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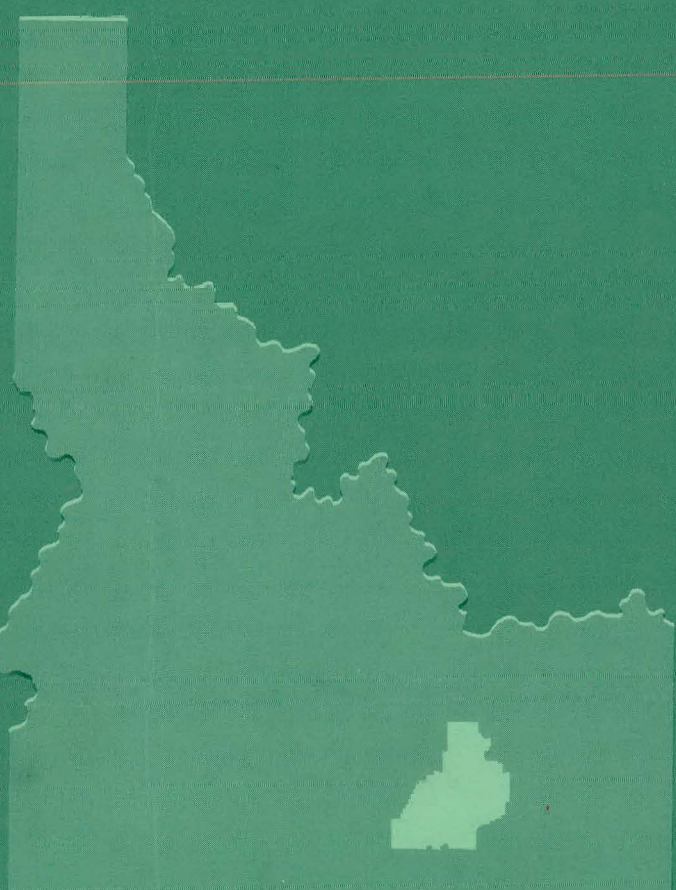
CONCEPTUAL DESIGN OF A GAS-COOLED LOOP FOR THE ATR

Edited by D. R. deBoisblanc, W. C. Francis, and L. H. Jones



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GAS-COOLED LOOP FOR THE ATR

July 31, 1961

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SUMMARY

This report presents the results of a conceptual design study for a gas-cooled loop to be inserted in one of the outer test facilities in the Advanced Test Reactor. A similar study for a high-pressure water loop is presented in IDO-16708. Both loops are designed to accommodate experiments conducted under programs of the Fuels and Materials Branch, Nuclear Technology, Division of Reactor Development, USAEC.

The design objectives called for a circulating gas loop capable of operation in a maximum fast neutron flux of 1.3×10^{15} n/cm^2-sec with an associated gamma heat of 22 watts/gram. The maximum temperature of the gas would be 1400°F. The loop proposed in this report has been designed for air cooling; other gases such as N_2 or He may also be used but with some changes in the operating parameters. One pound per second of air at 250 psi and 200°F is circulated in a 4" OD (2.5" ID) top re-entrant loop capable of removing 225 kw of fission plus gamma heat from a test specimen. The maximum outlet gas temperature with fission heat is 1400°F; without fission heat it is 900°F.

Constructed primarily of 347 stainless steel with 304 stainless steel in some out-of-pile regions, the proposed loop is estimated to cost $720,000 including design and contingencies. Time required for engineering, procurement, fabrication and installation is estimated to be twelve to fifteen months.

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CONCEPTUAL DESIGN OF A GAS-COOLED LOOP FOR THE ATR

1.0 Introduction

1.1 Historical

In the conceptual design for the ATR,[1] nine major test facilities were planned, five entirely within the core, and four outer test facilities providing neutron fluxes only slightly lower than the interior facilities. In April 1961, Phillips Petroleum Company was asked to undertake the conceptual design of one gas-cooled loop and one pressurized-water loop "to be built into the ATR to accommodate experiments under programs of the Fuels and Materials Branch, Nuclear Technology, Division of Reactor Development."[2,3] It was desired that the gas-cooled loop be developed from the basic concept presented in an earlier Phillips document,[4] and that the pressurized water loop be similar to the naval reactor loops designed for the ATR. This report describes the conceptual design for the gas-cooled loop, and includes a cost and time estimate for the engineering design and construction. A similar document, IDO-16708, has been prepared for the pressurized-water loop[5].

1.2 General Design Criteria

It is the intent of this report to describe a generalized gas-cooled test loop capable of accepting a wide variety of tests. Although the type and size of test specimens have not been specified, the system has been designed to handle the heat generation from the largest test specimen the tube will accommodate and to make provision for a modest amount of fission-product activity in the coolant stream. The final design has been "tested" by inserting a typical test section and calculating the resulting flow conditions and heat removal capabilities.

2.0 System Specifications

The following specifications are based primarily on values given in IDO-16667[1] for the ATR conceptual design, in IDO-24037[6] for the hazards analysis, in the BMI-16 report[8] and on experience obtained in the installation and operation of gas loops in the ETR.

2.1 In-Pile Conditions

The height of the active core has been specified as 48 inches in the conceptual design of the reactor. Since both the thermal and fast flux will drop very rapidly above and below the active core, the maximum test specimen length will not be much over 50 inches. The conceptual in-pile tube is designed for a test specimen whose maximum diameter is 2.5 inches and which fits into a round flow tube. No attempt is made to evaluate the possibility of flow tubes having other than round cross sections as this appears to be the least expensive and most acceptable shape.

Estimated average perturbed fast flux at midplane is 1.3×10^{15} n/cm^2-sec. Average thermal perturbed flux at midplane is estimated at 4.4×10^{14} n/cm^2-sec. The vertical maximum-to-average power ratio for the 48-inch active core length is estimated at 1.4 or less. With fuel on three sides of the in-pile tube, a rather pronounced lateral variation in fast flux would be expected. A lateral thermal flux gradient also would exist; however, the neutron scattering material surrounding the in-pile tube should reduce this to somewhat less than the fast flux gradient.

Maximum gamma heating for an in-pile tube is estimated at 22 watts per gram. Because of the lateral and vertical variation in gamma heating anticipated, this maximum value should be expected to exist only at a point near reactor midplane facing the center of the reactor. Gamma heating makes it necessary to consider the thermal stresses induced by internal heating of the tube wall as well as the effect of higher temperature on the properties of all structural material in the core region.

Heat removal capacity of the system will depend upon the type of coolant gas, specified inlet and outlet temperatures, and amount of heat transfer surface in the test specimen. In general, the loop is designed to recirculate inert gases. Air, nitrogen, helium, and others have been suggested. For convenience, the equipment has been sized for air flow; however, other inert gaseous coolants may be used. Proper allowance for different flow and heat-transfer characteristics should be made for coolants other than air.

Coolants must be as free from particulate and organic contamination as is economically possible. A shielded filter system is included in the main coolant system to remove particulate contaminants. Since particulate matter will circulate through the flux zone before removal on the filter, an excess of this material will aggravate filter removal problems. The filter must be designed so that the filter media can be replaced as simply and infrequently as possible. A by-pass coolant purification system could be incorporated in the closed loop to remove small amounts of moisture.

Maximum coolant temperature specified at the test specimen outlet is 1400°F. Coolant temperature must be reduced to 200°F inside the cubicle before it reaches the filter, turbines, flow elements and control valves. Coolant may be heated by regeneration and heaters to a maximum of 900°F before it is returned to the test specimen. If the test specimen outlet temperature is 1400°F, regeneration within the in-pile tube will raise the inlet temperature from 200°F to about 575°F. The maximum fuel element ΔT is thus 825°F limiting the loop capacity to 225 kw with air as the coolant.

The system must be designed to handle gas at a maximum pressure of 250 psig. Since the in-pile tube may, at times, be at atmospheric pressure, the external pressure imposed by reactor tank pressure is the controlling factor in the tube design. It is expected that the operating pressure will be 200 psig at the primary circulator inlet and 250 psig at the outlet. Approximately half of this differential pressure should be available for in-pile tube and test specimen pressure drop.

The system is designed for a nominal flow rate of 1 pound per second of air at 200 psig primary circulator inlet pressure. The flow rate for nitrogen would be approximately the same; however, the mass flow of helium would be considerably less (about 0.15 pound per second) because of its low density.

Because of the low mass of the coolant in the flux zone, activation of the coolant itself probably will not be the controlling factor in coolant activity. Contaminants that circulate through the flux zone and fission products could produce fields as high as 40 to 100 r/hr during operation. All of this will be within shielding and will drop to very low levels when the reactor is shut down. The system is designed so that all portions of the loop pressurized by the coolant, including instrument impulse lines, are contained in areas under negative pressure to prevent accidental release of activity to operating areas. Vents and pressure relief devices, as well as cubicle exhaust, will discharge to the stack.

2.2 Utilities

Electric requirements will be 50 kw of commercial power and 50 kw of diesel power for the two primary circulators. The loop heater will require approximately 50 kw of commercial power. The console will require approximately 3 kw of diesel power. About 1 kw of commercial power should be available at the cubicle for lighting.

Approximately 75 gpm of high-pressure demineralized water (HDW) should be available at the cubicle for the secondary side of the primary heat exchanger, primary circulator cooling, and sample cooling. Provisions must be made to drain low spots in the loop piping to a hot drain to dispose of solutions that may be used to decontaminate the loop. A drain facility should be available for the water side of the primary heat exchanger.

The main equipment cubicle and sample station should be maintained under a negative pressure and exhausted to the stack to prevent spread of air activity to the working areas. Containment should be as tight as possible to maintain this negative pressure. Experience has shown that approximately 1000 cfm of air flow to the cubicle exhaust system is required to do this. This volume of air should keep the ambient temperature in the cubicles within reasonable limits and maintain a face velocity across all openings of a least 150 ft/min. A more detailed study of cubicle cooling should be made to determine if a space cooler is required. If a space cooler is incorporated in the final design, additional power and cooling water will be required. The loop will discharge a small amount of filtered gas to the stack intermittently during operation to maintain pressure control. All of the gas contained in the loop will be discharged to the stack before removal of a test specimen.

Sufficient instrument air will be required to drive the flow control valve, temperature control valve, pressure control valve, pressure switches, and pneumatic instruments.

2.3 Cubicle Space and Location

The reactor conceptual design provides for a cubicle area located in the first or second basement for each of the major core facilities. The primary cubicle will occupy about 750 square feet of floor space. About 300 square feet of floor space adjacent to the primary cubicle may be used for a secondary cubicle to contain instruments and the sample station. In the general area of the cubicle, about 200 square feet of floor space is available for unshielded equipment, such as a power distribution system and makeup station. In the same general area, about 75 square feet of space is reserved for the operating console, which may be 30 feet in length.

The primary and secondary cubicles should be well sealed to minimize leakage of air through the wall. Primary cubicle walls should be made of high-density concrete block as has been customary at the MTR and ETR. These walls should provide sufficient shielding to maintain radiation levels outside the walls below 2.5 mrem/hr during full power operation. Considering the possibility of fission product activity within the primary cubicle during normal operation, two to three feet of high-density concrete will be required to provide adequate shielding. Because of the weight of shielding, the cubicle door will be a special problem for detailed design. Doors of this type have been mounted on tracks and moved by small electric motors. Shielding should not be required in the secondary cubicle walls. Highly radioactive samples will be shielded separately so that the secondary cubicle may be considered a working area. Floor loading will be a design consideration. The floor should be designed to carry about 5,000 lb/ft^2.

2.4 Console

The console design should adhere generally to accepted practice in the ETR experimental console area. Instruments should be grouped functionally on the panel, and consideration should be given to a graphic type of layout. The alarm system should be arranged functionally. Commercially available alarm units, such as those made by Panellit, have proven to be satisfactory. Wiring, tubing, terminal strips, pressure switches, and relays within the panel must be very well identified to facilitate repair, trouble shooting, and modification. Particular emphasis should be placed on accessibility of all console components. A complete set of reproducible "as built" schematic and construction drawings should be provided with the console.

2.5 Reactor Penetrations

The in-pile tube will occupy one of the outer core positions. Top and bottom reactor head penetrations are available for this core position. The in-pile tube presented in this concept will use only the top head penetrations. The upper portion of the in-pile tube will extend through the top head of the reactor. Test specimens will be removed and inserted through this portion of the in-pile tube by removing the top closure. Test specimen instrument leads will penetrate the top closure. A large, horizontal flange in the side of the reactor will be available for this core position. The concentric inlet and outlet pipes for the in-pile tube will penetrate the flange.

The in-pile tube should be supported vertically and horizontally from the reactor tank near the top of the tube in such a manner that it is free to expand downward with temperature changes. A horizontal vibration support several feet above the active core may be necessary. The reactor grid below the core can be used to provide horizontal support near the tube tip.

The concentric inlet and outlet piping should be fixed horizontally at the in-pile tube and permitted to expand freely through the horizontal flange. Expansion bellows must be designed to accommodate this expansion outside of the reactor.

3.0 General Description of Loop

The loop consists of a top re-entrant in-pile tube located in the reactor tank, a shielded cubicle housing all possibly radioactive equipment, and a console and auxiliary equipment which is located in a nearby unshielded area. Equipment inside the shielded cubicle includes two blowers, a regenerative heat exchanger, a primary heat exchanger, electric heaters, filters, and the associated valves.

An elementary flow schematic (Figure 1) illustrates the gas loop. Typical operating conditions are shown in Table I. The test specimen is located inside the flow tube in the in-pile tube. Air passes up through this flow tube. The inlet and outlet section of the in-pile tube are concentric within the reactor. Air leaves the outlet section of the in-pile tube just outside the horizontal reactor flange and passes through insulated high-temperature piping to the primary cubicle in the basement. In this piping, the maximum temperature and pressure of the air will be 1200°F and 250 psig.

Air from the outlet piping enters the regenerative heat exchanger in the primary cubicle where it gives up most of its heat to the returning air. It leaves the regenerative heat exchanger and passes to the air-water primary heat exchanger where it is cooled to 200°F. This low temperature preserves the integrity of the filter media, improves circulator and valve operation, and simplifies design.

Air from the primary heat exchanger passes through a shielded particulate filter to the primary circulators. Flow sensing devices are placed in the stream before and after the circulators. There are two primary circulators powered by completely independent sources of electricity. This feature will maintain circulation to dissipate specimen after-heat if one source of power fails.

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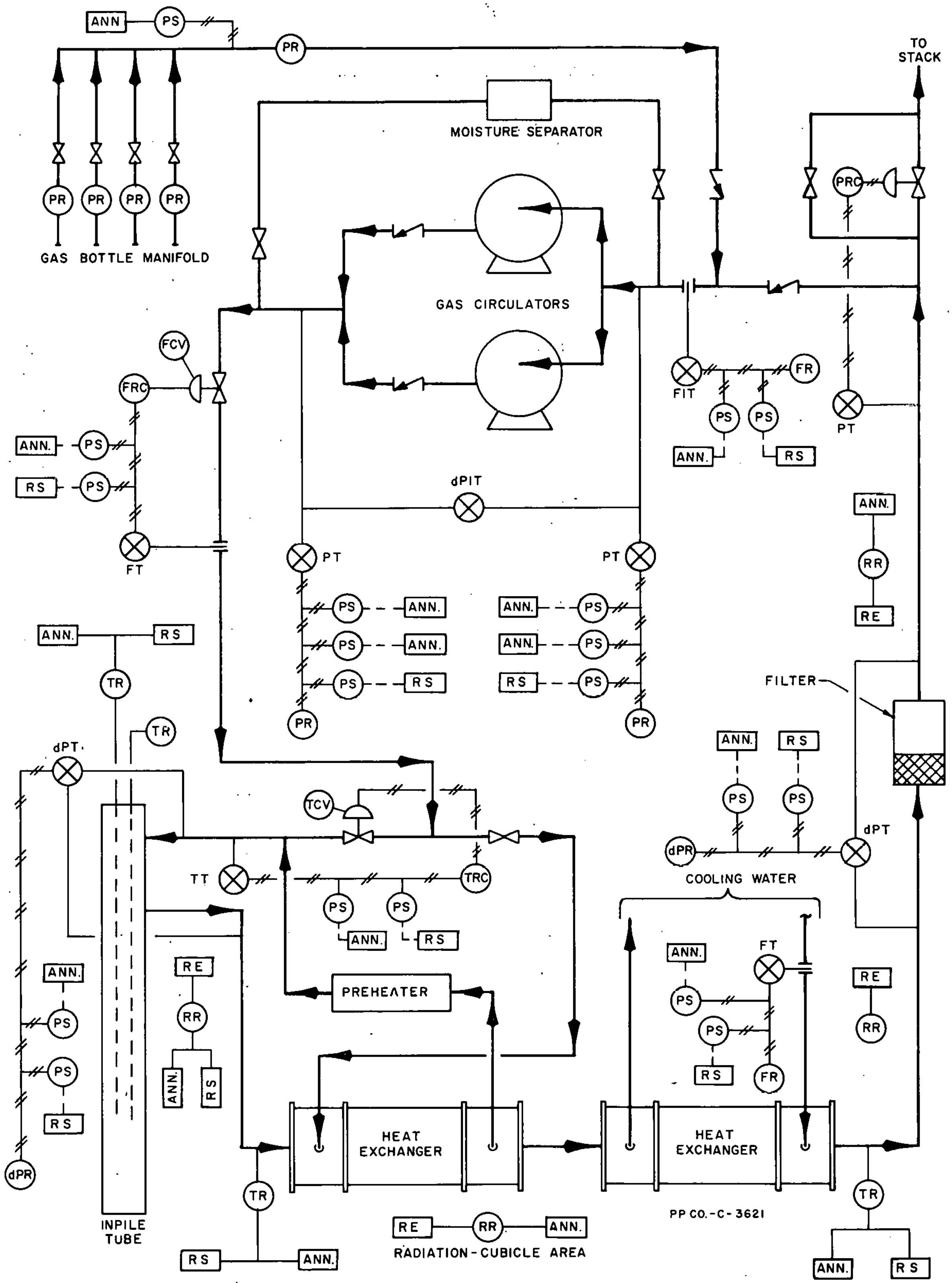

Figure 1   Gas-Cooled Loop Flow Diagram

TABLE I

DESIGN AND OPERATING CONDITIONS OF THE IN-PILE TUBE

Coolant Flow	1 lb/sec air
Coolant Pressure	250 psig
External Pressure (Design)	390 psi
Maximum Gas Temperature at Test Specimen Outlet	1400°F
Gas Temperature at Inlet to Test Specimen*	575°F - 900°F
Minimum Gas Temperature at Tube Inlet (Annulus Between Flow Tube and Thermal Barrier)	200°F
Maximum Coolant ΔT Due to In-Pile Tube Regeneration	375°F
Maximum Coolant ΔT across Test Specimen	825°F
Maximum In-Pile Heat Generation (Exclusive of Gamma Heating in the Pressure Vessel)	225 kw
Maximum Pressure Vessel Metal Temperature (Approximate)	300°F

* Gas film coefficients calculated from the following equation:[7]

$$h_f(\text{Btu/hr-ft}^2\text{-}^\circ\text{F}) = 7.34 \times 10^{-4} \frac{G^{.8} T_b^{\ .8}}{D^{.2} T_f^{\ .56}}$$

G = Flow (lb/hr-ft^2)

T_b = Coolant Temperature (°F)

T_f = Film Temperature (°F)

D = Hydraulic Diameter (ft)

A small by-pass stream may be taken from the circulator discharge through a drier containing activated alumina or some other suitable material for removal of moisture.

The main stream of air leaving the circulator flows through an automatic flow control valve to a tee. At this tee, the air stream is split for temperature control; one stream passes through the regenerative heat exchanger and a manually-controlled electric preheater, the other stream passes through an automatic temperature control valve which controls the inlet temperature by varying the amount of cold by-pass air. The two air streams join inside the cubicle and pass through the insulated inlet piping to the in-pile tube. At this point, the maximum temperature and pressure of the air should be 900°F and 250 psig.

The air flows into the in-pile tube inlet section just outside the horizontal reactor flange. Inside the in-pile tube, the inlet air flows into the annular space between the flow tube and thermal barrier down to the tip of the tube where it makes a 180° turn and passes up through the test specimen. Operating conditions calculated for a typical specimen in the test section are shown in Table II.

The loop is filled from gas bottles through pressure regulators that will maintain gas pressure above a pre-determined level and through a check valve that prevents back flow of contaminated air from the loop to the gas bottles. Gas enters the loop just upstream of the circulators.

Gas is discharged through a pressure control valve to the stack to maintain loop pressure below a preset level. During a shutdown, all of the gas pressure can be relieved through this valve prior to opening the in-pile tube for specimen removal.

High-pressure demineralized water (a reactor system utility) is circulated through the water side of the primary heat exchanger to remove specimen heat from the system. A small amount of water is required for cooling of the circulators.

3.1 Primary Coolant Piping

The design of the cubicle area piping and equipment is generally more straightforward than that of other sections of the loop and, with a few exceptions, is not complicated by intricate thermal stress problems. Heat losses to the cubicle are not considered in temperature loss to the primary coolant stream. One and one-half inches of fiberglas insulation is recommended on cubicle piping. Type 347 stainless steel is suggested for all primary piping because of its corrosion resistance, ability to hold pressure at high temperature, and ease of decontamination.[9]

Type 304 stainless steel is used for the coolant water piping because it is cheaper than 347 stainless steel. Three-inch pipe was selected on the basis of low pressure drop (4 psi per 100 feet of pipe). A tabulation of estimated pressure losses is shown in Table III.

TABLE II

DESIGN AND OPERATING CONDITIONS FOR A TYPICAL TEST SPECIMEN

Air Inlet Pressure	230 psi
Air Inlet Temperature	650°F
Air Flow	1 lb/sec
Heat Generation	200 kw
Peak Heat Flux (Midplane)	230,000 Btu/hr-ft^2
Average Heat Flux	115,000 Btu/hr-ft^2
Flow Tube ID	2.5 in.
Test Specimen (7 rods) OD	0.825 in. (each)
Test Specimen Length	48 in.
Air Outlet Temperature	1335°F
Midplane Air Temperature	970°F
Midplane Air Density	0.435 lb/ft^3
Flow Area	0.00813 ft^2
Midplane Air Velocity	283 ft/sec
Wetted Perimeter	2.16 ft
Hydraulic Diameter	0.0151 ft
G, Mass Flow Rate	4.42×10^5 lb/hr-ft^2
Midplane Heat Transfer Film Coefficient	285 Btu/hr-ft^2-°F
Midplane Surface Temperature	1775°F
Reynolds Number	7.7×10^4
ΔP Across Test Specimen	19.2 psi

TABLE III

PRESSURE LOSSES IN LOOP

Component	ΔP (psi)
In-Pile Tube	- 25
Circulators	+ 50
Heater	- 1
Heat Exchangers	- 5
Valves	- 14
Filter	- 1
Piping	- 4

All-welded construction is recommended for the primary system, with the exception of the air circulators and the filter, to minimize leakage when and if helium is used as a coolant. Flange joints may be used for the inlet and outlet connections to the circulators and filter to facilitate the removal, repair or replacement of these components.

When necessary to obtain satisfactory alignment between piping and equipment, welding should be done in the field. On the circulators and filter, slip-on flanges are suggested with welding in the field of at least one of each pair of flanges. The maximum, non-shock, service pressure rating for the flanges should be 700 psi at 200°F.

Raised face, slip-on type flanges with composition seals are used in the cooling water system because of the lower temperatures existing in these lines. All flanges in the cooling water system are 304 stainless steel and service rated for 300 psi.

3.2 Heat Exchangers

In order to conserve space and obtain high efficiency at a nominal expenditure, the regenerative heat exchanger should be a 347 stainless steel shell-and-tube heat exchanger, with all connections welded. The tubes should be in the form of a helix in order to achieve maximum heat exchanger area and to withstand expansion and severe repeated thermal shocks. The regenerative heat exchanger's preliminary design is on the basis of 1400°F air into the tubes and 700°F air out with a 1-1/2 psi decrease in pressure. Air on the shell side enters at 200°F and leaves at approximately 900°F with a 2 psi drop in pressure. The heat transfer area for this heat exchanger is approximately 21 square feet. Three inches of fiberglas insulation is recommended to minimize heat loss from the unit.

All-welded helical tube-and-shell construction is recommended for the primary heat exchanger. The tube side should be fabricated from 347 stainless steel to contain the hot loop coolant gas. The shell side should be made with 304 stainless steel through which flows the HDW cooling water. This heat exchanger's preliminary design is on the basis of 1400°F inlet air into the tubes and 200°F air out with a 2 psi pressure drop. It is designed so that the full heat load of the sample can be carried without the helpof the regenerative heat exchanger. The heat transfer area for this heat exchanger is approximately 16 square feet.

3.3 Particulate Filter

The assembly must be designed so that the filter with highly radioactive contents can be removed and replaced with a minimum of exposure to maintenance personnel and no spread of radioactive contamination outside the operating cubicle. The replaceable filter element should be made of fiberfrax material. The pressure wall is made of 304 stainless steel and is designed for a working pressure of 200 psig at 200°F. The filter should be enclosed in a four-inch thick wall of lead with an easily removable top. The filter system is placed in the flow stream ahead of the turbines and as close as possible to the point where coolant from the in-pile tube enters the cubicle. This provision should keep cubicle activity relatively low and prevent abrasive particulate matter from entering the turbines.

3.4 Gas Circulators

It has been established that a circulator of the de Haviland type will meet the gas loop requirements. Design requirements of the circulator include:

Suction Gas Pressure (psi)	200
Discharge Gas Pressure (psi)	250
Circulator Pressure Ratio	1.25
Gas Flow Rate lb/sec (Air)	1.0
Gas Temperature (^{o}F)	200
Estimated HP	32

The principal feature of the de Haviland gas circulator is the integral arrangement of the induction motor squirrel case and the centrifugal impeller on a single robust shaft mounted in self-lubricating gas bearings. This rotating assembly is housed inside a cylindrical welded steel casing which is hermetically sealed by welding the end cover when making the final closure. The heat generated in the motor is dissipated through the main casing to a water jacket formed by wrapping a stainless steel tube around the casing and bonding it to the casing. A water flow rate of 18 gallons per hour is required for cooling the casing. The motor size is approximately 32 HP with rotational speeds up to 24,000 rpm. These circulators can be supplied with pipe connections to suit the loop requirement. Two circulators are proposed for operation of the loop.

3.5 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. The preheater will be insulated with two inches of fiberglas insulation to minimize the heat loss from the system to the cubicle. The unit will be able to supply a maximum of 50 kw of electrical heat in manually-controlled steps to the loop inlet coolant gas.

3.6 Pressurizing and Control

The common method of handling gas is by means of portable high-pressure bottles. The bottle pressure provides a simple means for supplying makeup gas to the loop. To insure an adequate gas supply and uninterrupted operation, a manifold system will be used. Facilities should be provided for connecting four bottles to the manifold. To avoid full bottle pressure in the manifold, a pressure-regulating valve should be connected to the outlet of each bottle. By means of the regulators, the manifold can be maintained at approximately 50 psi above loop pressure. Another pressure regulating valve should be connected to the output of the manifold to maintain loop pressure. A check valve must be installed between the manifold regulator and the loop piping to prevent back flow. The loop is designed so that these bottles will provide emergency coolant flow for a short time. In order to maintain the loop at constant pressure a pneumatically-operated valve is suggested. This valve should be located in the loop vent line to the cubicle exhaust header. A signal should be taken from a pressure tap at the circulator inlet. This signal can be used to control the pneumatic valve, thereby controlling the pressure in the system. The loop is vented to stack exhaust by manually controlling the pneumatic valve.

Because the in-pile tube of the loop as well as the water-cooled heat exchanger are subject to water pressure greater than the system gas pressure, a means must be provided to monitor and record the moisture content of the loop gas in order to detect a water leak into the system. To accomplish this purpose, it is proposed that an electrically-operated hygrometer be connected to pressure taps in the circulator inlet and outlet headers. Depending upon the amount of moisture that can be tolerated in the loop during sample testing, it may become necessary to install a by-pass moisture removal system. Should such a removal system become necessary, it could be installed between the discharge and suction headers of the circulators. The vessel and amount of moisture removal material will be sized depending on the dew point of the gas required in the system.

3.7 Instrumentation

The flow sheet (Figure 1) summarizes the basic instrument requirements of the system. However, the minimum specifications for proper loop operation and for loop and reactor safety are given below.

3.71 Reactor Safety

Experience at MTR and ETR has indicated that the minimum number of loop parameters monitored by automatic reactor power reductions include flow, pressure and air temperature. For fuel tests, at least one fission break monitor must be added. Two separate, independent, continuously-recorded instrument systems must monitor each variable and have provisions to initiate automatic reactor power reductions.

3.72 Automatic Control

Each loop parameter monitored and controlled automatically must be continuously recorded. Sensing signals must be double-tracked in order to permit operation in case of failure of one signal. This requirement includes thermocouples to temperature controllers and two independent flow measuring systems.

3.73 Manual Control

Parameters of a secondary nature which can be operated by manual control from the console must also be indicated on the panel. For instance, HDW flow to the heat exchanger may be indicated on the panel and a manual loading station provided for adjustment of flow.

3.74 Annunciator System

Each parameter which must be controlled within certain values must be furnished with an annunciator which will warn the operator of departure from normal operating conditions. This is necessary because loops will not be given continuous operator surveillance. The annunciator must consist of at least a reactor control room annunciator, a local horn and a local light indicating which parameter is out of control.

3.75 Instrument Response Speed

Most monitored and controlled loop parameters can be handled by conventional instrumentation. However, instrument response speed is becoming more and more important for monitoring primary loop parameters such as coolant flow, pressure and temperature and sample temperature. For this reason, serious consideration should be given to instrument systems with very fast response, such as electronic transmitters on pressure and flow.

3.76 ATR Data Logging System

The ATR data logging system provides an ideal method for monitoring loop variables constantly, alarming when the individual point is off normal, and logging all variables at preset intervals. The readout system located near the loop console should be used for all process variables normally logged out by the operator.

Special consideration should be given to the requirements of the data system whenever transmitters are chosen for loop instrumentation. All recorders located at the panel must be capable of operating in parallel with the data system without upsetting either.

3.8 In-Pile Tube

The design of the in-pile tube is dictated, to a large degree, by the coolant conditions and physical facility size. The maximum inlet conditions of 900°F and maximum outlet temperature of 1400°F prohibit the use of the circulating gas stream through the bottom head because of the sealing problems and high pressure drop in the outlet section.

The design proposed consists of a concentric piping system for the inlet and outlet streams penetrating the reactor through one of the 12" or 8" flanges (see Figure 2). By using a re-entrant tube of this design, the need for a neutron scatterer in the lower portion of

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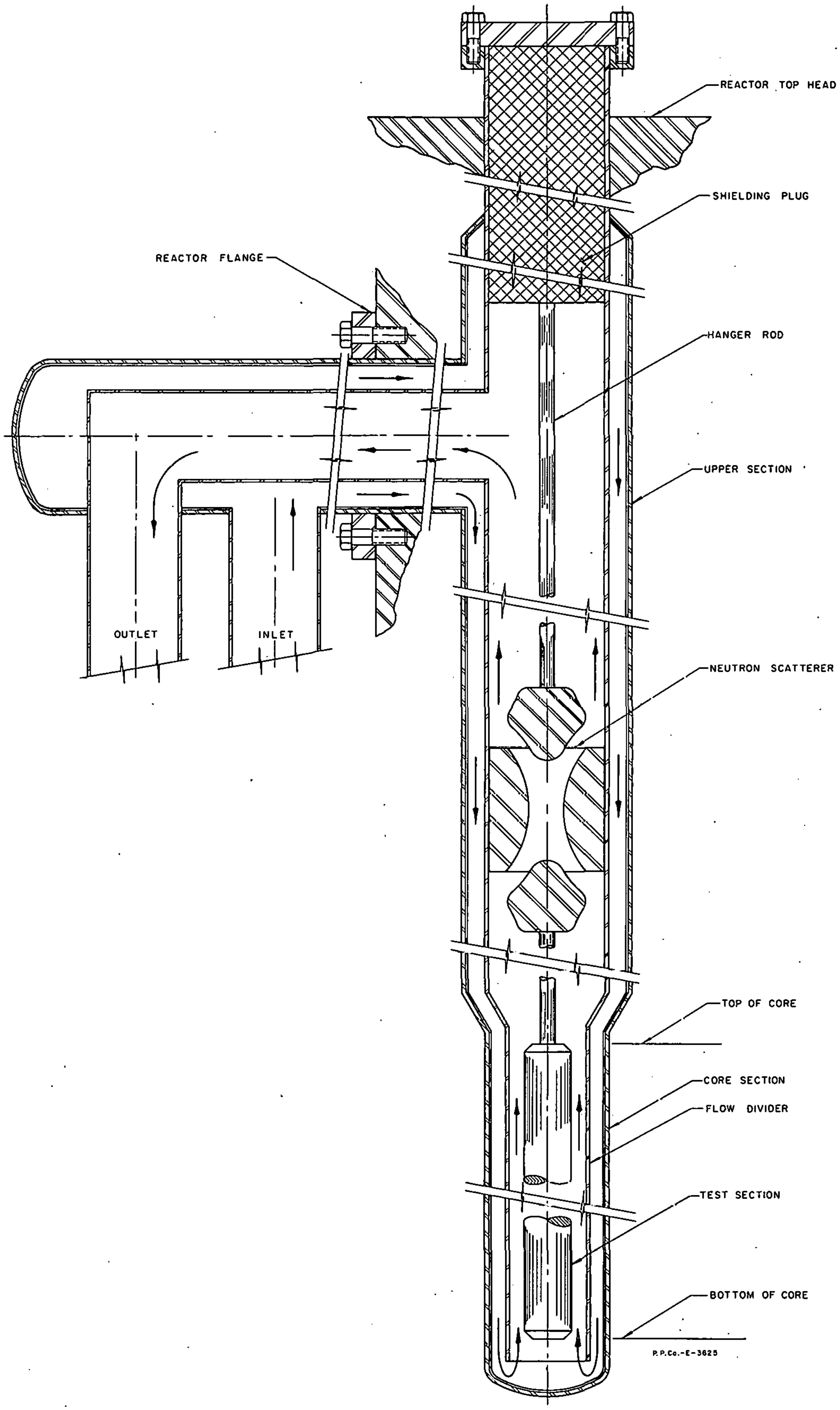

Figure 2 Gas-Cooled Loop In-Pile Tube Assembly

the pressure tube is eliminated, and no bottom head penetration is made. The top of the tube will penetrate the reactor top flange in basically the same manner that the water loop tubes will. Sample insertion and removal and instrumentation lead access will be through the penetration in the top head of the reactor.

It is anticipated that experiments inserted into this facility will be suspended from a rod or bar. This is necessary to support the upper neutron scatterer, the seal at the junction between the inlet and outlet streams and the thermal barrier and shield plug at the top. The use of a thermal barrier above the outlet piping permits low temperature sealing devices to be used. The shield plug is necessary to prevent neutron and gamma streaming out the tube during reactor operation. The test instrumentation will penetrate the top closure.

The outer cylinder of the assembly is the pressure tube. The gamma heat generated in the tube wall in the core section is transferred to the process water. Inside the pressure tube and forming a .030" gap between itself and the pressure tube is a .030" thick concentric cylinder running from just above the gas inlet through the core section. The purpose of this annulus is to minimize the heat loss from the inlet air to the reactor water. The cylinder is drilled with small holes to equalize pressure and fill the annulus with the system fluid. The flow tube occupies the center portion of the cylinder and forms an annulus for the inlet gas on the outside flowing down and the outlet gas flowing up through the flow tube. This arrangement of gas flow minimizes heat loss to the water and permits a lower pressure tube temperature. By enlarging the tube to the dimensions shown, the need for a neutron scatterer in the inlet annulus is eliminated, and the larger flow area offers less resistance to flow. Above the inlet and outlet piping, the tube can again be swaged down so that the outlet pipe becomes the pressure tube, permitting use of a smaller shield plug and thermal barrier.

The pressure tube thickness was determined by the Bureau of Ships Code for a cylinder subjected to external pressure; i.e., the Bureau of Ships exception of multiplying the factor B (ASME Code) by 1.33 was used for determining the wall thickness. This results in a wall thickness of 0.190 inch above the core section and 0.150 inch in the core section. These dimensions were determined using a design temperature of 500°F and an external design pressure of 390 psi. Although it was later determined that the metal temperature would not be this high, a lower temperature would not appreciably change these dimensions. The thermal stresses are within those specified by the Bureau of Ships Code. The tube must be anchored at the top cap, and a lateral brace should be provided. The tube growth from expansion should be taken in a downward direction by sliding up and down in the reactor core with a rather close fit so that the reactor core supplies some lateral support.

4.0 Insertions and Removals

The tube insertion should take place in two phases. The core section is inserted into position and supported while the inlet and outlet connections are made through the flange. After welding the inlet and outlet piping to the core section, the upper portion can be positioned and welded.

The tube will be removed by using the ATR handling cask. After the inlet section has been cut off and the lateral brace disconnected, the tube can be pulled into the cask and discharged.

Experiments will also be removed by using the handling cask. The experimental train is connected to the top closure and the test specimen, neutron scatterer, thermal barrier, and shield plug can all be removed as a unit. By use of this design, an experiment can be irradiated, removed for inspection, and re-inserted.

5.0 Cost and Time Estimate

An estimated cost and time schedule for each component of the gas loop is shown in Table IV. Total cost is expected to be approximately $720,000 with completion possible in 12 to 15 months after approval and assignment of the Architect-Engineer. The items which will mainly determine the final cost and time schedule are (1) the in-pile tube which will, of necessity, be a special fabrication job, (2) the compressors which are the key to the success of a loop of this type, (3) the engineering, and (4) the assembly and installation. An attempt has been made to recommend standard compressors which would be precision built to meet the rugged operating requirements of the loop. The console appears as a major cost and delivery item in Table IV but is essentially a standard type including instrumentation and is usually ordered as a complete unit. Ten thousand man-hours of effort have been allocated for assembly and installation.

With proper liaison and reasonable luck in fitting orders into vendors' schedules, the elapsed time for completion of the loop may be reduced to 10 - 12 months. Since in-pile tubes and compressors are notorious for time delays, arrangements for these components should be made as early as possible.

TABLE IV

COST AND TIME SCHEDULE FOR GAS SYSTEM

Component	Estimated $ Delivery Cost	Delivery Time Weeks
In-Pile Tube	$ 120,000	32 - 40
Circulators (2 each)	50,000	24 - 52
Heater	3,000	16 - 20
Heat Exchanger (Regn)	10,000	10 - 14
Heat Exchanger	10,000	6 - 8
Filter	2,000	6 - 8
Electrical Components	15,000	12 - 16
Console and Instrumentation	95,000	24 - 32
Piping, Valves, Fitting	20,000	4 - 6
Assembly and Installation	60,000	10,000 man-hours
Sub-Total	385,000	
Indirect - 30%	116,000	
Sub-Total	501,000	
A & E and Inspection - 15%	75,000	
Sub-Total	576,000	
Contingency - 25%	144,000	
TOTAL	$ 720,000	

7.0 References

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