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FORCED-TO-NATURAL CONVECTION TRANSITION TESTS IN PARALLEL SIMULATED LIQUID METAL REACTOR FUEL ASSEMBLIES*

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INTRODUCTION

The Thermal-Hydraulic Out of Reactor Safety (THORS) Program at Oak Ridge National Laboratory (ORNL) had as its objective the testing of simulated, electrically heated liquid metal reactor (LMR) fuel assemblies in an engineering-scale, sodium loop. Between 1971 and 1985, the THORS Program operated 11 simulated fuel bundles in conditions covering a wide range of normal and off-normal conditions. The last test series in the Program, THORS-SHRS Assembly 1, employed two parallel, 19-pin, full-length, simulated fuel assemblies of a design consistent with the large LMR (Large Scale Prototype Breeder - LSPB) under development at that time. These bundles were installed in the THORS Facility, allowing single- and parallel-bundle testing in thermal-hydraulic conditions up to and including sodium boiling and dryout. As the name SHRS (Shutdown Heat Removal System) implies, a major objective of the program was testing under conditions expected during low-power reactor operation, including low-flow forced convection, natural convection, and forced-to-natural convection transition at various powers.

The THORS-SHRS Assembly 1 experimental program was divided up into four phases. Phase 1 included preliminary and shakedown tests, including the collection of baseline steady-state thermal-hydraulic data. Phase 2 comprised natural convection testing. Forced convection testing was conducted in Phase 3. The final phase of testing included forced-to-natural convection transition tests. Phases 1, 2, and 3 have been discussed in previous papers.[1-3] The fourth phase is described in this paper.

THE THORS FACILITY

The THORS Facility, as employed for Phase 4 testing, is shown in Fig. 1, and a flow schematic is shown in Fig. 2. The two simulated fuel bundles were connected to upper and lower plena. The bypass line served two purposes. In low-flow forced convection, with primary flow supplied by the 1-L/s electromagnetic (EM) pump, and in natural convection, the bypass served as the return line between the upper and lower plena, with heat removal through the intermediate sodium-to-sodium heat exchanger (IHX). Secondary side flow was supplied by the 40-L/s EM pump, with ultimate heat rejection to the 2-MW sodium-to-air heat exchanger. In high-flow forced convection, the small EM pump was not operated, and primary flow was supplied by the 40-L/s pump. The bypass then operated in upflow, maintaining a constant pressure drop between the two plena. The IHX was not operated in these tests, and heat rejection was accomplished by the 2 MW heat exchanger. The 1-L/s EM pump, installed specifically for Phase 4 testing, facilitated the transition from low-flow forced convection to natural

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convection, since the sodium in the bypass line could continue to flow downward. Transition tests from high-flow forced convection to natural convection required that valves be reset during the tests to change the bypass from upflow to downflow and to begin operation of the IHX. Up to 2 MW of electric power could be supplied to the loop, regulated by silicon-controlled rectifiers, which allowed digital control of the power to different zones of the bundles. With this system, diametral power skews could be simulated. Programmable pump and bundle power control systems were available so that preprogrammed flow and bundle-power transients could be performed.

The two simulated fuel assemblies were of identical design, each containing 19 fuel pin simulators (FPSs) based on an LSPB driver assembly. The FPSs were 6.99 mm in diameter, spaced by 1.22 mm diameter wire wraps with a helical pitch of 305 mm. The edge gaps between the outermost row of FPSs and the hexcan were half-size (0.61 mm) to reduce the flow-to-power ratio in these subchannels, thus flattening the bundle radial temperature profile. The axial power shape was a chopped cosine, with a peak-to-mean ratio of 1.28. The heated length was 1016 mm. Each FPS included simulated lower and upper axial blankets and a simulated fission gas plenum (SFGP). The maximum FPS power was ~28 kW.

The THORS Facility was extensively instrumented for this test program. Since temperature distributions throughout the loop were of considerable importance during natural convection testing, thermocouples were placed throughout the "primary" side of the system. The bundles were also heavily instrumented, with 118 thermocouples placed in each bundle: three on the inner sheath of each FPS and 61 in the wire-wrap spacers. The upper and lower plena also contained substantial thermocouple coverage, in order to detect recirculating flows in these components. System pressures were monitored using NaK-filled transducers, and flows were measured using permanent-magnet flowmeters. The test section inlet flowmeters were removable, allowing sensitive, low-range flowmeters to be installed during natural convection tests. For flows greater than ±0.15 L/s, high-range flowmeters were employed. Data acquisition was accomplished using a sophisticated computer controlled data acquisition system, capable of monitoring up to 10,000 points per second from up to 500 instruments.

THORS-SHRS ASSEMBLY 1 PHASE 4 TESTS AND RESULTS

THORS-SHRS Assembly 1 Phase 4 tests were carried out from October to December 1985. The tests included transitions from high-flow forced convection and low-flow forced convection to natural convection at constant power, and combined flow and power transients, where the power was reduced as a function of time along an approximate post-scram decay power curve. The original test plan called for all of these tests to be conducted in single-phase flow only. However, it was later decided to include several tests in which sodium boiling and dryout were reached, to compare the transient results with those seen during steady-state tests.

In the originally-planned tests, no boiling was expected, and none was observed. Cessation of forced convection was accompanied by a sharp reduction in flow; the resulting increase in assembly temperatures then brought the system up to steady natural convection behavior. The only exception to this behavior occurred during the combined flow and power transients. In these tests, the power decreased faster than the flow in the initial stage of the transient, resulting in a decrease in bundle temperatures. Once the flow coastdown was completed, however, the bundle temperatures turned around and the system came to steady natural convection. In all of these tests, the transitional behavior was smooth, with no unexpected instabilities.

The behavior observed during the boiling and dryout tests was also consistent with that expected, based on data from previous boiling tests. The power at which boiling was first observed was ~12% of nominal power, with first dryout at ~16% of nominal power. Dynamic instabilities, such as geysering, that were observed in Phases 2 and 3 were also seen in these tests, and dryout was accompanied by pressure drop - flow (Ledinegg) instabilities, as noted in previous THORS tests both in this test program and in earlier simulated LMR bundles. Of particular note is the fact that boiling and dryout powers fell between the two extremes recorded during Phase 2 testing. The highest boiling and dryout powers in natural convection were observed during "quasi-steady" power increases (very small steps), while the lowest powers were seen during step increases in power from a zero-power, zero-flow condition. Since these two methods represent the least and most severe methods for producing boiling and dryout, respectively, it was expected that the Phase 4 results would fall within the power range thus established, and this was indeed the case.

CONCLUSIONS

Forced-to-natural convection transition tests were conducted in parallel simulated LMR fuel assemblies. For tests in which the flow remained single-phase, the transition from forced to natural convection was smooth, with no unexpected instabilities. For boiling and dryout tests, the transition was accompanied by dynamic and static boiling instabilities similar to those observed in steady-state natural convection testing. Powers at boiling and dryout were also consistent with expectations, falling between the most and least severe natural convection values established in Phase 2 testing.

REFERENCES

1. A. E. Levin, et al., "Steady State Temperature Profiles in Two Simulated Liquid Metal Reactor Fuel Assemblies with Identical Design Specifications," *Proc. Third Int. Top. Mtg. on Nuclear Reactor Thermal-Hydraulics, Newport, Rhode Island, October 15-18, 1985.*

2. A. E. Levin, et al., "Results of Natural Circulation Tests in Simulated LMFBR Fuel Assemblies and Their Relation to Decay Heat Removal System Design," *Proc. Int. Top. Mtg. on Fast Reactor Safety, Knoxville, Tennessee, April 21-25, 1985.*

3. S. D. Rose, et al., "Forced-Convection Boiling Tests Performed in Parallel Simulated LMR Fuel Assemblies," *Proc. Int. Top. Mtg. on Fast Reactor Safety, Knoxville, Tennessee, April 21-25, 1985.*

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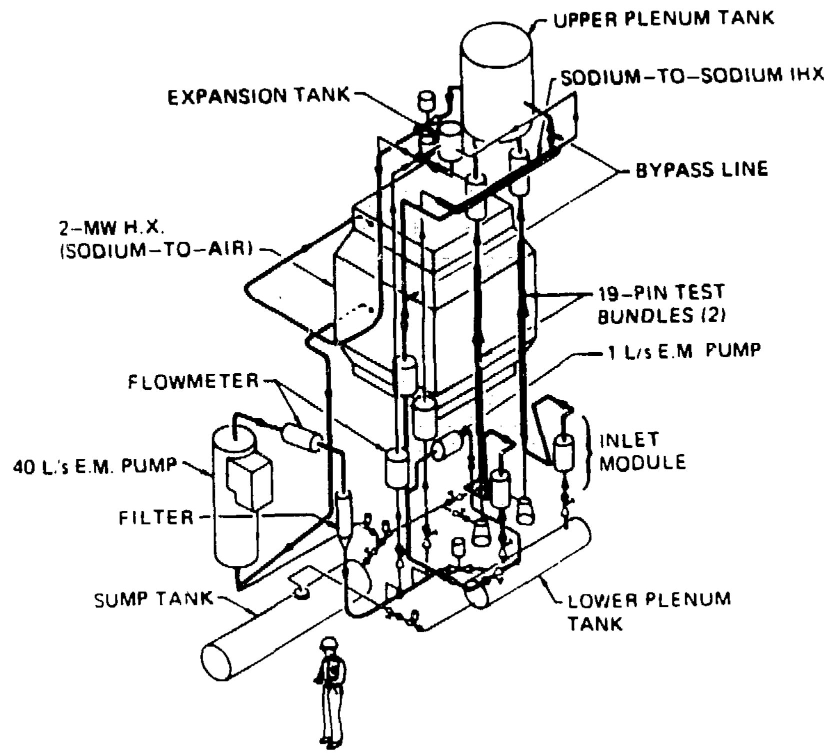

Fig. 1. THORS-SHRS Facility isometric flow sheet for Phase 4 operation.

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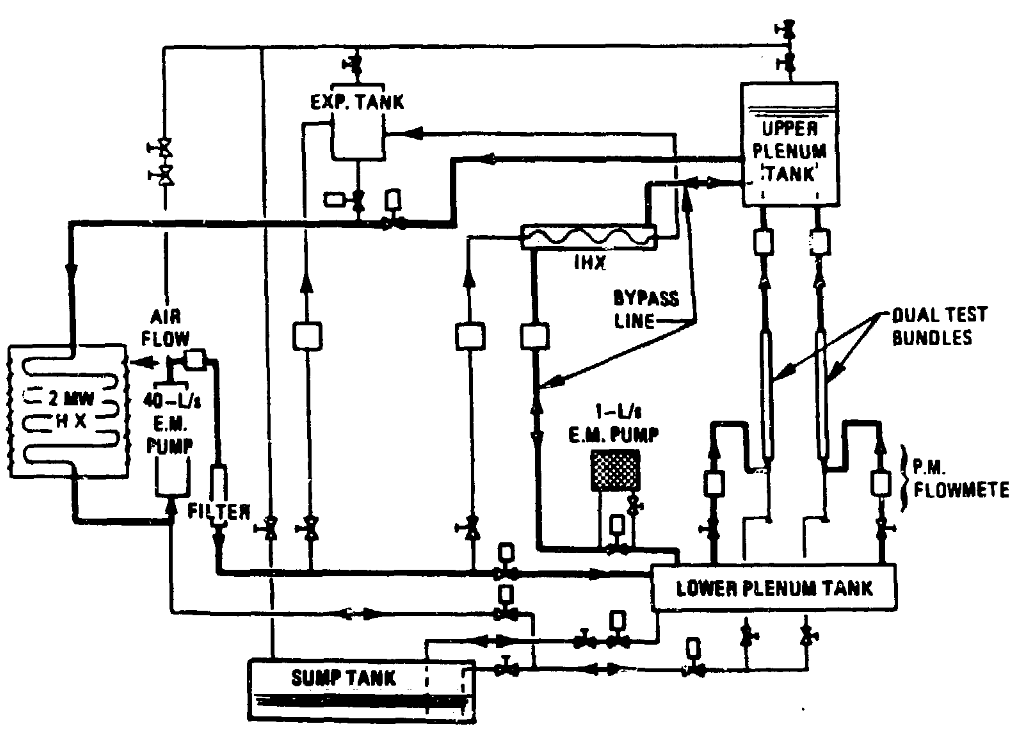

Fig. 2. THORS-SHRS Facility flow schematic diagram for Phase 4 operation.