MASTER

GA - 5938

DESIGN, CONSTRUCTION, AND INITIAL OPERATION
OF GENERAL ATOMIC IN - PILE LOOP

By
R. H. Simon

February 15, 1965

General Atomic Division
General Dynamics Corporation
San Diego, California

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report has been reproduced directly from the best available copy.

Printed in USA. Price \$4.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Va.

GENERAL ATOMIC
DIVISION OF
GENERAL DYNAMICS

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P.O. BOX 608, SAN DIEGO, CALIFORNIA 92112

GA - 5938
REACTOR TECHNOLOGY
(TID - 4500, 43rd. Ed.)

DESIGN, CONSTRUCTION, AND INITIAL OPERATION
OF
GENERAL ATOMIC IN-PILE LOOP

by
R. H. Simon

Prepared under
Contract AT(04-3)-314
for the
San Francisco Operations Office
U.S. Atomic Energy Commission

February 15, 1965

CONTENTS

PREFACE	iv
I. INTRODUCTION	1
II. FACILITY SYSTEMS AND COMPONENT DESCRIPTION	4
2. 1. In-pool Components	4
2. 1. 1. Vacuum Chamber	4
2. 1. 2. Facility Tube	9
2. 1. 3. Facility Tube Removal	13
2. 1. 4. Test Fuel Element	15
2. 2. Out-of-pool Components and Systems	16
2. 2. 1. Layout	16
2. 2. 2. Main Loop System Flow Circuit	20
2. 2. 3. Circulators	21
2. 2. 4. Electric Heater	28
2. 2. 5. Regenerative Heat Exchanger	28
2. 2. 6. Main Cooler	30
2. 2. 7. Full Flow Filter	30
2. 2. 8. Hot Helium Storage Tank	33
2. 2. 9. Helium Transfer Pump	33
2. 2. 10. Fission Product Trapping System	33
2. 2. 11. Scanner	36
2. 2. 12. Sampling Systems	38
2. 2. 13. Sample Blister	38
2. 2. 14. Junior Cave	40
2. 2. 15. Helium Charging System	46
2. 2. 16. Piping	47
2. 2. 17. Valves	49
2. 2. 18. Emergency Cooling System	52
2. 2. 19. Auxiliary Equipment Containment	52
2. 2. 20. Vacuum and Leakage Collection System	52
2. 2. 21. Secondary Water Cooling System	57
2. 2. 22. Fission Product Trapping System and Helium Circulator Cooling Water System	57
2. 2. 23. Make-up Water System	60
2. 2. 24. Liquid-nitrogen System	60
2. 2. 25. Fission Product Trapping Freon System	62
2. 2. 26. Cubicle Ventilation System	62
2. 2. 27. Depressurization System	64
2. 2. 28. Drain System	65

III.	CONTROL AND INSTRUMENTATION	66
3.1.	Control Panels	73
3.2.	Instrument Description	75
3.3.	Parametric Instrumentation	76
3.3.1.	Controlled Parameters	76
3.3.2.	Recorded Parameters	77
3.3.3.	Indicated Parameters	77
3.3.4.	Annunciators	78
3.3.5.	Scram Instrumentation	78
3.3.6.	Radiation Monitoring Instrumentation	79
3.3.7.	Intercommunication System	80
IV.	ELECTRICAL	81
4.1.	Electrical Distribution	81
4.2.	Electrical Installation	81
V.	SHIELDING	83
VI.	NUCLEAR DESIGN	86
6.1.	Thermal-neutron-flux Distribution	86
6.2.	Power Generation	90
6.3.	Cadmium-shutter Effectiveness	92
VII.	HEAT TRANSFER AND FLUID FLOW	93
7.1.	Heat Generation	93
7.2.	Heat Exchange	98
7.2.1.	Pressure Drop	98
7.2.2.	Heat Balance	99
VIII.	ACCIDENT EVALUATION	101
8.1.	Introduction	101
8.2.	Containment Design	101
8.3.	Analysis of Accidents	101
8.3.1.	Loss of Coolant	102
8.3.2.	Failure of the Main Cooler	104
8.3.3.	Failure of Circulators	105
8.3.4.	Inadvertent Closure of Line Valves	105
8.3.5.	Failure of the Purge Line Ahead of the First Trap	106
8.3.6.	Loss of Coolant to the First External Fission Product Trap	107
8.3.7.	Loss of Liquid Nitrogen	107
8.3.8.	Loss of Power	108
8.3.9.	Loss of Instrument Air	108
8.3.10.	Failure of Rupture Disks on Main Loop	108
8.3.11.	Failure of Main Loop Piping in the Facility Tube	108
8.3.12.	Failure of the Emergency Cooling System	109
8.3.13.	Maximum Credible Accident	109

IX. DESIGN AND CONSTRUCTION HISTORY.	113
X. OPERATING HISTORY OF GAIL III-A	114
10.1. Approach to Full Power	114
10.2. Mechanical Performance	120
10.3. Chemical Performance	121

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

PREFACE

The 40-Mw(e) High-temperature Gas-cooled Reactor (HTGR) being constructed at Peach Bottom, Pennsylvania, uses helium as the coolant and a fuel element consisting of a novel combination of graphite moderator and thorium-uranium dicarbide fuel particles coated pyrolytically with carbon. To test the HTGR fuel-element design under environmental conditions of radiation, temperature, and pressure that approximate those in the Peach Bottom core and to test the operability of a dynamic system containing a vented graphite-clad fuel element, the General Atomic In-pile Loop (GAIL) was designed and installed in the General Electric Test Reactor (GETR) at Pleasanton, California. The design, construction, and checkout of the loop required two years of intensive work. Nuclear heating of the first sample fuel element was begun on September 23, 1961, and full power was reached on October 12, 1961. Except for short periods, the loop has been at full power since that date.

Particular thanks are due to a number of people for their extraordinary efforts in bringing the GAIL to successful operation. These include Robert Stella who was responsible for, among other things, the gas-bearing circulators which have had trouble-free operation for over three years; Richard Vanek, who was responsible for the fission product trapping system; Walter Godsin and James Sleight, who were responsible for the assembly of the experiment (Godsin was also responsible for operation of the facility after full power was reached); and Dalton Sedgmore, Assistant Purchasing Agent, all of General Atomic. There were also William Clabaugh, Project Engineer for General Electric; Joseph Cochran, liaison between General Electric Engineering and General Electric Test Reactor operating personnel; Ned Biglieri, the General Electric engineer responsible for the out-of-pile portion of the loop; William Haïre, Project Engineer for Southwestern Engineering Company, and Ian MacTavish, Field Superintendent for Southwestern Engineering Company.

Many other people made important contributions to the design and operation of the in-pile loop. Although they are too numerous to thank individually, their efforts were important in making the GAIL project a success.

I. INTRODUCTION

In the Peach Bottom fuel element, fuel particles are dispersed in annular graphite compacts that surround a central graphite spine. A cylindrical sleeve of low-permeability graphite surrounds the fuel compacts. The fission heat generated is removed by helium coolant flowing upward past the element. The hot gas gives up its heat to water in a boiler and is then returned to the reactor by the circulators. A small amount of helium, which enters the fuel element through a porous plug at the top, flows downward inside the space between the compacts and the sleeve to purge the element of fission products that may escape from the fuel compacts. Before leaving the element the purge stream flows through an internal fission-product trap. It then passes out of the element and through a series of fission-product traps at successively lower temperatures.

The test facility consists of a single full-diameter, quarter-length Peach Bottom fuel element, a closed-loop helium gas circulating system in which the heat generated is removed, a fission-product trapping system, provision for sampling both the main loop and the fission-product trapping system, and their required containment cubicles and shielding. Because it contains all of the major components of an HTGR gas-handling system, it constitutes a pilot plant for fission-product-control study.

The test fuel element (see Fig. 1) is 3.5 in. in diameter and 43-1/2 in. long with a 22.5-in. active length. Except for its length, it is a duplicate of the Peach Bottom element; it contains a graphite spine, annular fuel compacts made with coated fuel particles, an internal fission-product trap (with provisions for bypassing), and a low-permeability graphite sleeve. Table 1 compares the loop parameters with those for the Peach Bottom design.

Nuclear heating of the first test element of this design, designated element III-A, was initiated on September 23, 1961, and full power was reached on October 12. Testing of this element continued until its scheduled removal on February 4, 1962, after about 2000 hr of testing, during which time about 133 Mw-hr of fission and gamma heat was produced. This is about 18% of the heat generated by a corresponding length of an average Peach Bottom element in three years at 80% load factor.

The element was operated at a maximum measured fuel temperature of 2700°F, which is approximately the same as the maximum anticipated

Fig. 1--Schematic diagram of the GAIL fuel element

in Peach Bottom. Some parts of the fuel reached calculated temperatures of 3000°F. The most significant information obtained, aside from the successful operation of the fuel element, was (1) the low level of radioactivity in the primary system ($0.03 \mu\text{c}/\text{cm}^3$ at loop conditions), (2) the ability of the fission-product trapping system to clean up the helium to extremely low levels of both radioactive and chemical contaminants, and (3) the ease of access to the system for maintenance after reactor shut-down.

Table 1
COMPARISON OF GAIL AND PEACH BOTTOM
REACTOR OPERATING PARAMETERS

	GAIL	Peach Bottom
Element diam., in.	3.5	3.5
Active length, in.	22.5	90
Helium pressure, psia	350	350
Inlet gas temp., °F	660	654
Outlet gas temp., °F	1400	1380
Purge flow rate, lb/hr	0.1-0.6	1.2*
Heat generation, kw	75	140*
Main coolant flow rate, lb/hr	240	520*

*Average per element.

Element III-B, the second element to be irradiated, was essentially the same as element III-A, except that the helium permeability of its sleeve was somewhat higher. In this element, the small amount of helium flowing inward through the microscopic pores in the sleeve serves as a very effective barrier against the simultaneous outflow of the gaseous fission products. Irradiation of element III-B began on March 17, 1962, and continued until March 18, 1964. The irradiation of this element is described in General Atomic report GA-5314, Irradiation Test of the GAIL III-B Fuel Element in the General Atomic In-pile Loop, July 18, 1964.

II. FACILITY SYSTEMS AND COMPONENT DESCRIPTION

The facility consists of a main coolant loop, Peach Bottom-type fuel element, a purge loop containing a fission-product trapping system, and provisions for measuring temperatures, flows, and pressures, and for sampling the gas in both loops at a number of points. A simplified flow diagram of the loop-coolant flow is shown in Fig. 2. The position of the facility tube in the GETR pool is shown in Figs. 3 and 4.

Major components in the main coolant loop include a pressure vessel (facility tube) that contains the test element, helium circulators, a full-flow filter, a regenerative heat exchanger, an electric heater, and a water-cooled heat exchanger for removing the heat generated in the fuel element.

The purge loop contains a water-cooled charcoal trap, a Freon-cooled charcoal trap, a heated copper oxide bed, a water-carbon dioxide trap cooled by liquid nitrogen, and a liquid-nitrogen-cooled charcoal trap. An emergency purge loop consisting of a water-cooled charcoal trap and a liquid-nitrogen-cooled charcoal trap parallels the purge loop.

A shielded cubicle contains out-of-pool major loop components, such as the helium circulators, heat exchangers, helium storage tank, and loop piping, valves, and instrumentation. A secondary compartment is provided for pumps and vacuum equipment. Adjacent to the main cubicle is a shielded region, known as the junior cave, which is equipped with a manipulator and a shielded viewing window to permit sampling of the purge stream at several points. A sample blister equipped with a sealed window and glove ports permits sampling of the main loop.

2.1. IN-POOL COMPONENTS

2.1.1. Vacuum Chamber

The experiment is located in the reflector pool of the General Electric Test Reactor (GETR), adjacent to the reactor pressure vessel. This location provides a perturbed thermal neutron flux of about $2 \times 10^{13}(\text{h}\nu)$. The facility tube contains the experimental fuel element and is positioned within a vacuum chamber that insulates it from the water of the reactor pool. The general arrangement of the in-pool equipment is shown in Fig. 3.

Fig. 2--Simplified flow diagram for the in-pile loop

Fig. 3--Location of the facility tube in the GETR pool

Fig. 4--In-pool arrangement

The piping within the vacuum chamber that is connected to the part of the loop remaining outside the pool consists of a line that brings helium coolant to the fuel element, a line that returns the heated helium to the heat exchanger in the main cubicle, a tempering-gas line that brings cooler helium from the circulator exit to the fuel element exit, if required, and two purge lines that carry fission products to the trapping and purification system which are also located in the main cubicle.

The purpose of the vacuum chamber is to provide a thermal barrier between the pool water and the facility tube assembly and the piping that contains the flowing helium. It also provides secondary containment for radioactive fission products in case of leakage from the in-pool portion of the loop. The vacuum chamber extends up to the main cubicle at the pool penetration flange in the reactor biological shielding. The atmosphere of the vacuum chamber and the main cubicle are not directly connected.

The vacuum chamber is made of 6061-T6 aluminum. An enlargement in the chamber, the disconnect box, is provided in the portion near the reactor-vessel head to contain the piping and thermocouple disconnects. Because of existing equipment in the GETR reflector pool, it was necessary to install the vacuum vessel in two pieces. The 1-1/2 in. thick bottom plate of the disconnect chamber was cut in two pieces following trial assembly of the entire vacuum vessel in the shop. This was rewelded in place in the reactor and the walls subsequently welded to this bottom plate. A removable flanged plate is removed to permit access to the disconnects when it is desired to remove the facility tube. The vacuum chamber is designed to withstand the peak pressure expected should the system lines rupture within the chamber. A 4-in. rupture disk on the chamber rated at 15 psig releases the loop gas to the main cubicle in case of rupture.

Welding in the GETR reflector pool was carried out under very difficult conditions. High radiation levels (30 to 150 mr/hr), particulate contamination (which required at times two pairs of coveralls and air breathing equipment), high humidity, and difficult work positions imposed by restricted access resulted in considerable worker discomfort. Working room was extremely limited by existing equipment and the fact that the annular space around the reactor is only 3-1/2 ft across. Despite these conditions, the welding of the aluminum vacuum chamber was remarkably good.

The vacuum chamber is flange-connected to the pool liner penetration flange located within the biological shield penetration. The penetration connection is made of stainless steel.

Shielding is provided within and above the vacuum chamber to minimize radiation upward from the fuel and the lines carrying fission products.

During normal loop operation, the facility tube is located in close proximity to the reactor vessel to take advantage of the high neutron flux. However, the vacuum chamber can be retracted in the core region up to 5 in. from the reactor vessel. The ability to adjust the location of the experiment with respect to the reactor provides a greater degree of flexibility than is found in most other in-pile loops. The jacking mechanism that provides the movement is shown on Figs. 3 and 4. This mechanism, or actuator, is similar in principle to the scissors jack used on automobiles. However, because it was submerged in the GETR pool, there were some special material requirements. For example, no copper-base materials were allowed. In addition, ordinary carbon steel could not be used nor could any lubricants. The problem was solved by using a Type 304 stainless steel actuating screw and a 17-4 PH ball nut. A long shaft with two universal joints was used to rotate the screw, and adjustable stops limited the movement.

In the fully retracted position a shutter consisting of lead, aluminum, and cadmium shields the fuel in the facility tube to minimize gamma and fission heat generation. The shutter was made in two semi-circular pieces, one of which was fixed and the other of which could be rotated by means of a chain and sprocket drive. The fixed part consisted of a semi-circular piece of aluminum-clad cadmium approximately 6 in. in diameter and 24 in. long. The cadmium was 0.2 in. thick and the cladding was 0.050 in. thick. The movable part consisted of a similar piece of aluminum-clad cadmium, slightly smaller in diameter, attached to which was an aluminum-clad semi-circular lead shield 1-1/4 in. thick. The latter had a diameter of 6-1/2 in., and thus it rotated outside the fixed cadmium section. The shutter support was bolted to the capsule ring of the GETR by means of four leveling screws that could be adjusted remotely. The sprocket was rotated by means of an extension rod with two universal joints. The shutter is shown in Fig. 5. During the time that the shutter is in use to minimize heat generation, helium is provided in the vacuum chamber annulus to assure the necessary conductance for removal of the small amount of heat still being generated. Thus, when the loop facility is shut down the reactor can continue to operate and the loop experiment need not be removed.

In order to provide shielding during the refueling operation the vacuum chamber may be flooded with water to a predetermined level. Two auxiliary systems are connected to the vacuum chamber--the evacuation system and the emergency cooling system. These systems are described in subsequent sections of this report.

2.1.2. Facility Tube

The facility-tube assembly consists essentially of a re-entrant type pressure vessel containing the fuel assembly and flow and thermal baffles,

Fig. 5--Shutter mechanism

coolant inlet and outlet piping, tempering-gas piping, purge gas piping, thermocouples, disconnect joints, and internal shielding.

The facility-tube pressure vessel is made of Type 321 stainless steel. It is designed for a pressure of 400 psig at a temperature of 1000°F. The upper end of the facility-tube assembly consists of a 1-1/2 in. helium-coolant inlet pipe, a 2 in. outlet pipe, a tempering-gas mixing chamber and line, two 1/4 in. tubing purge lines, a thermocouple ring, piping and thermocouple disconnects, and steel shielding. As shown in Fig. 6, the inlet helium flows down in the annulus between the pressure vessel wall and thermal baffles keeping the pressure vessel cool. The gas then enters the annulus between the fuel element and the thermal radiation baffles and flows upward. The thermal radiation baffles consist of three concentric cylinders of sheet metal, the middle one being dimpled to maintain clearances. The inner and middle baffles are Nichrome V, outer stainless steel. The middle baffle acts as a radiation shield and as a convection spoiler that inhibits natural convection in the stagnant helium between the baffles (dimensions are shown in Fig. 6). The tops of the inner and outer baffles are welded to the respective inner and outer baffle caps, which are in turn welded to the tempering-gas inlet baffle. As a result, the helium is prevented from bypassing from inlet to outlet. The weight of the fuel element is supported by clips that are attached to the bottom end of the outside baffle.

To promote turbulence, maintain a uniform hot gas annulus, and prevent the gas from channeling up one side, flow swirlers were welded to the inner baffle. These consisted of forty-two 0.070-in. tantalum wires, each one-inch long, placed at a 60° angle to the vertical and spaced in rows of six around the circumference. If necessary, tempering gas is brought from the circulator discharge to mix with the outlet helium flow for the purpose of decreasing the temperature of the helium leaving the facility-tube assembly to a 1400°F maximum. Thermocouples are provided to measure the temperatures of the fuel-compact internals, the graphite sleeve, and the helium at the test-section inlet, fuel-element inlet, and fuel-element outlet. Six thermocouples are attached to a thermocouple ring at the outlet from the element. The outlet pipe is insulated by metal ribbon that is dimpled and wrapped around the pipe. The surface of the ribbon has a baked gold finish to increase its reflectivity. Steel shielding is provided in the upper region of the facility tube to minimize vertical radiation above the fuel. The purge lines leave the bottom of the fuel element and pass between the pressure vessel wall and the thermal radiation baffles. Because of the small clearance, the lines are somewhat flattened in this region. They then pass out of the facility tube and are strapped to the inlet helium line to keep the purge gas warm.

Fig. 6 --Cross section of facility tube

2. 1. 3. Facility Tube Removal

The disconnects for the five lines connecting the facility tube to the remainder of the system are Marman flanges utilizing two concentric metal gasket seals. The space between the seals on each flange can be evacuated or pressurized with helium. Leakage, if any, is directed to the leakage collection system. The thermocouples are disconnected at two Cannon all-ceramic plugs. The removal of the facility tube involves the following steps:

1. The disconnect box is remotely surveyed for radiation level by means of an ion chamber installed in a hole through the lead shield on top of the box. If this instrument is inoperable for any reason, the pool water level is gradually lowered and a radiation survey is made with a portable instrument.
2. The vacuum chamber is filled with water to a level just below the bottom of the disconnect box.
3. The shield on top of the vacuum box is removed and the box opened by removing the top flange. The open box, the three large Marman flanges, and the location of the box with respect to the reactor vessel are shown in Fig. 7. To ensure that future facility tube Marman flanges would match the permanent ones in the pool, a jig with dummy Marman flanges was made up.
4. After removing the internal cast iron shield, the Marman flanges and thermocouple plugs are disconnected. The facility tube is then raised a few inches, and blind flanges are placed over the five Marman flanges.
5. A water gate and temporary half-cover are placed on the vacuum box. This prevents water from filling the section of the vacuum chamber leading to the cubicle. If water did leak into this portion of the vacuum chamber, it would take a considerably longer time to pull a vacuum because of water trapped in the thermal shielding on the hot pipe.
6. The reactor pool is refilled with water and the gates separating the reactor pool from the canal are removed.
7. The facility tube is pulled out of the vacuum chamber and moved to the canal where it is suspended with the Marman flanges above water.
8. After several weeks to allow some fission product decay, the blind flanges are removed and steel balls which are just smaller than the inside diameter of the respective pipes are dropped down the cold, hot, and tempering gas lines. Orifices are located in each line just above the pressure vessel to provide a seat for these

Fig. 7--Vacuum chamber disconnect box

balls. Rubber plugs are forced down the purge tubes to the point at which these lines are flattened as they pass between the outer thermal baffle and the inside of the pressure vessel.

9. All five lines are then filled with a Hypolon plastic mixture which sets up in less than 24 hr.
10. The pipes are cut off with an underwater saw just above the pressure vessel. This permits the use of a five-foot-long cask in place of a fifteen-foot-long cask for shipping.

2. 1. 4. Test Fuel Element

The fuel assembly (see Figs. 1 and 6) consists of annular fuel compacts located in a graphite cylinder, heat insulators, connections, and structure, an internal fission-product trap, purge lines, and thermocouples. The central hole within the fuel compacts contains a spine of graphite. Each compact consists of an annular cylinder of pyrocarbon-coated U^{235}/Th dicarbides dispersed in graphite. The compacts are 1-1/2 in. long and have an outside diameter of 2-3/4 in. and an inside diameter of 1-3/4 in. Fission heat is generated in the compacts and transferred by radiation and conduction to the graphite sleeve and thence to the helium coolant. The space between the compacts and the sleeve, which is a narrow annulus (0.003 in. to 0.007 in.) augmented by longitudinal grooves in the compacts, is swept by helium gas to purge the fission products entering this annulus. The helium gas is taken from the main helium stream at the discharge of the fuel element, passes down through the element and through an internal activated-charcoal trap at the bottom of the element, and out into the purge lines, which lead to the external fission product trapping and helium purification systems. A bypass around the internal trap was provided to test its efficiency.

To prevent gas from entering the purge line at the bottom of the fuel element, thus by-passing the compacts, a metal cap was shrink fitted over the lower end of the element. The thermocouples passed through drilled-out fittings brazed to this cap. Eight thermocouples were located within the fuel element as shown schematically by the dots in Fig. 1. The two thermocouples that measure the fuel temperature are located between the spine and the compacts. The two thermocouples that measure the sleeve temperature pass along the compact grooves and into diagonal holes that penetrate halfway through the graphite sleeves.

These four thermocouples, which are 0.083 in. OD, consisted of a tungsten wire and a tungsten-26% rhenium wire each 0.012 in. in diameter. The insulation was beryllium oxide and the sheath was tantalum 0.065 in. OD and 0.009 in. wall. A 0.003-in.-thick zirconium protector tube which fit loosely was slipped over the sheath. The thermocouple junctions were

grounded to the sheath. Other thermocouples were chromel-alumel with a stainless steel sheath. Gold braze junctions were made at the bottom of the fuel element to lead wires of copper and copper-nickel alloy sheathed in stainless steel. This type of lead was used because of the expense of the tungsten-rhenium.

Because of the limited life of the thermocouples at fuel temperatures (approximately 2800°F), an acoustic type of thermometer was installed in the GAIL III-A. This device measures the resonant frequency of a cavity in the fuel element by means of an electro-acoustic transducer that supplies energy to a tube connected to the fuel element cavity. The frequency at resonance is proportional to the square root of the absolute temperature. The resonant chamber in the GAIL III-A fuel element was machined in the center graphite spine of the fuel compacts.

During the loop shakedown, a dummy fuel element was installed in the vacuum chamber. By error the neutron and gamma shutter was left open, and the vacuum chamber containing the facility tube was not fully retracted when the reactor went to power following completion of the in-pool installation. This resulted in irradiation of the dummy fuel element, including the tantalum wires which were a mockup for the tantalum-sheathed thermocouples. The tantalum apparently oxidized as a result of air entering from the out-of-pile portion of the loop, which was still under construction. When gas was circulated, the irradiated tantalum, which was apparently in the form of a powder, was transported to the out-of-pile part of the loop. As a consequence, the completion of the out-of-pile portion of the loop and auxiliaries was carried out under irradiation conditions. One point source was greater than 50 r/hr. In order to increase the time available to work within the cubicle, the highest level irradiation spots were temporarily shielded.

2.2. OUT-OF-POOL COMPONENTS AND SYSTEMS

2.2.1. Layout

The containment cubicles, gas circulating system, fission-product trapping and purification system, and supporting equipment are located on the second floor of the GETR reactor building. The equipment location and cubicle design are shown in Fig. 8. The main cubicle, which is positioned on the second floor, is enclosed in concrete and steel. The concrete is dense and was installed in the form of interlocking blocks that were about 5 ft long, 1-1/2 ft high and 20 in. deep. Because of the limited space, and the large number of penetrations, the roof and some of the walls were made of steel plate. Where shielding was required, the steel walls were built up to a thickness of 12 in. in 2-in. -thick laminates. The entire inside of the cubicle was lined with steel plate, which formed a secondary containment.

Fig. 8--Out-of-pool equipment: plan view of upper and lower level of second floor

The cubicle is divided into two levels, with the fission-product trapping system equipment, the drain tank, and the depressurizer tank and compressor located on the first level and with the primary loop and associated equipment located on the second level. The equipment density in the cubicle is extremely high. The second level is divided into three compartments, the largest of which is open to the lower level and contains the major loop components, such as the heat exchanger, heater, cooler, full-flow filter, hot-helium storage tank, leakage-collection holdup tank, cubicle cooling system, ventilation blower and main-loop piping, valves, and instrumentation.

Partially separated from the main cubicle by a concrete block wall is the helium circulator cubicle. The other compartment on the second level is the pump room, which contains the gas transfer pump, leakage holdup transfer pump, vacuum-chamber pump, purge-containment blower, fission-product trapping-system sample vacuum pump and cubicle ventilation blower. The pump room provides access to the pumps for periodic inspection and maintenance. It is shielded from the components in the other compartment and is also surrounded by shielding. Access is through a door at the operating-mezzanine level. Access to the main loop circulators is through a door at the back of the pump room.

Access to the lower level is through an air lock. Access to the upper level, exclusive of the pump room and circulator room, is by ladder from the lower level. Lead brick or concrete block shielding is provided locally around the regenerative heat exchanger, main cooler, full-flow filter, hot-helium storage tank, and the purge lines up to the first trap to minimize radiation to personnel entering the cubicle for inspection and maintenance during accessible periods. The individual vessels in the fission-product trapping system are built into lead casks, as shown in Fig. 9.

The cubicle normally operates under a slight negative pressure to minimize out-leakage. The pump cubicle is ventilated as discussed in Section 2.2.26, "Cubicle Ventilation System."

In order to be effective as a secondary containment, stringent requirements for leak tightness were put on loop piping and electrical penetrations and access doors. Piping penetrations through shielding walls were welded to the steel cubicle liner and the penetrations filled with lead bricks and lead wool. Electrical penetrations, all of which went through the roof of the cubicle, were sealed by filling the junction boxes with epoxy resin. Cubicle access doors had gaskets which sealed against the flat faces of the door frames. Each had one or two main latches plus a number of dogs to decrease leakage. The leakage rate is tested periodically and maintained at less than 300 vol-%/day at 2 psig.

Fig. 9--Shielded casks containing Freon-cooled and liquid-nitrogen-cooled charcoal traps

The purge gas and the fission-product trapping system are sampled in a shielded containment cubicle called the Junior Cave, which is constructed with the same leak tightness requirements as the main cubicle containment structure and located adjacent to the main cubicle.

The main loop is sampled in a glove box, or sample blister, located adjacent to the pump room entrance. An unshielded auxiliary containment room, which is located on the north side of the main cubicle (i. e., next to the circulator cubicle) contains equipment for the various cooling systems. Adjacent to this room is the liquid-nitrogen head tank and the potable water storage tank. A Freon refrigeration system for chilling the cooling water is located below the ceiling of the first floor of the GETR.

Instrumentation consoles are located on a mezzanine floor midway between the second and third floors of the GETR. Electrical switch gear and rotating equipment is located generally throughout the second floor area and against the containment vessel wall on the first floor. Stack monitor instrumentation is located outside the building near the stack in a separate structure. Also outside the GETR containment is the liquid-nitrogen storage tank. A console is located in the GETR reactor control room which monitors and controls important loop parameters.

2. 2. 2. Main Loop System Flow Circuit

Helium flow is provided from either of two gas-bearing circulators. The flow passes through the electric heater and the heat exchanger shell where heat is added prior to entry to the facility tube. Provision is made to bypass the heat exchanger, and the conditions of the tests to date have been such that this has been done. After leaving the facility tube and re-entering the main cubicle, the coolant passes through the tube side of the heat exchanger and then through the loop cooler. The main flow then passes through an in-line filter (with provision to bypass) back into the suction of the circulators completing the flow circuit. A bypass is also provided between the discharge of the loop heater and the entrance to the loop cooler to allow out-of-pool testing of the loop.

It was decided at the beginning of the design period that as many components as possible would be purchased as catalogue items. Consequently, with a few exceptions, no development was carried out on valves, instruments, or pumps. The exceptions were the differential pressure transmitters, moisture monitors, and the main helium circulators.

The loop and components were designed and fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII,* where applicable, for lethal substances and applicable nuclear code cases. The loop and components were approved by the State of California and identified as California Special No. 1-61.

*ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, American Society of Mechanical Engineers, New York, 1959.

Components of the loop which are operated under helium pressure were mass-spectrometer leak tested to a minimum sensitivity of 5×10^{-8} atm cm³ of helium/sec. The components were fabricated so that no leaks were detected at the sensitivity selected. The entire loop was leak tested on completion and had a leak rate of less than 10^{-6} atm cm³ of helium/sec.

2.2.3. Circulators

Two De Havilland gas-bearing circulators of equal capacity are installed in parallel to pump the helium coolant through the loop. Only one circulator is operated at a time, and the other is held as an on-line standby unit in the event of a circulator failure. All rotating parts are carried on self-acting gas bearings that use the circulating fluid as lubricant.

The decision to use gas bearings was based on several considerations. The problem of radioactive gas and particle leakage through rotating seals, which are operationally sensitive to high rotational speeds, high temperatures and pressures, temperature changes, and particle entrainment, was eliminated. By using self-acting bearings (in which journal rotation induces in the bearing clearance an aerodynamic gas film sufficiently strong to support the impeller assembly) rather than pressure-fed bearings (in which externally supplied gas is used to balance the static forces acting on the journal), actual injection of particles into the bearing clearance is averted. The elimination of seals and bearing-pressurization problems reduces the auxiliary equipment required by the compressor. Gas bearings have three other advantages:

1. Contamination from lubricants is eliminated, and wear particles are minimized.
2. The load-carrying capacity of gas films is only slightly affected by temperature, whereas temperature critically affects the performance of conventional lubricants.
3. Irradiation has no effect on gas-film performance.
4. The potentially long life of fluid-film-supported bearings minimizes the access requirements for compressor maintenance.

Test requirements for the HTGR in-pile loop prescribe low-flow operation for extended periods. Such conditions (i. e., light loads and nonstop operation) apply ideally to self-acting gas bearings. When motor acceleration is properly controlled, metal contact between bearing and shaft occurs only at the instant of startup and, in the absence of external shock loads or of shaft displacement caused by debris, at the end of coast-down, when the load is negligible.

The first two circulators installed in the loop failed as a result of shaft displacement caused by construction debris that entered upstream from the circulators. This debris entered the system despite the fact that the next piece of equipment upstream from the circulators was the main loop filter and despite the elaborate precautions that were taken to clean and seal the piping before it was welded into the system. It is believed that this debris probably originated during field welding of branch lines. After these failures, Y strainers were installed immediately upstream from each circulator.

At the time when these bearing failures of the gas bearing circulators occurred, and before the cause of failure was known, a backup circulator was procured from the Turbocraft Company and installed in the loop. In the Turbocraft machine the impeller assembly shaft and electric drive motor shaft are independently supported on grease-lubricated ball bearings, the shafts being connected by a spline coupling. The entire assembly is contained within a ring-joint flanged pressure vessel, that met loop leak-tightness specifications. (The flange joint included a seal welding feature which was not used.) The amount of lubricating grease, Texaco UNI-TEMP 500, in the machine at assembly is less than 2 g. No provision is made for the further addition of lubricant during the expected life of the bearing. The original metal retainers in the electric motor bearings were replaced with phenolic retainers, so that all ball bearings within the machine are retained in phenolic cages.

The configuration of the Turbocraft machine closely resembles that of the deHavilland machine, and replacement required only minor piping changes. Its essential electrical characteristics duplicate those of the deHavilland circulator, and electrical modifications amounted to simply disconnecting the starting transformers used with the gas bearing machines.

When the De Havilland circulators were returned to England for rebuilding, the Turbocraft machine was operated to continue loop shake-down testing. The Turbocraft machine remained installed as a back-up until February, 1963, when it was replaced, because of a bearing failure, by a second De Havilland circulator.

The characteristics of the gas bearings are such that failure of the gas film results in metal contact, wear, and, in the case of journal bearings, instantaneous seizure. The most likely instance of metal contact arises when a foreign particle larger in diameter than the thickness of the gas film enters the load-carrying region of the bearing. In such a circumstance, the wear resistance of the shaft and bearing materials controls the amount of damage incurred.

Properties generally considered to indicate wear resistance are high melting point, hardness at elevated temperature, good thermal conductivity, and chemical inertness. Materials with a favorable combination of these properties appear to be the key to stop-and-start reliability for gas bearings.

The circulator is a horizontal, single-stage centrifugal type with an open-face impeller and pilot-type diffuser. The rotating assembly, a 2-in. -diam. shaft with the induction-motor squirrel cage in the center and the impeller and thrust plate at either end, is carried on 4-in. -long gas bearings that are located on either side of the rotor. Figure 10 is a schematic diagram of these components as located in the compressor.

The impeller is fixed concentric with the shaft by an interference-fit spigot and is secured by a locked nut inside the shaft. The thrust plate is also retained by a locked nut. The journal bearings are suspended by thin stainless steel diaphragms mounted in the housing. The stationary back plate of the thrust assembly is similarly, though more flexibly, located radially by a perforated diaphragm; axial loads are taken by a flexible tension rod attached to the center of the back plate. The shaft journals and bearings are maintained at acceptably low temperatures by an arrangement of heat deflectors and conductors that are situated adjacent to the impeller back-diffuser plate. The circulator housing is constructed in accordance with the ASME code for unfired pressure vessels. This requirement necessitated a modification of the standard De Havilland units. The heavier flange upset the cooling of the bearings and resulted in some redesign and development. The housing is seal-welded and is leaktight to the sensitivity of a helium mass-spectrometer leak detector.

Design requirements and operating conditions for the circulator are given in Table 2.

To meet acceptance tests, the circulators were tested in a closed helium loop at maximum operating conditions. Performance curves for speeds of 24,000 and 20,000 rpm are shown in Fig. 11. The circulators operated at maximum flow rate for 30 hr and at minimum flow rate for 10 hr. Over-all running time during the testing equaled at least 100 hr. This included at least 100 starts and stops, and a continuous 24-hr run at 650°F.

Each gas circulator has a separate power supply. The adjustable-frequency power source provides infinite speed control of the standard two-pole induction motor that is an integral part of the gas circulator. Circulator motor characteristics for full-load running conditions at 400 cps are 10 16-kva input, 41.9 amp, 140 v, 0.87 power factor, 79% efficiency, and 1.49% slip.

Fig. 10--Schematic diagram of helium circulator

Fig. 11--Performance curves for helium circulator

Table 2
CIRCULATOR DESIGN REQUIREMENTS AND
ACTUAL OPERATING CONDITIONS

	Design	Operation
Inlet gas temperature, °F	650	400 (norm.) 650 (max.)
Suction pressure, psig	300	340
Discharge pressure, psig	310	350
Helium flow rate, lb/sec	0.15 (max.)	0.15 (max.)
(at suction pressure, lb/sec)	0.05 (min.)	0.07 (norm.)
Circulator-housing design pressure, psig	400	---

It has been De Havilland's experience that starting gas-bearing circulators from a line-energized transformer, which provides maximum acceleration, gives the most satisfactory bearing life. The gas film is established at approximately 5 rps, and until this speed is attained, the bearings are in metal-to-metal contact. To minimize wear, it is desirable to accelerate as rapidly as possible, and by using a starting transformer the bearings are "floating" in approximately one-half revolution of the shaft. Locked-rotor motor characteristics at 400 cps are 64-kva input, 264 amp, 140 v, and 0.21 power factor.

The starting transformer is used to bring the circulator up to 3600 rpm. The motor-generator set with eddy-current coupling provides the circulator power from 3,600 to 24,000 rpm. As shown in Fig. 12, the circulator motors have their power supplies interconnected, so that either circulator motor can run on power supplied by either motor-generator set. In normal operation, circulator No. 1 is supplied by motor-generator set No. 1, and circulator No. 2 is supplied by motor-generator set No. 2. A manual selector switch is provided so that circulator No. 1 can be supplied power by either motor-generator set No. 1 or No. 2. In addition, there is an automatic transfer system that is initiated by a low-gas-flow signal from the loop which disconnects circulator No. 1 and its selected power supply from the line and energizes circulator No. 2 with its selected power supply.

In the GAIL, the use of two circulators and two power sources is an example of redundancy in the interest of greater reliability and safety. Unnecessary shutdowns of an in-pile loop are both costly and time-consuming. To further ensure reliability, the power-source control

Fig. 12--Schematic of helium circulator power supply

circuits are transistorized. In addition, push-button controls for the motor-operated potentiometer assembly, which varies the operating speed of the circulator, were provided to ensure that changes in circulator speed would be uniform and independent of operator action. With the push-button system, an accidental change in speed would be a small one, since the button must be pressed continuously to effect a continuous change.

Electrical interlocks prevent the circulators from operating when the flow of cooling water is interrupted or insufficient. A current-meter relay arrangement on the starting transformer circuit ensures that the circulator has started before it is switched to motor-generator set power. The switching voltage is prescribed by a relay on the motor-generator set. After the circulator is brought up to speed, a time-delay circuit prevents a circulator from being restarted during the coast-down period following an interruption of power.

2.2.4. Electric Heater

A 50-kw capacity electric heater is located downstream from the circulators (see Fig. 13) to control the return gas temperature. The heater is also used to heat the helium initially to the facility tube inlet temperature. It is designed for a maximum temperature of 1000°F. The heating units are U-shaped Chromalox resistance units; twelve of them are located directly in the helium stream in a 6-in. diam. pipe. The heat output is automatically regulated by a saturable-core reactor controlled by the helium temperature downstream of the heat exchanger on the main loop coolant return line to the fuel element. The control equipment for this heater is located outside the cubicle on the control mezzanine.

2.2.5. Regenerative Heat Exchanger

Experiments requiring inlet temperature conditions higher than the maximum available from the electric heater can be obtained by using the regenerative heat exchanger. This unit is made from four double-pipe sections totaling about 50 ft in length. The inner pipe is 2-in. schedule 10, Type 321 stainless steel and the outer pipe, or shell, is 4-in. schedule 160, Type 347 stainless steel. The hot helium from the in-pile section passes through the inner pipe on the way to the main cooler. The shell side is located between the electric heater and the inlet to the facility tube. This side of the regenerative heat exchanger can be and was bypassed in the initial experiments. The unit is sized to exchange 235,000 Btu/hr. It is designed, fabricated, and tested in accordance with the ASME Boiler and Pressure Vessel Code for the maximum loop temperature and pressure conditions.

Fig. 13--Main loop heater and circulator discharge valve

2.2.6. Main Cooler

The primary-loop main cooler is a single-wall gas-to-water type located along the north wall on the upper level of the cubicle. The purpose of the main cooler is to transfer heat from the hot-helium gas to a closed, demineralized, secondary-water system, which in turn transfers heat to the cooling-tower water through a secondary heat exchanger. The purpose of the secondary water system was to prevent the leakage of radioactivity into the GETR cooling tower water should the cooler fail. The cooler is designed to operate at 1400°F maximum helium inlet temperature without local boiling on the water side. To reduce thermal stresses at the helium inlet end of the cooler, 7-in. long thermal sleeves are installed which trap a stagnant gas layer between them and the wall of the tube. In addition, the secondary cooling water system is operated at about 250°F.

The helium cooler is made of three double pipe sections with the helium gas in the inner pipe. This pipe is 2-in. schedule 80, Type 321 stainless steel and has an over-all length of about 25 ft. The three water cooling jackets are each about 7 ft long and made of 3-in. OD pipe with a 0.065-in. wall made of Type 304 stainless steel. Expansion bellows on each of the three are made of Type 321 stainless steel. The water side is divided into two banks: The first flows in parallel with the hot helium; the second is made up of two passes, each of which is counter current to the helium flow. Either bank may be run dry by isolating the bank and draining it into a 55-gal. drain tank located beneath the ceiling of the first floor of the cubicle. Figure 14 shows the main cooler with the regenerative heat exchanger above it. The cooler is designed for the following performance conditions:

Shell design pressure.	150 psi
Tube design pressure.	400 psi
Shell design temperature	450°F
Tube design temperature	1325°F
Heat exchange (maximum).	382,000 Btu/hr.

2.2.7. Full-flow Filter

A full-flow filter is located upstream from the circulators and is paralleled with a bypass line. Remote valves controlled from the main loop panel allow flow through either path. During all loop operations, flow has been directed through the filter to protect the circulators from any particles entrained in the flowing helium.

The unit is located on the second level of the main cubicle. As shown in Fig. 15, the pressure shell of the unit is made of 8-in. schedule 40 carbon steel pipe with semi-elliptical heads. Flow enters the side of the cylindrical portion and flows radially inward through a 2-1/4-in. deep bed

Fig. 14--Main cooler and regenerative heat exchanger

Fig. 15--Loop filter

of laboratory grade 115K Fiberglas. It continues to flow radially inward through a micrometallic filter that is 2-in. OD and 18-in. long of porosity grade E. The helium then flows up through the center annulus of the micrometallic filter and out the top of the unit. The filter is surrounded by 2-in. -thick lead shield.

Originally, the filter did not have the Fiberglas prefilter, and it was decided to install the prefilter after the original micrometallic filter plugged during loop shakedown. It is believed that this was due to condensation of volatile material originating from some Apiezon wax which accidentally entered the main loop during leak testing operations.

2.2.8. Hot Helium Storage Tank

A storage tank as shown on the simplified flow sheet, Fig. 2, is provided to contain the loop or trapping system contents during maintenance. It is shielded by a 4-in. thickness of lead bricks.

The tank has a capacity of 10 ft³, and is designed, fabricated, and tested in accordance with the ASME Boiler and Pressure Vessel Code for 600 psig at 650° F.

A pump is used to transfer helium to and from the tank.

With a main loop volume of about 15 ft³, the equilibrium tank pressure resulting from transferring helium at operating conditions without using the transfer pump is about 210 psig. Using the transfer pump, the main loop may be reduced to atmospheric pressure. The maximum tank pressure will then be about 500 psig.

2.2.9. Helium Transfer Pump

The helium transfer pump is used to transfer helium between the loop and the hot helium storage tank and vice versa. The pump is a single stage diaphragm compressor with a capacity of 0.2 ft³/min when the inlet pressure is 15 psia and the outlet pressure 600 psia. The unit is made by Pressure Products Incorporated and has three Type 301 stainless steel diaphragms between the primary system and the hydraulic fluid. The unit is located in the pump room.

2.2.10. Fission-product Trapping System

The fission-product trapping and helium purification system (FPTS) is provided to remove radioactive fission products and gaseous impurities either directly from the fuel element purge stream or from a bypass stream taken from the main loop immediately downstream from the

circulators. The system returns essentially clean helium to the main loop. It consists of a series of adsorbent beds and filters, operated at various temperatures, through which the purge or bypass stream is passed. The equipment is located on the lower level of the main cubicle and is arranged as shown in Fig. 8. The flow path is shown on Fig. 2.

Charcoal trap No. 1 is water cooled and contained in a lead cask that is about 9-in. thick. The trap is designed to remove most of the fission products other than noble gases and to delay the latter. The trap consists of six vertical tubes, five packed with activated charcoal and one with fiberglass. The first tube is 2.5 in. in diameter and 26 in. long. It has a tight fitting 1/4-in. thick copper sleeve inside it as a heat distributor. The other five are 0.3 in. in diameter and essentially the same length as the first. The tubes are arranged in a plane and are connected to form an extended path to ensure a long residence time for the purge gas passing through the trap. This assembly is contained in a rectangular box 4-1/2 in. wide by 10 in. long by 28 in. high that forms the water jacket for the trap. Appropriate piping connections are made in the top of the box. The trap is designed to permit removal of the primary system from the jacket in a remote handling facility.

Surrounding the trap is a cask designed to shield the contents with 9 in. of lead. One wall of the cask is equipped with a scanning mechanism designed to permit remote positioning of a scintillation detector at various points on the centerlines of each of the trap tubes.

Charcoal trap No. 2, which is provided to reduce the concentration of noble gases, is cooled with Freon to minus 40°F. The trap is fabricated from a 3-in. -diam. 15-in. -long pipe and is installed in the position of a right circular cylinder. The vessel formed is filled with activated charcoal and wrapped with 1/4-in. copper tubing. The tubing is brazed to the outside of the trap to form a cooling coil. This assembly is wrapped with 2 in. of Fiberglas and the insulation vapor-sealed to maintain its efficiency. The trap is placed inside a cask which provides 6 in. of lead shielding for the trap contents.

A copper oxide bed is provided to convert carbon monoxide in the helium to carbon dioxide and hydrogen to H_2O . The bed is installed in a vertical 2-in. -diam. 12-in. -long pipe. It is packed with copper oxide pellets (CuO) that are 1/8-in. in diameter and 1/8-in. long. The bed is heated with 2 semi-circular "clam-shell" heaters, each of which provides 700 w of power.

The bed is insulated with 2 in. of 85% magnesia. Shielding, in the form of lead bricks, will be provided around the bed in the event that it becomes radioactive.

The CO₂-H₂O trap is designed to remove CO₂ and H₂O transported to it in the helium stream coming from the copper oxide bed. The trap is fabricated from a 2-in.-diam. 12-in.-long pipe that is packed with glass wool. This assembly is contained in a 4-in.-diam. 14-in.-long jacket which serves to contain the liquid-nitrogen coolant. The trap is installed in the vertical position, wrapped with 2 in. of Fiberglas insulation, and shielded with 4 in. of lead bricks.

Charcoal trap No. 3 is cooled by liquid nitrogen to minus 320°F. The trap is designed to remove most of the remaining noble gases not trapped by charcoal trap No. 2. The trap is fabricated from a 22-1/2 in.-long, 1-in.-diam. pipe enclosed in a cooling jacket 3 in. in diameter and 25 in. long. It weighs about 15 lb and is installed in the position of a right circular cylinder. The trap and cooling jacket are insulated with 2 in. of Fiberglas, and the resulting assembly is located in a cask that provides 6 in. of lead shielding around the trap.

Emergency trap No. 1 is used as a standby trap for charcoal trap No. 1. A 2-in.-diam. 21-1/2-in.-long pipe forms the primary system for this trap, which contains activated charcoal. Four vertical copper fins are brazed to the inside of the pipe to aid in cooling. The cooling jacket around the primary-system pipe is fabricated from a 4-in. diam. 24-in.-long tube. The trap is shielded by a cask that provides 9 in. of lead shielding.

Emergency trap No. 2 is liquid-nitrogen cooled and shielded by 6 in. of lead. It is used as a standby trap for the No. 2 and No. 3 charcoal traps. The primary system for this trap is built from a 2-in.-diam. pipe and is packed with activated charcoal. The primary pipe is 18 in. long and is enclosed in a 4-in.-diam. 20-in.-long cooling jacket. The trap, which is installed vertically, is insulated with 2 in. of Fiberglas and placed in a 6-in.-thick walled cask.

Flow element FE-4 is a calibrated pressure-drop device fabricated from 0.032-in. ID by 0.25-in. OD tube, 5-3/32 in. long between pressure taps. The pressure differential across the tube is detected by a transducer with a range of 0 to 20 in. of water, whose output signal is recorded in millivolts at the FPTS panel on FR-4.

A booster pump, which can be used to adjust the flow rate through the purge lines to the desired value, is located downstream from the traps. Normally, the purge gas is circulated by taking advantage of the pressure drop across the main loop and the flow rate is adjusted by means of a flow control valve downstream from charcoal trap No. 3. The booster pump is used only when the pressure differential is not sufficiently great to obtain the desired flow rate. The pump is a hydraulically driven,

reciprocating-diaphragm compressor made by Pressure Products Incorporated. A system of three diaphragms separates the primary system from the oil hydraulic fluid. The diaphragm in contact with the purge stream is welded to the pump head. Rupture of this diaphragm can be detected by means of the leak detection port in the pump head.

The piping for the fission-product trapping system is all 1/4-in. Type 304 stainless steel tubing with socket weld fittings. The purge line is secondarily contained between the point where it leaves the reactor pool penetration and the No. 1 charcoal trap and No. 1 emergency trap. Instruments and sample lines which take off from this line are also secondarily contained, as are the three valves around the liquid-nitrogen-cooled water and carbon dioxide trap. The purge and sample lines up to the No. 1 charcoal trap were also traced with heating wire to ensure that the temperature was maintained at approximately 600°F up to the No. 1 trap. The secondarily contained sample lines and valves are shown in Fig. 16.

2.2.11. Scanner

The fission-product trapping system scanner mechanism was designed to provide a means of gamma-scanning the charcoal-bearing tubes utilized in the No. 1 trap. The trap tubes were arranged in a vertical plane and connected to provide a long, tortuous path for the purge stream. The tube assembly was encased in a cask that provided 9 in. of lead shielding.

The cask was designed so that one entire wall could move in a lateral direction and a scintillation detector mounted on a sliding section of the wall could move in a vertical direction (see Fig. 17). A system of microswitch stops and motor drive mechanisms were utilized to position the scintillation detector head at seven vertical points on the center line of each one of the trap tubes. Positioned between the scintillation detector and the trap was the sliding section of the wall, with a 0.43-in. diam. collimating hole through the slide and a rotating lead cylinder containing three apertures with diameters of 0.069 in., 0.305 in., and 0.43 in. for additional collimating.

The scanner mechanism was controlled remotely, the control panel being located near a 256-channel analyzer that was used with the scintillation detector. At the control station, the operator could select the proper aperture size, depending upon the activity level of the point in the trap under observation, and position the scintillation head at any one of 52 positions on the trap tubes. The activity level at various energies was then determined using the analyzer and the data was utilized to determine the presence of various isotopes throughout the trap.

Fig. 16--Secondarily contained lines and valves

Fig. 17--Scanner

2. 2. 12. Sampling Systems

Main coolant gas is sampled in the sample blister; the fuel element purge gas is sampled in the junior cave. The location of the sample points is shown schematically on Fig. 2.

2. 2. 13. Sample Blister

The sample blister is located adjacent to the main-cubicle shield wall on the operating mezzanine (see Fig. 8). The blister contains stop valves on the piping leading to and from the system sample points, a gas chromatograph detector, a removable liquid-nitrogen-cooled charcoal trap, a point for connecting an activity sample container, and miscellaneous piping and valves.

The blister is a glove box normally kept under a slight negative pressure to ensure inleakage. A sealed plastic viewing window and glove ports are provided to permit handling of equipment within the blister. Also provided is a pass chamber that can be flushed to minimize the probability of internal air escaping to the GETR containment structure when samples or equipment are passed in and out of the blister.

The sampling equipment is connected to the helium loop at several sample take-off points and one sample return point.

Air-operated on-off type take-off valves are provided within the main cubicle. Lines are manifolded to limit the number of lines penetrating the main-cubicle wall to the blister. Stop valves on the lines within the blister control the flow. The gas sampling system flowsheet is shown on Fig. 18.

Samples can be passed through the gas chromatograph for direct reading of impurity content, or samples can be taken by connecting the sample container at a connection provided for that purpose. While loop gas is recirculating through the sample equipment to purge the sample system before a sample is taken, the system is under loop pressure. After the system is isolated by closing the valves, the gas pressure is reduced to atmospheric pressure by bleeding excess gas through the nitrogen-cooled cold trap where fission products, if any, are trapped. Samples are taken with the system at atmospheric pressure. The sample container is evacuated before filling and, therefore, draws in a known volume of gas from the sample system.

The sample system is connected to a clean-helium supply and a vacuum pump that discharges to the leakage collection system. These auxiliary systems are used to purge the sampling system of undesirable gases.

Fig. 18--Gas sampling system flow sheet

2.2.14. Junior Cave

The junior cave is a shielded containment vessel constructed with the same leak-tightness requirements as the main cubicle containment structure. It is located outside the main cubicle on the second floor of the GETR adjacent to the reactor biological shielding, and is approximately 6 ft long, 6 ft high, and 2 ft 9 in. deep. The cave is designed for a total fission product source activity of 1000 curies.

The junior cave contains two separate sampling systems: The first takes purge gas either directly from fuel compacts in the fuel element or from the discharge of the element internal trap, which is located below the fuel compacts, and circulates the gas through capsules containing test fission-product trapping materials. The efficiency of various trapping materials can be studied by intermittently passing purge gas through the capsules and then removing the capsules from the cave for analysis. Gas flowing through a test capsule bypasses the fission-product trapping system and returns to the main system upstream from the first trap in the fission-product trapping system. Figure 19 is a flowsheet for this system.

The second sample system determines the gaseous impurities, amount of water vapor, and radiochemical characteristics of the fuel element purge gas at selected points along the fission-product trapping system. Measurement of trace amounts of oxygen, nitrogen, carbon monoxide, and carbon dioxide is made with a two-column (silica gel and a molecular sieve) gas chromatograph. Since the long-term effect of radiation on the columns is questionable, an on-line spare chromatograph is included in the system. The amount of water vapor in the purge gas is measured with an electrolytic hygrometer. Included in this sampling system is adequate hardware to extract, by the dilution method, activity samples for radiochemical analysis. These analytical studies can be performed on gas samples from any of four different locations in the FPTs, as shown in Fig. 2. The four sample points are located in the purge line upstream from the No. 1 charcoal trap, downstream from the No. 1 charcoal trap, downstream from the No. 2 charcoal trap, and upstream from the water and carbon dioxide trap, respectively. The clean gas downstream of the No. 3 charcoal trap is sampled in the sample blister.

The gas analysis flowsheet is shown on Fig. 20; Fig. 21 shows photographs of the inside of the junior cave.

Penetrations are provided on the cubicle face of the cave for the admission of sample connections directly from the purge lines and connection to sample points at the several locations in the fission-product

Fig. 19--Trapping system junior cave

Fig. 20--Fission product trapping system, gas analysis equipment

Fig. 21--Two views of the interior of the junior cave

trapping system. The liquid-nitrogen supply and return are also provided in this face. Penetrations are provided in the opposite face of the cave for other utilities and service lines. These include electrical power and instrumentation signal lines, pneumatic lines, and a helium supply line. Vacuum and ventilation to the cave is also provided by connections from the main cubicle.

To reduce the radiation field to within working limits, the structure is shielded with 8-3/4 in. of lead jacketed by 1/2 in. of steel plate placed on the top and on the left and front faces. The remaining faces of the cave are shielded by the reactor biological shielding and the main cubicle shielding.

All operations within the junior cave are performed by a claw-type manipulator. The manipulator (as shown in Fig. 22) is a single-column device with a telescoping extension arm and grip fingers that is located within the cave, and a rack-and-pinion arrangement mounted on a chain-rotated assembly (to raise, lower, and rotate the column) that is located outside the cave. The effective annular work area of the grip fingers is defined by a telescope arm extension of 8-1/2 in. and rotation of the column through 180 degrees. The extension arm can be lowered to within 1 in. of the cave table top and raised to within 2-1/2 in. of the cave roof.

The grip fingers are a V-shaped beryllium-copper spring held at the "V" by a slotted piston attached to a flexible shaft. The fingers grip as the spring is constrained when drawn into the tubular extension arm. The flexible shaft can be rotated to impart wrist action to the fingers.

Sealing the manipulator to containment specifications was accomplished by an O-ring sliding and rotating seal between the flexible shaft piston and the inner tubular surface of the extension arm, and a collapsible rubber hose seal between the outer surface of the extension arm and the cave containment shell.

The manipulator performs the following tasks:

1. Locates and holds an airmotor which opens and closes all conventional sample valves.
2. Operates the push-pull sample selector valves of the gas chromatographs.
3. Locates and holds an air-operated shears that cuts laboratory trap capsules from connecting tubing.
4. Opens and closes lead shield doors in front of test capsules.
5. Removes insulation from test capsules.

Fig. 22--The manipulator

6. Removes test capsules from heater location.
7. Seals, with soft solder, sheared tubing connections of test capsules.
8. Seals sheared ends of loop sample tubing with soft solder.
9. Transfers test capsule to air lock position for dropping into cask located below cave table.
10. Operates airlock for capsule transfer from cave to cask.
11. Exchanges inappropriate finger grips and replaces broken finger grips.

Observation into the cave is provided by a high-density lead-glass window of shielding effectiveness equivalent to the cave structure. The window is of sufficient size to give adequate view to the entire working volume of the cave.

After the sampling procedures, the test capsules and samples are removed from the cave structure. The capsules are removed in a cask through an airlock located in the bottom of the cave. With the exception of activity samples, the sealing and handling of all test capsule samples is performed remotely with the manipulator. Activity samples are collected in a semi-evacuated sample vial located in an unshielded sample blister exterior to the cave structure.

Instrumentation within the cave includes provisions for measurement of local gamma activity in the purge line and gross activity within the cave area.

2.2.15. Helium Charging System

The charging system, which is located outside the main cubicle and is designed for manual operation, supplies high-purity helium for filling and purging of the main loop and subsequent main loop make-up requirements. Through suitable valving, including a backflow check valve, high-purity helium from this charging system can be supplied to the junior cave, sample blister interseal disconnect chambers, and upstream from charcoal trap No. 1 of the fission-product trapping system.

The helium is supplied from a standard cylinder. Two pressure regulators are required. The first pressure regulator, located upstream from the purifier, maintains a minimum back pressure of 350 psig on the helium purifier. A second pressure regulator downstream from the purifier provides pressure control of 0 to 400 psi to allow loop filling and make-up at various pressures. Each regulator is equipped with pressure indicators to indicate upstream and downstream pressure.

The helium supply line is equipped with three valves to allow the air trapped in the lines during helium bottle replacement to be vented, ensuring an air-free helium supply to the purifier.

The helium purifier consists of a 10- μ filter, a molecular sieve cartridge for water vapor removal, and an oil vapor cartridge. This unit is designed to limit the impurities in the make-up helium to the following values:

Water vapor	Less than 100 ppm/volume
Hydrocarbons	Less than 10 ppm/weight

During normal loop operation, the water vapor and hydrocarbon impurities in the main coolant circuit are considerably lower than the values given above. Average values determined during prior operation are noted below:

Water vapor	Less than 1 ppm/volume
Hydrocarbons	Less than 5 ppm/weight

Figure 23 is a photograph of the helium charging system.

2.2.16. Piping

The HTGR coolant circuit can be divided into three temperature ranges: low, 650° F and below; intermediate, 650° to 1050° F; and high, 1050° to 1450° F. Since GAIL temperatures duplicate these temperature ranges, the materials selected for piping, components, and valves are typical for these temperature ranges and economically suitable for reactor construction. The circulator housing material is SA-201 Grade B carbon steel and connecting piping upstream and downstream is also carbon steel. A low alloy steel (SA-213 T5 5.0% Cr, 0.5% Mo) is a representative intermediate range material used for valves on either side of the circulators. All high-temperature piping and the major portion of the primary loop piping and valves are austenitic stainless steel SA-312 TP 321. The fission-product trapping and sampling systems are SA-213 TP 304 stainless steel assembled using sleeves and fillet welds. It is hoped that future examination of loop piping will show whether or not carburization of these materials occurs and at what relative rate. It should be noted that the flow baffle facing the fuel element in the fuel compact region of the in-pile tube is made of Nichrome V, a material highly resistant to carburization.

The first pass of all high-temperature pipe welding was made with an inert gas-shielded tungsten arc welder using consumable type weld backing rings. Subsequent passes were generally made using coated rod and arc welding.

Fig. 23--Helium charging system

In the GAIL test loop, the entire facility tube--loop piping that extends into the reactor and contains the test fuel element--is replaced after irradiation of the fuel element is completed. The removable facility tube is joined to the out-of-pile portion of the loop by three double-gasketed Marman flanges. The interspace between the gaskets of each flange is sniffed with a vacuum system for indications of primary system helium leakage past the first gasket. The flange connections as they appeared during construction may be seen in Fig. 24.

2.2.17. Valves

The primary loop valves are a ball-sealed type of straight-through-flow construction manufactured by the P-K Division of General Kinetics Corporation. The ball is moved in and out of the flow line by a cage which functions similarly to a gate valve stem. Where the ball seats, the flow is slightly contracted as in a venturi. This construction and random rotation of the ball within the cage affords a self-cleaning feature, and the well for the ball retaining cage below the venturi section serves as a trap for particulate matter. The straight-through features, with minimum pressure loss at rated flow, reduces the head requirements of the circulators. The two circulator discharge valves are shown in Fig. 13. These valves "see" a maximum temperature of 650^oF and have a forged body of low alloy steel. Figure 25 shows an intermediate temperature valve in the foreground and a high-temperature valve in the background. The body of the latter valve is made of Type 321 stainless steel bar stock. All primary system valves of pipe line size were ordered with factory-welded pipe studs to avoid seat distortion due to welding. Seat leakage acceptance tests were required at the supplier's shop after the pipe studs were welded to the valves. Although a welded bellows seal was used on all these valves as well as the Powell valves mentioned below, a conventional packing was used on the stem as a secondary seal. This was done to retain the inherent vibration damping characteristics of packing-sealed valves.

Originally, all valves located in the junior cave (see Fig. 21) were manually-operated bellows-sealed Powell and Hoke valves, with the exception of two activity sample size-determining solenoid valves which did not serve as a system seal. The manual valves were turned by a single air motor held and located by the junior cave manipulator. All manual valves had metal-to-metal seats, so that seat deterioration due to irradiation would not be a problem. Loop operation established that levels of radioactivity in the sampling system did not limit valve seat materials to metals. Replacement of the manual valves with rubber-seated solenoid valves manufactured by Skinner Electric Valve Company solved a seat scoring problem arising from metallic powder fouling and pitting of the metallic valve seats. The metallic powder was formed by a 60-cycle chatter in the energized solenoid of an activity sample valve.

Fig. 24--Marman flanges

Fig. 25--Main loop valves

Valves used in the fission-product trapping system were mounted for easy maintenance as shown in Fig. 26. These valves were bellows-sealed Powell valves with air operators.

Instrument valves, check valves, rupture disks, and relief valves used in the loop are typical of gas handling equipment that meets the particular operating temperature and pressure requirements dictated by their loop location. All these valves are of the bellows-sealed type. All rupture disks were seal-welded.

2.2.18. Emergency Cooling System

The emergency cooling system, which is shown on Fig. 27, provides a means of admitting helium to the vacuum annulus of the vacuum chamber, thereby increasing the direct transfer of heat from the GAIL fuel element to the GETR pool. The system is put into operation in case of low loop flow and/or low loop pressure. The former has a time delay to avoid false operation. Helium is supplied from a size 1A cylinder. This is used to charge an accumulation cylinder (also size 1A) with sufficient helium to pressurize the vacuum chamber to 15 psia. Double valves are used to increase reliability.

2.2.19. Auxiliary Equipment Containment

Some auxiliary systems which do not normally contain radioactive materials are located in an unshielded steel cubicle 4-1/2 ft by 11-1/2 ft by 6-1/2 ft high located on a mezzanine outside the main cubicle (see Fig. 8). Systems located here are those which serve the main loop but are separated from the radioactive main loop coolant by the primary containment. The equipment located here includes the main loop cooler demineralized water system, the FPTs and circulator cooling water system, and the FPTs Freon system. Some of this equipment is shown in Fig. 28. In case of leakage of radioactive gas to these systems, the auxiliary containment is provided as an extra precaution to minimize leakage of the radioactive gas to the GETR containment building.

The auxiliary containment steel liner is designed, fabricated, and leak-tested to the same requirements as the main cubicle liner. The space available in this area was so limited that the auxiliary containment room had to be cut in half in order to be placed in position. In addition, in order to install the equipment, the floor of the containment room was cut out, the equipment hoisted into position, and the floor then rewelded.

2.2.20. Vacuum and Leakage Collection System

A system is provided to collect and contain leakage from points in the system most likely to leak radioactive gas. Figure 27 shows a

Fig. 26--Fission product trapping system
valves and booster pump

Fig. 27--Vacuum and leakage collection system and emergency cooling system

Fig. 28--Auxiliary equipment containment systems

schematic drawing of the vacuum and leakage-collection system. This gas is held up in tanks, filtered and cleaned, and then discharged to the cubicle.

The main evacuation pump serves several purposes. During normal operation, this pump maintains a high vacuum on the vacuum chamber to minimize heat losses to the reactor pool water. The same pump also maintains a vacuum on the space between the seals of the facility-tube disconnect flanges. Leakage, if any, into the vacuum chamber is directed through the vacuum pump and a filter to the low-pressure holdup tank. Leakage from the disconnect interseals is also directed to the tank through the same pump. The vacuum pump can also be used to evacuate the main loop. A slight, negative pressure is maintained on the purge-line secondary containment by the purge-containment vacuum pump. The sample lines to the junior cave and sample blister are also evacuated by separate pumps to purge the lines of gas. The gas from the interseals, the FPTs sample vacuum pump, and the purge-line containment pump discharges through a filter into the 10 ft³ low-pressure holdup tank. The various loop relief valves discharge directly into the tank, by-passing the filter. When the pressure in this tank reaches 15 psia, a leakage-transfer pump transfers the gas to the 5 ft³ high-pressure holdup tank. The gas is stored here until it becomes necessary to relieve excess gas through an iodine trap and filter to the main cubicle ventilation system and out the stack. The loop overpressure connection ties in upstream from the iodine trap, as do the junior cave sample bleed, the sample blister sample bleed, and the sample blister vacuum pump discharge. Radiation detectors are included on the system to monitor activity in the various lines.

The vacuum-chamber pump, a two-stage mechanical booster pump, produces vacuum down to one micron of mercury. The two stages are mounted on the same frame: the first stage is a roughing unit, which has relatively high pumping capacity; the second stage is a high-vacuum lobe-type rotary pump. There is a three minute time delay between the starting of the two stages. The purge-containment blower is a vacuum pump of centrifugal design, which maintains a negative pressure on the containment piping around the highly radioactive portions of the fission-product trapping system. The junior-cave and sample-blister vacuum pumps are utilized during sampling operations to provide vacuum down to 100 μ .

The low-pressure holdup tank is the first receptacle of leakage from the potential leak points within the loop. The tank is approximately 2 ft in diameter, 4 ft high, and has a capacity of 10 ft³ at a design pressure of 15 psia. The high-pressure holdup tank receives and stores gas from the low-pressure holdup tank before release to the stack. The tank is approximately 1-1/2 ft in diameter, 4 ft high, and has a capacity of 5 ft³ at the design pressure of 300 psi.

The holdup transfer pump, a single-stage diaphragm compressor, serves to pump gas from the low-pressure to the high-pressure hold tank. The pump operates automatically from pressure signals transmitted from the low-pressure tank.

The iodine trap and filters, an in-line arrangement, are provided on the discharge from the high-pressure tank prior to entry to the ventilation system. The trap consists of three Durex type-H canisters mounted in series, each containing activated charcoal. The three canisters are mounted within pressure cans.

High-efficiency CWS filters are included in various locations throughout the system for the filtration of particulate material. These filters are efficient to 99.95% on particles of greater than 0.3μ in size.

2.2.21. Secondary Water Cooling System

Demineralized potable water is utilized in the closed-circuit secondary cooling system, which supplies coolant to the main cooler. Flow is provided by two circulating pumps, one of which is normally a standby unit. Heat is dumped to the cooling-tower water through the secondary heat exchanger. Figure 29 is a piping and instrumentation diagram of the various cooling water systems.

The circulating pumps (centrifugal type) have a 15-gpm capacity at a 50-ft head and a maximum temperature limitation of 350°F .

A secondary pump gland seal cooler supplies cooled demineralized water to the secondary pump shaft seals.

The shell side of the secondary heat exchanger contains cooling-tower water; the tubes contain demineralized water at 80 psi. The exchanger is sized for a heat-removal capacity of 110 kw and a maximum design temperature of 650°F . The system also includes a 20-gal expansion tank which is pressurized by nitrogen to 80 psig. The pressurization is necessary to allow operation of the secondary cooling water system at 230° to 240°F without boiling.

2.2.22. Fission-product Trapping System and Helium Circulator Cooling Water System

The FPTs trap No. 1, emergency trap No. 1, and the helium circulators are cooled by a closed-cycle water cooling system that consists of two circulating pumps (one on standby), a trap water cooler, circulator water cooler, water surge tank, and a cooling-tower water chiller (see Fig. 30).

Fig. 29--Cooling water systems

Fig. 30--FPTS and circulator cooling water system

The centrifugal circulating pumps have a capacity of 15 gpm at a 200-ft head and a maximum operating temperature of 150° F.

The trap water cooler is a Ross No. 200-8 BcF single-pass type with brass bonnets. Effluent water from the FPTs traps passes through the tubes while chilled GETR cooling tower water passes through the shell.

The circulator water cooler is a Graham Heliflow Model 18x4C14S. Chilled cooling-tower water passes through the tubes and demineralized coolant to the circulator through the shell.

The water surge tank is fabricated from a standard 30-gal AISI Type 304 stainless steel drum. The tank has a rubber-gasketed head that is fastened in place with a clamp. A liquid-level control valve within the tank draws make-up from the demineralized potable water supply. The tank is located in the auxiliary containment room.

Chilled cooling-tower water is provided by a 7-1/2 ton Worthington refrigeration unit to the trap water cooler, circulator water cooler, and auxiliary containment space cooler. The unit contains a booster pump, heat exchanger, condenser, and compressor. Heat is dumped to the GETR cooling-tower water. The chiller was necessary to ensure adequately cool water for the helium circulators.

2.2.23. Make-up Water System

GETR potable water is supplied to a demineralizer unit that purifies the water before introduction into the secondary-cooling-water system and the FPTs cooling water system. This was necessary because of low-level contamination in the GETR make-up water. A Milton-Roy positive displacement make-up pump delivers demineralized potable water to the system for make-up (see Fig. 29).

2.2.24. Liquid-nitrogen System

The FPTs liquid-nitrogen cooling system consists of a head tank, storage tank, trap-supply and return-line solenoid valves, block valves, and relief valves (see Fig. 31).

The liquid-nitrogen head tank located in the GETR has a nominal capacity of 300 gal and is 4 ft in diameter, and 8 ft 11 in. high, but only 150 gal are stored in the tank in order to avoid overpressurization of the GETR containment in case of tank or line rupture. For a similar reason, the tank is located outside of the auxiliary equipment containment room. Isolation valves are provided to isolate the system in case of leakage of radioactive products into the nitrogen system, or upon cubicle isolation.

Fig. 31--Liquid-nitrogen system

These valves are actuated by a radiation detector that senses activity in the liquid-nitrogen supply line.

The storage tank is located outside of the GETR containment building on a pad next to the GETR cooling water tower. It has a nominal capacity of 2160 gal, is 6 ft in diameter and 12 ft 6 in. high. It is connected to the inside head tank by a 1/2-in. copper tube, which passes, insulated, under the ground and up and through the flange penetration on the northeast wall of the GETR. The line connecting the storage tank with the head tank is equipped with manual valves and an automatic isolation valve that closes whenever the GETR containment is isolated and thus isolates the large tank from both the small tank and the GETR containment.

A liquid-nitrogen flask supplies liquid nitrogen to the sample blister cold trap.

2.2.25. Fission-product Trapping Freon System

The FPTs refrigeration system for cooling charcoal trap No. 2 includes a heat exchanger, a solenoid valve, a thermostat, and an expansion valve for the refrigeration system, which are located in the cubicle and are mounted on the wall above the charcoal trap No. 2 cask. The compressor, filter drier, and moisture indicator are located in the auxiliary equipment containment room. The compressor and solenoid valve power are controlled by the refrigeration system switch that is located on the FPTs console. They are wired in parallel with the valve in series with the Ranco thermostat that senses the trap-helium outlet temperature. The moisture and liquid indicator turns yellow when too much water vapor is present in the refrigerant. A sample point is installed on the compressor inlet line.

2.2.26. Cubicle Ventilation System

Located within the cubicle is a ventilation system designed to maintain a negative pressure of 2 to 5 in. of water on the main cubicle, junior cave, sample blister, pump room, and auxiliary equipment containment area, and to isolate the containment system in the event of a high-activity release from the loop.

The ventilation system includes a mechanical blower located in the pump room, two high-efficiency air filters, an iodine trap, radiation monitors, and associated piping as shown in Fig. 32.

The mechanical blower takes suction from the main cubicle through a high-efficiency filter and discharges to the stack through an iodine trap and the second high-efficiency filter. Air flow into the main cubicle is

Fig. 32--Ventilation system

from the GETR containment through the auxiliary containment, junior cave, pump room, and sample blister.

Valves, located on all inlets, close on a signal of high radiation or high pressure in the main cubicle. The valves on the interconnecting lines between the various units being ventilated will open should the pressure in the units become higher than the main cubicle pressure.

The exhaust blower located in the pump room is a centrifugal machine with a rating of 19 cfm at 3 psi.

The cubicle-cooling blower is a centrifugal machine rated at 2000 cfm which circulates the air in the main cubicle. The cubicle cooler is an air-to-water heat exchanger that dumps the cubicle heat to the reactor cooling tower water. This system is located within the main cubicle.

The iodine trap and filter are the same as those described for the vacuum and leakage collection system. However, the iodine trap is composed of only one charcoal cartridge.

The ventilation system valves, which are pneumatically operated shut-off valves, isolate the individual containments upon receipt of high-radiation or high-pressure signals.

The auxiliary equipment containment room space cooler is an air conditioning unit that recirculates the containment air over cooling coils supplied from the chilled-water system.

2. 2. 27. Depressurization System

A depressurization system is provided (see Fig. 32) to reduce cubicle pressure in case of a major line rupture, which conceivably could raise the main cubicle pressure as high as 1.8 psi. This system consists of a compressor, high-pressure receiver (200 psi), and the necessary piping, valves, and instrumentation. On a signal of cubicle pressure above atmospheric (about 1 in. of water), the compressor will take suction from the cubicle atmosphere and pump into the receiver until the cubicle pressure drops to essentially atmospheric pressure. The compressor is sized to perform the maximum pressure reduction in seven minutes. The receiver is sized to accommodate a volume of gas equivalent to the main loop contents at standard conditions of temperature and pressure. The compressor and tank are located in the lower level of the main cubicle. The tank is movable and is rolled out of the cubicle when access is necessary.

2.2.28. Drain System

The cooling jackets of the main cooler can be drained by means of solenoid valves to a 55-gal drain tank located below the ceiling of the first floor of the cubicle. The relief valves and vents on the same system also lead to the drain tank. In case of high liquid level, the drain tank can be dumped to the radioactive building drain. A small sump is provided in the floor of the cubicle. The bottom of the sump has a drain line which penetrates the 3-ft-thick concrete floor of the GETR. There is a valve on this line located near the ceiling of the first floor of the GETR.

III. CONTROL AND INSTRUMENTATION

There are three basic types of instrumentation used on the loop. The first is that necessary to protect the reactor, the second is used for the protection of the loop, and the third is used for the acquisition of data.

All instrumentation needed for the loop is centralized at the local control panel in the experimental area. Critical parameters are repeated and recorded in the reactor control room. An annunciator on the control room panel indicates loop trouble. Additional annunciators on the local panel indicate the source of the trouble.

Critical parameters have two levels of action: (1) alarm and (2) scram, or rundown, of the reactor. Tables 3, 4, 5, 6, and 7 give the various parameters being measured and the location of the recorder, or indicator. Table 8 sets forth the normal operating condition and levels of alarm and of scram, or rundown, settings.

The loop is fully instrumented to measure required fuel and coolant temperatures, flow rates, and pressures. All points of interest throughout the system furnish data to recorders, thus providing information for post-operation analyses. Suitable instrumentation is provided for reactor shutdown should a potentially serious condition be indicated. Reactor scram is initiated by facility-tube exit-gas high temperature, circulator-intake-gas high temperature, low flow, or low pressure of the main-loop gas. High temperature of the exit gas also opens a valve in the tempering gas line protecting the loop piping. In addition, a reactor rundown is initiated by high activity at the test section exit or in the purge line. Intermediate levels of these parameters and other warning signals are annunciated. The general system is designed so that all parameters concerned with the operation of the system and the contained experiments are under direct control of the loop-system operator. Should a transient occur, the operator is able to make suitable system adjustments to bring about a system equilibrium condition. Fast-acting transients involving temperature, pressure, or flow excursions cause automatic reactor scram by the experiment when these parameters have exceeded preset limits.

Primary-heat-exchanger water flow is metered and a low flow causes an alarm. Discharge-water high temperature also operates an annunciator.

A separate, continuous monitoring system is provided to determine cubicle exhaust-gas activity before release to the GETR stack.

Table 3
TEMPERATURE INSTRUMENTATION

Recorder	Indicator	Transmitter	Element	Alarm	Scram	Panel*	Application
TR-3	---	---	TE-20, 22 26 to 29 48, 49			M	Primary loop gas temp
TR-4	---	---	TE-18 to 19	TAH-4	X	M	Test section, outlet gas temp
TR-4a	---	---	TE-18 to 19	TAH-4a	X	R	Test section, outlet gas temp
TR-4b	---	---	TE-27	TAH-4b	-	M	Cooler discharge temp
TR-5	---	---	TE-1 to 15, TE-23, 62, 63	TAH-5	-	M	Test section temp
TR-6	---	---	TE-24, 25	TAH-6	-	M	Cooler water temp
TRC-7	---	---	TE-21 or TE-30	TAH-7	-	M	Main loop heater control
TR-8	---	---	TE-31, 33, 36, 37, 44, 64, 71	---	-	F	Fission-product trapping system gas temp
TR-8	---	---	TE-45 to 47	---	-	F	Water cooling system temp, charcoal trap No. 1 and circulators
TR-8	---	---	TE-50 to 53	---	-	F	Purge line temp inlet to lab traps in junior cave
---	TIS-1	---	TE-16	---	X	M	Test section exit gas high-temp scram
---	TIS-2	---	TE-17	---	X	M	Test section exit gas high-temp-scram
---	TIC-9	---	TE-38	---	-	F	Copper oxide bed heater control
---	TI-10	---	TE-32, 34, 35, 39, 40, 42, 69	---	-	F	Fission-product trapping system gas temp
---	TI-10	---	TE-70	---	-	F	Water and CO ₂ trap jacket
---	TI-10	---	TE-41	TAH-10	-	F	Gas exit charcoal trap No. 3
---	TI-10	---	TE-43	TAH-11	-	F	Gas exit emergency charcoal trap No. 2
---	TI-10	---	TE-58 to 61	---	-	F	Liquid-nitrogen inlet lines
---	TI-10	---	TE-72	---	-	F	Liquid-nitrogen inlet to sample blister cold trap
---	---	TS-1	---	TAH-8	X	L	Circulator inlet gas temp
---	---	TS-4	---	TAH-8	X	L	Circulator inlet gas temp
---	---	TS-5	---	TAH-8	X	L	Circulator inlet gas temp
---	TI-15	---	TE-65 to 68	---	-	L	Ambient temperatures
---	TI-16	---	---	---	-	L	Chilled cooling tower water
---	TIC-14	---	TE-54 to 57	---	-	J	Lab trap exit lines in junior cave
---	---	TS-12 [†]	---	TAH-12	-	L	Exit gas line surface temp
---	---	TS-13	---	TAH-13	-	F	High cooling water temp from trap No. 1
---	---	TS-14	---	---	-	L	Chiller control
---	---	TS-18	---	TAH-18	-	L	Chilled cooling tower water

*F = FPTS, J = junior cave, L = local, M = main, R = reactor.

[†]Opens valve in tempering gas line.

Table 4
PRESSURE INSTRUMENTATION

Recorder	Indicator	Transmitter	Element	Alarm	Scram	Panel*	Application
PR-1	-----	PT-1	-----	PAL-1	X	M	Main loop pressure
PR-2a	-----	PT-1	-----	PAL-2a	-	R	Main loop pressure
-----	-----	PT-1	-----	PAL-20	-	M	Main loop pressure
-----	-----	-----	-----	PAH-1	-----	-----	-----
DPR-1	-----	DPT-1	-----	dPAH-1	-	M	Differential pressure across facility tube or main loop filter
DPR-1a	-----	DPT-1	-----	-----	-	R	Differential pressure across facility tube or main loop filter
DPR-2	-----	DPT-2	-----	-----	-	M	Differential pressure between facility tube inlet and purge line
-----	PI-2	PT-2	-----	-----	-	M	Hot helium storage tank
-----	PI-4	-----	-----	-----	-	L	Expansion tank (secondary cooling)
-----	PIS-6	-----	-----	PAH-6	-	L	Low-pressure holdup tank
-----	PI-8	PT-8	-----	-----	-	L	High-pressure holdup tank
-----	PIS-7	-----	PE-9	PAH-9	-	M	In-pile facility tube vacuum system
-----	DPI-10	DPT-10	-----	-----	-	R	Main loop moisture monitor flow
-----	DPI-11	DPT-11	-----	-----	-	J	FPTS moisture monitor flow
-----	PI-11	PT-11	-----	-----	-	L	Low-pressure holdup tank heater pressure
-----	PI-12	-----	-----	-----	-	M	Facility tube vacuum/pressure
-----	PI-17	-----	PE-17	-----	-	B	Gas sample blister sample exhaust vacuum
-----	PI-18	-----	PE-18	-----	-	J	Junior cave sample exhaust vacuum
-----	PI-19	-----	-----	-----	-	L	Junior cave sample
-----	PI-20	PT-20	-----	-----	-	M	Depressurizer receiver
-----	PI-20a	PT-20	-----	-----	-	L	Depressurizer receiver
-----	PI-21	-----	-----	-----	-	L	Sample blister sample
-----	PI-22	-----	-----	-----	-	M	Helium buffer line to sample blister
-----	PI-23	-----	-----	-----	-	L	Helium buffer line to junior cave
-----	PI-24	-----	-----	-----	-	L	Fission-product trapping system - moisture monitor housing
-----	PI-25	-----	-----	-----	-	L	Main loop moisture monitor housing
-----	PI-28	-----	-----	-----	-	L	Junior cave sample dilution tank
-----	PI-31	-----	-----	-----	-	L	Potable water tank
-----	dPIS-100	-----	-----	dPAH-100	-	L	Main cubicle pressure differential
-----	-----	-----	-----	dPAL-100	-----	-----	-----
-----	dPIS-101	-----	-----	dPAH-101	-	L	Auxiliary containment pressure differential
-----	dPIS-102	-----	-----	dPAH-102	-	L	Sample blister pressure differential
-----	-----	-----	-----	dPAL-102	-----	-----	-----
-----	dPIS-103	-----	-----	dPAH-103	-	L	Junior cave pressure differential
-----	dPIS-104	-----	-----	dPAH-104	-	L	Pump room pressure differential
-----	-----	PT-4	-----	PAL-3	X	L	Low-pressure scram
-----	-----	PT-6	-----	PAL-3	X	L	Low-pressure scram
-----	-----	PS-2	-----	PAH-2	-	L	Main loop pressure relief
-----	-----	PS-3	-----	PAH-3	-	L	Main loop pressure relief
-----	-----	PS-5	-----	PAH-5	-	L	Gas storage pressure relief
-----	-----	PS-7	-----	PAH-7	-	L	Hot helium storage tank
-----	-----	PS-8	-----	PAH-8	-	L	Purge gas line containment
-----	-----	PS-8a	-----	-----	-	L	Purge gas line containment pump switch
-----	-----	PS-10	-----	PAL-10	-	L	Charging manifold
-----	-----	PS-11	-----	PAH-11	-	M	Holdup transfer pump switch
-----	-----	PS-12	-----	-----	-	L	Demineralized water pump No. 1 (secondary cooling)
-----	-----	PS-13	-----	-----	-	L	Demineralized water pump No. 2 (secondary cooling)
-----	-----	PS-14	-----	PAH-14	-	L	High-pressure holdup tank relief
-----	-----	PS-15	-----	PAH-15	-	L	Low-pressure holdup tank relief
-----	-----	PS-19	-----	PAL-19	-	M	Emergency cooling accumulator reserve
-----	-----	PS-26, 27	-----	-----	-	L	Chilled cooling water pumps
-----	-----	PS-29	-----	PAH-29	-	M	High-cubicle-pressure liquid-nitrogen shutoff
-----	-----	PS-105	-----	-----	-	L	Depressurizer receiver

* Opens valve in tempering gas line: B = sample blister, J = Junior cave, L = local, M = main, R = reactor.

Table 5
FLOW INSTRUMENTATION

Recorder	Indicator	Transmitter	Element	Alarm	Scram	Panel*	Application
FR-1	---	FT-1	FE-1	---	X	M	Main loop gas flow
FR-1a	---	FT-1	FE-1	FAL-1a FAL-1	-	R	Main loop gas flow
FR-1b	---	FT-2	FE-2	FAL-2 FAL-1b	-	R	Main loop gas flow
FR-2	---	FT-2	FE-2	---	X	M	Main loop gas flow
FR-4	FI-4	FT-4	FE-4	---	-	F	Fission-product trapping system gas flow
---	FIS-3a&b	---	---	FAL-3	-	M	Water from coolers, coolant flow
---	---	FT-3	FE-1	---	-	L	Low flow scram
---	FIS-4	---	---	FAL-4	-	L	Circulator coolant
---	FIS-5	---	---	FAL-5	-	L	Circulator coolant (aux.)
---	FI-6	FT-6	FE-6	---	-	L	Cubicle ventilation exhaust flow
---	---	---	Relays	FAL-6	-	M	Main loop gas flow
---	FI-7	---	---	---	-	L	Water flow to charcoal traps
---	FI-8	---	---	---	-	L	Water flow to circulators

*B = sample blister, J = junior cave, L = local, M = main, S = scanner.

Table 6

MISCELLANEOUS INSTRUMENTATION

Recorder	Indicator	Transmitter	Element	Alarm	Scram	Panel*	Application
---		---	Relays	PAL-3	---	M	Failure of PT-1, PT-4, or PT-6
---		---	Relays	TAH-1	---	M	Failure of TIS-1, TIS-2, or TR-4
---	HI-2	---	HE-2	---	---	B	Main loop moisture monitor
---	HI-3	---	HE-3	---	---	J	FPTS moisture monitor
---	LLI-1	---	---	LAL-1	---	L	Liquid-nitrogen tank, liquid level
---	LLI-2	---	---	LAL-2	---	L	Expansion tank (secondary cooling)
---	LLI-2	---	---	LAH-2	---	L	Expansion tank (secondary cooling)
---	---	LLS-3	---	---	---	L	Drain tank, high level
---	---	LLS-4	---	---	---	L	Drain tank, low level
---	---	LLS-5	---	---	---	L	Cubicle floor sump, high level
GCR-1	---	---	GCE-1 & 2	---	---	J	Junior cave gas chromatographs
GCR-3	---	---	GCE-3	---	---	B	Main loop gas chromatograph
SCR-1	SCI-1	---	SCE-1	---	---	S	Charcoal trap No. 1 scintillation detector
SCR-1	SCI-1	---	SCE-2	---	---	S	Junior cave scintillation detector

*B = sample blister, J = junior cave, L = local, M = main, S = scanner.

Table 7

LOOP ACTIVITY MONITORS

Element No.	Recorder No.*	Application
1	RR-1	Gas outlet from facility tube (γ)
2	RR-2	Gas outlet from facility tube (γ)
3	RR-1	Heat exchanger (γ)
4	RR-1	Cooler (γ)
5	RR-1	Circulator No. 2 (γ)
6	RR-1	Circulator No. 1 (γ)
7	RR-1	Electric heater (γ)
8	RR-1	Purge-line containment exhaust (γ)
9	RR-1	Junior-cave sample exhaust and bleed (γ)
10	RR-1	Inlet to FPTs (γ)
11	RR-1	FPTS downstream of trap No. 1 (γ)
12	RR-1	FPTS return to main loop (γ)
13	RR-1	Auxiliary cubicle room monitor (β, γ)
14	RR-1	Cubicle room monitor (β, γ)
15	--	Sample blister sample exhaust and bleed (γ)
16	RR-1	Holdup tank discharge to cubicle (γ)
17	RR-1	Vacuum chamber pump discharge (β, γ)
18	RR-1	Junior cave working area (β, γ)
19	RR-4	Ventilation exhaust to stack
20	RR-1	Junior cave inlet to experimental traps (γ)
21	RR-1	Junior cave outlet from experimental traps (γ)
22	RR-1	Sample blister area monitor (β, γ)
23	RR-1	Liquid nitrogen system (γ)
24	RR-1	Facility tube disconnect flanges (γ)

* RR-1 located on main panel; RR-2 located on reactor panel; RR-4 located in stack shack.

Table 8

GAIL TYPICAL OPERATING PARAMETERS

Function	Typical Operation	Alarm	Scram
Main Loop			
Facility tube flow, lb/hr	240	90%	80%
Loop flow, lb/hr	241	90%	80%
Facility tube exit gas temp., °F	1380	1400*	1480
Facility tube ΔP, psi	7.15	8.3	----
Loop pressure-high, psia	350	353	----
Loop pressure-low, psia	350	330	300
Facility tube exit gas activity, curies/cm ³	0.0000002	0.0002	0.001†
Max. internal fuel temp., °F	2860	----	----
Electric heater outlet temp., °F	610	650	----
Gas temp. at circulator intake, °F	360	420	650
Hot helium storage tank press. psig	10	550	----
Auxiliary Systems			
Chilled cooling tower water, °F	55	70	----
Cooling water flow to circulators, gal/hr	150	100	----
Vacuum chamber press., μ	50	100	----
Heat exchanger cooling water temp. at outlet, °F	250	350	----
Cooling water flow to cooler, lb/hr	2600	2400	----
Activity in low press. holdup tank, curies/cm ³	0	0.005	----
Low-pressure holdup- tank press. psia	14.7	15	----
Fission Product Trapping System			
Outlet gas temp. from liquid-nitrogen-cooled charcoal trap, °F	-320	-250	----
Activity in FPTs line to 1st trap, curies/cm ³	0.002	0.8	1.0†

* Opens tempering gas line.
† Reactor rundown.

The controls and instruments located at the reactor console allow the reactor operator, in event of an emergency, to introduce emergency cooling, which increases the heat loss from the experiment, thereby reducing the gas and fuel assembly temperature. If the loop fails to respond, the gas coolant may be transferred to the hot-helium storage tank, reducing the loop pressure and automatically causing a reactor scram.

3.1. CONTROL PANELS

The loop control main panel (see Fig. 33) is located on a balcony midway between the second and third floors. It is formed from three sections, each 7 ft high, and is 10 ft long. Rear access panels may be removed for maintenance. Signal and power wiring enters from above.

The left section contains radiation indicators and recorders, and loop and auxiliary system temperature recorders, and annunciators associated with the instrumentation.

The center section contains fuel-element and facility-tube temperature recorders, the loop-temperature controller, and temperature-control switches and annunciators connected to the reactor-control circuitry.

The right section contains a graphic flow circuit of the main loop and contains pressure, flow, and differential pressure instrumentation and valve control mechanisms. Annunciators associated with this instrumentation are located at the top of the section.

The fission-product trapping system panel is also located on the balcony between the second and third floors. It is a single section 6 ft high and 6 ft long, and rear access panels may be removed for maintenance. Because of its location at the edge of the GETR stairwell and the hoisting bay, a hinged floor section was used to gain access to the rear panels.

The left region of the FPTs panel contains a schematic of the FPTs flow circuit with the necessary valve control switches. The center and right regions contain flow and temperature controllers, recorders, and indicators. At the bottom of the panel are located saturable reactor units for control of the purge-system heaters.

The junior cave panel is located on the second floor adjacent to the junior cave. It is a single section 7 ft high, approximately 18 in. wide, and movable. It contains control and readout instrumentation for the junior cave gas chromatographs and indicators for pressure, radiation, temperature, flow, and humidity.

Fig. 33--Main loop panel

The sample blister panel is located on the mezzanine floor and is adjacent to the sample blister. It is a single-section panel approximately 6 ft high by 18 in. wide and is also movable. It contains control and readout instrumentation for the gas chromatograph and indicators for pressure, flow, and humidity.

The data center rack contains the scanner console, which controls the operation of the scanning mechanism on charcoal trap No. 1. It also contains the readout instrumentation for the scintillation detector in charcoal trap No. 1 and the junior cave. This instrumentation includes an oscillograph, electric typewriter, and an X-Y plotter.

The stack monitor panel cabinet is located in the stack monitor structure. This cabinet contains the necessary electronic equipment required with the Kanne chamber radiation detector and cubicle exhaust flow instrumentation. The cabinet is mounted on wheels to permit removal for required maintenance. Power is supplied from the reactor control room.

Two circulator control panels, one for each circulator, are located on the instrument balcony directly across from the main panel. Each is approximately 7 ft high by 5 ft long. Each panel contains indicators for meter current, alternator current and voltage, and circulator speed. The necessary start, stop, and speed control buttons are located on each panel. Panel No. 1 also contains the circulator selector switch and an "auto-manual" selector switch.

The control room panel is located in the GETR control room. Power to the panel is supplied from a power source in the room. The panel is approximately 6 ft high by 15 in. wide. The panel includes slave recorders that monitor the most important loop parameters: facility-tube outlet temperature, system pressure, system flow, differential pressure, and loop activity. Also included are controls that enable certain operations to be performed remotely from the control room. These include: initiation of emergency cooling, helium transfer, and cubicle exhaust to stack. Included also are annunciators that monitor all main-panel alarms and give specific alarms for critical loop parameters.

The readout instrumentation for the acoustic thermometers, which is located at the right end of the main panel, records fuel temperature.

3.2. INSTRUMENT DESCRIPTION

As mentioned earlier, it was decided that all instrumentation should be standard catalogue items in order to avoid component development work.

This was true for all instruments except differential pressure transmitters, moisture monitors, and thermocouples.

Differential pressure transmitters were used to measure the differential pressure across the main loop orifices, the differential pressure across the facility tube, fuel element purge passage, and flow in the purge line. All of the above were standard differential pressure transmitters with high-pressure casings, but with the additional requirement that the units be all-welded to minimize the possibility of helium leakage. Because of the limited head available, the transmitter which measured flow in the purge line required some development work. As finally built, the unit had a maximum differential pressure range of 20 in. of water. An unusual feature of the differential pressure transmitter which measured the differential across the fuel element purge passages was the fact that the unit had to be secondarily contained to conform with the requirements put on the purge line and all connections to it upstream of the No. 1 charcoal trap. This secondary containment was in effect a pressure vessel flanged at one end. This increased the space occupied by this instrument about tenfold.

The differential pressure transmitters were standard Beckman Hygrometers. These units are built into threaded sections of standard 1/2 in. pipe. In order to ensure against helium leakage, these units were canned in a small pressure vessel. Helium from the charging system was used to pressurize the can to loop pressure.

All thermocouples were standard chromel-alumel, iron constantan, or copper constantan, except those measuring fuel element and graphite temperatures. These last were tungsten, tungsten-rhenium couples and are described in Section 2.1.4, "Test Fuel Element."

3.3. PARAMETRIC INSTRUMENTATION

3.3.1. Controlled Parameters

Loop inlet temperature is controlled by heating the main gas stream with the loop heater. The rate of heater input is controlled by TRC-7, which receives a temperature signal from TE-21, inlet gas to the facility tube, or TE-30, outlet gas from the heater.

The copper oxide bed temperature of the fission-product trapping system is maintained with the copper oxide bed heater. TE-38 measures exit-gas temperature from the heater and transmits the control signal to TIC-9.

The experimental traps in the junior cave have heaters whose temperature is controlled by TIC-14.

3.3.2. Recorded Parameters

Differential pressure across the facility tube or the loop filter is recorded on dPR-1 and dPR-1a; the differential pressure between the facility tube inlet and the purge line upstream of charcoal trap No. 1 is recorded on dPR-2.

Helium flow is maintained with one of the two circulators. Flow is measured by two calibrated orifices and recorded on FR-1 and FR-2 on the main panels and FR1a and FR-1b on the reactor control panel. Flow rate is manually controlled by changing the speed of the alternator units on the frequency generator and, hence, circulator speed. Fission-product trapping system flow is recorded on FR-4 and is adjusted by the positioning of a pneumatic-controlled valve located downstream from the liquid-nitrogen-cooled charcoal trap.

System loop pressure is recorded on PR-1 on the main panel and PR-2a on the reactor control panel. Overpressure conditions are corrected by manual blowdown of gas or relief through the rupture disks. The addition of helium makeup is performed manually from the charging system.

Individual area radiation monitor points are recorded on RR-1, which is on the main loop panel. The common annunciator must be used in conjunction with the individual indicator to determine the point of high activity. The activity of the main loop gas leaving the facility tube is recorded on RR-2, which is located on the reactor panel, as well as on RR-1. Cubicle exhaust-gas activity is recorded on RR-4. Interlocks from the recorder will cause stack closure if set points are exceeded.

TR-3 measures general system temperatures, both in and out of pool. TR-5 monitors facility-tube temperatures; TR-4 and TR-4a measure facility-tube outlet-gas temperature. TR-4b measures the helium temperature leaving the main cooler. Secondary water-system temperatures are recorded on TR-6 and FPTs helium and cooling water temperature on TR-8.

The junior cave and sample blister gas chromatographs have recorders associated with them.

3.3.3. Indicated Parameters

Sym-ply-trol pyrometer indicating switches (TIS-1 and TIS-2) indicate the temperature of the helium leaving the test section. These devices also

connect to the scram circuitry. Flows in the secondary water system are indicated by FIS-3-a and -b, water to traps by FI-7, and water to circulators by FI-8. The system storage tanks are instrumented with pressure indicator gauges. These tanks are: hot-helium storage tank, expansion tank, low-and high-pressure hold tanks, and depressurizer receiver tank. The liquid nitrogen tank and the expansion tank on the secondary cooling system have liquid level indicators. Additional FPTs gas temperatures and liquid-nitrogen system temperatures, are indicated on TI-10. Chilled cooling tower water is indicated locally on TI-16.

Moisture monitors HI-2 in the junior cave and HI-3 in the sample blister determine the moisture content in the fission-product trapping system and main loop, respectively. The flow through these instruments is measured by differential pressure transmitters, DPT-10 and DPT-11, respectively. The junior cave and sample blister include extensive pressure instrumentation that provides part of the essential data for sampling. In addition, the moisture monitors have pressurized housings with indicators (PI-24, PI-25).

PIS-9 indicates the vacuum in the chamber during operation; PI-12 indicates chamber pressure during shutdown and emergency-cooling operation.

Cubicle ventilation exhaust flow is indicated on FI-6 and is adjusted by the positioning of a pneumatic control valve. Differential pressure between the GETR and the various cubicles is indicated on local mercoid switches, DPIS-100 to 104. The ambient temperature of the various cubicles is indicated on TI-15, a microvoltmeter. The liquid nitrogen lines have a radiation monitor that indicates on the main loop panel (RI-23). The same is true of the purge lines at the disconnect flanges in the vacuum chamber (RI-24).

3.3.4. Annunciators

Four banks of annunciators are included, one at the top of each section of the control panel. The left and right hand sections of the panel are general loop-alarm conditions; the center bank has alarms which result in reactor power reduction. Critical alarm conditions are also indicated on the reactor control room panel. All main panel annunciators include acknowledge and reset provisions.

3.3.5. Scram Instrumentation

In order to secure reliability each type of scram was connected to three instruments. To avoid spurious scrams, two out of these three had to reach a scram point before a reactor scram was initiated.

Low flow in the main loop is measured by two flow transmitters on one orifice, and one on the other orifice all of which are tied to the scram circuitry. In addition, the emergency cooling helium valves are opened (after a 60 sec time delay which allows the second helium circulator to come in line, if available) to the in-pool vacuum chamber, and the valves between the vacuum chamber and the vacuum pump are closed. A low-flow scram can also be initiated by a low flow of water to the helium circulator cooling system. Low flow in the system, after a time delay of 3 sec to avoid spurious signals resulting from minor flow fluctuations and to allow the standby water pump to come on line, will automatically shut down the affected circulator. This will of course result in low main loop flow and a subsequent reactor scram.

High temperature, as sensed by two of the three temperature switches downstream from the main cooler and upstream of the helium circulators, initiates a scram. Likewise, high temperature of the exit gas leaving the facility tube will initiate a scram. This temperature is sensed by four thermocouples, two of which are connected to a temperature recorder and the other two individually to two temperature indicating switches.

Low loop pressure is sensed by three pressure transmitters, any two of which upon reaching the scram point will initiate a reactor scram. Simultaneously, emergency cooling of the facility tube is initiated.

3.3.6. Radiation Monitoring Instrumentation

Radiation measurement is used primarily to determine whether a dangerous situation exists within the loop environs. Additional instrumentation is provided for information purposes. A separate stack-monitor system is provided for the cubicle exhaust before entry to the GETR stack.

Radiation area-monitor units consist of gamma detectors with integral amplifiers. They are used for area monitoring at various locations throughout the loop. The detectors transmit signals to individual panel-mounted indicator units. Each unit has a separate high-level alarm point, which is transmitted to the panel annunciator. The multiple decade indicator scales have top ranges of 10^6 r/hr. Those units which measure radiation in loop components or piping are shielded from other radiation sources.

Radiation control is provided at two points in the loop where high activity readings call for immediate corrective action. High facility-tube-outlet radiation or high purge-system-inlet radiation may indicate unsuitable fuel element operation and will result in an automatic reactor-power reduction and possible shutdown of the loop if conditions warrant.

Another critical position is the facility-tube disconnect box, where,

if conditions warrant it, high activity may result in a shutdown of the loop to assure that a buildup of activity will not prevent the removal of the facility tube.

Cubicle exhaust is passed directly to the stack; a side stream is monitored before the gas enters the stack. The radiation signal is obtained by a Kanne chamber, which transmits through a micromicroammeter to a recorder. A high-alarm condition will result in cubicle and stack isolation.

The scintillation detector assembly is designed to detect and discriminate between various radioactive isotopes at two specific locations in the loop: the purge-return line to the FPTs from the laboratory traps (capsules) in the junior cave, and charcoal trap No. 1 in the FPTs. Two detector heads (SCF-1 and SCF-2), each a Harshaw No. 7S8 integral line assembly with NaI crystal and Dumont No. 6292 photomultiplier tube, are used. A third assembly can be used at various locations in the cubicle.

The detector located in the junior cave remains stationary, whereas the one associated with charcoal trap No. 1 is mounted in the trap scanning mechanism, which is designed to expose the detector crystal to the gamma radiation being emitted from the isotopes in each of the tubes in the trap.

Each of the detector heads is connected, one at a time, to a Nuclear Data Model ND101, 256-channel analyzer (SCI-1) which feeds data to a Tektronix Type 503 oscilloscope and an IBM computer readout typewriter (SCR-1).

3.3.7. Intercommunication System

An intercommunication system is provided to allow the loop operator to talk to personnel inside the cubicle, at the junior cave, in the auxiliary equipment containment room, and in the stack shack.

IV. ELECTRICAL

4.1. ELECTRICAL DISTRIBUTION

Normal power is supplied at 440 v from the GETR experiment bus located on the first floor of the GETR. Major equipment, supplied directly at 440 v, includes the circulators, circulator coolant pumps, main heater, purge line heaters, cubicle cooling blower, and several vacuum pumps. Two 15-kva transformers supply 110-v power to small pumps, blowers, lights, and heaters. Generally, any loads in excess of one horsepower are supplied directly at the higher voltage.

Emergency power is supplied at 440 v from the GETR experiment bus located on the second floor of the GETR. The auxiliary circulator is supplied at 440 v. A 5-kva regulated-voltage transformer supplies the main control-panel instrumentation with 110-v power. A separate 10-kva transformer supplies several small pumps and the alarm and safety circuitry. A single-line electrical diagram of the distribution system is given in Fig. 34.

The circulator motors utilize variable-frequency current to change their speed and corresponding output flow. Either 440-v normal or emergency power can be supplied to each circulator through individual-frequency generator units. Output frequency up to 400 cycles is obtained by the control of a magnetic clutch between the input 60-cycle drive motor and output alternator.

4.2. ELECTRICAL INSTALLATION

All electrical power leads were carried within rigid conduit. This was also true of control circuits. All electrical penetrations were located in the roof of the cubicle and the auxiliary equipment containment room roof. Connections within the cubicle used shipboard cable exclusively. Power and electrical instrument leads were brought out of the junior cave and sample blister through Blue Ribbon and Cannon connectors. Since the panel boards in each of these cases were movable, flexible cable was used.

Fig. 34--Single-line electrical diagram

V. SHIELDING

It was assumed for the shielding design that a large percentage of fission products escape from the system to the main cubicle as a result of primary system rupture and that large quantities of fission products are plated out in various sections of the loop. During normal operation, essentially all of the fission products are retained by the fuel element or the individually shielded fission-product trapping system traps, which reduce the calculated dose rates by several orders of magnitude. Details of the assumptions and results of the analysis are given below.

The in-pool shielding was based on the maintenance requirements of the reactor and requirements for direct work on the facility. In both cases, the pool water level was assumed to be about 6 in. below the top of the reactor pressure vessel.

For direct maintenance of the reactor, access to the top head is required 8 to 10 hours after reactor shutdown. The assumptions were:

1. There is 0.05 curie/cm^3 of activity in the main loop.
2. There are 50 curie/cm^3 of activity in the purge stream.
3. That 0.2% of the potential loop plate-out occurs in the region of the disconnect joints (~ 190 curies).
4. There is direct beaming of radiation from the fuel up the evacuated secondary containment.
5. The maximum contribution from all loop in-pool components to a man on the vessel head is 100 mr/hr .

The shielding required was calculated to be about 5 in. of lead in certain locations. A shielded radiation detector (RE-24) is located above the disconnect flanges (see Fig. 4) and calibrated to indicate the dose level at shutdown. The contribution of plate-out to the radiation level indicated is estimated from decay curves obtained during reactor shutdown and by comparison with decay curves obtained from detectors located elsewhere in the system. In actual practice, the radiation level at the disconnects was $< 100 \text{ mr/hr}$.

The cubicle shielding-thickness requirements were based on a loop power of 100 kw operating for about three years. The resulting equilibrium fission-product activity for potential helium contaminants having half-lives greater than 10 min is about 1×10^5 curies. The following are potential coolant contaminants: (1) Xe, Kr, (2) I, Br, and (3) Se, Sr, Y, Sn, Sb, Te, Cs, Ba, La, and Sm. Other fission products are either nondiffusing or reactive with graphite, and thus never leave the fuel compacts.

The upper and lower levels of the main cubicle are shielded with 20 in. of ferrophosphorous concrete and/or the equivalent amount of steel or lead. The concrete density is about 5 g/cm^3 . The resulting dose rate at the surface was calculated to be about 200 mr/hr. The distribution of contaminants within the cubicle is assumed to be about 75% of the equilibrium noble gases, 10% of the halides, and 10% of the others.

For shielding calculations of the lower level of the main cubicle, it is assumed that 100% of all equilibrium fission products with half-lives greater than 10 min are distributed uniformly in the cubicle. The dose rate through 20 in. of ferrophosphorous concrete is about 300 mr/hr.

The dose-rate calculations for normal operation were based on activity levels of 0.05 curie/cm^3 in the main-loop lines and 50 curie/cm^3 in the FPTs lines. In order to gain access to the cubicle during normal operation, the purge lines up to the No. 1 charcoal trap were shielded with 4 in. of lead. However, the dose rates in practice were so low that this lead was removed. General dose rates in the lower level of the cubicle were less than 50 mr/hr during normal operation. The main loop cooler and regenerative heat exchanger are partially shielded.

Each trap of the fission-product trapping system is individually shielded. The estimated radioactivity of the trapped fission products used for design purposes and the shielding thickness are given in Table 9.

Table 9
ESTIMATED RADIOACTIVITY

Trap	Gamma Activity at 100 kw (curies)	Lead Shielding (in.)
Charc. No. 1	60,000 mixed f. p.	9
Emerg. No. 1	60,000 mixed f. p.	9
Charc. No. 2	33,000 Xe and Kr	6
Charc. No. 3	33,000 Xe and Kr	6
Emerg. No. 2	33,000 Xe and Kr	6

Shielding thicknesses in the junior cave (approximately 8 in. of steel or equivalent) are designed to handle safely a 1000-curie sample. If samples of greater activity are taken, internal shielding would have to be added.

VI. NUCLEAR DESIGN

A fuel loading of 195 g of 93% U^{235} was planned for the first experiment to be tested in the loop. It was expected that this loading would result in a fission-power generation rate of about 65 kw in the experiment. This estimate was based on the results of measurements made in a nuclear mock-up of this experiment.

6.1. THERMAL-NEUTRON-FLUX DISTRIBUTION

Figure 35 illustrates the approximate neutron-flux distribution in this experiment for a loading of 60 g of fully enriched UO_2 (about 50 g of U^{235}) homogeneously distributed in all of the graphite comprising the experiment. It may be seen in Fig. 35 that the average thermal-neutron flux in the experiment is about 2.0×10^{13} nv. This value was measured by the central wire of a nuclear mockup for a 50-g loading.

Figure 36 illustrates the vertical (axial) thermal-neutron-flux distribution along the axis of the experiment. This distribution is based on a measurement from the nuclear mockup. The measurement was taken at the start of a GETR fuel cycle (no xenon present) with all control rods inserted 17 in. into the top portion of the 36-in.-high core.

Calculated peak-to-average values for the flux distribution in the fuel are as follows: radial, 1.6; vertical, 1.36 (beginning of cycle), 1.30 (end of cycle).

The relative radial thermal-neutron-flux distribution through the fuel element is shown in Fig. 37. These results were obtained from a P-3 transport-theory cell calculation in which an effective thermal-neutron energy of 0.0297 ev was used throughout the cell and with a symmetrical thermal source in the surrounding water region. The flux was nearly constant across the interior region with the ratio of the average value in the fuel to the unperturbed value in the water equal to 0.316.

The same calculation was repeated with the water annulus maintained at the cold temperature, but with effective thermal-neutron energies within the loop of 0.0579 and 0.080 ev. The corresponding ratios of the average flux in the fuel to the unperturbed value in the water were 0.376 and 0.415, respectively.

Fig. 35--Thermal neutron flux distribution

Fig. 36--Axial neutron flux distribution

Fig. 37--Relative radial thermal neutron flux

The unperturbed value was normalized to the results of the IBM 704 calculation of GETR Cycle 5 to obtain average values over the entire volume of the fuel of 2.4 , 2.8 , and 3.1×10^{13} respectively.

6.2 POWER GENERATION

Based on the experimental thermal-neutron-flux measurement, a 50-g loading will provide a fission-power level of about 40.0 kw, of which 38.3 kw are due to thermal neutron fission and 1.7 kw is due to epithermal neutron fission. A 65-kw fission-power generation rate is desired. The calculated effect on the power in the loop brought about by increasing the fuel loading in the experiment is seen in Fig. 38. From this curve, it may be seen that it is not reasonable to expect that the fission power in the experiment will exceed 100 kw. The plot indicates that the 195-g loading will provide about 80 kw of fission power. If the power level generated by the experiment is higher than desired, it may be adjusted downward by moving the experiment laterally outward from the pressure vessel.

To reduce the power generation in the experiment with the GETR operating at rated power (30 Mw), the fuel assembly can move 5 in. laterally outward from the pressure vessel. In this "shutdown" position, the experiment is shielded from neutrons and gammas by the cadmium neutron shutter and lead thermal neutron shield respectively. The mechanical arrangement of the shutter is shown in Fig. 5. With the reactor operating at 30 Mw(t), and the fission power in the experiment adjusted to 65 kw, the predicted thermal-power-generation rates in the experiment for the operating and shutdown positions are given in Table 10.

Fig. 38--Effect of fuel loading on power

Table 10

PREDICTED THERMAL POWER GENERATION IN GAIL ELEMENT
AT GETR POWER LEVEL OF 30 Mw

	Operating	Retracted
Power (thermal neutron fission), kw	60	3
Power (epithermal neutron fission), kw	5	1
Gamma heating (core gammas), kw	11	1
Decay heat	(*)	4†
Total	76 kw	9 kw

* Included with fission.

† Decay heat following 65-kw fission-power generation, for irradiation times in excess of 50 hr. One hour after a reduction in fission-power level from 65 kw to 5 kw or less, this value falls to about 0.5 kw.

The experiment in the shutdown position is calculated to generate 12% of the operating power after a long irradiation time.

The effect of moving the experiment from its normal operating location to the shutdown position decreases the core reactivity by less than 0.17% $\Delta k/k$.

The effect of inadvertant flooding of the gas and insulating chamber of the experiment with water affects the core reactivity much less than 0.1% $\Delta k/k$.

6.3. CADMIUM-SHUTTER EFFECTIVENESS

The effectiveness of the cadmium neutron shutter was evaluated by performing two-cell calculations using a three-group diffusion theory code on the IBM 650 computer, which permits current boundary conditions interior to the cell. One calculation was made of the cell including the loop with the fuel element in place and a 2-in. annulus of water outside the pipe. A zero-current boundary was assumed at the outer boundary of the cell. The second calculation repeated the first, except that a thermal neutron black absorber was positioned at a radius of 2.5 in. and thickness of 0.160 in. The resulting average thermal fluxes in the fuel element from the two calculations were compared to determine the effectiveness of the shutter in decreasing the flux in the fuel. The ratio of the average flux in the fuel with the shutter in place to that without the shutter was 0.3.

VII. HEAT TRANSFER AND FLUID FLOW

7.1. HEAT GENERATION

The fuel element facility tube incorporates a re-entrant type construction wherein the coolant passes downward through an outer annular section of the pressure vessel and returns upward through the center to provide coolant to the fuel element (see Figure 1).

With a total power generated in the test section of 72 kw and a weight flow in the test region of 230 lb/hr, the maximum fuel temperature occurs between 6 and 16 in. from the lower end of the fuel depending on control rod position. A radial temperature distribution at 15 in. is given in Fig. 39. Actual measured temperatures are shown in the figure. The maximum temperature effect of the flux variation across the fuel is shown in the figure and represents a difference of about 200°F. A longitudinal plot of the calculated maximum fuel temperature is given in Fig. 40. Early in the GETR cycle the maximum fuel temperature is located nearer the bottom of the element owing to power peaking which results from deep insertion of the control rods.

Under conditions in which the normal heat-removal capacity of the primary cooling system is reduced or lost completely, the heat generated in the test fuel element is reduced in an emergency by a reactor scram initiated from a loss of flow or a loss of pressure. When the loop is shut down (i. e., no coolant flow) and the reactor is still operating, the test section is shielded with the lead-cadmium shutter shown in Fig. 5.

In this case, the heat still being generated in the test section by either fission-product decay or neutron and gamma leakage through the shield is removed by heat loss to the reactor pool water. Heat transfer is by radiation and by conduction through the walls of the test section. To increase the heat loss, the vacuum in the facility tube, which normally insulates the pressure vessel, is broken by the injection of helium from an accumulator. This constitutes the emergency cooling system. Parallel sets of valves between the accumulator and vacuum vessel are provided to minimize the effect of valve failure. The accumulator is provided to prevent overpressurization of the vacuum vessel.

RADIAL DISTRIBUTION OF TEMPERATURE GAIL FUEL ELEMENT III A

Fig. 39--Radial temperature distribution in element

Fig. 40--Maximum fuel temperature

Helium injection into the vacuum vessel is provided under the following conditions:

1. Loss of flow (automatic).
2. Loss of pressure (automatic).
3. Excessive gas temperatures (manual).
4. Loop shutdown with reactor in operation (manual).

The first three conditions are accompanied by reactor scram; the fourth requires a reactor shutdown to move the test section away from the reactor and to place the shutter in position. Calculations show that the heat generation is highest for the last case; therefore, if the temperatures are acceptable for this case, it can be concluded that overheating will not occur for the other cases. The following analysis is for the last case above.

The following basic assumptions are used in analyzing the temperature distribution in the test section for the case in which the loop is shut down, the facility tube retracted, the shield in place, and the GETR reactor in operation.

1. The flow of heat is radial only.
2. Heat transfer is by radiation and conduction, i. e., no heat transfer by convection.
3. The temperature drops occur between the metallic shells; the temperature drop in the metal is negligible.
4. The heat generation is independent of azimuthal orientation in each plane normal to the axis of the test section.
5. The peaking factor is 1.8, which is the value for a fresh core.
6. The test section is displaced radially a distance of 4 in. away from its normal operating position.
7. The gamma and fission heating is reduced by a lead and cadmium shield.

Physics calculations show that the fission heat generated in the test fuel with the reactor at full power is reduced to approximately 4.5% by the combination of displacing the test section and interposing the shutter. The gamma radiation heating is likewise attenuated from an average value of 0.8 w/g to about 0.06 w/g. The gamma heating values are shown in Fig. 41. The total heat generated in the test section is about 5.5 kw.

Fig. 41--Gamma heating

The radial temperature distribution in the various components of the test section is calculated to be as follows:

Fuel maximum temperature	2000°F
Inner baffle (Nichrome V)	1700°F
Middle baffle (Nichrome V)	1420°F
Outer baffle (321 SS)	1250°F
Pressure vessel (321 SS)	600°F
Facility tube (aluminum)	180°F

Those calculated temperatures are higher than the temperatures actually attained because of the conservative nature of the assumptions. For example, axial conduction decreases the peak temperatures somewhat, and considerable natural convection occurs in the helium-filled vacuum chamber.

In the emergency cooling situations in which the reactor is scrammed, the temperatures will be lower than calculated above. The high thermal capacity of the fuel element precludes any rapid rise in temperature. It takes approximately 90 sec after scram for the temperature in the fuel to equilibrate. At this time the residual heating has decayed to approximately 3.5% of full power. This is considerably lower than the heating rates considered above.

7.2. HEAT EXCHANGE

The primary-loop main cooler is the heat sink for the primary loop. The cooler is designed for a maximum capacity of 100 kw and a minimum capacity of 15 kw. Design requirements are that the water must not boil and that the temperature of the helium leaving the cooler must always be less than 600°F. The helium flow rate can vary from 0.05 to 0.15 lb/sec, and the heat-load variation is better than sixfold; therefore, it is necessary that the exchanger be designed with a variable area on the water side. This was accomplished by splitting the water side into two banks as described in Section 2.2.6 "Main Cooler."

7.2.1. Pressure Drop

Loop pressure-drop calculations were made on the basis of a helium flow rate of 0.11 lb/sec. While this does not represent the maximum pressure drop, the results clearly defined the minimum pipe size that could be used in the external loop (not including facility tube). A standard pipe

size of 2 in. gives a total pressure drop of 5.4 psi, and a 1-1/2 in. size gives a total loss of 9.5 psi. To balance the head available from the circulators against the pressure losses in the loop and test section, while still retaining an allowance for uncertainties and changes, a 2 in. pipe was used for the main helium flow.

7.2.2. Heat Balance

Heat balance calculations on the external loop show a heat loss to the cubicle and the circulator cooling water of 18 kw and a heat balance on the facility tube indicates a loss of 10 kw to the pool. The calculations on the external loop assumed a 2-in. thick insulation. A typical heat balance diagram of the loop is shown in Fig. 42.

Fig. 42--Heat balance diagram

VIII. ACCIDENT EVALUATION

8.1. INTRODUCTION

Potential hazards in the operation and maintenance of the loop have been examined as well as results of a major system component failure. The results of this evaluation are discussed in the paragraphs that follow. It is shown that the reactor can be scrammed and the loop safely shut down and cooled following an operation or system failure. In addition, it is shown that even in the event of the very improbable maximum credible loop accident, the severity of the GETR maximum credible accident is not changed.

8.2. CONTAINMENT DESIGN

The entire gas loop facility is located within the GETR containment building, which constitutes the final containment. The primary containment is the loop piping. Secondary containment is provided by the aluminum vacuum chamber for the in-pool portion of the loop and by the main cubicle, a shielded, steel-lined compartment for the out-of-pool portion of the loop. In addition, unshielded containment is provided for such auxiliary systems as the demineralized water system and the vacuum systems in order to minimize the consequences of failure of main loop components that could release radioactive gas to these auxiliary systems. A multiple-failure sequence is required, therefore, to release contaminated helium coolant to the GETR containment vessel. A general arrangement showing the location of equipment within the cubicles is presented on Fig. 8. The in-pool portion of the loop is shown in Fig. 3. The vacuum chamber extends up to the main cubicle.

8.3. ANALYSIS OF ACCIDENTS

The multiple containment of the loop has been so designed that the consequences of any type of system accident less serious than a maximum credible accident would be limited to an energy release or a release of radioactive contaminants to the secondary containment; this greatly minimizes the possibility of contaminating the GETR containment vessel. During normal operation, all system leaks are collected in the vacuum and leakage collection system or the cubicle and are eventually exhausted through the cubicle ventilation system as described in Sections 2.2.20 and 2.2.26.

Several system failures have been selected for analysis that are believed to represent the worst conditions. These failures and the reasons for their selection will become apparent in the sections that follow. The following conservative assumptions have been made in order to evaluate the consequences of hypothetical loop accidents:

1. The total power generated in the fuel assembly is 100 kw.
2. The activity in the loop has reached the shutdown initiating condition whereby 930 curies of activity are available for release from the loop.
3. The loop gas pressure is 400 psia.

8.3.1. Loss of Coolant

All loss of coolant failures will lead to similar transient temperatures in the fuel element and facility tube pressure vessel. System failures, such as loss of secondary flow to the heat exchangers, failure of the circulator, inadvertent closure of line valves and line rupture, were examined. All loss of flow accidents will be subject to the same corrective action; namely, a reactor scram, emergency cooling system actuation, and an evacuation of the GETR containment building if activity levels so dictate.

Although the probability is very slight, it is assumed for the purposes of evaluating the severity of such an incident that the return line from the in-pool facility tube in the cubicle is instantaneously severed and displaced, resulting in minimum flow resistance to gas escaping from the loop. As a result of this hypothetical failure, the following sequence of events will occur:

1. In approximately 0.20 sec the contents of the main loop and fission product trapping system are release to the cubicle.
2. A temperature transient is in progress.
3. A reactor scram and emergency cooling to the loop fuel element is initiated by a signal resulting from the loss of flow and/or pressure, and in 5 sec the power in the test section is reduced to less than 10 kw.
4. Circulators are shut down.
5. Valves in the cubicle exhaust system isolate the cubicle on a signal of high radioactivity and/or high cubicle pressure, and the cubicle depressurization is actuated.
6. The isolation valves on the outlet side of the circulators close within 0.01 sec after the loop pressure reaches 235 psig.

Calculations show that fuel temperatures decrease continuously after the scram is initiated and that the inner baffle reaches a maximum temperature of 2300°F about 1 min after reactor scram. The pressure vessel temperatures peak out at $\sim 900^{\circ}\text{F}$ 2.8 min after the scram and emergency cooling are initiated. It can be seen that no damage will occur to the in-pool components as a result of the thermal transient in this extreme case of a complete loss of coolant.

The active fuel is contained within a graphite body capable of withstanding the pressure difference resulting from a sudden depressurization; therefore, even if the active fuel compacts or particles should break up from outgassing during a sudden change in pressure, the graphite body would prevent the resulting particulate matter from reaching the cubicle.

The total main loop activity is limited such that 930 curies of fission-product activity is the maximum activity that can be released from the loop in the case of any predicated credible accident and associated loop blowdown.

The isotopic distribution of fission products within the main loop will consist primarily of those fission products with half-lives greater than 3 min and less than 100 hr. The short-lived isotopes are reduced in activity owing to the holdup action of the fuel bodies, and the long-lived isotopes are reduced in activity by the continuous cleanup action of the FPTs.

The adsorption of noble gas fission products in the liquid-nitrogen-cooled FPTs traps is not pressure dependent, although it is temperature dependent (adsorption increasing with decreasing temperature). The noble gas fission products will not therefore desorb in significant quantities as a result of sudden depressurization. Other fission products are held up within the internal fuel element trap and the No. 1 charcoal trap by adsorption and chemical bonding. Following the postulated loop rupture the reverse blowdown of the 0.1 lb of FPTs helium inventory through the No. 1 trap and fuel element internal trap will desorb a small fraction of these fission products and carry them into the main cubicle. Experimental data indicate that less than one hour's production of halides will be desorbed by the reverse flow.

The activity released to the cubicle is thus limited to the activity contained within the piping of the main loop and FPTs and the amount desorbed from the fuel element internals and the No. 1 charcoal trap, and would therefore not exceed 930 curies.

The pressure in the cubicle is estimated to reach a maximum of 1.8 psig. A pump and tank (cubicle depressurizer shown in Fig. 32).

located within the cubicle are designed to start on a signal of high cubicle pressure (slightly above atmospheric); the pressure is restored to near atmospheric in about 7 min, thus minimizing the release of fission products to the building. The cubicle leakage is less than 300% of the cubicle volume per day at 2 psig.

Assuming that the maximum concentration of fission products available in the system (930 curies) exists and that the entire contents of the loop are dumped into the cubicle, the resultant release to the GETR containment in the first 5 min has been calculated to be 4.8 curies of long-lived noble gases, 0.45 curies of iodine, and 0.05 curies of bromine.

It is assumed that 80% of the radioactivity stays in the immediate vicinity of the second floor stairwell in a 1000 ft³ cloud through which persons must pass. The other 20% is transferred by an unexplained mechanism to the other floors, where it presents a concentration that is 10% of the concentration in the second floor vicinity. It is assumed that the total time to evacuate is 5 min, with the operator spending the first 2 min of residence in the cloud on the second floor and the remaining 3 min on the first floor. Using these assumptions, the maximum dose is calculated to be 4 rems to the whole body, primarily from external radiation sources, and 62 rems to the thyroid, primarily from internal radiation sources resulting from the inhalation of radioiodine.

This analysis had not taken into account the plateout of iodine on the cold cubicle walls. More realistically, a decontamination factor of 100 for the plateout of radioiodine should be used, in which case the thyroid dose would be 0.7 rems.

From the above discussion it can be seen that even in the extreme case of a complete line severance, the system is automatically shut down and sufficient time is available for the reactor operating personnel to safely evacuate the building. It should also be observed that this major hypothetical accident will result in a negligible increase in the release of activity external to the reactor containment building.

8.3.2. Failure of the Main Cooler

The main cooler is a single-wall gas-to-water type. A closed, demineralized secondary water system transfers heat through a secondary heat exchanger which in turn transfers heat to the cooling tower water.

For radioactive contaminants to escape to the cooling tower water system, a failure in the main cooler and a failure of the secondary heat exchanger would be required. This is an extremely remote possibility, because 150 psig relief valves are provided on both banks of the main

cooler shell side which will exhaust the loop contents to the cubicle should there be a failure of the main cooler tube side. Furthermore, the secondary heat exchanger tube-side has been pressure tested to 285 psig and has a steady state rating of 150 psig in accordance with the ASME Pressure Vessel Code. Even if the pressure relief valves were to fail, the shell side of the secondary heat exchanger would fail before the heat exchanger tubes, the integrity of the cooling tower water supply system would therefore not be violated. These concurrent failures appear to eliminate this as a probable accident. If there was a loss of circulation of the secondary water, the piping downstream from the main cooler, the circulators, and the pipe upstream of the electric heater will experience a moderately rapid increase in operating temperature. Piping downstream from the heater and fuel element inlet temperature will experience a more gradual rate of temperature increase, since the electric heater control automatically reduces power to the heater if heater exit temperature exceeds the set value. Reactor scram will be initiated by either high circulator intake temperature or high fuel element exit gas temperature. The reactor scram and emergency cooling will occur when the gas entering the circulators reaches a temperature of 650°F , or when fuel element exit gas temperature reaches 1480°F . In either case, the reactor scram will be initiated in approximately 1 min following loss of secondary water circulation without having exceeded safe operating temperatures in any loop components or piping.

8.3.3. Failure of Circulators

One circulator provides the required flow for full power operation. The second circulator is not operated concurrently with the first. If a circulator should fail or require repair, the failed unit is temporarily removed from the system and operation continued on the alternative circulator without a back-up circulator in the system. If the operating circulator should fail during operation, the reactor would scram automatically, and the low flow would initiate emergency cooling.

The resulting maximum temperatures would be essentially the same as those discussed in Section 8.3.1, "Loss of Coolant," except for the additional cooling that would be provided by circulator coastdown.

8.3.4. Inadvertent Closure of Line Valves

Valves in the main loop include a bypass valve for the full flow filter, the auxiliary circulator shutoff valve, and facility tube gas exit valve. Appropriate controls are included to prevent incorrect selection of valves during loop operation.

The flow control valve, however, must be continuously variable to provide adequate loop flow control. It is possible, by operation error, to

close the flow control valve. The same sequence of events would occur as those given in the hypothetical loss-of-coolant accident, except that the fission products would be retained within the main loop. The rise in temperature of the fuel and associated parts during the few seconds intervening between a sudden flow stoppage and the instigation of emergency cooling is minimized by the natural heat capacity of the assembly. The resulting maximum temperatures will be essentially the same as that discussed in Section 8.3.1. "Loss of Coolant."

Since no coolant flow occurs either by forced circulation or natural convection, the average gas temperatures and pressure of the fluid must remain relatively constant. No danger exists, therefore, of failure of the main loop system rupture disk.

The inadvertent valve closure is included here merely to point out that a near instantaneous flow stoppage would result in no more than an operating inconvenience, because the high heat capacity of the fuel assembly provides excellent protection against any sudden change in heat-transfer characteristics in the fuel region.

8.3.5. Failure of the Purge Line Ahead of the First Trap

Fission products produced in the fuel are normally purged by a directed stream of main coolant gas. The purge gas containing fission products passes through a trap within the fuel and a series of external traps located within the main cubicle as described earlier, and returns to the main coolant stream. The main purge line from the fuel element to the first external trap contains all fission products swept from the fuel region not retained in the internal fission-product trap. The degree of contamination in the purge gas flowing to the first external trap depends upon the efficiency of the fuel element trap and the fission-product retention characteristics of the active fuel. A second purge line bypasses the fission-product trap within the fuel element and provides gas samples containing fission products normally trapped within the fuel element. The gas flowing in this line may contain a higher concentration of halides and other fission products. If a failure in either line occurs, the system contents will be emptied in less than 1-1/2 min to the main cubicle. The cubicle exhaust system will be isolated if the stack activity monitor setting is exceeded.

The time to empty the main coolant system is much greater than that considered in the hypothetical "loss of flow" accident, resulting in negligible increase in fuel assembly temperatures.

In the unlikely event that one or both purge lines break ahead of the No. 1 charcoal trap, the slow build-up of the cubicle pressure and the

relatively rapid cubicle pump-down to the high pressure receiver would result in less activity released to the GETR containment building than that discussed in Section 8.3.1. "Loss of Coolant."

A purge line that breaks beyond the first external trap is expected to release primarily noble gases, because a backflow check valve at the exit of the purge system will cause the main coolant gas to pass through the first trap. The gas contained in the purge lines and traps downstream from the break and ahead of the check valve will also contain primarily noble gases. Those gases that have not been condensed by the cold trap are expected to be released. In any case, a break downstream of the first trap is of lesser magnitude with respect to fission-product release.

8.3.6. Loss of Coolant to the First External Fission-product Trap

The purge lines leading from the fuel element are discharged into charcoal trap No. 1, located within the main cubicle. The trap is cooled by a demineralized water circulating system that transfers heat from the purge gas to the heat exchanger cooled on the secondary side by water from the cooling tower.

Should the water cooling system fail or the purge flow stop, natural-convection heat transfer from the surface of the trap to the cubicle air will maintain the trap pressure vessel wall below the maximum allowable wall temperature of 400°F.

It should be noted that this cooling system also supplies cooling water to the standby charcoal trap No. 1. Under normal operation this trap will be isolated from the main system. If this trap were in operation during a cooling water failure, the same conditions would exist as described above.

8.3.7. Loss of Liquid Nitrogen

Liquid nitrogen is supplied to the No. 3 charcoal trap and, when in operation, the standby No. 2 charcoal trap.

A typical No. 3 charcoal trap is constructed to contain enough liquid nitrogen for 4 hr of continuous operation without warm-up following a loss of liquid-nitrogen flow from the supply tank. Normally, corrective action could be taken to restore flow within this period; if not, slight quantities of H₂O and CO₂ contained within the H₂O and CO₂ trap and the long-lived noble gas fission products from the No. 3 charcoal trap would be returned to the main loop.

When the main loop gas activity reaches a measured value of 0.001 curies/cm³, the reactor will automatically be started on a "run down".

8.3.8. Loss of Power

A loss of the normal power supply automatically scrams the reactor. The emergency GETR power supply, a 150-kw diesel-generator, will have been operating at partial capacity and will pick up the shut-down electrical load. Failure of the emergency power to pick up the loop circulator load, however, results in only a negligible increase of fuel assembly temperatures, because the reactor scram will be accomplished in less than half the time required for the conditions described in Section 8.3.1, "Loss of Coolant," and the coolant is not lost, which provides additional heat capacity to the system.

The emergency cooling system is designed to flood the vacuum chamber with helium from a loss of power to the actuators or a loss of instrumentation.

8.3.9. Loss of Instrument Air

All pneumatic valves in the main loop are designed to maintain loop flow without instrument air. If the loss of instrument air should precipitate a main stream valve closure, the effects would be the same as that discussed in Section 8.3.4, "Inadvertent Closure of Line Valves."

It is possible that the valves leading to the hot helium storage tank, although normally closed, could open. The loop contents would be relieved to the tank and the same sequence of events would occur as described in Section 8.3.1, "Loss of Coolant," but with less severity because the time to scram the reactor would be approximately the same, whereas the time to exhaust the loop would be greater. Helium make-up valves and valves on the sampling system are all manually operated. A failure of automatic controlled valves will, therefore, not release loop contents.

All valves in the ventilation system fail closed, and all valves in the emergency cooling system fail open.

8.3.10. Failure of Rupture Disks on Main Loop

Two separate rupture disks are located on the main loop. The main loop is relieved in the event of overpressurization through the rupture disks into the 10-ft³ holdup tank, which is part of the vacuum and leakage collection system (see Section 2.2.20). The same sequence of events would occur as described in Section 8.3.1, "Loss of Coolant," except that the loop contents would not be discharged to the cubicle.

8.3.11. Failure of Main Loop Piping in the Facility Tube

The in-pool portion of the loop is contained in an aluminum vacuum chamber. The purpose of the aluminum vessel during normal operation

is to act as a thermal barrier between the loop pressure vessel and the GETR pool water.

The consequence of the main loop piping failure would be to fill the vacuum chamber with loop contents. The vessel is designed for the resulting static pressure of 100 psig. A rupture disk is provided, however, that will relieve the pressure at 15 psig to the cubicle, resulting in the same degree of contamination of the cubicle and GETR containment building as discussed in Section 8.3.1, "Loss of Coolant." As discussed earlier, when a reactor scram has occurred and emergency cooling has been provided, the temperature starts to decrease. In this case the accident, in effect, provides emergency cooling. The temperature rise of the in-pool components would therefore be less than that discussed in Section 8.3.1, "Loss of Coolant."

8.3.12. Failure of the Emergency Cooling System

An emergency cooling system has been designed to flood the vacuum chamber with helium on a signal of low flow and low pressure, thus increasing the conductivity sufficiently to remove the heat during an emergency condition such as inadvertent closure of line valves, as described in Section 8.3.4. In order to improve system reliability, a helium supply tank with a low-pressure warning device and two independent valves in parallel are provided.

Warning lights on the loop panel and reactor control panel warn that a low pressure exists in the vacuum vessel after a loop-initiated reactor scram, indicating that the emergency cooling system has failed to operate. The rate of temperature increase in the loop pressure vessel is relatively slow, so that sufficient time will be available for the operator to relieve the loop pressure to the hot helium storage tank before danger of a loop pressure vessel failure would be imminent. This action may be initiated from either the loop control panel or the reactor console.

8.3.13. Maximum Credible Accident

A study has been made to investigate the credibility of an accident in which a failure of both the facility tube and the aluminum vacuum box could take place:

If it is postulated that the pressure vessel instantaneously fractures circumferentially, the maximum force that can possibly be imposed on the bottom head of the vacuum chamber would be equal in magnitude to the loop pressure acting over the inside area of the chamber immediately surrounding the 4-1/2 in. diameter pressure vessel. The resulting stresses are much less than the yield strength of the 6061-T6 aluminum vessel.

It can therefore be concluded that loop pressure temporarily applied to the lower thimble of the vacuum chamber cannot cause failure. It should also be noted that since no axial clearance exists between the bottom hemispherical head of the pressure vessel and the support cup in the vacuum chamber, the head cannot be accelerated by the pressure forces before coming in contact with the bottom plate; thus, no inertial forces can be applied to contribute to the pressure forces. Reaction upward is constrained by pipe lines leading to the loop.

Although it is assumed in this case that maximum loop pressure is applied to the lower region of the vacuum chamber, this is actually very unlikely, because the source impedance of the helium piping supplying the blowdown, although lower, is significant with respect to the impedance offered by the 0.06 in. annulus between the pressure vessel and the vacuum chamber locally around the pressure vessel. The pressure forces can be expected to be less than loop operating pressure.

As the helium leaves the annulus immediately surrounding the facility tube pressure vessel, the available flow area increases greatly, presenting a nearly insignificant flow restriction enroute to the 4-in. rupture disk located in the main cubicle. In no case can the upper large diameter regions of the vacuum chamber be exposed to pressures in excess of the design 100 psig pressure rating by rupture of the facility tube or piping.

Other mechanisms were also considered which substantiate the incredibility of this postulated accident, namely:

1. At no time is an explosive mixture present within the loop, and thus no large-magnitude, short-duration overpressures can be initiated.
2. Another possible mechanism is a failure of the vacuum chamber resulting in a sudden inflow of cold pool water submerging the hot facility tube. The maximum equivalent thermal stress in the facility tube has been computed for this case, however, and it was found that the Type 321 stainless steel vessel material could be subjected to several hundred such thermal cycles without failure according to the limits set forth by Section III (Nuclear Vessels) of the ASME Pressure Vessel Code.
3. Combustion of the fuel element following loop rupture if the circulator isolation valves fail to close and air is pumped to the facility tube during circulator coastdown has been analyzed. A calculational model was used that was geometrically the same as that used for the loss of coolant case. A combustion heat source was added, and gap properties were altered to simulate the burning process. The calculation shows that the stainless

steel pressure vessel will remain intact throughout the burning accident, since its peak temperature will be no greater than 1870°F.

Since circulator isolation valves are checked for proper operation on a routine basis, it is unlikely that they would fail to close during the postulated loss of coolant accident. It is concluded on the basis of these calculations that a failure of the pressure vessel by this mechanism is incredible.

4. The credibility of a postulated accident has also been considered in which the reactor fails to scram during a loss of coolant situation. This situation is believed to be extremely remote, because the failure of six independent safety circuits would be required in addition to the failure which initiated the accident.

The following sequence of events would be required for such an accident to occur:

The loss of coolant accident as postulated in Section 8.3.1 would first be initiated. Two of the three low-pressure circuits and two of the three low-flow circuits must fail to function as the loop flow and pressure drop below the scram setpoints. The loop fuel element would continue to generate power for about 5 sec before the outlet gas thermocouples reach 1480°F. This would scram the reactor, unless two out of three of these circuits failed to operate. If loop and reactor power were to continue during this loss of flow accident, no unsafe condition or experiment damage will result for the first 15 sec.

If all safety circuits fail and manual operator action cannot be taken within 15 sec, it appears that pressure vessel integrity will be maintained with a delay of up to 1 min, even though emergency cooling is not initiated. From this analysis it is concluded that this accident is not credible.

Since analysis shows that the accidents described above are incredible, it is postulated that the maximum credible accident of the loop would be the highly improbable failure of the return line from the in-pool facility tube described in the loss of coolant accident (Section 8.3.1) plus a coincidental failure of the cubicle depressurizer.

The temperature transient and power decay would be identical to that described in the loss of flow accident. The only difference would be the increased amount of activity that would be released to the GETR containment due to the malfunction of the depressurizer.

If it is assumed that the loop contents instantaneously dumped into the cubicle with the resultant pressure of 1.8 psig, the release to the GETR containment in the first 5 min has been calculated to be 0.9 curies of halides and iodine and 8.8 curies of long-lived noble gases.

It is assumed that 80% of the radioactivity stays in the immediate vicinity of the second floor stairwell in a 1000 ft³ cloud through which persons must pass, and the other 20% is transferred by an unexplained mechanism to the other floors, where it presents a concentration that is 10% of the concentration in the second floor vicinity. It is assumed that the total time to evacuate is 5 min, with the operator spending the first 2 min of residence in the cloud on the second floor and the remaining 3 min on the first floor. Using these assumptions, the maximum dose is calculated to be 7.3 rems to the whole body, primarily from external radiation sources, and 112 rems to the thyroid, primarily from internal radiation sources resulting from the inhalation of radioiodine.

This analysis has not considered the plateout of iodine on the cold cubicle walls. More realistically, a decontamination factor of 100 for the plateout of radioiodine should be used, in which case the thyroid dose would be 2.0 rem.

The dose rates at the GETR containment perimeter are shown below as a function of time. These values are based on a continuous release rate from the cubicle to the enclosure of 300%/day.

<u>Time After Accident</u>	<u>Dose Rate</u>
0	0
15 min	0.65 r/hr
30 min	1.1 r/hr
1 hr	1.7 r/hr
2 hr	2.4 r/hr
4 hr	3.2 r/hr
8 hr	3.7 r/hr (max)
16 hr	2.1 r/hr

It can be seen that even in this highly improbable case the magnitude of the accident is considerably less than the GETR maximum credible accident and gives reasonable assurance that the health and safety of the public will not be endangered.

IX. DESIGN AND CONSTRUCTION HISTORY

Although some earlier survey studies had been made, active work on the loop was started in October 1959, with a scope study by the Vallecitos Atomic Laboratory of General Electric Company, and initial design and specification of components which were to be supplied by General Atomic, such as the helium circulators, the fission product trapping system, and the facility tube. In early February 1960, the Atomic Power Equipment Department of General Electric was given a contract to design, construct, and install the loop in the GETR.

The fission product trapping system was assembled at General Atomic in a plywood mockup of the available space and tested as far as could be done without actual fission products. It was shipped to the GETR in November 1960. The main loop was assembled in the General Electric shops at San Jose and put through a series of tests in December 1960.

Southwestern Engineering Company was given a sub-contract by General Electric to install the facility in the GETR. They commenced work in July 1960 on utilities, structural and shielding. Installation of the vacuum chamber and other in-pool equipment was initiated in December 1960 during a one week reactor shutdown. Work re-commenced in late January and was completed in March 1961. The main loop was sufficiently complete by the middle of March 1961 so that helium could be circulated.

Shakedown and construction continued simultaneously until September 23, 1961, at which time nuclear heating of the sample fuel element was initiated. Full power was reached on October 12, 1961.

X. OPERATING HISTORY OF GAIL III-A

GAIL III-A was operated for four GETR cycles. During that time it generated 133 Mw-hr of thermal power and underwent 43 thermal cycles as a result of reactor scrams and rundowns. The average burnup was approximately 8850 Mwd/ton of uranium plus thorium. This is equivalent to a residence of an average element in the Peach Bottom reactor of approximately 4-1/2 months. In the peak region of GAIL, burnup is accelerated by a factor of 2.25.

The most significant fact to be noted from this first test was the low level of radioactivity in the loop. During full-power operation the main cubicle was entered on various occasions, and even the purge lines upstream from the No. 1 charcoal trap could be approached without appreciable hazard. In the general vicinity of these lines the radiation level was about 50 mr/hr.

Most of the first cycle was spent in a succession of planned step increases to full-power operation. The mechanical performance of the facility was generally quite good, though some difficulties occurred.

10.1. APPROACH TO FULL POWER

The GAIL III-A experiment was inserted in the GETR during the week of September 18, 1961. After leak-checking, evacuating, and filling the loop with helium three times, the system temperature was raised by means of the electric heater in order to remove the adsorbed gases and bring the helium purity within specifications.

When this had been completed, nuclear heating was initiated on September 23, 1961. The fuel element was moved toward the reactor in discrete steps that produced fuel element powers of 6, 22, 43, 66, and 72 kw when the GETR was operated at 30 Mw. During each of these steps the GETR was gradually increased to 30 Mw over a period of several hours. Table 11 summarizes typical fuel element temperatures during the escalation to full power (see Fig. 1 for thermocouple locations). Using the data from Table 11, heat-transfer data were calculated; a comparison of loop values with values predicted for Peach Bottom is shown in Table 12.

Table 11

SUMMARY OF LOOP TEMPERATURES

		Loop Temperatures ($^{\circ}\text{F}$)											
Power (kw)	Flow (lb/hr)	Pool Inlet Gas	Element Inlet Gas	Turn around	Stand- off	Bottom of Trap	Top of Trap	Hot Side of Fuel	Cold Side of Fuel	Hot Side of Sleeve	Cold Side of Sleeve	Element Outlet Gas	Pool Outlet Gas
6	255	660	605	615	640	635	635	790	790	715	715	670	665
22	255	640	600	640	685	680	695	1290	1220	1080	980	840	800
43	250	500	480	550	620	600	650	1750	1630	1450	1230	950	880
66	230	500	510	650	700	700	760	2600	2400	2100	1800	1300	1130
72	230	500	515	640	700	700	760	2700	2500	2400	1900	1380	1175

Table 12

COMPARISON OF PEACH BOTTOM AND 75-KW GAIL
HEAT-TRANSFER DATA

	Peach Bottom	GAIL		
		Average	Hot Side	Cold Side
Heat-transfer rate, Btu/hr/ft ² :				
Average element	68,000 ^a	150,000		
Hottest point	102,000	---	240,000	150,000
Temperature, °F:				
Fuel (maximum)	2,550	---	2,700	2,500
Sleeve ID	2,150	2,355 ^b	2,650 ^b	2,060 ^b
Sleeve centerline	2,000	---	2,400	1,900
Sleeve OD	1,880	1,945 ^b	2,150 ^b	1,740 ^b
Sleeve ΔT	270	410 ^b	500 ^b	320 ^b

^a Calculated assuming 804 elements and 110 Mw(t) in core.

^b Obtained using linear thermal gradient with graphite thermal conductivity of 15 Btu/ft²-hr-°F.

After the fuel element had been moved to a position calculated to produce 75 kw, temperature data were taken at nearly constant flow ($\pm 1\%$) as the reactor power was raised in steps. The hot-side fuel and sleeve and the outlet-gas temperatures are plotted in Fig. 43 as a function of reactor power and the corresponding fuel-element power for this particular fuel-element position. Inlet-gas temperature measured at the bottom of the fuel element was approximately 600°F . Since the calculated fuel-element power was approximately 10% low, the reactor was shut down and the experiment was moved 0.75 in. closer to the core. The design power of 72 kw was achieved at this position.

The activity levels in the main loop and the purge stream were followed closely from the beginning of operation. During the escalation to full power, it was observed that the fission-gas release was extremely low for fuel temperatures below 2000°F . A spectrum analysis showed the release to be predominantly from recoil, as characterized by the lack of half-life dependence. These results can be explained on the basis that a small fraction of the fuel particles had defective coatings. After reaching the full design power of 72 kw and fuel temperatures of 2700°F , evidence of a diffusional-type release was obtained. At this time, the gross activity concentration in the purge stream was approximately $250 \mu\text{c}/\text{cm}^3$. The main loop exhibited a gross-activity concentration of $0.026 \mu\text{c}/\text{cm}^3$ under the same conditions, which yields a ratio of approximately 10^4 for purge-stream to main-loop gross activities. An effective permeability constant of $4.2 \times 10^{-5} \text{ cm}^2/\text{sec}$ for the fuel element sleeve was calculated on the basis of $\text{Kr}^{85\text{m}}$ release data. Using flow rates and fuel-element power data, a calculation was made of the fractional release as a function of temperature and is plotted in Fig. 44. The gross radioactivity levels during the escalation to full power are shown in Table 13

Table 13
APPROXIMATE LOOP ACTIVITY
LEVELS IN GAIL

Power (kw)	Max. Fuel Temp. ($^{\circ}\text{F}$)	Activity Level ($\mu\text{c}/\text{cm}^3$)	
		Purge Stream	Main Loop
6	790	5	(*)
22	1290	12	(*)
43	1750	32	0.02
66	2600	500	0.08
72	2700	600	0.08

* Background.

Fig. 43-- Temperature versus power.

Fig. 44--Fractional release versus fuel temperature

10.2. MECHANICAL PERFORMANCE

Although the mechanical performance of the loop was generally satisfactory during the first four cycles, a few difficulties did occur.

1. A bellows that formed the flexible joint between banks on the water side of the loop cooler failed. Later examination showed that the failure was due to stress-corrosion cracking, probably as a result of corrosion from chlorides leached out of the 85% magnesia insulation and inadequate stress relief during manufacture.
2. In adjusting water flow to the two cooler banks, an operator apparently starved one of the banks to a point at which boiling occurred and a vapor lock resulted in that section. Consequently, the second bank of coolers received helium at a considerably higher temperature than specified for the design. Immediately thereafter the loop pressure increased to the alarm point owing to the temperature change. The operator attempted to relieve the overpressure by dumping some loop helium into the stack. He apparently opened both dump valves simultaneously or in series so that the loop had an open line to the stack. Before corrective action could be taken, the low-pressure alarm and then the scram point was reached. To prevent a recurrence of this problem, an additional rotometer was installed so that the flow to both banks could be determined independently. In addition, the procedures to be used when blowing down the loop to the stack were clarified.
3. The concentration of solids in the GETR cooling tower water is quite high. As a consequence, the strainer upstream of the chiller system frequently became clogged. This problem was resolved by installing a second strainer in parallel with the first.
4. Continuous in-line analysis for moisture was planned for routine loop operation; however, the pressure drop from one loop sample point was greater than anticipated, and as a result, the flow rate was not measurable. Consequently, intermittent checks were made at the other main loop sample point, which produced a lower and therefore measurable flow of helium. On the basis of these checks, the water concentration was the order of 0.25 ppm.
5. The water-carbon dioxide trap is designed for blowdown when either ice or solid carbon dioxide plug the trap and reduce the flow in the fission-product trapping system. The plugging was infrequent but presented a serious problem when it occurred during reactor operation owing to the length of time required to restore the trap to its optimum condition (the trap was well insulated). It was

discovered that a narrow orifice had been formed at the entrance to the unit as a result of weld shrinkage. Since the entrance was at liquid-nitrogen temperatures, even a very small amount of moisture would tend to plug the line at this point. Some relief was obtained by throttling the liquid nitrogen flow. An improved model was installed with a larger entrance line, and with provision for heating to decrease the time for blowdown if plugging should occur.

6. The Turbocraft circulator, which was used as a backup to the DeHavilland circulator, has greased packed ball bearings. It had a bearing failure during the shakedown period and another during the first cycle of operation, and was eventually replaced by a second De Havilland gas-bearing circulator
7. Although the initial leak test indicated that the loop was very tight, it was found after a period of operation that there was a slow leak amounting to about 1 vol-%/day. Numerous checks were made, but the source of this leak was not discovered. Since it did not hinder operations, it was ignored. Although the main loop and auxiliary lines were all welded, there were a number of places that were not, such as the calibration plugs on the differential pressure transmitters, the two blowdown valves to the stack, the water-carbon dioxide trap blowdown, the loop evacuation connections which were connected to the vacuum pump, and the sample ports on both the junior cave and the sample blister.

A number of components that gave concern during the design and shakedown period performed exceedingly well. These included the De Havilland circulators, the main loop filter, the main loop valves, the junior cave sampling system, the sample blister, the vacuum box, the vacuum and leakage collection system, the scanner, the fission-product trapping system, and the loop heater. There was considerable question whether the thermocouples would have an appreciable life. All of them survived the four cycles of GAIL III-A.

10.3. CHEMICAL PERFORMANCE

The helium purity specifications set for the loop are:

H ₂ O		< 10 ppm
CO		<100 ppm
CO ₂		<100 ppm
N ₂		< 10 ppm
O ₂		< 10 ppm

These impurity levels were not exceeded at any time the loop operated above 500°F, except that on one occasion there was a high nitrogen level.

Chromatographic analysis shows that the FPTs returns exceedingly clean helium to the main loop. Nitrogen, which is removed in charcoal trap No. 3 by low-temperature adsorption, was retained in the trap only as long as adsorption sites were available and liquid-nitrogen temperatures (-320°F) prevailed. Small changes in exit-gas temperature permitted the release of quantities of nitrogen. The problem of nitrogen release was observed during periods when the liquid-nitrogen supply to the trap was throttled in a conservation effort.

On December 7, 1961, the liquid-nitrogen supply to the junior cave trap was inadvertently reduced to the point where radioactive gases were returned to the main loop during the purge operation prior to sampling. In addition, a sample of the main-loop gas showed the nitrogen level to be approximately 35 ppm. Further activity sampling of the main loop indicated that only krypton had been released. Activity and impurity levels were both reduced with an apparent half-life of approximately 2 hr at an FPTs flow of 0.7 lb/hr. Generally the loop impurity levels were as follows: nitrogen, <4 ppm; oxygen, <1 ppm; carbon monoxide, not detected; H₂O, 0.25 ppm; and CO₂, not detected.

The hydrogen content of the purge stream was determined by analyzing for moisture upstream and downstream of the copper oxide bed. Results showed that the hydrogen concentration was approximately 1 ppm, showing the bed to be essentially 100% efficient.

Ba-La¹⁴⁰ isotopes were identified on the first two scanner settings, or first inch of length, in charcoal trap No. 1. The total amount of activity was relatively low, which pointed to recoil xenon as the precursor element from the small fraction of broken particles. This was further substantiated by the fact that the travel time to the first trap is approximately 7 sec.

Iodine was not detected in charcoal trap No. 1 during periods of operation, even when the internal trap was bypassed.

Purge-stream sampling immediately following reactor shutdown showed that the activity diminished by a factor of approximately 40 within 5 min. Small percentage decreases continued over the next 40 min. Figure 45 is a plot of this data.

During the course of the GAIL III-A experiment program, gas samples were collected routinely from the main-loop gas stream (just after leaving the reactor) and from the purge gas stream (before entering the first charcoal trap).

Fig. 45--Purge-gas activity transient following GETR scram

The samples were counted by a Nuclear Data Corporation 256-channel pulse-height analyzer and a 3-in. NaI (Tl) scintillation crystal. A total of about 200 individual gas samples was collected during the operation of fuel element GAIL III-A. Many of these, however, were not adequate for calculation of release fraction data. The main-loop data are at best only an estimate, because the specific activity was very low and the counting was hindered by background conditions in the GETR containment building.

Counting efficiency values for Kr^{87} , Kr^{88} , Kr^{89} , and Xe^{138} were obtained from an experiment in which uranium stearate was irradiated in the General Atomic TRIGA reactor and the samples counted under identical geometry conditions to those at the GAIL experiment site. Counting efficiencies for the remaining isotopes were taken from a curve obtained by counting National Bureau of Standards calibrated samples of Co^{60} , Cs^{137} , and Ce^{144} .

The data are corrected to loop temperatures and pressure. The values used were 23 atmospheres pressure, 600°F for the purge gas, and 1100°F for the main-loop gas at the sample points. The samples counted were at or below atmospheric pressure and at room temperature.

Duplicate samples were collected: one for the short-lived activities and one for the long-lived isotopes. The first sample was collected and allowed to decay for 2 hr to minimize the contribution of short-lived isotopes to the principal photopeaks used. The sample was then counted for $\text{Kr}^{85\text{m}}$, Kr^{88} , and Xe^{135} . After another decay of several days, the sample was again counted for the long-lived Xe^{133} and Kr^{85} isotopes. The Xe^{133} count was complicated by the lead excitation photopeak near the same energy, and the Kr^{85} was never detected at the reactor site.

The second sample was allowed to decay for about 15 min, and the gaseous parent activities were removed by evacuation of the vial. The daughter products (particulate matter plated out on the walls of the vial) were then counted for Rb^{89} and Cs^{138} .

The gross-activity values reported in Tables 14 and 15 for the main loop and purge stream respectively are at the indicated FPTs purge flow rate. These values are based on the Kr^{88} data with Kr^{88} being 0.5% of the gross noble-gas activity at 2 min decay. Since no Kr^{89} was ever seen in the main-loop samples, the gross-activity values for the main loop should probably be lower than those reported.

Table 14

GAIL III-A FUEL ELEMENT MAIN LOOP GROSS ACTIVITY
(Assuming 2-min Delay)

Sample Date	GAIL Power (kw)	Accum. Power (Mw-hr)	Hot-side Temperature		FPTS Purge (lb/hr)	Gross Activity at System T/P ($\mu\text{c}/\text{cm}^3$)
			Fuel Element ($^{\circ}\text{F}$)	Sleeve ($^{\circ}\text{F}$)		
10/1/61	42					6.96×10^{-2}
10/13/61	66	15	2581	2044	0.4	0.264
10/19/61	66	17	2507	1973	0.6	3.24×10^{-3}
10/20/61	66	18	2498	1960	0.6	0.264
10/31/61	67	23.6	2734	2027	0.48	4.51×10^{-3}
11/7/61	65	33	2687	2000	0.48	0.129
11/10/61	66	37.8	2686	2018	0.61	0.384
11/10/61	66	37.8	2667	1958	0.61	0.248
12/12/61	66.5	63.6	2537	1779	0.66	0.18
12/12/61	66.5	63.6	2532	1765	0.68	0.18
12/20/61	69	75	2514	1756	0.33	0.14
1/19/62	69	107	2355	1516	0.71	0.4
1/23/62	69	115	2389	1478	0.47	0.9
1/24/62	67	116	2344	1630	0.47	0.2
1/26/62	69	120	2465	1241	<0.3	7.0
2/2/62	70	130	2560	1298	0	294

Table 15

GAIL III-A FUEL ELEMENT PURGE STREAM GROSS ACTIVITY
(Assuming 2-min Delay)

Sample Date	GAIL Power (kw)	Accum. Power (Mw-hr)	Hot-side Temperature		FPTS Purge (lb/hr)	Gross Activity at System T/P ($\mu\text{c}/\text{cm}^3$)
			Fuel Element ($^{\circ}\text{F}$)	Sleeve ($^{\circ}\text{F}$)		
9/25/61	5.5	- - -	- - -	- - -	?	0.76
9/26/61	5.5	0.26	789	714	?	0.79
9/27/61	21	- - -	1140	970	?	2.76
9/27/61	21	- - -	1140	970	?	2.64
9/27/61	21	- - -	1140	970	?	2.4
9/28/61	21	- - -	1210	1000	?	4.56
9/28/61	21	- - -	1210	1000	?	3.12
9/28/61	21	- - -	1210	1000	?	6.36
9/28/61	21	- - -	1210	1000	?	3.12
9/30/61	21	2.1	1688	1336	?	6.12
9/30/61	42	2.1	1688	1336	?	14.4
9/30/61	42	2.1	1688	1336	?	18.0
9/30/61	42	2.1	1688	1336	?	13.2
10/1/61	42	- - -	- - -	- - -	?	13.2
10/1/61	42	- - -	- - -	- - -	?	9.12
10/2/61	42	- - -	1677	1313	- - -	15.6
10/3/61	42	- - -	1877	- - -	0.6	16.8
10/10/61	42	12	1724	1320	- - -	9.12
10/10/61	42	12	1724	1320	0.7	7.08
10/12/61	66	14	2540	2033	0.5	360
10/12/61	66	14	2540	2033	0.42	230
10/12/61	66	14	2540	2033	0.3	167
10/13/61	66	15	2581	2044	0.7	252
10/13/61	66	15	2581	2044	0.7	208
10/20/61	66	18	2498	1960	0.6	254
10/20/61	66	18	2498	1960	0.6	104
10/20/61	66	18	2498	1960	0.6	197
10/20/61	66	18	2498	1960	0.6	52.8
10/22/61	66	21	- - -	- - -	?	135.6
10/30/61	66	22	2276	1706	0.62	131.3
10/30/61	66	22	2435	1807	0.53	120
10/31/61	67	23.6	2732	2031	0.49	552
10/31/61	67	23.6	2747	2034	0.46	2270
10/31/61	67	23.6	2724	2014	0.49	314
11/7/61	65	33	2735	2020	0.53	544
11/7/61	65	33	2745	2033	0.52	816
11/10/61	66	37.8	2705	1980	0.6	696
12/6/61	67.4	55	2468	1725*	0.66	284
12/7/61	67.4	56.2	2562	1792	0.66	732
12/12/61	66.5	63.6	2547	1804	0.70	362
12/12/61	66.5	63.6	2505	1756	0.69	242
12/12/61	66.5	63.6	2482	1738	0.67	422
12/20/61	69	75	2514	1756	0.39	1.07 $\times 10^3$
1/19/62	69	107	2355	1525	0.7	726
1/23/62	69	115	2407	1488	0.5	1206
1/23/62	69	115	2407	1478	0.47	1098
1/25/62	69	119	2404	1637	<0.3	2.3 $\times 10^3$

* From this sample on, the sleeve temperature given is that of the cold side only.

During the final week of GAIL III-A operation, a 24-hr test was performed to allow main-loop activity to reach an equilibrium point with no purge stream flow. The peak observed was at $294 \mu\text{c}/\text{cm}^3$ gross activity or 83 curies in the main loop ($2.83 \times 10^5 \text{ cm}^3$ volume). However, there is some question of the validity of some of the data.

Xenon and krypton release fraction data were calculated and plotted against the accumulated power (Mr-hr) on the element. These data are shown in Figs. 46 to 52. The release fractions were also plotted against half-life and are shown in Fig. 53. A more detailed account of the radioactivity analysis is given in GAMD 3378.*

*D. R. Loffing and L. R. Zumwalt, HTGR In-Pile Loop Experiment Activity Analysis, GAIL III-A Fuel Element, General Atomic Report GAMD-3378, September 28, 1962.

Fig. 46--Release fraction Kr^{85m}

Fig. 47--Release fraction Kr⁸⁷

Fig. 48--Release fraction Kr^{88}

Fig. 49--Release fraction Kr^{89}

Fig. 50--Release fraction Xe^{133}

Fig. 51--Release fraction Xe^{135}

Fig. 52--Release fraction X_e^{138}

Fig. 53--Fractional release versus half life