in tandem. The other two are held in reserve. Another pressure-regulating valve was connected to the output of the manifold to drop the supply pressure to a value of about 50 psi above the loop operating pressure.

CONTROLS AND INSTRUMENTATION

The control and instrumentation system was designed to provide flexibility in experiment operation and maximum safety for personnel, the loop, and reactor facilities. The design was affected by the environment in which the loop would operate and by the requirements and operating procedures stipulated by the reactor management, as well as by the desire to obtain specimen and loop engineering data.

Automatic controls were utilized to maintain the system gas temperature, gas pressure, and gas flow at preselected values. Gas temperatures at the specimen inlet and outlet were selected as the main system-control parameters. Thermocouples at these positions sense the temperatures and recorder-controller units record them. Variations from preselected values are detected and are used to control system gas flow and to regulate the distribution of gas by the diverter valve at the inlet to the concentric piping. All other variables are adjusted manually, to bring the loop operating conditions within the range of this control.

Manual and automatic control facilities were provided to adjust the system gas-flow rate. Means were also provided for manual control of the flow rate of the cooling water in the heat exchangers and concentric piping cooling jackets and for the manual control of the input power to the electrical preheater. Either one of the heat exchangers and any single blower or two blowers can be remotely selected for operation. To insure uninterrupted operation, some duplicate temperature-control facilities were provided. A view of the control console is shown in Figure 12.

FIGURE 12. BMI-16 CONSOLE

Additional facilities were included in the system to provide adequate engineering data and to assist in the operation of the loop. The safety circuits were designed to protect personnel, the loop, the specimen, and the reactor. The system was designed to provide safety without incurring excessive or needless reactor downtime. The safety circuits were designed so that in most cases a loop malfunction, or off-normal operating condition would initiate a loop cooldown. This is accomplished by automatically turning off the heater and increasing the coolant-gas flow and water flow to maximum. In selected critical areas the loop cooldowns were backed up with means for initiating a reactor power reduction. These circuits were made flexible so that any available degree of reactor power reduction can be assigned to any one of several off-normal conditions. In many cases a loop cooldown is preceded by a warning. Annunciator panels were used to provide visual and aural warnings of deviation from normal operation conditions.

Each instrument was selected to provide a safe condition in the event of a failure associated with the instrument. The automatic valves and control circuits were selected to provide maximum cooling if there is a loss of instrument air or instrument power. Interlocked control circuits were devised to automatically start a spare blower if trouble is encountered with the operating unit or units. Valve-position indicator lights and a schematic diagram of the loop were placed on the control panel to facilitate operation of the loop. A test manifold system was provided to simplify the checking of set-points on the pressure switches.

System Pressure Control

A system of pneumatically operated components was selected for the function of loop pressure control. A signal was taken from a pressure tap in the blower inlet header to sense any change in loop pressure. The signal was fed to a pressure transmitter that provides a low-pressure output proportioned to the high-pressure input. The low-pressure output from the pressure transmitter was then connected to a combination recorder-controller unit and to two pressure switches, which are a part of the safety circuits.

The output signal from the control unit was connected to two other pressure switches. One of these switches was set to operate when the loop pressure drops below a preselected value. The other switch was set to operate on a rise in loop pressure. These switches in turn control the position of air-operated valves in the gas supply and exhaust lines. Make-up gas is supplied from high-pressure tanks and the exhaust gas is discharged to the ETR stack. The pressure switches were also connected to the annunciator panels to provide a visual and aural indication of valve action. Panel indicator lights were used to indicate valve positions. An electrical interlock was provided to prevent both valves being open at the same time.

The control system was backed up by means of the two pressure switches associated with the safety circuits. Both of these switches were set to operate on low loop pressure. If the control circuit fails to maintain normal loop pressure, one of these switches operates an annunciator and provides a loop cooldown when the pressure drops to a preselected value. If the loop pressure continues to drop, the second switch initiates a reactor power reduction when the pressure drops to a second preselected value. The control system was protected on high-pressure excursions by means of a rupture disk and an overload-relief valve connected in a bypass line around the automatic

exhaust valve. Air-to-open valves were used in the supply and exhaust lines to provide fail-safe operation in the event of an instrument air or instrument power failure.

System Flow Control

An orifice plate and a differential-pressure transmitter were used to measure the system gas flow. The orifice plate was installed in the gas line between the blower outlet header and the electrical preheater. This location was selected because of the constant temperature expected at this point. The differential-pressure transmitter converts the differential pressure across the orifice to a proportioned low-pressure air signal.

The output from the differential-pressure transmitter was fed to a pneumatically operated recorder-controller which provides a continuous record of system flow. The control section of this instrument compares the air signal from the transmitter to a control value and transmits a proportional signal to the flow-control valve.

The air signal from the orifice differential-pressure transmitter was also connected to two pressure switches to provide a safety back-up for the control system. One of these switches was set to provide an annunciator signal and a loop cooldown when the flow drops to a preselected value. The other switch was set to provide a second annunciator signal and to initiate a reactor power reduction if the flow continues to drop.

System Temperature Control

System temperatures are dependent upon several variables. Of primary importance are specimen power generation and system-gas-flow rate. Also affecting the loop temperatures are the preheater power input, the rates of flow of water in the heat exchanger and the cooling jackets, and position of the diverter valve.

The temperatures of specimen inlet and specimen outlet gas are the basis of control of the loop. The gas-flow rate is used to control the specimen outlet-gas temperature and the diverter-valve position is used to control the specimen inlet-gas temperature. When the specimen outlet-gas temperature rises, the gas flow is increased to reduce the temperature differential between the inlet and outlet gas. When the element inlet-gas temperature rises, more gas is diverted to the inlet channel adjacent to the water jacket, and the gas arrives at the inlet to the element at a lower temperature.

Because the fuel specimen is the source of most of the heat generated in the system, it was decided to utilize the thermocouples on or near the element to provide the main system-temperature control. Either one of two recorder-controller units can be used to record the temperatures measured by the thermocouples and to provide the necessary control actions. Two alarm circuits built into the recorders were used to initiate a loop cooldown followed by a reactor power reduction if the element or gas temperatures go above preselected values. Provision was made to permit the selection of either recorder-controller unit from the console panel. Patch panels and cords were provided to facilitate the interchanging of the control thermocouples if necessary.

Potentiometric-type recorders were selected for this application as well as for nearly all other thermocouple applications in the system, because of the long connecting leads required between the thermocouples and the control panel.

Upscale drive was provided in the main temperature recorders to protect the reactor, the specimen, and the loop in the case of a thermocouple or amplifier failure. The circuitry was designed so that the diverter valve goes to the maximum cooling position as a result of an instrument air or instrument power failure. Panel lights were provided to indicate the position of the diverter valve.

The loop temperatures are also dependent to a considerable extent upon the rate of flow and the temperature of the cooling water used in the heat exchanger and the concentric-piping cooling jackets. Consequently, it was necessary to provide means for measuring and controlling these factors. Essentially identical facilities were provided for the heat-exchanger water system and the cooling-jacket water system. Iron-constantan thermocouples were used to measure the temperatures of the water leaving the heat exchanger and cooling jackets. The signals from these thermocouples were fed to pneumatic-type recorders through intermediate electropneumatic converters. The pneumatic signals were also connected to pressure switches in the safety circuits to provide a warning if either temperature exceeds a preselected value. A second pair of switches was used to initiate a loop cooldown if either temperature continues to increase. The electropneumatic converters were equipped with downscale thermocouple and amplifier fail-safe protection.

Orifice plates were installed in the water lines to measure the flow in each line. Pressure taps on each side of the orifice were connected to suitable differential-pressure transmitters. The outputs of these instruments were connected to pneumatic-type recorders to provide a permanent record of water flow. The signals from the transmitters were also connected to pressure switches to provide warnings and loop-cooldown action when required, as in the case of the water-temperature instrumentation.

Manual control facilities were provided at the panel for remotely changing the rate of water flow through either the heat exchanger or the water jackets. This was accomplished by means of remotely controlled, air-operated valves in the water lines. Air-to-close valves were selected to provide maximum water flow in the case of an instrument-air or instrument-power failure. Panel lights were used to indicate the positions of the valves.

The loop temperatures are also affected by the heat supplied to the system from the preheater. To insure adequate control of the heater and provide necessary operating information, facilities were provided to manually control the heater power input and to measure and record the power input and the temperature of the gas leaving the heater.

A manual controller was used to regulate the input power to the heater by remotely varying the saturating current in a saturable core reactor which in turn supplies the heater power. A heater-power sensor, in the form of a thermal converter, was used to determine the heater power. The output from the converter was used to supply a permanent record on a suitable recorder. A switching circuit in the recorder was used to provide an annunciator signal when the heater power goes above a preselected value.

This recorder is used primarily to supply engineering information and it performs no control function other than initiating an alarm.

A Chromel-Alumel thermocouple was installed in the gas stream to measure the temperature of the gas emerging from the heater. The output of the thermocouple was connected to a suitable recorder to provide a permanent record of the temperature at this point. The recorder was equipped with two alarm cams to provide safety-circuit action. One cam provides an annunciator warning when the gas temperature increases above a preselected value. The other cam initiates a loop cooldown if the temperature continues to rise above a second selected point.

The recorder and the manual controller for the heater power were mounted on the console panel as an integrated unit. It would be possible to provide automatic control of the heater power by utilizing the signal available in the recorder unit.

The control system was backed up with downscale drive on the heater gas-temperature recorder in the event of a thermocouple or amplifier failure. Loss of instrument power will initiate a loop cooldown.

Measuring and Recording Equipment

Additional facilities were included in the instrumentation system to provide operational information and engineering data. Provision was made to measure temperature, pressure, and flow in selected sections of the loop as well as to provide for a continuous record of the moisture content of the loop gas. A suitable radiation-monitoring system was included to provide adequate information concerning the activity levels existing in critical areas.

Temperature

The three recorder-controllers (one standby on the outlet gas) were used to record and control the temperature of the inlet and outlet gas at the fuel specimen. In addition to the three recorder-controllers, four strip-chart recorders were used to provide records of test-specimen temperatures. These units provide a continuous record of the temperature of the specimen and should disclose any significant changes that occur in temperature profiles.

A similar strip-chart unit is used to record the temperature of the pressure wall in the fuel-element area. Six iron-constantan thermocouples attached to the test-section pressure wall permit a choice of inputs for the third recorder. The temperature profile of the pressure wall will be determined during the first fuel-element irradiation. The hottest couple in the group will then be selected for continuous use. The balance of the couples are available for use if the selected couple fails.

Two alarm cams were included with each recorder to provide annunciator signals and a loop cooldown followed by a reactor power reduction if any of the temperatures rise above preselected values. Downscale drive provides thermocouple and amplifier fail-safe protection. The loss of instrument power results in a loop cooldown. A patch panel arrangement was used to permit a choice of input thermocouples.

Two multipoint recorders were included in the instrumentation to collect engineering data. One unit is a 12-point recorder and provides information relative to the operating temperatures existing in selected sections of the loop. At the present time seven points on this unit are being used for this purpose. The second unit provides engineering data relative to fuel-subassembly temperatures and will handle up to 24 thermocouples.

Three additional single-point recorders were provided to record the temperatures of the blower bearings. An iron-constantan thermocouple was installed at each bearing position. Four thermocouples in each blower were connected to a sequencing switch which continuously scans them. The output of each sequencing switch was connected to a recorder. The sequencing switches connect each thermocouple to the appropriate recorder for a period of approximately 10 sec. The cycle time for each blower, thus, is about 40 sec. An alarm cam in each recorder was used to protect the system against loss of gas flow in the event any of the operating blower bearing temperatures rise above a predetermined safe limit. The operation of the circuitry is such that if a bearing temperature exceeds the selected value, the affected blower is stopped and a spare blower is started. This is done automatically. The flow-control valve is opened to insure maximum available flow through the loop during the transition. The usual protection was afforded for thermocouple and amplifier failure and for the loss of instrument power.

In a typical specimen irradiation the recorder-controllers and recorders might be used as shown in Table 1.

Pressure

Means were provided to continuously record the outlet pressure of the blowers. A pressure tap was installed in the outlet header for this purpose. A pressure transmitter was used to convert the signal available from the pressure tap to a proportional low-pressure signal which was connected to a pneumatic-type recorder on the control panel. The signal from the transmitter was also connected to a pressure switch to provide an annunciator warning in the event the pressure at this point drops below a preselected value. The purpose of this instrumentation is to provide operational and engineering data. No control functions are performed.

Pressure taps were provided in the supply-gas manifold and in the supply line downstream of the main supply-pressure regulating valves. These pressure taps were connected to suitable pressure transmitters to provide proportional low-pressure signals. The outputs from the transmitters were connected to gages on the control panel to provide an indication of the pressure available in the manifold and supply line. The purpose of this equipment is to supply operational information.

Pressure taps were also provided in the loop piping to determine the differential pressure across the fuel element. The pressure taps at the inlet- and outlet-gas passages were connected to a suitable differential-pressure transmitter. The proportional low-pressure output from the transmitter was connected to a pneumatic-type recorder to provide a continuous record of the differential pressure across the element. The primary purpose of this instrumentation is to provide engineering data pertinent to fuel-element investigations. This equipment could reveal an impending fuel-element failure caused by blistering or other gross mechanical changes which would affect coolant-gas flow.

TABLE 1. TYPICAL RECORDER UTILIZATION

Type of Instrument	Temperature Range, F	Use
<u>Automatic Controllers</u>		
Recorder-controller	0-2000	Element outlet-gas temperature control
Recorder-controller	0-2000	Element outlet-gas temperature control
Recorder-controller	0-1500	Element inlet-gas temperature controller
<u>Temperature Measurement and Sensing Devices</u>		
Recorder	0-2000	Element temperature recorder
Recorder	0-2000	Element temperature recorder
Recorder	0-2000	Element temperature recorder
Recorder	0-2000	Element temperature recorder
Recorder	0-400	Pressure-wall temperature recorder
Recorder	0-300	Heat-exchanger outlet-water temperature recorder
Recorder	0-400	No. 1 blower-bearing temperature recorder
Recorder	0-400	No. 2 blower-bearing temperature recorder
Recorder	0-400	No. 3 blower-bearing temperature recorder
Recorder	0-300	Shield outlet-water temperature recorder
Multipoint recorder	0-1000	Miscellaneous loop temperature
Recorder	0-800	Heater outlet-gas temperature recorder
Temperature indicator	0-1000	Heater temperature indicator
Multipoint recorder	500-2000	Fuel-element temperature recorder

The output from the differential-pressure transmitter was also connected to three pressure switches associated with the loop safety circuits. One switch was set to provide an annunciator warning and to initiate a loop cooldown if the differential pressure drops below a preselected value. The second switch provides a warning and initiates a reactor power reduction if the differential pressure continues to drop. The third switch provides a warning if the differential pressure rises above a preselected value. The system was also protected against the loss of instrument air or instrument power.

Flow

Although adequate instrumentation was provided for sensing, recording, and controlling the gas flow through the loop, it was considered necessary to also provide some indication of the flow through each individual operating blower. Such information would have some engineering value and would be helpful in operating the loop. Consequently, differential pressure taps were connected across the diffuser section of each blower. These tubes were connected to suitable differential-pressure transmitters to convert the signals to proportional low-pressure signals. The outputs were connected to suitable gages on the control panel.

The outputs from the transmitters were also connected to pressure switches to provide protection against the loss of flow in the operating blower. One pressure switch was used for each blower. If the flow through the operating blower drops below a preselected value, the safety circuits provide an annunciator warning and start a preselected standby blower. Electrical interlocks were employed to prevent the safety circuits from operating during the time any particular blower is not intended to be in operation. Unlike the high-bearing-temperature protection, these safety circuits do not stop the affected blower. This is the responsibility of the loop operator. The system was protected against the loss of instrument air.

Gas Moisture

Because the in-pile tube of the loop and the water-cooled heat exchangers are subject to water pressure equal to, or slightly greater than the system gas pressure, means were provided to continuously monitor and record the moisture content of the loop gas in order to detect leakage in either the in-pile-leg pressure wall or the heat exchangers.

To accomplish this purpose, an electrically operated hygrometer was connected to pressure taps in the blower inlet and outlet headers. An orifice plate in the hygrometer restricts the gas flow through the instrument to a very small value. An electrical signal is transmitted which is proportional to the amount of moisture present in the gas. This signal was then connected to an electropneumatic converter for conversion to a proportional pneumatic signal. The output of the converter was fed to a pneumatic-type recorder to provide a permanent record of the moisture content of the gas. The output from the converter was also fed to a pressure switch to provide an annunciator warning. The system was protected against loss of instrument air or instrument power.

Activity Monitoring

A radiation-monitoring system was provided to indicate the activity levels existing at critical points in the loop system. To accomplish this purpose, five sensors, consisting of ion chambers, were located on the particle filter, on the loop piping immediately downstream of the particle filter, on the loop piping immediately downstream of the heat exchangers, on the cooling-water return line from the heat exchangers, and on the machinery cubicle wall just inside the door.

The purpose of the first sensor is to determine the level in the filter where particulate products might be retained. The second sensor indicates the activity level of the gas upon leaving the filter. The third sensor is a backup for the second. The purpose of the fourth sensor is to detect the leakage of the loop gas into the cooling-water lines. The last sensor indicates the activity level existing in the machinery room. The outputs from the sensors were connected to standard meter-relay stations. Each of these units is provided with an integral visual alarm with adjustable set-points and is capable of supplying an electrical signal that is proportional to the incoming signal by which it is actuated. The outputs of the first two units were fed through electropneumatic converters to suitable recorders to provide permanent records of the activity levels in the filter and in the loop gas immediately after leaving the filter.

The signals from the converters were also fed to pressure switches to provide an annunciator warning in the event that the radiation level in either of these areas exceeds a predetermined value. If the radiation level in either area continues to rise, another pressure switch operates to provide a second annunciator warning and to initiate a loop cooldown and a reactor power reduction. The outputs from the three remaining meter-relay stations were fed to a multipoint recorder to provide permanent records of the activity levels in the loop gas, the heat-exchanger cooling water, and inside the machinery room. The only warnings provided on these three channels are the visual warnings that are an integral part of the meter-relay stations. These circuits were protected against loss of instrument air.

A gas-sampling system has been established so that samples can be removed from the loop periodically and analyzed by use of appropriate equipment.

Miscellaneous Controls

Manual controls were provided on the console to energize and de-energize the heater and to permit selection of either heat exchanger. An air switch was also provided to permit selection of the main recorder-controller facilities. Air-to-close valves were selected for use with the heat exchangers to provide fail-safe operation as a result of the loss of instrument air. Panel lights were provided to indicate the positions of these valves.

The blower safety features discussed previously, and operating policies at the ETR, resulted in the adoption of a seemingly complex blower starting procedure. However, in practice the procedure is quite simple and easy to apply. To circumvent a complete loss of flow as the result of a general power failure at the reactor site the operating blower was connected to the failure-free power source. Pushbutton switches were provided for each blower to permit the selection of either failure-free or commercial

power. Because of the safety interlocks, it was necessary to use three pushbuttons for each blower for the purpose of starting a unit. Two of the pushbuttons were combined in a single on-off toggle switch but because of the safety interlocks it was not practical to use these switches directly for starting. Consequently, a "momentary make" pushbutton switch was included in the starting circuits for this purpose. The starting switch overrides the low-flow safety circuit while it is depressed.

Motor-operated valves were used in the blower inlet and outlet passages to automatically open and close these valves whenever a blower is started or stopped. Two separate electrical interlocks were provided for each blower circuit to prevent both the "open" and "close" circuits from being energized at the same time. Power for the valve motors was taken from the failure-free facility to insure dependable operation of the valves. Panel lights were used to indicate the positions of the valves and to indicate when the blower motors are energized.

Safety Circuits

The loop safety circuits have been discussed in connection with instrumentation and control functions of the loop. In an installation such as the ETR, where a large number of experiments are in progress, it is important to hold reactor power reductions and downtime to a minimum. Consequently, each conceivable malfunction, or off-normal operation was considered with respect to its ultimate effect on the safety of the loop, the subassembly, and the reactor installation. Wherever possible, an attempt was made to correct an off-normal condition by a loop cooldown because this action does not affect the reactor or other experiments. A total of 17 loop cooldowns are available from the instrumentation system. In the most vital areas, the loop cooldowns were backed up with reactor power reductions in the event the cooldown fails to correct an off-normal condition. Several degrees of reactor power reduction are available from the reactor console. The assignment of power reductions to specific malfunctions or off-normal conditions was made by the Reactor Safeguards Committee. The loop power-reduction circuits were made flexible to permit any arrangement specified by the Committee.

In the typical loop cooldown the heater power is turned off immediately. The gas-flow control valve opens fully to provide maximum gas flow through the loop. The throttle valves in the heat exchanger and water-jacket lines open fully to provide maximum cooling in these areas.

Wherever possible, safety-circuit action was limited to providing a visual and aural warning. Most of the off-normal conditions in this group are related to the loop operation and the warnings merely indicate that some corrective action should be taken by the operator. However, if a warning signal is ignored over a long period of time, a loop cooldown will be initiated from some other source before the experiment is endangered.

TRANSFER EQUIPMENT

The insertion of specimens into the loop and the removal of specimens from the loop are effected by use of special equipment which is shown by Figure 13. A top shield was designed to replace the ETR top-head shield. The shield was made of reinforced concrete and was provided with an opening directly above, and concentric with, the center line of the BMI-16 in-pile tube. A clearance hole was also provided in the shield for an adjacent experiment which projects through the top of the reactor vessel and the concrete shielding. Means were then devised to provide shielded passage between the top of the open in-pile tube of the loop and the opening in the special concrete shield. This was accomplished by means of a spool piece consisting of a steel-jacketed, lead cylinder with a 6-in. inside diameter and 2-in. -thick walls. A shoulder was provided at the top of the spool piece to provide support from the concrete shield. A recess was provided in the shield so that the top of the spool piece is flush with the top of the concrete shield when properly positioned.

A guide arrangement was then devised to assist in the positioning of the spool piece on the top of the BMI-16 in-pile tube. The guide arrangement was made of two pieces. One piece was designed to bolt on the top of the in-pile tube in place of the top cap. The upper half of this piece was tapered on the inside diameter to receive a mating part that was welded to the lower end of the spool piece. With this arrangement the columnar beaming up from the test section is contained in a closed, shielded channel.

Since a cask was required for transportation and storage of irradiated elements, it was expedient to design it so that it could also be used in the removal of irradiated elements from the loop. Figure 14 shows the casks prior to shipment from Battelle to the reactor site. Calculations indicated that 10 in. of lead would provide sufficient shielding. A steel-jacketed, lead-filled type of construction was used with the inside diameter of the inside tube just large enough to receive a fuel specimen. A sliding end gate was provided at each end of the cask. A metal shear for separating the fuel element from the draw-bar assembly was incorporated into the cask as an integral part of the upper end-gate and is operated by closing the gate. Means were provided for attaching a hydraulic ram to the cask for the purpose of opening and closing the gate. A sliding plug and O-ring seal were incorporated into the upper gate; and an O-ring seal was provided in the lower gate to insure gastight integrity for the cask during handling and shipment.

It was also necessary to provide a shield for the draw bar. The shield was made from a 6-inch-OD steel tube with a 1-inch-thick wall. A flange was welded to the bottom end of the tube for the purpose of attaching the assembly to the top of the fuel-element cask. The upper end of the assembly was closed with a steel cap with a hole through which to pass a lifting mechanism.

A method was also needed to prevent streaming from the open end of the spool piece when the fuel-element cask was removed from the top of the reactor shielding during a transfer. This was accomplished by providing an open loop shield with a sliding door. A hollow-steel-shell construction was used for both the shield and the sliding door. Both parts were then filled with lead. With the sliding door in the closed position, the assembly provides a circular shield 26 in. in diameter by 6 in. thick.

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FIGURE 13. SCHEMATIC LAYOUT OF SPECIMEN TRANSFER SYSTEM

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FIGURE 14. COMBINATION TRANSFER AND SHIPPING CASKS

During the removal of a specimen from the loop the open loop shield is placed in position over the spool piece with the sliding gate open. (The draw-bar portion of the fuel-element assembly prevents streaming at this point.) The cask is then placed over the open loop shield. Both gates in the cask are opened. The draw-bar shield is bolted to the top of the cask. The fuel-element assembly is then drawn up into the cask. The lower gate in the cask and the gate in the open shield loop are then closed. The fuel element is sheared from the draw bar by closing the upper gate in the cask. The draw-bar shield is removed from the cask and the shield and draw bar are deposited in the storage canal. The cask is removed from the top of the reactor for storage or transportation. At this point it is necessary to insert a dummy fuel element or a new fuel element in the in-pile tube before the open loop shield, the spool piece, and the top concrete shield can be removed from the top of the reactor.

The insertion procedure is essentially the reverse of the removal procedure except that a cask and the draw-bar shield are not required. Although some streaming from the test section occurs when the gate in the open loop shield is opened, an element can be inserted in this manner without danger to personnel.

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