Conf-821068--1

CONF-821068--1

MASTER

DE83 001943

A THORAX PRETEST PREDICTION OF A SODIUM-BOILING TRANSIENT IN A 19-PIN SIMULATED LMFBR DRIVER BUNDLE*

S. D. Rose

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830, USA

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

Prepared for Presentation at the

Tenth Meeting of the Liquid
Metal Boiling Working Group (LMBWG)

KfK, Karlsruhe, F.R.G.

October 27-29, 1982

DISCLAIMER

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

By acceptance of this article, the publisher or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering the article.

---

*This research is sponsored by the Office of Reactor Research and Technology, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

A THORAX PRETEST PREDICTION OF A SODIUM BOILING TRANSIENT IN A 19-PIN SIMULATED LMFBR DRIVER BUNDLE

S. D. Rose

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830, USA

SUMMARY

Experiments will be conducted in the Thermal-Hydraulic Out-of-Reactor Safety--Shutdown Heat Removal System (THORS-SHRS) Assembly 1 loop at Oak Ridge National Laboratory (ORNL) to model the behavior of a reactor during degraded decay heat removal conditions. The test section is to consist of two parallel 19-pin electrically-heated driver bundles, typical of U.S. Large Developmental Plant (LDP) Liquid Metal Fast Breeder Reactor (LMFBR) design. Analysis of these experiments will include using THORAX, a two-dimensional boiling model which assumes an equilibrium mixture two-phase flow (with slip). A THORAX prediction is presented for a single-bundle forced convection boiling-to-dryout transient at 15.8 kW/pin. The thermal-hydraulic behavior for this test is predicted to be very similar to the equivalent transient previously performed (and successfully modeled by THORAX) in 19-pin THORS Bundle 6A which was of Fast Flux Test Facility (FFTF) design. The boiling behavior is two-dimensional in nature with ~13 s of boiling predicted before clad dryout conditions are reached.

INTRODUCTION

A primary task of the ORNL Breeder Reactor Safety Program is that of the THORS program. THORS objectives include determining the characteristics of sodium boiling in an LMFBR core at low flow and at natural convection conditions. Boiling tests have been carried out extensively in three test bundles in the THORS facility [1]. The first bundle [2] contained a six-channel central blockage which had only limited effects on system thermal-hydraulic behavior. Testing of 19-pin Bundle 6A [3] and 61-pin Bundle 9 [4] unblocked bundles indicates that the thermal-hydraulic behavior of boiling transients is determined by two-dimensional effects. (This conclusion is equally valid from analysis of the 19-pin in-reactor Sodium Loop Safety Facility (SLSF) W-1 experiment [5].) Analysis of boiling transients has been carried out with subchannel code SABRE-2P, a version of the single-phase transient code SABRE-2 [6] modified to include a boiling model, and THORAX [7,8], a two-dimensional boiling model.

Future experimentation at ORNL will address modeling the behavior of a reactor core during degraded decay heat removal conditions. The THORS facility is being modified extensively and will be designated the THORS-SHRS Assembly 1. The test section will consist of two parallel 19-pin simulated driver bundles. Operation of the facility is scheduled for October 1983.

In this paper, results from a THORAX pretest prediction for a boiling transient in the THORS-SHRS Assembly 1 are presented. The experimental facility and THORAX model are described, and the prediction is also compared with experimental results [3] from a similar transient carried out in Bundle 6A.

THORS-SHRS ASSEMBLY 1

The THORS facility is an engineering scale, high-temperature sodium loop for testing simulated LMFBR assemblies. The power supply and heat rejection capabilities are each 2 MW. Flow is provided by an electromagnetic pump (EM) rated at 40 L/s. Experimental data are recorded by a computer-controlled data acquisition system (DAS). Up to 500 instruments can be accommodated on the DAS and scanned at up to 10,000 points per second.

A facility flow diagram for the THORS-SHRS Assembly 1 is shown in Fig. 1. Figure 2 shows a cross section of the simulated LMFBR driver bundles which are of identical design, typical of the U.S. LDP LMFBR. The two bundles will be in parallel with a third unheated line which will serve a dual purpose. In forced convection, this line will operate in upflow as a bypass to help provide a constant pressure drop boundary condition. During natural convection tests, this line, which will contain a sodium-to-sodium intermediate heat exchanger (IHX), will operate in downflow to provide a more prototypic coolant path between the upper and lower plena.

The fuel pin simulators shown in Fig. 2 are 6.99 mm in diameter spaced by 1.22-mm diameter wire-wraps on a 305-mm axial pitch. The 1.016-m heated zone has a chopped cosine power distribution with a peak-to-mean ratio of 1.28. Unheated lengths of 356 mm above and below the heated section simulate axial blankets, and a simulated fission gas plenum 813 mm in length is included above the simulated upper axial blanket.

The THORS-SHRS Assembly 1 test program is designed to simulate postulated, low-probability accidents that might occur in an LMFBR at decay heat power conditions. The thermal-hydraulic behavior in single-phase and two-phase conditions will be characterized under natural and degraded forced convection conditions. The effects of loss-of-heat sink (reduced inlet subcooling) and a parallel, heated bundle on loop thermal-hydraulic behavior will also be investigated. Tests simulating the transition from forced convection to natural convection will also be performed.

THORAX MODEL

Experience using SABRE-2P (with a two-phase multiplier boiling model) indicated that a fast executing 2-D model would be preferable to a full subchannel model. The THORAX model was developed at ORNL for analysis of boiling data from Bundle 6A, Bundle 9, and SHRS Assembly 1.

Results from THORS sodium boiling tests indicate that the timing of the important phenomena, primarily boiling initiation and cladding dryout, are determined by 2-D thermal-hydraulic behavior, that is, by the rates of mass, momentum, and energy transfer in the direction perpendicular to the fuel pins. Therefore, it is not possible to use the 1-D models that have been developed for LMFBR safety analysis to extrapolate the results of THORS testing to transients involving full-size fuel pin bundles. Some of the existing 2-D boiling models available are of limited use due to various problems, including (1) the inability to reach an adequately converged solution; (2) the limitation of only an inlet mass flow boundary condition instead of a test section pressure drop boundary condition (the latter is necessary for modeling transients in which changes in test section conditions can cause changes in the inlet flow); and (3) unreasonable computer time requirements for real transients. With these problems in mind, the THORAX model was developed with the following features:

1. The simplest possible 2-D model, two interacting flow channels, is used to represent the flow in the hexagonal bundle. As shown in Fig. 3, one channel represents the interior subchannels and the other the edge subchannels. This is a rational way to divide the flow field, because of the different power-to-flow ratios in the interior and edge regions of the bundle. The total axial length of the bundle is divided into 50 evenly spaced axial nodes. The vicinity of an arbitrary axial node J is shown in Fig. 4. The bundle is divided into the two flow channels and the surrounding structure is nodalized as shown in this figure. Heat transfer from the bundle duct wall radially outward to the outer housing is explicitly modeled in THORAX, and the effect of this heat transfer for any given test can be computed. A staggered pressure-velocity grid is utilized in the fluid flow domain. The locations of pressures, velocities, enthalpies, and two-phase mixture densities are shown in Fig. 5. The locations of the control volumes used to formulate equations for the conservation of mass, energy, and axial and transverse momentum are also shown in Fig. 5.

2. The basic assumptions of the two-phase flow model are those of the compressible equilibrium two-phase mixture flow in which the difference in the component velocities is obtained from a correlation for slip ratio:

Local Slip = 1 + 10 x Local Mixture Quality .

The form of this correlation was derived from data in Ref. 9. The spatial integration of the mixture void fraction involves assumptions as to the form of the transverse enthalpy profile. There is also a provision for integrating (relaxing) the two-phase density temporally to smooth out dynamic instabilities. Film dryout is assumed to occur when the calculated two-phase quality becomes unity.

3. The equation set which describes the two-dimensional, transient, two-phase fluid flow and heat transfer consists of the following:

Conservation of Mass
Conservation of Energy
Conservation of Axial Momentum
Conservation of Transverse Momentum
Conservation of State
Mixture Properties

The coupled set of these highly nonlinear equations are solved using the powerful SIMPLE algorithm of Spalding and Patankar [10]. This algorithm involves evaluating the necessary coefficients to put the conservation equations in linear form. The system of linearized equations is solved on an iterative cycle which involves techniques of successive point over-relaxation and successive line relaxation.

THORAX PREDICTION FOR SHRS ASSEMBLY 1

The THORAX model has been successful in the analysis of both forced flow and natural convection boiling transients [7,8]. Extrapolation of results to full-size fuel assemblies is also presented in Ref. 9. A controlled flow reduction forced convection boiling-to-dryout test is selected here. The test (351A/B Run 103) will be conducted under similar conditions in both SHRS bundles individually and will be at conditions very similar to those of a transient previously performed in 19-pin Bundle 6A (Test 73E Run 102A). The test conditions are for a bundle power of 15.8 kW/pin with a constant inlet temperature of 451°C. The required initial steady-state test section inlet flow is 1.26 L/s. The preset flow reduction transient is to be initiated by reducing the power consumed by the EM pump. In this way, the flow is to be reduced to 0.49 L/s in 4 s.

This test has been modeled using THORAX as follows. First, a steady-state calculation was performed at the high flow using a test section pressure drop of 179.0 kPa. The test section inlet pressure was ramped down to 50.7 kPa linearly over the first 3.6 s and then kept constant for the remainder of the test. The test section inlet temperature was held constant at 451°C for the entire test. The transient calculation time step was 50 ms.

The test section inlet flow computed by THORAX is shown in Fig. 6. Boiling is predicted to initiate at ~8 s near the end of the heated section central in the bundle. The static instability then begins to reduce the inlet flow; the flow decrease accelerates as the boiling region grows to encompass the entire bundle flow area (~18 s). This results in the inlet flow reducing to almost zero at 21.5 s when the maximum quality, predicted by THORAX to be in the center of the bundle near the end of the heated section, becomes unity (the dryout criterion). Figure 7 shows the test section inlet flow for Test 73E Run 102A, THORS Bundle 6A and THORAX results [7]. [Bundle 6A also had 19 pins but was of FFTF design with a 914-mm heated length.] The transient behavior in this test was very similar to that predicted for SHRS Assembly 1: in Bundle 6A, boiling initiation (~7 s) and dryout (~21 s) occurred slightly earlier.

Calculated mass flux fields for the SHRS Assembly 1 are given in Figs. 8, 9, and 10 at 12, 18, and 21.5 s into the transient, respectively. Flow area (or radius squared) is plotted linearly on the horizontal axes of these plots, and the mass flux vectors are located radially in the centers of the interior and edge channels. For clarity, the scale on the horizontal axes are exaggerated with respect to the vertical axes of axial position in the bundle. The THORAX model shows clearly the transient growth of the boiling region. Most of the flow is diverted around the boiling region into the subcooled edge channel until this region extends almost across the entire bundle cross section. At dryout, the two-phase region extends axially for ~1.5 m with boiling across the whole bundle for the upper axial blanket and part of the simulated fission gas plenum.

REFERENCES

1. P. A. Gnadt et al., 'THORS — A High-Temperature Sodium Test Facility Rated at 2.0 MW,' *Proceedings of the International Conference on Fast Reactor Safety Technology*, Seattle, Washington. Vol. V, pp. 2311-2321 (August 19-23, 1979).

2. J. F. Dearing, S. D. Rose, and W. R. Nelson. 'A Comparison of COBRA III-C and SABRE-1 (Wire-Wrap Version) Computational Results with Steady-State Data from a 19-Pin Internally Guard Heated Sodium-Cooled Bundle with a Six-Channel Central Blockage (THORS Bundle 3C),' *Proceedings of the International Conference on Fast Reactor Safety Technology*, Seattle, Washington. Vol. IV, pp. 1706-1715 (August 19-23, 1979).

3. J. L. Wantland et al., 'Sodium Boiling Incoherence in a 19-Pin Wire-Wrapped Bundle,' *Proceedings of the International Conference on Fast Reactor Safety Technology*, Seattle, Washington, Vol. IV, pp. 1678-1685 (August 19-23, 1979).

4. S. D. Rose et al., 'Experimental and Numerical Thermal-Hydraulic Results from a 61-Pin Simulated LMFBR Subassembly,' *Trans. Amer. Nucl. Soc.*, 34, pp. 880-882 (1980).

5. J. F. Dearing and S. D. Rose, 'Two-Dimensional Modeling of Sodium Boiling in the W-1 Sodium Loop Safety Experiment,' *Trans. Amer. Nucl. Soc.*, 39, pp. 1067-1069 (1981).

6. J. D. MacDougall. *SABRE-2: A Computer Program for the Calculation of Transient Three-Dimensional Flows in Rod Clusters*, AEEW-R 1104, United Kingdom Atomic Energy Authority (1978).

7. J. F. Dearing, 'Two-Dimensional Computational Modeling of Sodium Boiling in Simulated LMFBR Fuel Pin Bundles,' *Trans. Amer. Nucl. Soc.* 38, pp. 755-757 (1981).

8. S. D. Rose et al., 'Two-Dimensional Modeling of Sodium Boiling Transients in Simulated LMFBR Fuel Bundles,' *International Topical Meeting on Liquid Metal Fast Breeder Safety and Related Design and Operational Aspects*, Lyon-Ecully, France (July 1982).

9. A. Kaiser, W. Peppler, and L. Voros, *Flow Pattern, Pressure Drop and Critical Heat Flux of a Two-Phase Sodium Flow*, EURFNR-1266 (April 1975).

10. S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, Hemisphere Publishing Corporation, McGraw-Hill Book Company (1980).

FIGURE CAPTIONS

Fig. 1. THORS-SHRS Assembly 1 facility flow diagram.

Fig. 2. THORS-SHRS Assembly 1 bundle cross section.

Fig. 3. Cross section of THORS-SHRS Assembly 1 showing the two THORAX computational flow channels.

Fig. 4. Control volume scheme used in THORAX near axial node J for SHRS Assembly 1.

Fig. 5. Nodalization scheme for Pressure, Density, Velocity, and Enthalpy in THORAX near axial node J.

Fig. 6. THORAX pretest prediction of test section inlet flow for forced convection Test 351A/B Run 103 at 15.8 kW/pin in a 19-pin simulated LMFBR driver assembly (THORS-SHRS Assembly 1).

Fig. 7. Test section inlet flow for Test 73E, Run 102A, THORS Bundle 6A experimental data and THORAX results.

Fig. 8. THORAX mass flux field at 12 s into THORS-SHRS Assembly 1 test 351A/B Run 103.

Fig. 9. THORAX mass flux field at 18 s into THORS-SHRS Assembly 1 test 351A/B Run 103.

Fig. 10. THORAX mass flux field at 21.5 s into THORS-SHRS Assembly 1 test 351A/B Run 103.

ORNL-DWG 81-1607A ETD

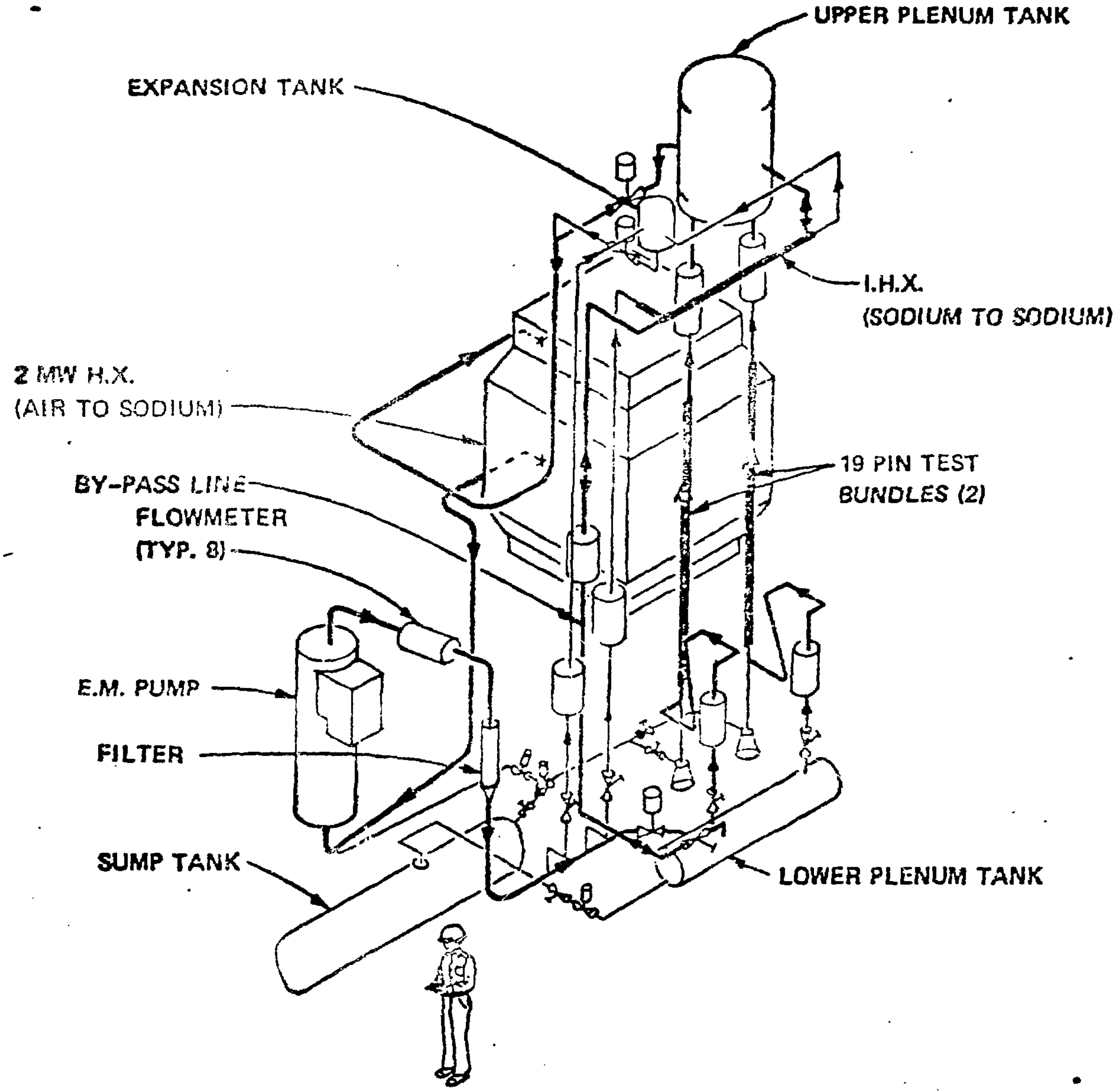


Fig. 1 THORS SHRS Assembly 1 facility flow diagram.

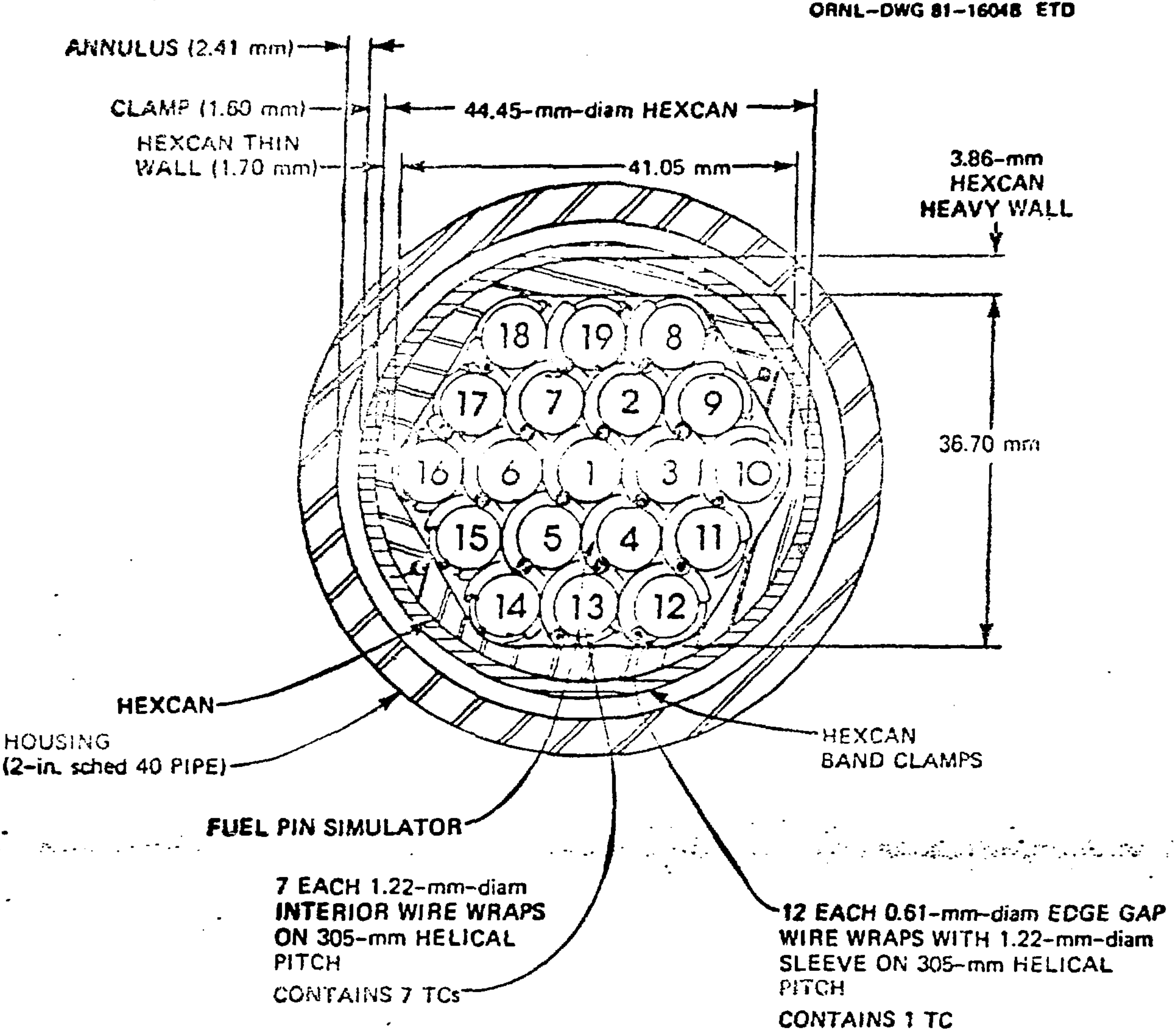


Fig. 2. THORS-SHRS Assembly 1 bundle cross section.

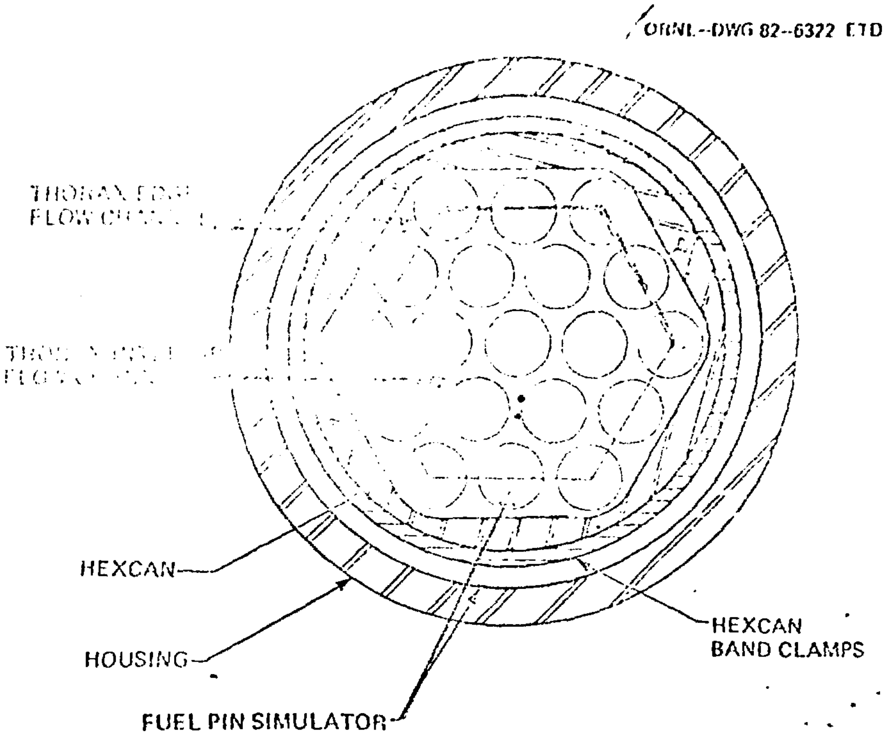
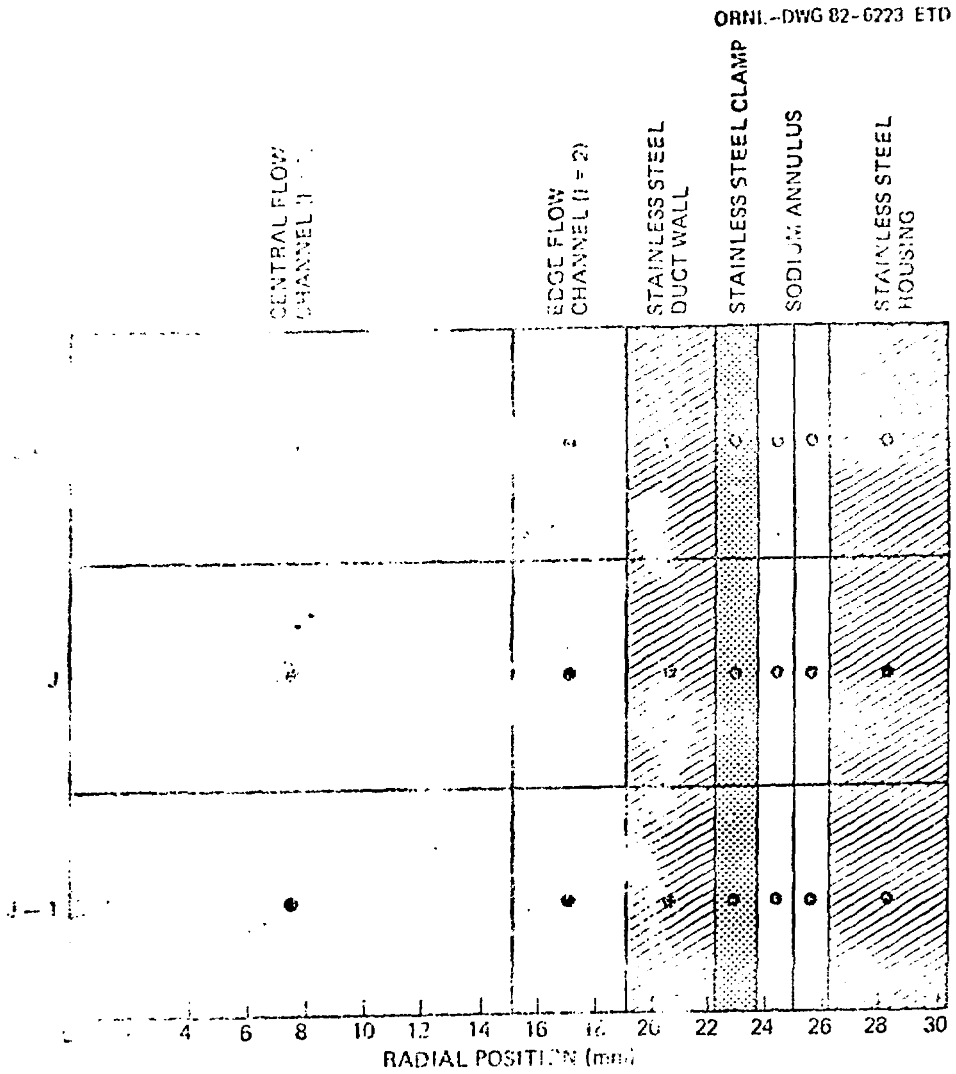
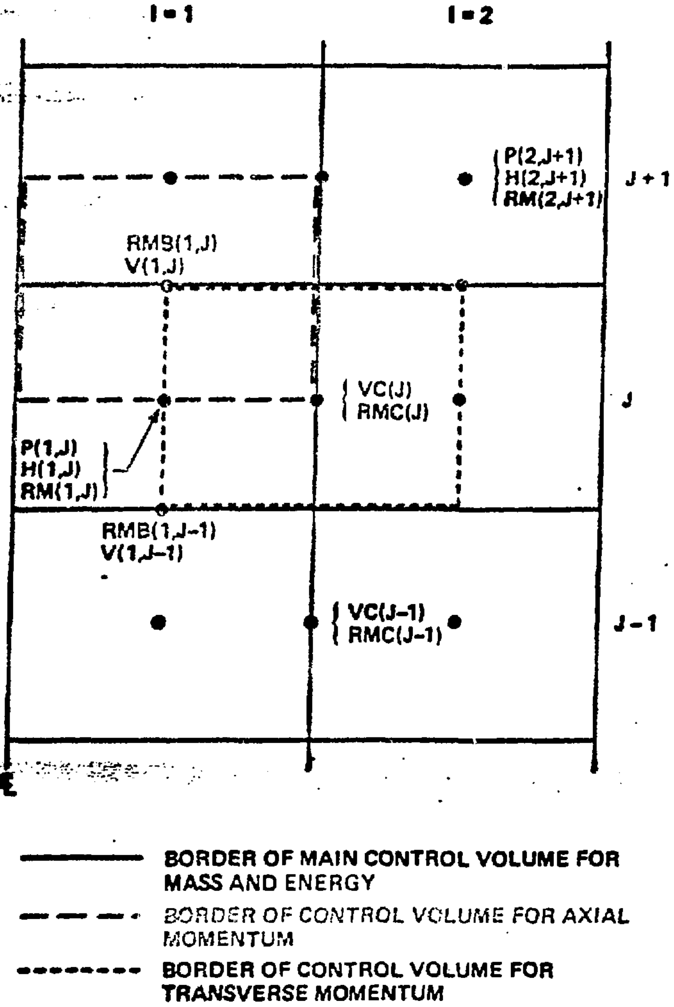


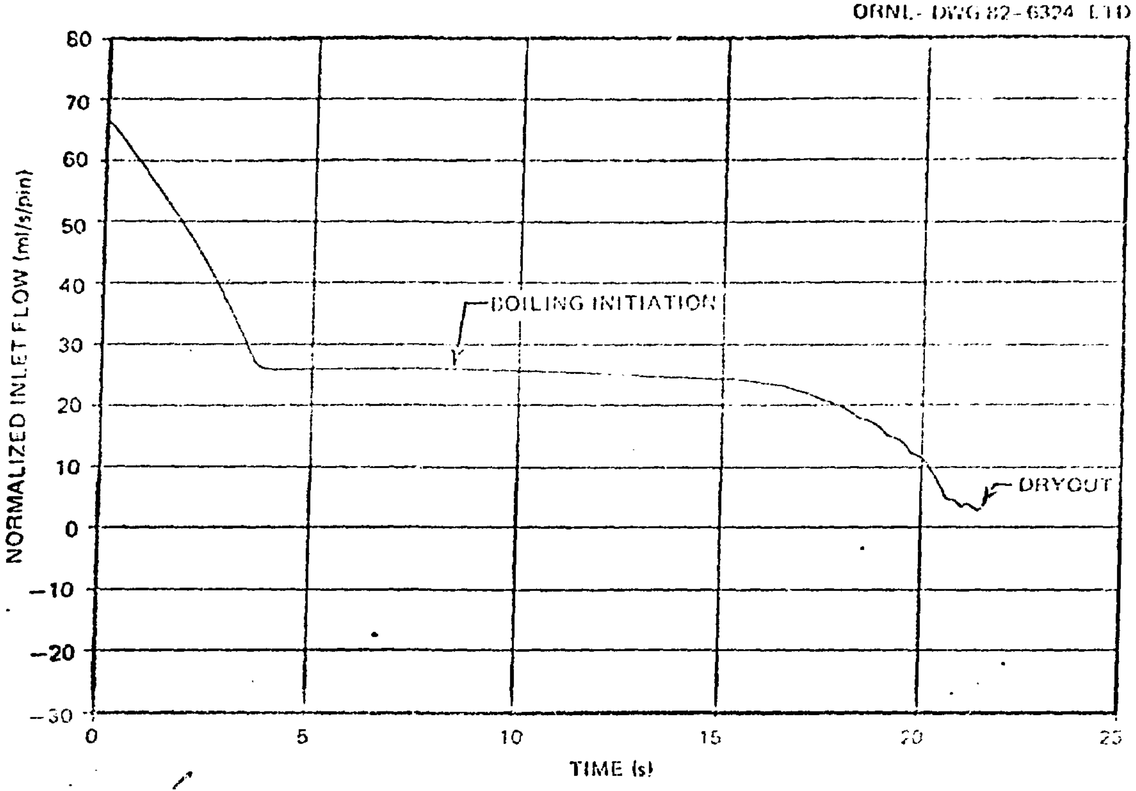
Fig. 3. Cross section of THORS SHRS Assembly 1 showing the two THORAX computational flow channels.



[illegible] [illegible] Control volume scheme used in THORAX near axial node J [illegible] SR [illegible] 1.

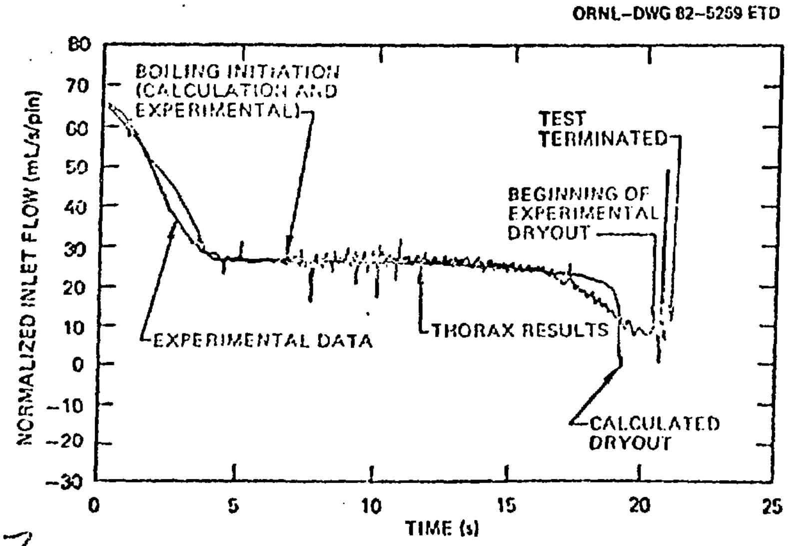
Fig. 5 NODALIZATION SCHEME FOR PRESSURE, DENSITY, VELOCITY, AND ENTHALPY IN THORAX NEAR AXIAL NODE J.





6

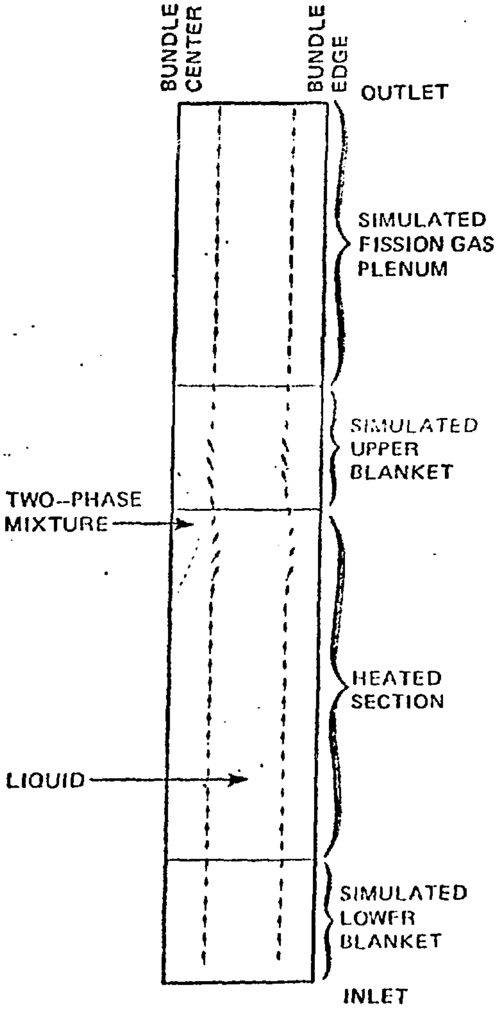
Fig. ~~12.15~~. THORAX pretest prediction of test section inlet flow for forced-convection Test 351 A/B Run 103 at 15.8 kW/pin in a 19-pin simulated LMFBR driver assembly (THORS-SHRS Assembly 1).



7

Fig. ~~12.16~~. Test section inlet flow for Test 73E, Run 102A, THORS Bundle 6A experimental data and THORAX results.

ORNL-DWG 82-6325 ETD



8

Fig. THORAX mass flux field at 12 s into THORS-SHRS Assembly 1 Test 351 A/B Run 103.

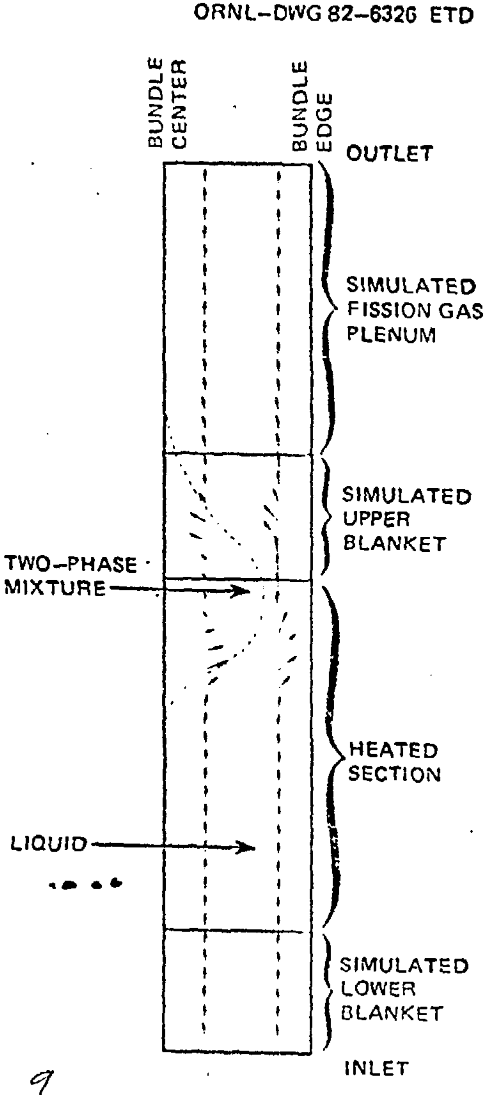


Fig. 9 THORAX mass flux field at 18 s into THORS-SHRS Assembly 1 Test 351 A/B Run 103.

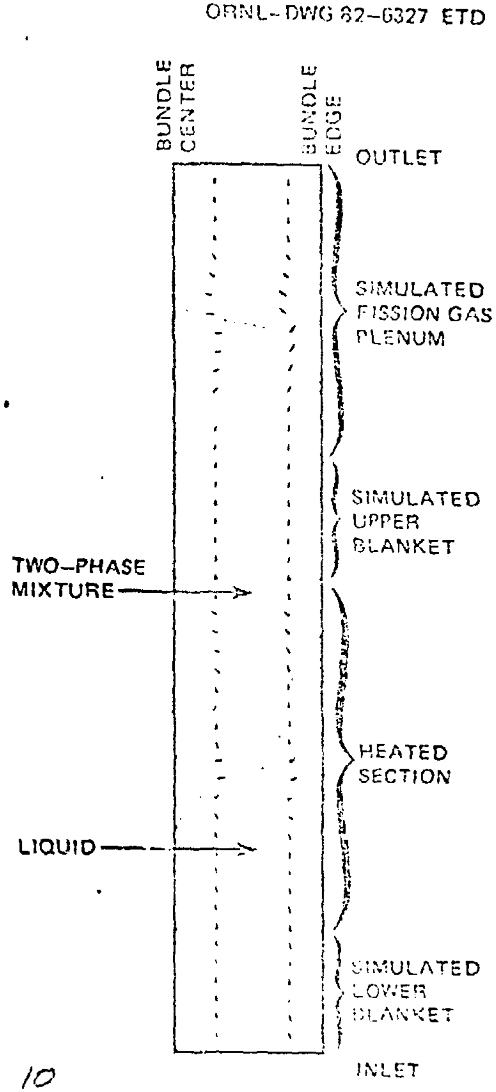


Fig. 10 THORAX mass flux field at 21.5 s into THORS-SHRS Assembly 1 Test 351 A/B Run 103.