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THORS — A HIGH-TEMPERATURE SODIUM TEST FACILITY RATED AT 2.0 MW

P. A. Gnadt, A. H. Anderson, N. E. Clapp, and B. H. Montgomery
Oak Ridge National Laboratory

and

C. W. Collins and R. D. Stulting
Union Carbide Corporation Nuclear Division
Oak Ridge, Tennessee 37830, U.S.A.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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ABSTRACT

The Thermal-Hydraulic Out-of-Reactor Safety (THORS) facility at Oak Ridge National Laboratory (ORNL) is a high-temperature sodium test facility operated for the United States Breeder Reactor Safety Program. The facility is primarily used for testing large simulated Liquid-Metal Fast Breeder Reactor (LMFBR) fuel subassemblies. The facility has recently been upgraded to provide a 2.0-MW test bundle power input and heat removal capability. A new test section, which will be capable of operating at 980°C and which will accommodate a 217-pin bundle, has also been added. A 61-pin bundle is currently under test in the facility. A description of the test facility is presented, along with a brief summary of the 8-year operating history of this safety-related test facility.

INTRODUCTION

The breeder reactor programs in the United States and abroad have generated a strong need for improved understanding of core thermal-hydraulic phenomena in sodium-cooled reactors and for detailed investigations of safety-related occurrences in the core. The requirements for information on local flow and temperature patterns in unperturbed fuel subassemblies have been identified by the Fast Test Reactor core designers. The evaluation of the damage potential of flow coastdowns, partial inlet blockages, heated zone blockages, and blockages arising from fuel failure because of loss of flow is necessary for assurance of Liquid-Metal Fast Breeder Reactor (LMFBR) safety. It is also important that the reactor designers have experimental data to validate and develop practical analytical models by which data obtained from (relatively) small experiments can be applied to a full-size reactor.

A large-scale sodium flow facility, originally called the Fuel Failure Mockup Facility [1], was built in 1970 for testing 19-pin, simulated LMFBR fuel subassemblies. In 1976, the name of the facility was changed to the Thermal-Hydraulic Out-of-Reactor Safety (THORS) Facility.

FACILITY DESCRIPTION

The THORS Facility is a large, high-temperature sodium system in which test assemblies designed specifically to simulate LMFBR core segments are subjected to thermal and hydraulic testing at normal and off-normal Fast Test Reactor operating conditions. The test assemblies are composed of bundles of electrically heated pins having the same axial power density and external configuration as the LMFBR fuel pins; the reactor fuel is thus simulated by special purpose cartridge electric heaters [fuel pin simulators (FPSs)].

The test facility shown in Fig. 1 includes a 40-liter per sec centrifugal pump, a 40-liter per sec electromagnetic (EM) pump, two test section housings into which the test bundles are inserted, a 2.0-MW test bundle power supply, a 2.0-MW heat dump system, a 0.5-MW heat dump system that can be used for lower power testing, an expansion tank at the test section outlet to simulate the free liquid surface of the reactor, a sodium purification system, a bypass line in parallel with the larger test section housing to simulate the flow passages among the many other reactor fuel elements, and instrumentation needed to monitor the facility parameters. An isometric view of the THORS facility is shown in Fig. 2, and Table I presents the principal capabilities of the facility.

The new test section housing is fabricated from Hastelloy X material and is rated for operation at 980°C and 690 kPa. It is long enough to accommodate simulated full-length Clinch River Breeder Reactor (CRBR) fuel pins and large enough in diameter to accommodate a 217-pin bundle. The original 19-pin test section housing is still installed and can be operated in parallel with the new one. Figure 3 is a photograph of the new housing and a 61-pin test bundle, which is ready for installation. Figure 4 shows the bundle and housing installed in the facility; the 2.0-MW heat exchanger

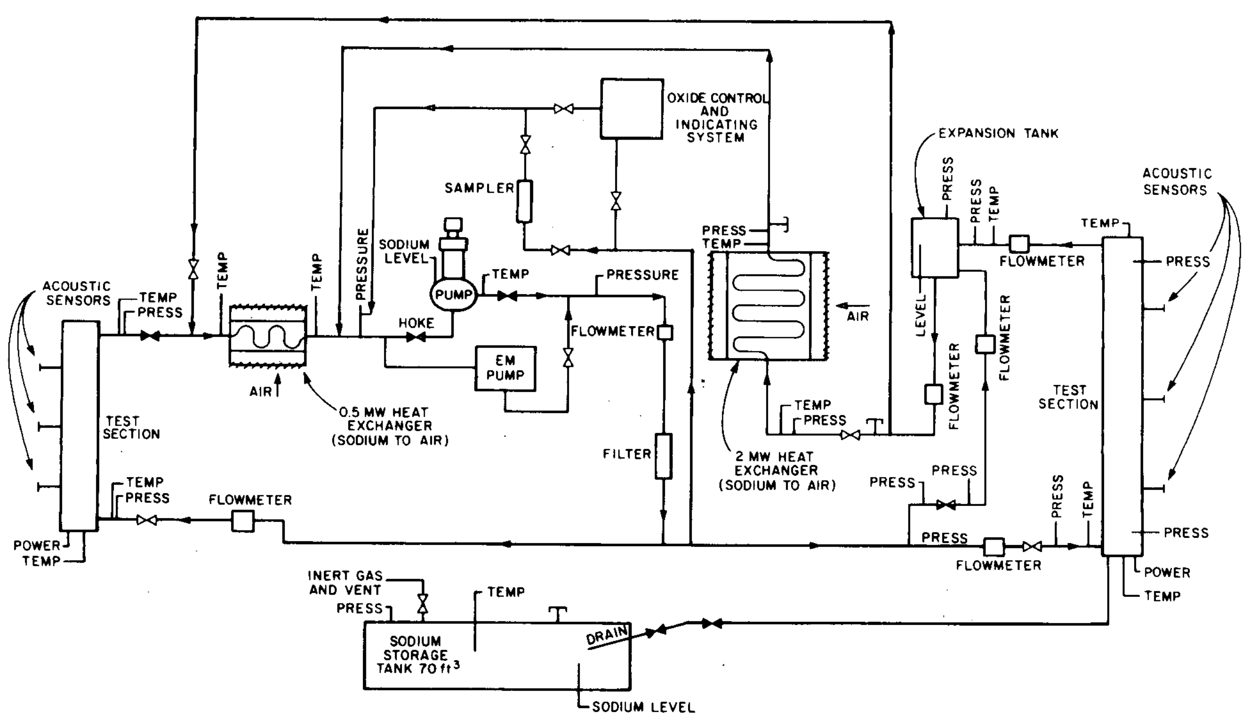


Fig. 1. THORS facility flow diagram.

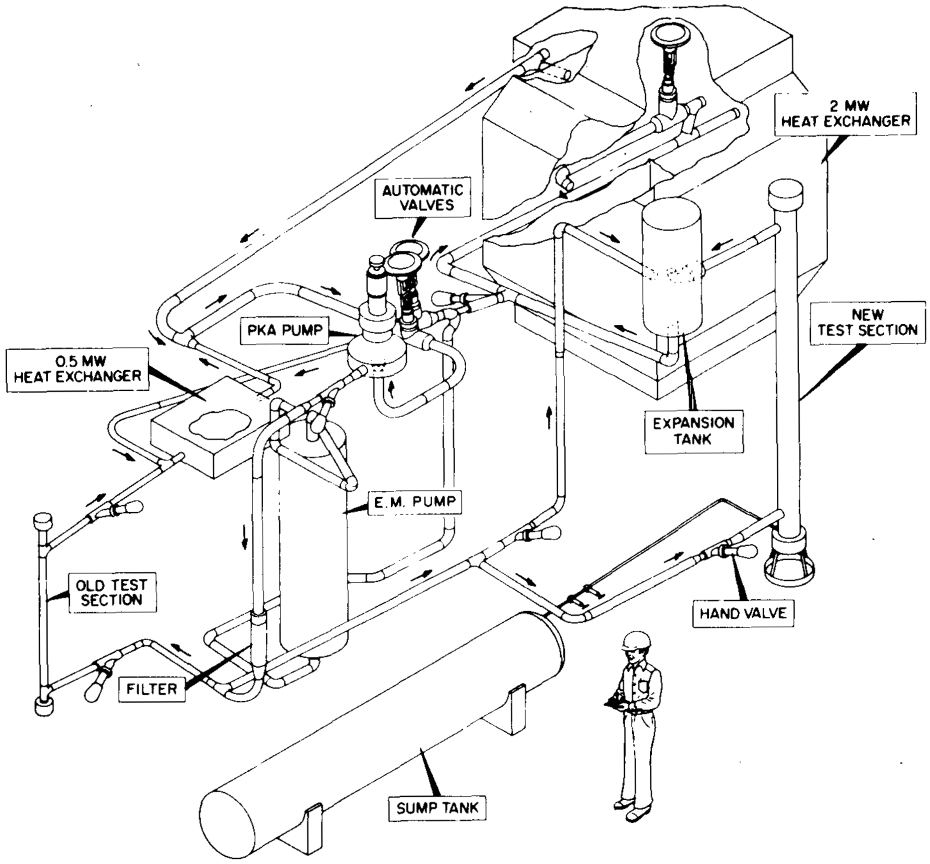


Fig. 2. THORS facility isometric drawing.

TABLE I

Principal Design Characteristics of the THORS Facility

Test Section Housing Design Pressure	690 kPa
Test Section Housing Design Temperature	980°C
Test Section Housing Operating Temperature	300–980°C for 1000 hr
Test Section FPS Power	2000 kW
Heat Removal Capability	2500 kW @ 540°C
Facility Piping System Design Pressure	690 kPa
Facility Piping System Design Temperature	700°C

is also shown. In the 2-MW sodium-to-air heat exchanger, sodium at temperatures of up to 700°C flows in parallel through forty 22-mm serpentine stainless steel tubes.

The FPSs are connected to a variable voltage power supply with a voltage range from 40 to 400 V and a total load capacity of 2.0 MW. A pair of silicon-controlled rectifiers (SCRs) are provided for each of 37 circuits. (For the 61-pin bundle, two FPSs are connected in parallel.) The SCRs act as switches that are electronically controlled to provide power control from 0 to 100% in 1% increments [2]. The individual FPSs are electronically

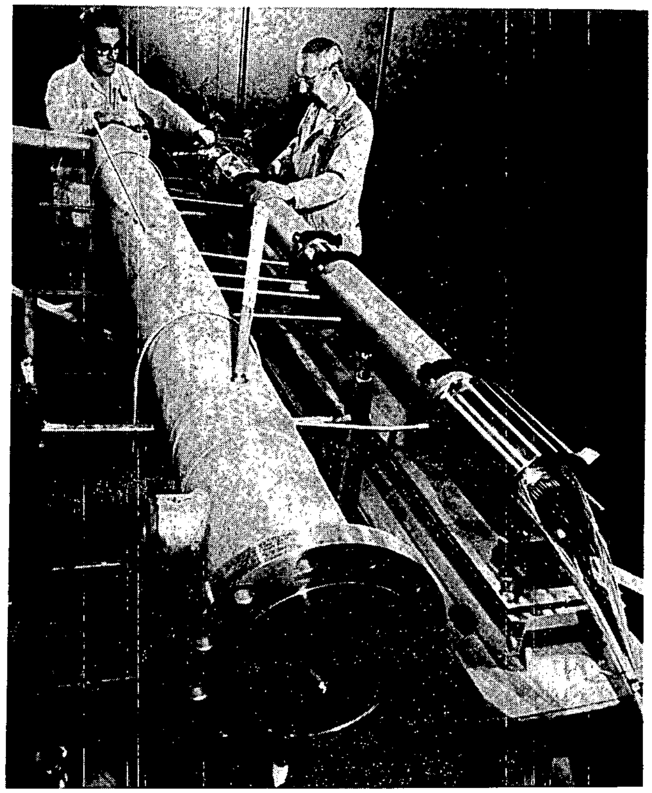


Fig. 3. THORS facility photograph showing test section housing and 61-pin bundle.

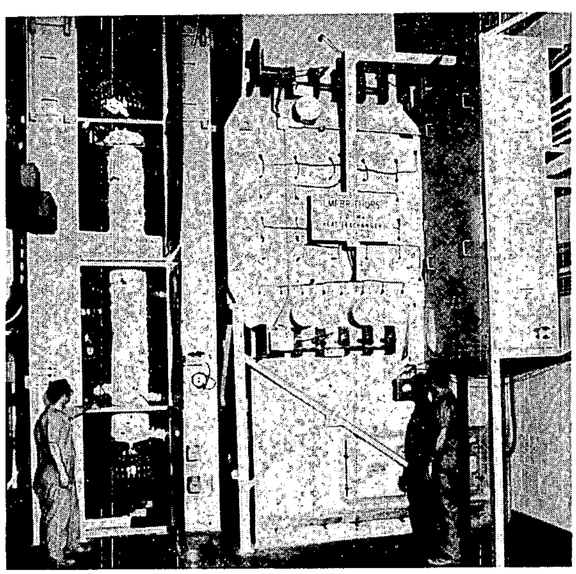


Fig. 4. THORS facility photograph showing 61-pin test bundle housing and 2.0-MW heat exchanger.

protected to prevent electrical damage in the event of a short circuit [3]. Figure 5 is a schematic diagram of the electrical supply system for the test bundles.

The flow diagram of the THORS facility (Fig. 1) shows the relevant loop instrumentation. Table II gives the type, range, and accuracy of the instrumentation [4-7].

Facility piping is trace-heated with ~350 tubular cartridge heaters. The preheat temperatures are monitored by ~700 sheath-type thermocouples, which are connected to multipoint recorders.

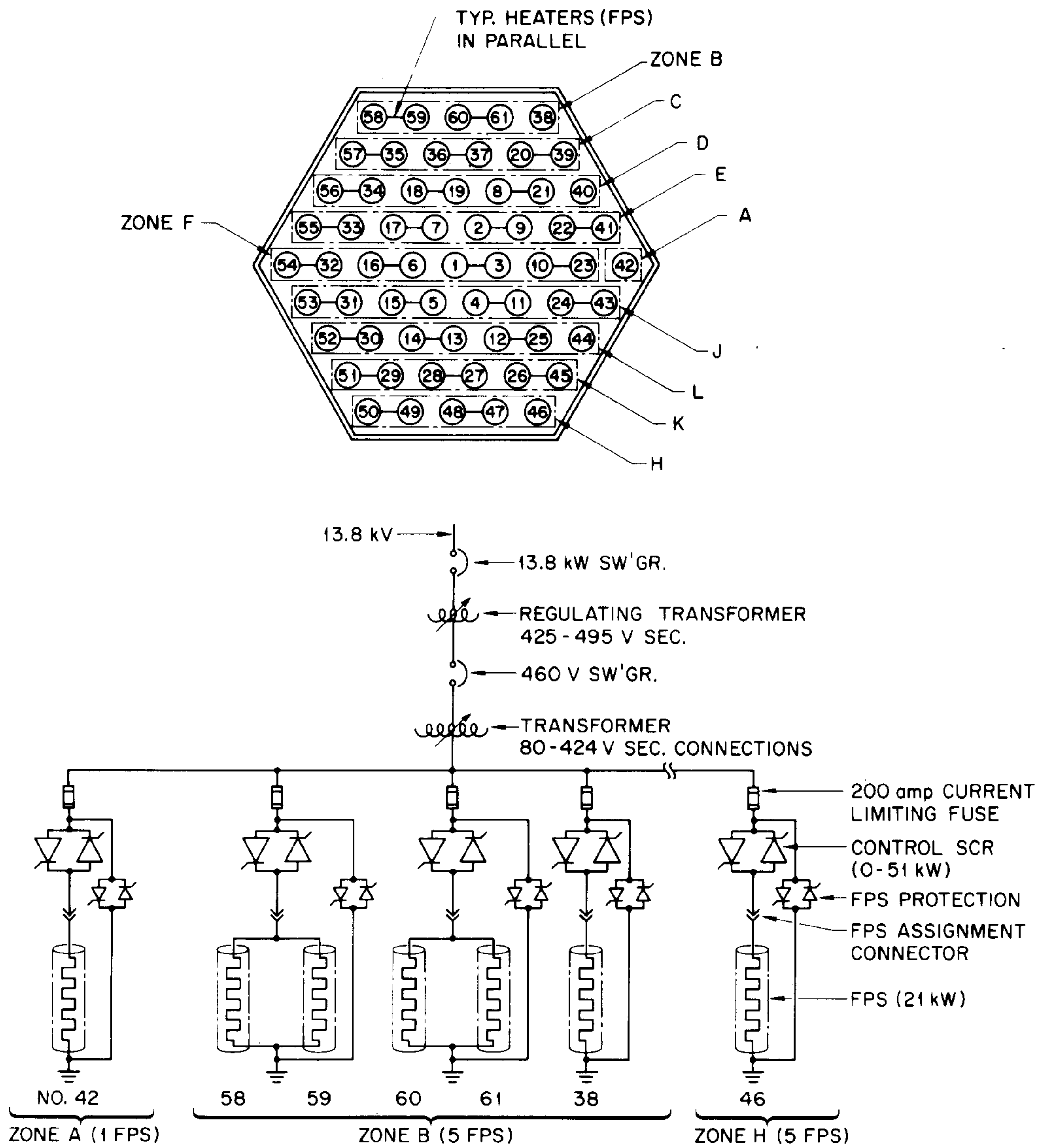


Fig. 5. Sixty-one pin-bundle connections to 2.0-MW power supply. (Power is limited to 1.3 MW in this configuration.)

TABLE II

THORS Loop Instrumentation

Measurement	Type	Range	Accuracy
Pressure	Diaphragm NaK Pressure Sensor	0–1030 kPa 0–690 kPa	±1% ±1%
Differential Pressure	Diaphragm NaK Differential Pressure Sensor	0–5080 mm W.C.	±1%
Temperature	Chromel-Alumel Thermocouple	0–1090°C	±1%
Flow	Magnetic Flowmeter	190–6050 liter per min 0–190 liter per min	±1% ±1%
Level	Single & Twin I-tube Probes	0–1220 mm	±1%
Power	Thermal Watt Converters	0–30 mV	±1%
Boiling	Hydrophone Accoustic Sensors	0.1–120,000 Hz	0.3 V/psi

Data are recorded during actual bundle testing using a 512-channel data acquisition system (DAS) controlled by a PDP-8E computer. Data are logged at the rate of up to 10,000 points per sec and stored on magnetic tape for subsequent processing and display. At the THORS DAS operating console, data may be displayed on a high-speed lineprinter or on two cathode-ray-tube (CRT) terminals. A data management system [8] has been developed to provide operating and data logging programs and the capability of translating DAS-generated data into a tape format that can be used in IBM computers.

TEST BUNDLES

An elevation view of a test bundle (bundle 9A) installed in the test section housing is shown in Fig. 6. It consists of 61 electrically heated 5.84-mm-diam pins spaced by 1.42-mm-diam helical wire wrap spacers on a 305-mm pitch. This bundle has a heated length of 914 mm with an axial chopped-cosine heat flux distribution. The unheated simulated fission gas plena, located downstream of the heated section in a portion of the dummy rod length, are 1537 mm long.

Figure 7a is a photograph of the partially assembled bundle, Fig. 7b is a close-up photograph of the 61 FPSs installed in the tubesheet, and Fig. 7c is a photograph of the duct at the end of the FPS assembly.

A typical FPS used in the test bundles is shown in Fig. 8. Voltage is applied to the heating element through the copper lead at the open end of the FPS, and the electric circuit is completed at the opposite end, where the element is grounded through the end plug to the sodium. This particular FPS is rated at 51.8 kW/m. The FPSs are described in Refs. 9 and 10.

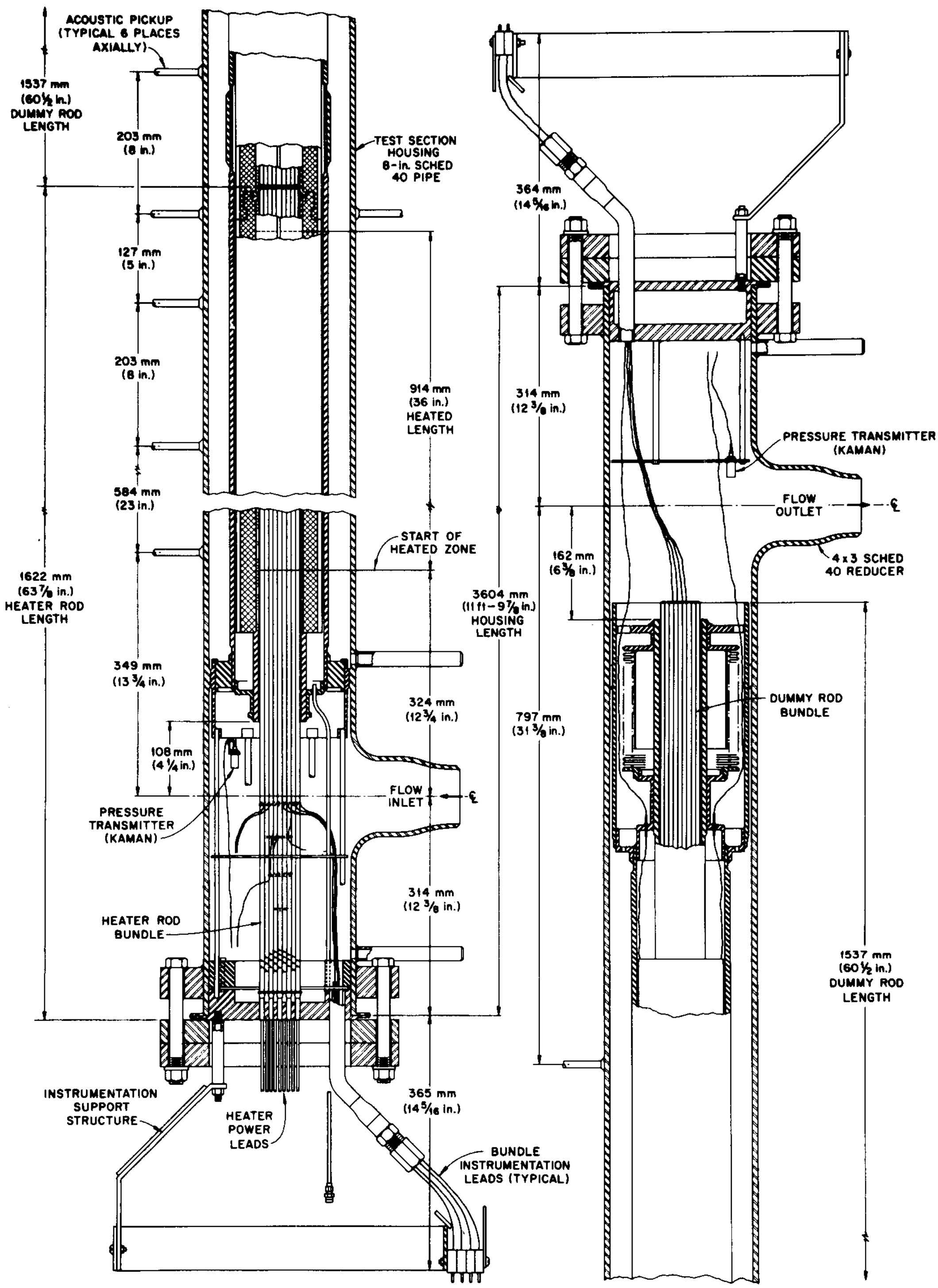
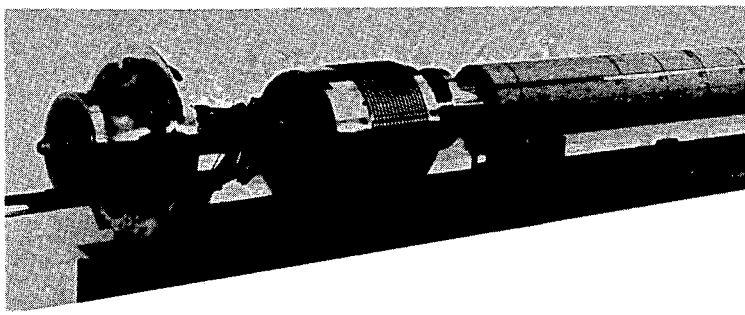
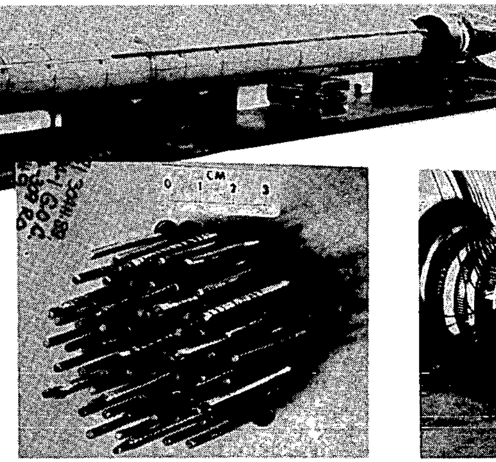


Fig. 6. Typical THORS bundle (9A) test section assembly.



(*a*)



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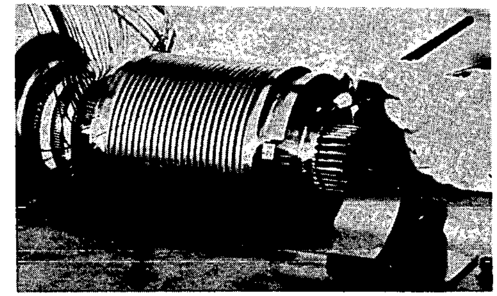
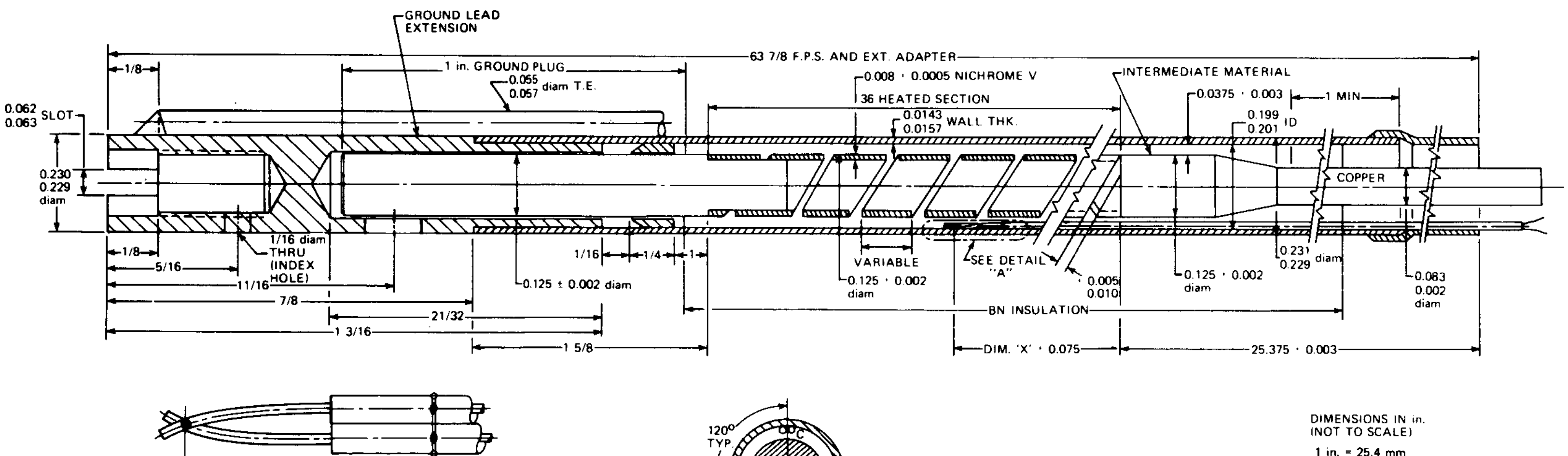


(*c*)

Fig. 7. THORS bundle 9A. (*a*) 61 pin bundle in partial assembly; (*b*) 61 FPSs installed in bundle 9 tubesheet; (*c*) duct end of FPS assembly.



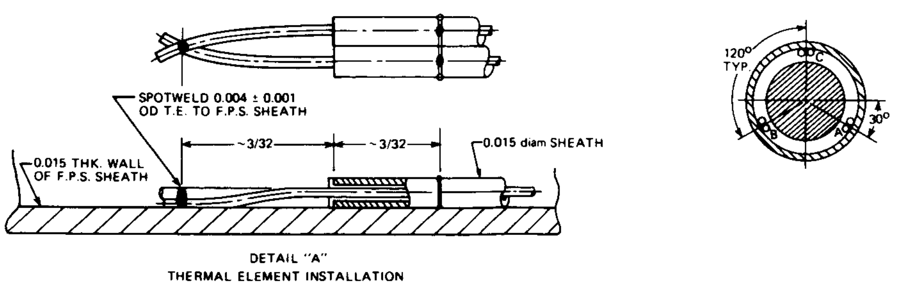


Fig. 8. BRP bundle 9 FPS.

FACILITY OPERATION

Seven test bundles have been built since testing was initiated in 1970, and they have been operated in 12 different configurations. Table III shows the operating history of these bundles. Bundles 1A and 1B were unblocked bundles in a scalloped duct [11]. Bundle 2, which was enclosed in a hexagonal duct, was originally designed to obtain thermal-hydraulic data; in this configuration it was referred to as bundle 2A [12]. After completion of the test program with this configuration, the bundle was still viable and was inverted in the test section and operated with blockage plates of various sizes installed at the inlet of the bundle. In this latter configuration, it was referred to as bundle 2B [13]. Bundle 3A [14], which was in a scalloped duct with dummy wire-wrap segments on dummy edge rods and which contained a six-channel central blockage in the heated zone, was used for single-phase experiments. Bundle 3B [15,16] was identical to bundle 3A, but its test program (which followed the bundle 5 tests) included quasi-steady-state sodium boiling and inert gas injection. Bundle 5, which was enclosed in a hexagonal duct with half-size (0.17-mm) wire spacers between the FPSs and the duct wall, was designed for operation in four configurations. Bundles 5A [17] and 5B [18] contained a blockage along one of the hexagonal sides that blocked one-third of the flow area. Tests for bundles 5C [18] and 5D [19] were run with the blockage plate removed. Bundle 5D was the first

Table III

THORS Facility Operating Experience

Bundle Identification	Number of Pins	Blockage Configuration	Reactor Simulation	Operating Time (hr)
1A	19	None	Thermodynamic Simulation Only	1,300
2A	19	None	Thermodynamic Simulation Only	
2B	19	13- and 14-Channel Inlet	Thermodynamic Simulation Only	3,010 (2A and 2B)
1B	19	None	Thermodynamic Simulation Only	894
3A	19	6-Channel in Heated Zone	Thermodynamic Simulation Only	3,039
3B[a,b]	19	6-Channel in Heated Zone	Thermodynamic Simulation Only	537
5A,5B,5C	19	12-Channel Edge Gap	Thermodynamic Simulation Only	3,252
5D[a,b]	19	None	Thermodynamic Simulation Only	2,827
6A	19	None	FFTF Simulation	7,864
3C	31[c]	6-Channel in Heated Zone	FFTF Simulation	3,666
9	61	None	CRBR Simulation	[d]
			Total	26,389[d]

[a] Boiling tests.

[b] Boiling tests with gas injection.

[c] Nineteen central pins, 12 guard heat pins.

[d] Bundle 9 testing in progress.

THORS bundle taken to temperatures high enough to produce steady-state sodium boiling; these tests were run in October 1974. Bundle 6A was designed with a low thermal capacity duct surrounding the bundle. The main objectives for this bundle were to establish steady-state temperature distributions at various flow-power ratios for comparison with data from previous bundles [20]. The bundle was also used for transient free convection tests [21] and for transient sodium boiling tests (including several partial dry-out) [22-24]. The objective of bundle 3C tests was to investigate axial and radial boiling propagation behind a blockage. A six-channel blockage plate was attached to the central pin in the heated zone, as in bundles 3A and 3B. An unheated section was added downstream of the FPSs to give a simulation of the fission gas region in the reactor. The test program for bundle 9, the 61-pin bundle now installed in the facility, will incorporate all tests that have been run with the smaller unblocked bundles. Hence, a comparison of results can be made for 19- and 61-pin bundles. This comparison should give an insight into the effect of size on test bundle performance.

Sodium has been circulated in the THORS facility at temperatures as high as 700°C; sodium temperatures in the test section, however, have reached 1010°C. Power levels have been as high as 36.0 kW/m in each pin.

Plans are being made for fabricating and testing additional bundles. Under consideration at the present time are (1) a bundle to investigate the effects of duct heat capacity on bundle internal temperatures, (2) test bundles for advanced fuels, and (3) a bundle to measure the effects of pin bowing.

SUMMARY AND CONCLUSION

The THORS Facility has been in use since 1970 to obtain data for fast reactor safety technology from simulated LMFBR fuel subassemblies. The system has recently been upgraded to 2.0-MW test bundle power input and heat rejection capability. Seven different bundles have been built and operated in 12 different configurations. The facility has logged over 27,000 hr at sodium temperatures ranging up to 1010°C. Sodium boiling tests have been run to investigate axial and radial boiling propagation in simulated reactor subassemblies. Experiments with inlet blockages and heated zone blockages have produced data to provide an insight into the problems associated with fast reactor safety. Thermal-hydraulic data obtained from tests in bundles of 19-, 31-, and 61-pin sizes can be used to provide core designers with experimental data to verify and/or develop computer models.

ACKNOWLEDGEMENT

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