FINAL SYSTEM DESIGN DESCRIPTION
OF THE
EBR-II REACTOR HYDRAULIC TEST FACILITY (RHTF)

by

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ABSTRACT

The design and construction of the EBR-II Reactor Hydraulic Test Facility (RHTF) is described. Rehabilitation of the 0.6-scale model reactor vessel and core used in the original studies of flow distribution in EBR-II and the installation of this equipment into the RHTF are covered. The main justification for the facility is discussed with reference to the need to generate experimental data through the use of hydraulic modeling techniques to enable prediction of detailed flow distributions within EBR-II for any given core loading. Mechanical, electrical, and instrumentation design features are comprehensively described. The plans for utilization of the facility are briefly set forth, and the various phases of the proposed test program and methods for data acquisition and analysis are summarized. The principles of operation, including core-loading changes, startup, routine operation, and shutdown, are delineated. The report concludes with a brief discussion of safety and hazards considerations.

1.0 INTRODUCTION

1.1 Background and Objectives

During the period from 1958 through most of 1960, a series of flow tests was conducted to obtain information to assist in designing Experimental Breeder Reactor No. 2 (EBR-II). This work, which was conducted by the Franklin Institute, Philadelphia, Pa., is documented in Ref. 1. To facilitate this work, a 0.6-scale flow model of the EBR-II reactor vessel and grid-plate structure was designed and built along with a piping system and associated pumping equipment and instrumentation. Water at 110°F was used as the test fluid, and the data from the tests were converted, on the basis of similarity principles, for application to liquid-sodium flow in EBR-II. The actual configurations of the reactor-vessel plenums and subassembly flow inlets and outlets were built to geometric scale, but the flow paths through the core and blanket subassemblies were hydraulically modeled by orifices. Orifice diameters were selected so that the model and actual EBR-II subassemblies operated at the same value of the Euler number and the same overall pressure drop. The orifices were calibrated so that the orifice pressure drops during the tests could be used to determine the flow rates through the subassemblies. Pressure tubing from the upstream and downstream sides of selected subassembly orifices within the model reactor was connected to external instrumentation to allow collection of data for analyzing the coolant-flow distribution within the reactor. In addition to the tests to determine the coolant-flow distribution, the following auxiliary tests were conducted:

A. Manipulation of the inlet flow-control valves of the model to permit quasi-static simulation of the hydraulic conditions at different periods of a flow transient following cessation of electric power to one of the two primary-sodium pumps in the actual reactor.

B. Ink injection into selected subassemblies for visual and photographic study of flow mixing in the upper plenum. For these tests, the model reactor vessel was fitted with a transparent cover to enable photography of the outlet plenum.

In recent years, the primary mission of EBR-II has changed from that of demonstrating the concept of the fast-breeder reactor for application in a central station power plant to that of test-irradiating fuels and materials for the LMFBR program. This change has brought about the need for a facility in which the effects of changes in core and blanket configurations on the distributions of flow and pressure drop in the reactor can be studied. The primary objective of the EBR-II Reactor Hydraulic Test Facility (RHTF) is the gathering of experimental data, through the use of hydraulic-modeling techniques, from which the detailed flow distribution within the reactor can be predicted for any given core loading.

Current and projected loadings in EBR-II differ significantly from the loading used in the past hydraulic studies by the Franklin Institute. Since those studies, a large number of experimental subassemblies, with widely differing hydraulic characteristics, have been installed in the reactor. In addition, the active core region in the reactor has been extended from the first six rows to the first seven rows. The recent replacement of the depleted-uranium blanket subassemblies in rows 8-10 with low-flow stainless steel reflector subassemblies has also contributed to the overall change since the completion of the Franklin Institute tests.

Almost all the subassemblies in EBR-II are uninstrumented, so the coolant flow rates through them must be calculated from a knowledge of the total flow rate through the reactor. The EBRFLOW code² was developed and is routinely used at present for this purpose. In addition to the total flow rate through the reactor, the required inputs to each EBRFLOW problem are the hydraulic characteristics of each reactor subassembly and an "effective pressure drop fraction" for each of the subassemblies in the core region. This latter input is briefly discussed in the following paragraphs.

The Franklin Institute studies demonstrated the existence of appreciable entrance pressure losses for EBR-II subassemblies in the core region. The magnitude of these losses was found to be different in the various rows of the core; even within the same row, they differed for the different types of subassemblies. A large part of these entrance losses is considered to be due to the close positioning of the subassembly lower adapters in the high-pressure plenum and the consequent heterogeneous flow patterns within this plenum.

The largest pressure drop within a core subassembly is that for a row-7 position, the first core row the high-pressure coolant encounters. Because of the entrance losses cited above, the available pressure drop within any subassembly in rows 1-6 is less than that in row 7, and could vary with the type and specific location of the subassembly within the core. A quantitative measure of this variation is the ratio of the total pressure drop within any core subassembly to the total pressure drop within a row-7 subassembly. This ratio is called the "effective pressure drop fraction." For the present heterogeneous loadings in EBR-II, there is no analytical means of predicting the effective pressure drop fractions from the experimentally determined fractions for the homogeneous loading used by the Franklin Institute. Therefore, the EBRFLOW analyses continue to use the Franklin values even though the current effective pressure drop fractions conceivably are different from those values. The RHTF will enable experimental determination of the effective pressure drop fractions for current EBR-II loadings and thus reduce the uncertainty in the calculated subassembly flow rates.

1.2 Summary Description of Facility

The RHTF consists of a 0.6-scale model of the EBR-II reactor vessel, core, and blanket along with an associated closed circulating water loop. It is to be operated at approximately 110°F and with a maximum pressure of about 50 psig at the reactor-vessel inlet. Figures 1 and 2, respectively, are a schematic diagram and a photograph of the facility. Apart from some minor differences, the model vessel and its internals are geometric replicas of their counterparts in EBR-II. The model vessel and core used for the RHTF is the same equipment used in the Franklin Institute studies. It had been stored at ANL-East for over a decade and was made suitable for reuse by extensive cleanup and rehabilitation at ANL Central Shops.

To house the RHTF, a prefabricated metal building (formerly the AFSR building) with a floor area of 32 x 35 ft was moved from the EBR-I site to the EBR-II site. The building was placed on a concrete slab just south and across the road from the Inspection and Test Facility (ITF) building and is designated as building No. 789. Existing lighting, furnace, 3-ton crane,

Fig. 2. Photograph of the RHTF

and air compressor were moved with the building. Additional utilities (power, water, and drain) were provided to facilitate installation and operation of the RHTF.

In addition to the model reactor vessel, core, and blanket, the major components of the facility are a coolant-circulating pump, a filter, a makeup-and-storage tank, an expansion-head tank, and a heat exchanger. The coolant-circulating pump takes suction directly from the model reactor vessel. Coolant flow leaves the pump discharge, passes through the main throttle valve (see Fig. 2), and splits into two separate branch lines, one of which contains the coolant filter. Each branch line contains a throttle valve to control coolant flow rate to the inlet nozzles of the high-pressure plenum of the model reactor vessel. These nozzles are on opposite sides of the vessel. Smaller lines attached to these two branch lines contain throttle valves to control coolant flow rates to the inlet nozzles of the low-pressure plenum of the vessel; these nozzles are also opposite each other. A heat exchanger piped in a side loop around the coolant pump removes pumping heat to allow operation of the loop at a constant temperature.

The system is equipped with appropriate local-pressure and -temperature indicators in each branch line and one thermocouple in the line between the vessel outlet and the pump inlet. A cutout switch shuts down the coolant pump when loop temperature exceeds a preset value. Selected measurements of static pressures and differential pressures (for flow) of subassemblies in the vessel, along with the differential pressures (for flow) from each of the branch lines, are routed through multiple-pressure tubing lines to a mechanical-electronic scanning system and from there into pressure transducers (not shown in Fig. 1). The resulting electrical signals, along with the signal from the thermocouple, are then supplied to a data processing system (DPS). The DPS converts the signals into the proper units and provides sequential display, recording, and transmission to the EBR-II Data Acquisition System (DAS) for data collection and analysis. The RHTF is provided with direct communication with the DAS for calling up computer programs and for displaying data at the RHTF after they have been stored and/or processed by the DAS.

A 6-in. blind flange is on the northwest corner of the facility, at the end of the north 6-in. line supplying the high-pressure plenum of the

vessel. This provision is made for the possible future addition of a single-subassembly flow loop to be operated in parallel with the model reactor vessel.

1.3 System Design Requirements

The major function of the RHTF is to provide a specified flow of water at a given temperature to the 0.6-scale model reactor vessel for study of coolant flow distribution by flow-modeling techniques. Table I shows the major system design specifications. The pump discharge capacity of 3400 gpm provides up to 200 gpm to the heat-exchanger loop and about 1600 gpm to each of the two major 6-in. branch lines. Each of the 3-in. lines running off the 6-in. branch lines takes off about 300 gpm. Therefore, the maximum flow to the high-pressure plenum is 2600 gpm, and to the low-pressure plenum it is 600 gpm. Calculated maximum pressure drop through the model reactor is approximately 141 feet of water, so the total head of 240 ft developed by the pump is more than adequate to sustain the design flow rate through the loop and model reactor.

The temperature of the water supplied to the model vessel will normally be 110°F, the same as that used in the Franklin Institute studies. The heat-exchanger loop provides a heat-removal capability sufficient to maintain this temperature. The full-flow filter, in one of the 6-in. branch lines, removes particulate matter and maintains the high quality of the water. A chromate rust inhibitor at a concentration of about 4000 ppm is added to the loop water to protect the carbon steel piping and components from corrosion. The makeup-and-storage tank serves two purposes: (1) it provides a means for adding water and chromate rust inhibitor to the system; (2) it provides a storage volume of more than half the system water inventory to facilitate partial draining of the system for repairs or core loading changes.

Valves are provided at selected locations in the loop to allow flexibility in control of coolant flow through the model reactor. Although only one coolant-circulating pump is provided, the use of separate branch lines to feed opposite sides of the high- and low-pressure plenums of the model reactor vessel adequately simulates actual reactor operation with two separate pumps.

TABLE I. System Design Specifications for the EBR-II Reactor
Hydraulic Test Facility (RHTF)

Pump capacity, gpm max.	3400
Pump developed head, ft	240
Pump motor power, hp.	250
Pump NPSH ^a required, ft	17
Pump NPSH available, ft at 110°F water temperature.	40
Flow to each of two high-pressure-plenum inlets, gpm max.	1300
Flow to each of two low-pressure-plenum inlets, gpm max	300
Loop water to heat exchanger, gpm max	200
Cooling water to heat exchanger, gpm max.	40
Total flow through reactor vessel, gpm max.	3200
Total flow through subassemblies in rows 1-7, gpm max	2600
Total flow through subassemblies in rows 8-16, gpm max.	600
Pressure drop through core, ft max.	~141
Water temperature at reactor-vessel inlet, °F	110
System water capacity, gal.	~1200
Storage-tank capacity, gal.	~750
Reactor-vessel capacity, gal.	~700
Loop fluid is demineralized water with approximately 4000 ppm of chromate rust inhibitor added	
Piping design specifications: 150 psig at 150°F	
Filtration provided by one full-flow filter in 6-in. branch line ^b	

^aNet positive suction head.

^bInlet line to filter is actually 8 in.; outlet line is reduced to 6 in.

A major design consideration in the facility was the instrumentation and means of data collection and analysis. Instrumentation requirements were as follows:

(1) Adequate out-of-core system instruments were required to monitor flows, temperatures, and pressures.

(2) A sufficient number of representative subassemblies within the core and blanket regions required orifices and tubing connections to allow measurement of coolant flow distribution throughout the model reactor.

(3) A number of static-pressure probes were required at selected locations in the high- and low-pressure plenums and near the subassembly outlets.

(4) Approximately 300 bulkhead fittings were required on the model reactor vessel to facilitate connection of the internal copper-tubing lines to the external Poly-Flo polyethylene tubing (Imperial-Eastman Corp.), which was in turn routed to the mechanical-electronic pressure scanner.

(5) An efficient and convenient system of data collection for computer analysis was required to allow experimenters to monitor, collect, store, and analyze the profuse quantities of data from the facility. The equipment and methods of data collection, storage, and analysis are described in detail in Section 2.3.

Other important design considerations were:

(1) Cost. For economy carbon steel pipe and components are used throughout the facility.

(2) Layout. All system components and piping were designed and assembled to fit within the 32 x 35-ft confines of the available building.

(3) Ecology. Only water of acceptable purity will be discharged from the drainage system of the facility. Chromated water removed from the system during routine core loading changes will be stored temporarily in the storage tank. System water dumped to the drain will be run through a portable demineralizer to remove chromate rust inhibitors.

(4) Cavitation. An overhead expansion-head tank is connected to the main loop and will normally be about half full. It provides a free surface area to accommodate fluctuations in system water volume due to temperature changes, and it also provides a static head on the system to increase net

positive suction head (NPSH) and thereby eliminate cavitation in the sub-assembly orifices and pump suction. The unfilled volume of this tank is normally pressurized with air to provide additional head.

(5) Supports. All system components and piping are provided with adequate supports and restraints that allow system movement due to thermal expansions.

(6) Safety. All aspects of the facility required analysis so that it could be operated in a safe manner without danger to equipment or personnel.

2.0 DETAILED DESCRIPTION

2.1 Building

The RHTF building, No. 789, is east and across the road from the Laboratory and Office (L & O) building and south and across the road from the Inspection and Test Facility (ITF) building. This location was chosen because it provides convenient access to other buildings and services and is very close to power, raw-water, and waste-water-drainage services.

The building is the former AFSR building, which was moved from the EBR-I site to its new location at the EBR-II site and installed on a reinforced concrete slab. The floor space of the building is approximately 35 x 32 ft. The 3-ton building crane, 17.8-cfm (100-psi) air compressor, and hot-air, oil-fired furnace that were in the building were also moved and remain in use in the building. Crane coverage is approximately 24 ft wide over the length of the building; hook height is 15 ft. The crane has a motor-operated trolley and hoist, and its bridge is manually operated.

A 2-in. raw-water supply line with stop valve enters the northeast corner of the building. This in turn supplies a 1½-in. raw-water coolant line to the system heat exchanger, a drinking-water fountain, and a 1-in. valved hose connection for miscellaneous use. A sump in the northwest corner of the building is connected by a 4-in. drain line to a site waste-water drainage ditch outside the building.

Electrical power is supplied to the building through underground conduits from the 500-kW yard substation, building No. 773, just across the road to the north. All building circuit breakers and the 250-hp, 460-V,

3-phase, part-winding type of motor starter for the loop coolant-circulating pump are mounted on the north wall. A number of 110-V electrical outlets and two 480-V, 60-A receptacle outlets for welders are in the building. The building is provided with telephone and fire-alarm service and is connected to the site paging system.

Personnel access is through 3-ft x 7-ft doors on the east and west sides of the building. A 12-ft-wide by 13-ft-high freight door is on the west side of the building.

2.2 Major Components and Piping System

2.2.1 Model Reactor Vessel

The RHTF model reactor vessel is a 0.6-scale replica of the actual EBR-II reactor vessel. The model vessel was built by the Sun Ship Company and is rated for a pressure of 125 psig at a temperature of 160°F. Fig. 3 is a drawing showing the principal components of the model vessel and reactor. Either of two flat heads may be used on the vessel. One head is constructed of 1-3/4-in.-thick carbon steel and is capable of taking rated vessel pressure and hydrostatic tests. The other, 1-in.-thick Plexiglas with a strongback, is for use during certain experiments (such as visual studies of flow distribution with the dye-injection technique) when the pump is operating and pressure at the core outlet is relatively low. This head must not be subjected to large hydrostatic pressure.

Upper and lower grid plates form high- and low-pressure plenums, each of which receives coolant through two nozzles on opposite sides of the vessel. The subassemblies are supported on the upper grid plate and extend down through the high-pressure plenum, the lower grid plate, and into the low-pressure plenum. Coolant from the high-pressure plenum enters the subassemblies in rows 1-7 through holes in the subassembly lower adapters. Coolant leakage from the high-pressure plenum flows down through a central leakoff plenum and is returned to the main loop through a drain line containing a valve and flow-monitoring orifice assembly. Coolant from the low-pressure plenum enters the bottom of the outer blanket subassemblies. All subassemblies discharge into a common outlet-plenum area of the reactor vessel.

Fig. 3. Reactor Vessel and Core of RHTF

Flow-distribution baffles are located in the high- and low-pressure plenums as well as in the outlet plenum of the reactor vessel.

Before the RHTF was installed, the model vessel and all internal parts (grid plates, plenums, flow baffles, etc.) were thoroughly cleaned and had all grease, rust, and scale removed. Flange surfaces and certain critical machined surfaces--such as the grid plates and the surfaces of the bottom central leakoff plenum, which have close-tolerance holes in them--were left bare and unfinished. All other interior surfaces were coated with a white epoxy paint to inhibit rust.

2.2.2 Subassemblies

The subassemblies are not exact models of their counterparts in EBR-II. Geometric similarity is used on certain portions, but other portions are modeled hydraulically by means of orifices that serve also as flow-metering sensors,^{1,3} as discussed in Section 2.3. All the subassemblies are similar in construction to the core subassembly shown in Fig. 4, except as noted in the following descriptions of the individual types of subassemblies.

The orifices in the upper sections of all the subassemblies are about three-fourths of the way downstream from the flow entrance. The static-pressure tap at the lower, or high-pressure, inlet to the orifice is 2-1/2 inside tube diameters from the orifice face. The static-pressure tap at the upper, or low-pressure, exit from the orifice is eight inside tube diameters from the orifice face. The actual distance of these taps from the orifice faces is different for each type of subassembly, because the inside tube diameters are different. Thin, sharp-edge, concentric orifices are used throughout.

During the cleanup and rehabilitation program, all the subassemblies were disassembled down to the individual parts, which were then thoroughly cleaned to remove all grease, rust, and scale. All subassemblies were refitted with new stainless steel orifice plates, because the old orifice plates were badly corroded and flow-calibration tests verified the need for replacement. All core subassemblies were reassembled using soldered joints, which proved to be expensive and time-consuming. Special fixtures and epoxy cement were used to assemble all the remaining subassemblies. This technique proved to be much faster and very satisfactory.

Fig. 4. Core Subassembly of the RHTF

Following is a description of the various types of subassemblies used.

2.2.2.1 Core and Inner-blanket Subassemblies. Each core and inner-blanket subassembly is composed of two separable sections. The upper section is hydraulically modeled by orifices. The lower-adapter section is a true geometric 0.6-scale model of the lower adapter of an actual subassembly. The upper portion of the lower adapter contains an insert that fits into the lower portion of the upper section. An O-ring seal prevents flow from entering the subassembly at this juncture. The lower adapter is oriented in the high-pressure plenum by mating the slotted end of the adapter with a key bar.

2.2.2.2 Outer-blanket Subassemblies. As with the core and inner-blanket subassemblies, the upper section of this subassembly is hydraulically modeled. The portion of the lower end which comes between the reactor grid plates is also a 0.6-scale model of its counterpart in the actual subassembly; however, the lower end plug in the low-pressure plenum only hydraulically simulates the inlet geometry of the actual outer-blanket subassembly.

The end piece of the lower adapter of the subassembly contains the flow inlet hole and is held in the lower end of the subassembly by a tight-fitting O-ring stretched over the end piece. This O-ring also prevents flow from entering the subassembly through the juncture of the end piece with the lower end of the subassembly.

2.2.2.3 Safety-rod Subassemblies. In these subassemblies, the lower adapter and the outer jacket (those parts between the upper and lower grid plates of the reactor) are true geometric 0.6-scale models of their actual EBR-II counterparts, except for the internal components of the lower adapter. The upper portion of the subassembly is hydraulically modeled. No provisions are made to simulate the functional purpose of the actual safety-rod subassemblies during scram. The models are fixed at the core elevation in which they would normally be during reactor operation.

The model safety-rod subassembly is an epoxy-cemented assembly of several components. The outer jacket houses the lower adapter and is cemented to it at the bottom. The jacket is also cemented to the upper section of the subassembly at a joint close to the surface that rests on the

upper grid plate in the reactor. A hexagonal tube is cemented to the upper end. This tube and a top lifting fixture attached to it protrude into the outlet plenum.

2.2.2.4 Control-rod Subassemblies. In these subassemblies, the lower adapter and outer jacket are geometric 0.6-scale models, except for the internal components of the lower adapter. The upper portion is hydraulically modeled. The subassembly has essentially the same type of components as the model safety-rod subassembly. It differs from the safety-rod subassembly in that the outer jacket is fixed between the reactor grid plates while the upper portion is free to be raised or lowered to simulate the positioning of the EBR-II counterpart. For the first series of tests, the control-rod subassemblies are fixed at a typical elevation in which they would normally be in the reactor (74% of the fuel section inserted).

2.2.3 Piping System

The main function of the piping system and the components external to the model reactor vessel is to provide a closed flow loop in which the temperature and flow rate of water to the model subassemblies within the vessel can be controlled. For economy reasons, the piping system and all major components except the makeup-and-storage tank were fabricated from carbon steel. The makeup-and-storage tank, which was obtained from surplus, is stainless steel.

The piping system is shown in Figs. 1 and 2. Table II lists the major equipment items, their weights, the number and type of connections, and the supports. The piping system is designed for 150 psig at 150°F; however, the normal operating temperature is 110°F. All piping design, erection, testing, and fabrication were carried out in accordance with the Code for Pressure Piping (ANSI B 31.1).

The 3400-gpm, 240-ft-head coolant-circulating pump (made by Allis-Chalmers) takes suction directly from the 8-in. outlet of the reactor vessel, through an 8-in. x 12-in. reducing elbow and a 12-in. rubber expansion joint. The pump discharges through a 10-in. x 8-in. reducing expansion joint into an 8-in. line containing the main 8-in. throttling globe valve. Discharge from the valve splits into two branches, one of which contains the coolant filter,

TABLE II. Major Components of the RHTF

<u>Component Name, (Designation), and Weight Empty</u>	<u>Number, Size, and Type of Connections</u>	<u>Type of Support and Holddown</u>
Model Reactor Vessel, (R-1), 9500 lb	1 - 8-in. 150-lb flg. outlet conn. 2 - 6-in. 150-lb flg. high-pressure-plenum conn. 2 - 2-1/2-in. 150-lb flg. low-pressure-plenum conn. Misc. drains and vents	Three existing pipe legs, 4-in. Schedule 80. Vessel shimmed to attain proper elevation for piping. Tank legs bolted to floor by 3-3/4-in. expansion bolts as per holes in support pads.
Makeup-and-Storage Tank, (PC-T-1), 3000 lb	1 - 1-1/2-in. screwed fill conn. 1 - 3/4-in. air-inlet conn. 1 - 1/2-in. vent conn. 1 - 2-in. drain and storage conn. All other existing con- nections plugged or flanged shut	Four existing pipe legs, 4-in. Schedule 40. Tank shimmed to attain proper elevation for piping. Tank legs bolted to floor by 4-3/4-in. expansion bolts as per holes in support pads.
Primary-coolant Filter, (PC-F-1), 1500 lb	2 - 8-in. 150-lb flg. conn. 2 - 1-in. drains	Supported on pad with 3/4-in.- dia roller rods to attain proper elevation for piping.
Coolant-circu- lating Pump and Motor, (PC-P-1), 4300 lb	1 - 12-in. 125-lb flg. conn. (suction) 1 - 10-in. 125-lb flg. conn. (discharge)	Pump baseplate shimmed as necessary for leveling and proper elevation, filled with grout, and bolted to concrete floor.
Expansion-head Tank, (PC-T-2), 250 lb	1 - 1-in. pipe vent on top 1 - 1-in. pipe conn. on bottom Level gauge and other misc. plugged conn.	Hung and adequately supported by building main frame in the most elevated part of the building.

TABLE II (contd)

<u>Component Name, (Designation), and Weight Empty</u>	<u>Number, Size, and Type of Connections</u>	<u>Type of Support and Holddown</u>
Rubber Expansion Joints, (PC-X-1 and PC-X-2)	PC-X-1: 10-in. x 8-in. reducer PC-X-2: 12-in. x 12-in.	Bolted to pump discharge nozzle. Bolted to pump suction nozzle.
Heat Exchanger, (PC-H-1), 450 lb	2 - 1-1/2-in. screwed coolant-water inlet and outlet conn. 2 - 3-in. screwed shell- side inlet and outlet conn.	Supported at proper elevation by cross braces welded to north and south pipe legs on makeup- and-storage tank.
Pump Motor Starter	1 - partial-winding, magnetic type, for use with 2-step part-winding AC induction motor, 250 hp, 460 V, 3-phase, 60 Hz	Mounted on building north wall. Four-inch conduit buried in building concrete slab connects starter to pump motor.

which has 8-in. flanges. Both branches reduce to 6-in. pipe size and contain 6-in. throttling globe valves for adjusting flow rate in each line. The two branch lines are then routed back to opposite sides of the model reactor vessel. A 3-in. low-pressure-plenum supply line with throttle valve takes off from and runs directly below each of the 6-in. lines. In this way, the high- and low-pressure plenums of the reactor vessel are supplied by 6-in. and 3-in. pipelines on opposite sides of the vessel. The main straight runs of the four pipelines (two 6-in. and two 3-in.) have 300-lb orifice flanges for flow monitoring.

The makeup-and-storage tank is located between the pump and the south branch line and is connected to the reactor vessel through a manifold of a 2-in. pipe, valves, and a water transfer pump. The heat exchanger is supported on cross braces between the pipe support legs of the makeup-and-storage tank. Three-in. supply and return pipelines, with a throttling valve in the return line, connect the heat exchanger to the main loop on either side of the pump. Raw-water-coolant supply and return pipelines connect the heat

exchanger to the building raw-water supply and drain. A flowmeter (0-70 gpm) in the heat-exchanger-coolant supply line monitors the flow rate of the cooling water. The expansion-head tank, mounted in the uppermost region of the building, is connected to the pump suction line by a 1-in. pipeline containing a gate valve. An air-line piped to the tank is used to pressurize the tank for increasing the head on the reactor core and the coolant-pump suction as required. For making a possible future connection, a blind flange is provided on the end of the straight run of the north 6-in. branch line. A single-subassembly flow loop may be connected at this point and operated in parallel with the model reactor vessel and core. Temperature, pressure, and flow instruments are provided on the loop as described in Section 2.3.

Materials of construction for the facility are as follows:

(1) Pipe. All piping materials are Schedule 40, ASTM A-106, Grade B, or approved equal.

(2) Fittings. Weld fittings 3 in. and larger are standard-weight, ASTM A-234, seamless steel butt-welding type, dimensioned to ANSI Standard B-16.9, or approved equal. All fittings 2 in. and smaller are 2000-lb, screwed, ASTM A-105, Grade II, forged steel, or approved equal.

(3) Flanges. Except as noted in the construction drawings, all flanges are 150-lb, slip-on type, ASTM A-181, Grade I, fabricated in accordance with the requirements of the latest edition of ANSI B-16.5, or approved equal. Orifice flanges are 300-lb, welding-neck type, ASTM A-105, Grade I, furnished with compressed asbestos gaskets. All flanges have 1/16-in. raised facings.

(4) Valves. The main 8-in. throttle valve, the two 6-in. main-branch throttle valves, and the two 3-in. low-pressure-branch valves are new, cast steel, 150-lb valves manufactured by William Powell Company. All other valves are surplus used equipment, but in good, serviceable condition, and are cast or forged steel, stainless steel, or brass.

(5) Insulation. No pipe or equipment insulation is used, because the operating temperatures are low and heat dissipation is desirable.

(6) Flange Bolts, Studs, and Nuts. All studs are ASTM A-307, Grade B, or approved equal. All nuts are heavy, hexagonal ASTM A-307, or approved equal.

(7) Gaskets. All pipe gaskets are Garlock No. 950, 1/16-in. compressed asbestos, or approved equal. Gaskets are not required at the flanged expansion joints on the pump suction and discharge. All flange gaskets

except those for the orifice flanges are fabricated to the same outside diameter as the flange and with the same number of mating clearance holes. The orifice-flange gaskets conform to the outside diameter of the orifice plates.

Since the loop will normally operate at 110°F, pipe expansion and flexibility were not difficult problems. However, because of the large size and relative inflexibility of the pipe, and the desire to shorten piping lengths and reduce the overall size of the loop, pipe flexibility and loop layout were major considerations in the design. To save space and money, the loop is laid out with the coolant pump and the makeup-and-storage tank in the center of the piping system. The reactor vessel, coolant pump, and makeup-and-storage tank are anchored in place, and the entire piping system is allowed to expand freely in an eastward direction away from the reactor vessel and the pump. All main system piping is supported close to the floor on adequate structural and roller supports to facilitate free expansion of the loop toward the east. The coolant filter, located on a small platform on the east side of the loop, rests on a number of 3/4-in. roller bars that provide for filter movement in conjunction with pipe expansion. Only one spring hanger is used in the facility; it supports the relatively short run of pipe between the reactor-vessel outlet and the suction nozzle of the coolant pump.

During initial checkout of the loop, two deficiencies were noted. The coolant-circulating pump vibrated excessively, and the rubber expansion joint downstream of the pump outlet exhibited a tendency to expand beyond its rating. The excessive pump vibrations were traced to slight movements in the pump base, which caused misalignment between the pump and its motor. This problem was eliminated by installing structural support brackets on the pump nozzles. To prevent excessive movement of the expansion joint, a restraining bracket was installed on the piping immediately downstream from the expansion joint.

According to the Code for Pressure Piping (ANSI B 31.1), the allowable stress for this system is 30,000 psi at a temperature of 200°F. All sections of piping in the system were analyzed; their stresses are well below the allowable stress. Except for the rubber expansion joints, all sections of the piping system can safely withstand 200°F; the temperature of the expansion joints should be limited to 150°F.

The total pressure drop through the system is calculated to be about 220 ft of water, with approximately 140 ft of this across the reactor. Since

the coolant pump is rated at a total developed head of 240 ft, there is a slight excess head available. The pump requires a NPSH of 17 ft. With the overhead expansion-head tank half filled with water, providing a static pressure head of about 20 ft, the total NPSH available at the pump is about 40 ft. The expansion-head tank will also be used to accommodate fluctuations in the system water volume due to temperature changes and leakage. The head provided by the tank will prevent cavitation in the subassembly orifices and at the coolant-pump suction.

To operate the RHTF at a constant temperature of 110°F, approximately 95% of the heat input from the pump, which amounts to 605,000 Btu/hr, must be removed. Only about 16,000 Btu/hr of this heat are dissipated through the uninsulated walls of the piping, so about 589,000 Btu/hr must be removed by the heat-exchanger loop around the pump. With a reactor-coolant flow of about 200 gpm through the shell side of the heat exchanger, for example, the coolant temperature must be lowered approximately 6°F (from 110 to 104°F). This amount of temperature reduction would require a raw-water flow of 30-40 gpm through the four-pass tube side of the heat exchanger, and the temperature rise of the water would be 35-40°F. The heated raw water is discharged out through the building sump and a 4-in. drain to the waste drainage ditch.

2.3 Instruments, Controls, Alarms, and Protective Devices

2.3.1 General Description

Figures 5 and 6, respectively, are a schematic diagram of the RHTF instrumentation and a photograph of the instrumentation console. The instrumentation system is designed to monitor flow, temperature, and pressure at selected locations in the loop and model vessel. The loop piping contains pressure, differential-pressure (for flow), and temperature indicators. Static-pressure probes are at selected locations in the reactor vessel, and differential-pressure taps are across the orifices in individual instrumented sub-assemblies in the vessel. The loop contains one thermocouple, which is located in the outlet line of the reactor vessel, and a high-temperature pump-motor cutout switch near the pump discharge. The system is provided with a mechanical pressure scanner, pressure transducers, an electronic scanner and

Fig. 5. Schematic Diagram of the RHTF Instrumentation System

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Fig. 6. Photograph of RHTF Instrumentation Console

data processing system (DPS), and a data-communication system interconnecting the RHTF with the EBR-II Data Acquisition System (DAS) for analysis, storage, and retrieval of the data.

Pressure-signal (Poly-Flo) tubing from the reactor-vessel wall is connected to the automatic, mechanical pressure scanner. Selected pressures are then multiplexed by the scanner to pressure transducers, a signal conditioner, the electronic scanner, and then to a digital-to-analog (D/A) converter. The measurements are displayed in engineering units (psia, psid, and °F) on a digital voltmeter. The signal from the thermocouple at the vessel outlet is processed and indicated separately by a digital temperature indicator and then routed to the electronic scanner. A permanent record of all measurements may be obtained from a digital printer. The RHTF operators also have the option of transmitting all data over the cable to the DAS for recording and analysis and of recalling and displaying the raw or processed data from the DAS.

The pressure scanner, the DPS, and the data-communications system are adequately interfaced for operation as a single system. The vessel outlet temperature, the flow rates taken from the flow orifices in the four branch lines (two high-pressure-plenum inlet lines and two low-pressure-plenum inlet lines), and selected pressures and flow rates from the vessel will be automatically processed and recorded by the DAS.

The instrumentation system also provides for manual stepping of the pressure and electronic scanners to monitor the temperature, pressure, and flow measurements. These data may be logged manually from the digital voltmeter, recorded by the local printer, and/or transmitted to the DAS as desired.

Data for system flow rates, temperatures, and gauge pressures in the piping loop may be acquired by periodic manual logging of data from local indicators during an experiment. Provision is also included for entering manually logged data, such as experiment identification, date, and time, into the instrumentation system.

In about two minutes, the system can operate through a complete scan and record one measurement each of 50 differential pressures (for flow rates), 25 absolute pressures, and one temperature. Since the pressures in the RHTF fluctuate slightly during operation, several measurements of each pressure are made and averaged for greater accuracy. At the discretion of the

experimenter, one to 15 measurements may be made and recorded for each pressure. Approximately three minutes are required for a complete scan of all points with 15 measurements each, if recorded by the printer, and slightly less time is required if data are transmitted to the DAS only. Overall system accuracy is expected to be better than 1% of full scale for an individual transducer.

2.3.2 Detailed Description

2.3.2.1 Loop Flow Measurements. System flow rates are measured with orifices and Barton Model 227 local differential-pressure gauges. Orifice flanges are in each of the two 6-in. lines to the high-pressure plenum and in each of the two 3-in. lines to the low-pressure plenum of the reactor vessel. Accuracy is estimated to be $\pm 2\%$ of indication from one-half to full flow. In addition to local readout, the differential pressures may be read out on the digital voltmeter, recorded by the printer, and/or transmitted to the DAS.

2.3.2.2 Loop Temperature Measurement. Temperature in the loop is measured with Marsh Instrument Company bimetal thermometers with dial indicators. These thermometers have a range of 40-240°F and an accuracy of $\pm 1\%$ of full scale. They are located at the pump discharge, the two inlets to the high-pressure plenum of the reactor, the reactor outlet, and the heat-exchanger outlet.

The high-temperature pump-motor cutout switch, located near the pump outlet and interlocked with the pump motor, is set at approximately 150°F and is provided as backup protection. The one thermocouple, in the vessel outlet line, is connected to the instrumentation system for readout on the digital voltmeter, recording by the printer, and/or transmission to the DAS.

2.3.2.3 Loop Pressure Measurement. Gauges for measuring local loop pressures are at the following locations:

<u>Location</u>	<u>Range, psig</u>
Pump discharge	0-160
Filter inlet	0-100
Filter outlet	0-100
High-pressure-plenum inlet, south	0-100
Low-pressure-plenum inlet, south	0-100

<u>Location</u>	<u>Range, psig</u>
Reactor-vessel outlet	0-100
High-pressure-plenum inlet, north	0-100
Low-pressure-plenum inlet, north	0-100

These gauges, made by Ashcroft, have a dial size of 4-1/2 in. and are accurate to approximately 2% of full range.

2.3.2.4 Vessel Pressure and Flow Measurement. The measurements within the model reactor vessel are used to determine the pressure and flow in selected subassemblies and the absolute pressures at various locations within the vessel. Two pressure-tubing connections are required for each differential-pressure measurement. The locations of the pressure taps within the model will vary with the requirements for a given experiment.

The pressure signals will be routed through copper tubing within the vessel and Poly-Flo tubing outside the vessel. The plastic tubing, which will carry the signals to the pressure scanner, is in cable trays.

2.3.2.5 Pressure Scanner. The mechanical-electronic pressure scanner uses a valve-and-manifold switching method, with the valves grouped according to the sequence required and operated by arms driven by air-cylinder actuators. The scanner has five poles with 25 positions each, obtained by three stages of multiplexing, to sequentially switch 125 pressures in such a manner as to provide 25 inputs to each of two differential-pressure transducers and one absolute-pressure transducer. The pressure-signal tubing coming from the reactor vessel can be connected, through quick-disconnect couplings, to the scanner input connectors in any desired sequence. This provides flexibility of selected pressures and sequences for each test.

The pressure scanner is mechanically capable of scanning at a faster rate than will be used. The usable scan rate is limited by certain design features, such as the speed of the printer in the DPS and the settling time, which is the time required for the fluid volume traveling in the connecting lines from the scanner to and into the transducer to reach or approach a steady-state condition. Scan speed can be increased, but at a sacrifice in accuracy, by permitting the traveling volume to approach but not completely reach the steady-state condition. Venting also increases the overall scanning time required.

The factors discussed in the preceding paragraph are all inter-related and require optimization for the particular application. Venting, full settling time, and relatively large and accurate transducers are used for greater accuracy. These factors are expected to provide an overall system accuracy of better than 1% of full scale for an individual transducer.

2.3.2.6 Pressure Transducers. The instrumentation system uses three pressure transducers, one for each of the ranges 0-10 psid (differential), 0-50 psid, and 0-100 psia. If necessary, any pressure transducer can be replaced with one of a different range. The transducers are of the strain-gauge type and have the following minimum accuracies as quoted by the manufacturer:

<u>Range</u>	<u>Characteristic</u>	<u>Accuracy</u>
0-10 psid	Linearity and hysteresis	0.75%
0-50 psid	Linearity and hysteresis	0.4%
0-100 psia	Linearity and hysteresis	0.4%
All	Repeatability	0.1%
All	Temperature sensitivity	0.01%/°F
All	Zero change	0.01%/°F

2.3.2.7 Data Processing System. The DPS provides for manual or automatic scanning and processing of pressure data. It includes: conventional controls and indicators; all coupling and interface units required for use with the pressure transducers, the mechanical pressure scanner, and the data-communications system; all necessary power supplies; and signal-conditioning equipment for converting measured values to engineering units (psid, psia, and °F) for local readout. A manual data entry is provided to permit the inclusion of identification and other manual inputs as desired. Digital-voltmeter readout is displayed on the front of the panel, a digital printer with paper-tape output is provided, and means for interfacing with the DAS are included.

The basic operating speed of the DPS is 20 channels per second. The system provides for a time delay after each switching action of the pressure scanner--to allow for pressure-settling time--and then electronically scans the outputs of the transducers. The system then steps the pressure

scanner to the next point for each transducer simultaneously. This sequence of alternating mechanical and electrical stepping takes advantage of the faster scanning rate of an electronic device relative to that of a mechanical device.

The basic DPS, including the power supplies for the pressure transducers and signal conditioning, has an accuracy better than 0.1% of full scale $\pm$ one digit.

2.3.2.8 Data-communications System. The communications system between the RHTF and the DAS includes: an input/output board for the DAS Sigma-5 computer; a transmission cable linking the two facilities, which are physically separated by a distance of several hundred yards; and a terminal that includes a cathode-ray-tube type of display operating in conjunction with a teletype keyboard in the RHTF. The terminal provides the RHTF operators with a display of raw pressure and temperature data being taken. After being computed by the DAS, either the water flow rate or the equivalent sodium flow rate can be displayed. The keyboard permits the operators to communicate directly with the Sigma-5 computer for calling up programs, taking data, performing calculations, and recording data on a magnetic tape.

3.0 EXPERIMENTAL PROGRAM

3.1 Hydraulic Modeling of Reactor Subassemblies

The premise on which flow modeling is based is the theory of similitude. Similitude means that all physical quantities which govern a certain phenomenon in an actual subassembly have the same relative influence in the model. The requirements for flow similitude are satisfied if the model and the actual subassembly are geometrically, kinematically, and dynamically similar. Exact or ideal modeling in a complex system is usually impractical, if not impossible. It is not the purpose of the RHTF model subassembly to simulate the actual subassembly in every respect, but to provide an adequate description of the behavior of the actual subassembly and to yield data related quantitatively to the actual reactor system within a reasonable degree of accuracy. This is the underlying philosophy involved in the EBR-II core mockup.

The geometric scale of the model reactor was set at 0.6 of full scale in the past, and all major components of the model were made accordingly. Simulation of the fuel elements by suitable orifice plates was chosen in the past to simplify construction of the subassemblies and reduce cost. The same scheme was used in the present RHTF experimental work.

Theoretical considerations of flow modeling are discussed in Chapter 3 of Ref. 1, and the procedure for selecting the orifice sizes is described on page 32 of that reference. Orifice diameters were originally selected so that the model and actual EBR-II subassemblies operated at the same value of Euler number and the same overall pressure drop.³ The RHTF test plan required only initial calibration measurements to ensure that this condition still held.

3.2 Plan for Utilization of the RHTF*

3.2.1 General Procedure

The first series of experiments planned for the RHTF can be divided into the following four phases of experimental work:

Phase I. Initial experiments using the "nominal" core loading of Ref. 4 (the first EBR-II core), and comparing the results with those of the Franklin Institute study.¹

Phase II. Studies of flow distribution in a simulated, typical EBR-II loading with depleted-uranium blanket for extended operation at 62.5 MWt. The throttle valves will be set to obtain the current ratio of high-pressure to low-pressure flow in EBR-II.

Phase III. Repetition of the experiments in Phase II for a loading with four rows of stainless steel reflector subassemblies, instead of the depleted-uranium blanket, in rows 7-10.

Phase IV. Repetition of the experiments for the core loading of Phase III, but with a few different values of core-to-blanket flow ratio simulating different throttle-valve positions.

* Because of a change in priorities and a need to obtain flow-distribution data with a stainless steel reflector, Phase-III and Phase-IV experiments were done after the Phase-I experiments. The work of those three phases was completed while this report was in the final stages of preparation.

Only the principal objective of determining the flow distribution within the core and blanket regions for balanced operation with two pumps will be covered in all the phases of experimental work. For each of the loadings under study, data will be gathered to determine the flow rates through a representative set of the core and blanket subassemblies. These data will be analyzed, as outlined in Section 3.3, below, by suitable analytical and numerical techniques, including the EBRFLOW program.²

Before being loaded into the model reactor vessel, the model subassemblies equipped with orifice taps were calibrated in the subassembly-calibration loop at EBR-II to obtain the necessary data relating the flow rates and the overall pressure drops across the subassemblies as well as the pressure drops across their internal orifices. New stainless steel orifices were installed in all the driver, inner-blanket, and outer-blanket model subassemblies initially used in the Franklin Institute studies. New orifice sizes are being developed only for the various experimental subassemblies, the row-6 driver subassemblies, and the proposed stainless steel reflector subassemblies.

Future experiments may be made with total flow rates ranging from about 2000 to 3000 gpm. The temperature and flow rate of the loop water will be maintained constant during each of these tests. For each experimental run, the total coolant flow rate and the coolant temperature will be stabilized. A series of scans will then be made of the pressure drop across the subassembly orifices and the static pressures in different selected locations within the model reactor. Frequent manual checks will be made of the flow rates in the main branches and of the various loop temperatures. All branch flow rates and the water temperature at the reactor outlet will also be transmitted to and recorded by the DAS.

Details of the different phases of the experimental program are outlined in subsequent sections of this report.

3.2.2 Calibration of Model Subassemblies

Before the subassemblies are loaded into the model vessel, all those that are instrumented (those to be connected to external tubing lines and to the RHTF instrumentation system) are calibrated in the subassembly calibration loop. These calibrations provide data which allow calculation of

the flow distribution to the various subassemblies in the model reactor and also establish the operating conditions for reproducible, single-phase flow measurement. Pressure taps on any unused instrumented subassemblies are capped off when they are installed in the RHTF, so those subassemblies do not require calibration.

The EBR-II subassembly calibration loop, which uses water flow, is in the pump-pit wing of the power plant (building No. 768) and is set up to flow-test full-sized standard and experimental reactor subassemblies as well as model reactor subassemblies used in the RHTF. The loop tests only one subassembly at a time. The subassembly is supported in a grid plate similar to that in the actual reactor vessel, and suitable upper and lower grid-plate adapters are used to simulate any desired reactor location. When the 0.6-scale model subassemblies are tested, special grid adapters are used. Internal pressure leads from the orifice taps in the subassembly are brought out through the top flange of the test loop.

A flow-vs-pressure-drop calibration is made for subassemblies tested in the loop. Pressure drop is measured across the orifice as well as across the entire subassembly. To prevent flashing or cavitation in the orifice restrictions, an outlet pressure of 30 to 40 psi is maintained in the loop. Table III shows the calibrations made on instrumented model subassemblies for the Phase-I loading of the RHTF. Additional calibrations of model subassemblies are required to determine orifice configurations for simulating experimental, stainless-steel-reflector, and row-6 driver subassemblies for Phases II, III, and IV of the experimental program.

TABLE III. Calibrations of Instrumented Model Subassemblies for Phase-I Loading

<u>Type of Subassembly</u>	<u>Row No.</u>	<u>Number of Subassemblies</u>	
Core	1-5	6	} These S/As calibrated specifically for the rows indicated
	1 and 2	3	
	1-3	4	
	1, 2, and 4	5	
	1, 2, and 5	5	
Inner Blanket	6	3	
	7	3	
Outer Blanket	8 and 9	4	
Control Rods	5	2	
Safety Rods	3	1	

Flow and pressure in the calibration loop are measured with a turbine-type flowmeter with the required flow range and a Barton differential-pressure gauge with a range of 0-100 psig. Table IV lists the calculated maximum variations in the operating range.

TABLE IV. Maximum Variation in Calibrations Made
in EBR-II Subassembly Calibration Loop

Subassembly Type	Row No.	Maximum Calibration Variation ($\pm$) in Operating Range, %	
		Overall	Orifice Only
Core	1 and 2	1.2	1.3
	3	1.3	1.7
	4	1.6	2.3
	5	1.9	3.3
	6	3.1	3.1
Inner Blanket	7	1.0	3.1
Outer Blanket	8 and 9	5.6	6.2
Control Rods	5	2.9	3.3
Safety Rods	3	1.9	4.2

3.2.3 Phase-I Experimental Work⁵

This initial phase consisted of experimental runs with a mockup of the "nominal" core described in Ref. 4. This core loading was very nearly simulated in the Franklin Institute tests, so data from this phase can be compared directly with the Franklin Institute data. Table V shows the loading for the "nominal" core for Phase I. Upon completion of the subassembly calibrations, the model reactor was loaded in accordance with that loading. The loop was thoroughly cleaned with a suitable detergent, flushed with clean water, and filled with demineralized water to which a chromate rust inhibitor had been added. During Phase-I experiments, the branch valves in the loop were adjusted to give the same flow split between core and blanket regions as shown in Table XII of Ref. 4. This simulated the current throttle-valve position for the reactor.

TABLE V. Loading of "Nominal" Core for Phase-I Experiments

Row No.	Numbers of Subassemblies				
	Driver	Safety	Control	Inner-blanket	Outer-blanket
1	1	0	0	0	0
2	6	0	0	0	0
3	10	2	0	0	0
4	18	0	0	0	0
5	12	0	12	0	0
6 ^a	6	0	0	24	0
7	0	0	0	36	0
8-16	0	0	0	0	510
Totals	53	2	12	60	510

Total subassemblies of all types = 637

^aIn the Franklin Institute studies, all 30 row-6 positions were loaded with inner-blanket subassemblies.

3.2.4 Phase-II Experimental Work

Reference 6 gives a typical EBR-II core loading for extended operation at 62.5 MWt. This loading will be used for Phase-II experimental work. It consists of the following 127 subassemblies in the first seven rows of the reactor: 49 drivers; 9 partial (half-worth) drivers; 23 depleted-uranium blanket subassemblies; 11 regular control rods; 1 stainless steel control rod; 2 safety subassemblies; and 32 experimental subassemblies. In addition, the 510 outer-blanket subassemblies in rows 8-16 will be simulated.

The 32 experimental subassemblies include oxide-fuel and structural experiments, along with other irradiation subassemblies containing boron carbide, tantalum, magnetic materials, etc. The experimental subassemblies are of different types (Mark B7, A19, B37, F37, H37, and B61A) and have different flow rates depending on the irradiation samples contained in them and the reactor position in which they are designed to be installed. It will be necessary to use the existing calibration data for each of the experimental subassemblies being simulated and select appropriate orifice

diameters to represent each of them in the model reactor. This will involve individual calibration of each of the model experimental subassemblies in the water calibration loop before it is loaded into the model reactor. After the simulated loading is established, the experimental work will be identical to that of Phase I, except that the branch valves adjusted during Phase I will be left undisturbed (or restored to the same position) and the flow partition will be dictated by the relative flow resistances of the core and blanket regions.

3.2.5 Phase-III Experimental Work

The reactor core loading simulated for this phase of testing was very similar to the run-56 loading in EBR-II. The stainless steel reflector subassemblies in rows 7-10 of the actual loading were represented in the RHTF loading by model subassemblies with orifices that simulated the hydraulic characteristics of the actual reflector subassemblies. Experimental subassemblies in the actual loading were also properly simulated in the RHTF loading by installing newly designed orifices in the model subassemblies. After the new orifices were installed, the model subassemblies were flow-tested and calibrated in an external single-subassembly water loop before they were loaded in the reactor model. Experiments were then conducted as in Phase I, again with no change in position of the branch valves.

3.2.6 Phase-IV Experimental Work

The preliminary design of the stainless steel reflector was made on the assumption that the throttle valves in the reactor will be left undisturbed in their previous settings. Recent EBR-II operation with the radial steel reflector has shown no undesirable effects arising from this choice. However, for the sake of operational flexibility, it is conceivable that future EBR-II operation could involve changes in the throttle-valve positions from their present settings. The Phase-IV experimental work was conducted to gather the necessary test data in support of this possible future need.

The core loading used in this phase of experimentation was the same as in the Phase-III work. Experiments were conducted at a fixed total flow rate from the pump, but with different ratios of core-to-blanket flow rates. These ratios were changed by opening up or throttling the valves in the branch lines that feed the core and outer-blanket regions of the model reactor.

3.2.7 Subsequent Studies

Experimental work beyond Phase IV will consist of routine experiments in support of reactor operations and possibly new areas of testing that could effectively make use of the RHTF capabilities.

The level of experimental activity to determine the reactor flow distribution for subsequent core loadings will depend to a certain extent on the adequacy of the results from Phases I-IV for this purpose. It will also be affected by the changes in EBR-II core loadings from one run to the next. If analysis of the data from Phases I-IV results in reliable correlations of these data, the amount of subsequent experimentation will be minimal and will be determined primarily by core loading changes. Whenever appreciable changes are made in the EBR-II core loading, it will be necessary to simulate the new loading in the RHTF so that the analytical prediction techniques can be rechecked with the new data.

As experience is gained with the RHTF, new areas of hydraulic research pertinent to EBR-II operation and of specific interest to the LMFBR program can be explored. One such field of experimental work is discussed below.

Studies of two-phase, two-component flows indicate that the axial pressure gradient in an all-liquid flow channel will be increased by the introduction of a small volume fraction of noncondensable gas. This means that if a liquid-flow channel is operated with a constant pressure drop from entrance to exit, the introduction of gas lowers the liquid flow rate in such a way that the new two-phase pressure drop equals the previous all-liquid pressure drop. The same should be expected in a reactor subassembly, working between plenums of essentially constant pressure, if fission gas is released into the sodium flow. At a slow or moderate leakage rate, the time required to release the fission gas could be of the order of several

minutes, and the thermal performance of the subassembly during this time can be evaluated only if there is a knowledge of the associated decrease in coolant flow rate.

An essential requirement for experimentally simulating the above condition is the availability of two points in a flow system between which the pressure drop will remain constant irrespective of the rate at which a small amount of liquid is drawn through a branch loop between these points. With a large flow through the model reactor, the pressure drop across it will remain essentially constant even if a comparatively smaller flow through the external parallel loop varies with gas injection into that leg. The availability of this constant- ΔP source at the RHTF makes it a unique location where such single-subassembly experiments can be performed in the future.

3.3 Analysis of Data

Since each type of subassembly in the model reactor has an independent external calibration of orifice pressure drop vs flow rate, the flow rate through each subassembly with orifice taps in the combined loading can be directly obtained from a measurement of its in situ orifice pressure drop. This flow rate can be further checked, in selected cases, by comparing it with the value predicted from the overall pressure drop across the subassembly measured from the static-pressure taps in the model vessel. The flow rates thus obtained can be used to compute a normalized flow-distribution mapping for the reactor and to determine a value for effective pressure drop fraction for each reactor position. These values will then serve as the two-dimensional counterpart of the row-wise (one-dimensional) effective pressure drop fractions reported on page 203 of Ref. 4. The values, in turn, can be used in the EBRFLOW program to extend the prediction scheme to different total flow rates and to other core loadings hydraulically similar to the test configuration.

4.0 PRINCIPLES OF OPERATION

4.1 General

The RHTF is a relatively simple, easy-to-operate, low-pressure and low-temperature water loop. Loop operation is supervised by an EBR-II staff

engineer. Except for those periods when core loading changes are being made and when experimental runs are in progress and data must be collected and analyzed, loop operation and maintenance are performed by one permanently assigned technician. The initial loading of the core and all subsequent changes of core loadings require the services of one or two additional technicians.

4.2 Core Loading Changes

Before any changes in the reactor are made, a loading diagram including a sequence of subassembly installation is prepared by the RHTF staff engineer. Core positions in the RHTF are numbered identically to positions in the EBR-II. Core-loading operations require that one technician be inside the model reactor vessel to place subassemblies and run pressure tubing while another man on the work platform passes subassemblies, tubing, and tools, as required, into the vessel. Figure 7 shows the inside of the model reactor vessel partially loaded with subassemblies. Because of complications arising from placing the instrumented model subassemblies, installing holddown bars on subassemblies connected to the high-pressure plenum, and routing pressure-tubing lines between model subassemblies, the sequence of loading is very critical. Generally, loading commences in the southwest part of the core, opposite the pressure-tubing-outlet bulkhead fittings in the vessel wall. After installation of each successive row of subassemblies and a holddown bar, 3/16-in. annealed copper tubing is connected to the instrumented subassemblies and run along the row of subassemblies to the vessel wall and then around the wall to a selected bulkhead fitting. The bulkhead fittings have male connectors compatible with copper tubing on the inside and male connectors for use with the Poly-Flo tubing on the outside. Each bulkhead fitting has an assigned number, which is recorded in conjunction with a specific core location for a given loading.

Different colors of the Poly-Flo tubing may be used to designate different row locations in the reactor. The tubing is placed in cable trays that lead around the vessel and terminate at the instrument panel located just southwest of the model reactor vessel (see Fig. 6). Each line of tubing is equipped with the male end of a quick-disconnect coupling that mates with a female end on the instrument panel. These fittings are also identified by

Fig. 7. Interior of Model Reactor Vessel Partially Loaded with Subassemblies

number. There may be as many as 300 signals coming through the tubing from the model vessel during an experiment, but only 125 connections are available on the instrument panel. Therefore, some quick-disconnect couplings will be switched during an experimental run, so as to monitor and record all signals from the facility.

Before loading changes are made when the facility is full of chromated water, approximately 500-600 gal of water will be pumped from the model vessel to the makeup-and-storage tank. This will lower the water level below the upper grid plate and allow access into the model vessel. Removal of 44 1-in. nuts and use of the building crane are required to remove the vessel head. Air vent valves on the model vessel and at the high points of the piping system must be open when water is being drained from the facility.

4.3 Facility Startup

After the core is loaded in accordance with the loading diagram for a particular experiment, the vessel head is bolted in place. The facility should be completely filled with chromated water to the middle of the gauge glass in the overhead expansion-head tank. This may be done by adding water and chromate to the makeup-and-storage tank and pumping from there into the main loop. As the loop and model vessel are filled with water, all high-point vent valves should be opened to ensure that all air is vented from the system. A 50-psi hydrostatic test should be applied to the system following any loading change.

The remaining steps for starting up the facility are as follows:

- (1) Check to see that the air compressor is operating and maintaining a pressure of about 100 psi in the air receiver. Observe that the pressure-reducing valve in the air supply line to the pressure scanner is adjusted to supply air at about 70 psi. Establish air pressure to the expansion-head tank as directed by the Facility Manager.

- (2) Verify that all building circuit breakers in the building north wall are "on," including the coolant-pump-motor disconnect switch.

- (3) Check that all pressure-signal plastic tubing lines are free of air and connected to the pressure scanner as required for the experiment to be run.

(4) See that power is supplied to the facility instrumentation console. Check all instrumentation components and make startup adjustments as specified in the B and F Instruments Operating Manual. Similarly, check out the printer, the temperature indicators, and the data-communications system as specified in the instruction booklet for these items. Before transmitting data to the EBR-II DAS, alert DAS personnel so that they can make all necessary arrangements.

(5) Close the 8-in. main throttle valve of the loop and open the two 6-in. and two 3-in. valves in the main high- and low-pressure coolant branch lines.

(6) Press the start button on the starter of the coolant-pump motor.

(7) Slowly open the main (8-in.) throttle valve and start water flowing to the model reactor vessel.

(8) Adjust the main (8-in.) throttle valve, the two 6-in. high-pressure branch valves, and the two 3-in. low-pressure branch valves to achieve the main-loop and branch flow rates required for the particular experiment.

4.4 Routine Operation

When starting up the system, the loop water temperature will normally be about 70°F. Pump heat input will cause a rise in loop temperature of approximately 1°F per minute, so the operating temperature of 110°F will be reached in less than one hour. After operating temperature has been reached, but before taking any experimental data, adjust loop flow to the shell side of the heat exchanger and raw-water coolant to the tube side of the heat exchanger to maintain a constant loop-water temperature of 110°F. Adjust all other loop flow-control valves to reestablish the required flow rates. Set up the front-panel controls on the instrumentation console for operation as required for the particular experiment. Operate the keyboard of the display terminal for programs in the DAS as required, in accordance with instructions supplied by DAS personnel.

Other items to be checked periodically during routine, at-temperature operation are:

(1) Maintain the operating log book, making required periodic notations of system pressures, temperatures, and flow rates.

(2) Check the differential pressure across the main coolant filter. This should be compared with the pressure drop across the filter, for the given flow conditions, noted in the past.

(3) Check water level in the overhead expansion-head tank. A slight rise will be noted as loop temperature increases to 110°F, but then the level should remain constant.

(4) Check the coolant pump and its motor bearings for signs of overheating or vibration.

(5) Check the facility for leaks, and make note of any for future maintenance.

(6) Check the air system, and drain accumulated water from system low points each day.

4.5 Loop Shutdown or Layup

The loop may be shut down essentially by reversing the steps outlined in the facility startup instructions (Section 4.3, above). The coolant pump is shut off at the motor starter. If the pump is to remain shut down for any period of time, the pump-motor disconnect switch should also be turned off. The raw-water-coolant supply valve to the heat exchanger and the main 8-in. throttle valve should be shut off. All other flow-control valves may be left as is or shut off, as desired by the Facility Manager.

The instrument console should be secured in accordance with the manufacturer's instructions. The air system and compressor should be shut down. Circuit breakers for all electrical systems except those for required utilities, building lighting, heating, etc. should be turned off.

If core loading changes are anticipated, water should be pumped from the model vessel to the makeup-and-storage tank. If water must be drained from the loop to the waste drainage system, it must be passed through the portable demineralizer to remove all chromate rust inhibitor.

If the loop is to be layed up for a prolonged period of time, a "wet" layup procedure will be used. The system will be left completely full of water containing the normal concentration of chromate rust inhibitor.

5.0 SAFETY AND HAZARDS ANALYSIS

5.1 General

Because of the relatively low pressures and temperatures associated with the RHTF, it is regarded as a safe facility to operate. Anticipated hazards are mostly of the "industrial" variety, such as dropped loads, personnel falls, small-tool accidents, small fires, electrical accidents, etc. Hazards of this type will be minimized during operation of the RHTF by adhering to the Atomic Energy Commission Standard Health and Safety Requirements Manual (Report No. IDO-12028).

Heavy loads may be handled in the building by the existing 3-ton crane. The large freight door provides access for delivery of heavy objects below the building crane. Care will be taken to ensure that the capacity of the crane is not exceeded and that only wire slings of adequate rating are used for a given lifting job.

Additional manpower will be used for all loading changes or major modifications of the facility. Whenever a technician is at work in the model reactor vessel, a helper must be present on the work platform to provide the necessary tools, handle subassemblies and components, and assist in the event of accidents or emergency. The building is interconnected with the EBR-II site paging and alarm system as well as telephone service to ensure adequate communications during emergencies.

5.2 Radiation and Fires

There are no radiation hazards connected with the RHTF. None of the materials or components used in construction (except for a few surplus items from the BORAX V facility) were ever exposed to radiation or contamination. Before they were installed in the RHTF, the few surplus items from BORAX V were thoroughly checked and proved to be free of radiation or contamination.

Only nonradioactive demineralized and raw water will be used for the main loop and the heat exchanger, respectively. Only nonradioactive model subassemblies and components will be used in the model reactor vessel.

There are no unusual fire hazards in the facility. The building and main loop are constructed of metal. The wooden work platform for the model

vessel is coated with fire-retardant paint. No excessive amounts of combustible materials will be allowed in the building. The building is heated by a standard oil-fired furnace supplied from a buried storage tank outside the building. The principal fire hazards are the building electrical and instrumentation equipment. This equipment will be deenergized when personnel are not in attendance.

Fire-fighting equipment includes an available 1-in. water hose for general fires (connected to the 2-in. water supply in the northeast corner of the building) and two wall-mounted portable CO₂ fire extinguishers for electrical and flammable-liquid fires. Fires may be reported by phone or by a manual-pull fire-alarm station on the building wall immediately outside the west personnel entrance. The alarm station sends a coded signal to the continuously manned EBR-II fire station several hundred yards away.

5.3 Air and Water Pollution

The RHTF complies with the standards given in Executive Order 11282 (Air Pollution) and Executive Order 11288 (Water Pollution). The facility will neither generate nor discharge effluents capable of causing air or water pollution.

Loop water, containing about 4000 ppm of added chromate rust inhibitor, will be pumped into and stored in the makeup-and-storage tank when minor repairs or core loading changes are being made. If loop water is to be dumped to the drain and discharged to the EBR-II waste-water drainage system, a portable demineralizer will be used to remove all chromate from the water before it leaves the building.

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