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Energy Division

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Washington, DC 20555

Dear Jim,

Enclosed is a draft letter report that presents the results of the TRAC-PF1 upper-vessel-circulation calculation for the Surry TMLB′ accident sequence. The AB sequence calculation is completed and a discussion of the results will be included in the final version of the report.

Please call me if you have any questions or require futher information.

Sincerely yours,

Rudy

Rudolph J. Henninger
Safety Analysis

RJH:bn

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DRAFT

VAPOR CIRCULATION IN THE UPPER VESSEL OF THE SURRY PWR FOR THE TMLB′ ACCIDENT SEQUENCE

R. J. Henninger

I. INTRODUCTION

The above-core structures can provide a significant heat sink during a degraded core accident. In order to determine the extent to which the structures affect an accident, TRAC-PF1[1] calculations for the Surry Pressurized Water Reactor were performed. The sequence chosen was a total loss of feedwater with failure of the emergency core cooling (ECC) system (TMLB′). Core outflow conditions, that consisted of time-dependent steam and hydrogen mass flows and vapor temperatures, were used as boundary conditions for the TRAC-PF1 calculations. These core outflow conditions were calculated by means of the MARCH code and were provided to us by Battelle Columbus Laboratories.[2]

II. MODEL DESCRIPTION

A. TRAC Model

The TRAC model for the upper part of the Surry vessel is shown in Fig. 1. The model consists of 7 axial levels, 3 radial regions and 2 azimuthal sectors. The inner two radial nodes model the region inside of the core barrel. The first five axial levels correspond to the region between the core support plate and the upper support plate. The upper two axial levels model the upper head. In each of the four nodes inside of the core barrel there is a pipe that provides a connection between the bottom of the upper plenum and the upper head. These four pipes represent the 53 control rod guide tubes (CRGT) in the Surry vessel. Flow through the CRGTs is restricted by a small total flow area of 0.1254 m^2 near their tops. Small-area flow paths between the downcomer and upper head and the downcomer and the inner radial regions were also modeled. The hot leg with the pressurizer is connected to one of the two azimuthal sectors.

In TRAC-PF1, only one heat slab is allowed per node. The vessel noding was therefore chosen so that "thin" structures within the core barrel could be separated from "thick" structures such as the upper support structure and vessel walls. Thin structures were typically 0.006 to 0.008 m thick. The heat slabs in the fifth axial region, which includes the upper support are 0.022 m thick and those in the the outer radial node which models the vessel range from 0.15 to 0.30 m thick, depending upon the presence or absence of nozzles and flanges. The mass of the CRGTs was divided equally between the vessel component and the pipes used to represent the guide tubes. All of the heat-slab masses and surface areas were obtained from Westinghouse via Battelle Columbus Laboratories.[3]

B. Boundary Conditions

One of the boundary conditions for these calculations is the pressure in the hot leg. The other boundary condition, as indicated in Fig. 1, is the flow at the core outlet. The conditions for the TMLB′ sequence are given in Figs. 2-4. As shown in Fig. 2, the mass flows decrease from the time of core uncovery at 5730 s until approximately 8760 s. At 8760 s, the core slumps into water below the core region producing an increase in core outflow. The vapor temperature shown in Fig. 3 increases with the center (higher-power) node leading the outer node. The calculation was stopped when the temperature returned to the saturation temperature and the flow from the core region was steam. Figure 4 gives the total pressure and the hydrogen partial pressure at the core outlet central and outer radial regions. The total pressure remains near the relief valve setpoint (16.3 MPa) throughout the transient, and the fraction of flow that is hydrogen increases as the accident proceeds.

C. Initial Conditions

The TRAC-PF1 calculation of the TMLB′ sequence was begun when the core was uncovered and the vapor temperature at the core outlet began to increase above the saturation temperature. The initial conditions for the TMLB′ sequence were that the vessel and hot leg were at the saturation temperature corresponding to 16.3 MPa (622 K). This seems a reasonable assumption especially for the thin structures. The vessel temperature is not very important in these calculations because, as we shall see, there is not much flow to either the upper head or the downcomer.

III. RESULTS FOR THE TMLB SEQUENCE

The TMLB´ calculation was run at the initial conditions for 400 s (from 5360 to 5760 s). As the temperature of the vapor flowing from the core increased after 5760 s, a flow pattern similar to that depicted in Fig. 5 is developed. This pattern consists of two major convection cells. Most of the upflow is in the central radial cell that is on the side of the vessel next to the hot leg. The returning downflow is in the outer radial cells. The axial mass flow at the top of cell 2 in the vessel is given in Fig. 6. This pattern persists until the rapid flow increase that occurs when the core slumps at 8760 s. The flows within the upper plenum can be compared to the inflow from the core and the outflow through the hot leg which are given in Fig. 7. Comparison of Figs. 6 and 7 shows that the flow within the vessel remains large compared to the inflow and outflow. The vapor from the core is therefore well mixed with vapor in the upper plenum before it exits through the hot leg. This is seen in Fig. 8, which gives the core outlet vapor temperature and the vapor temperature in the hot leg. The decrease in temperature is a result of the mixing of the vapor from the core with the vapor already in the vessel. Until the flow increase at 8760 s, the temperature in the hot leg remains relatively low. The energy flows in the vessel are given in Fig. 9. This figure indicates that the major energy removal mechanism up to 8760 s is flow out through the hot leg. The heat slabs participate very little. The flow is therefore driven by density differences between the vapor in the vessel and the vapor leaving the core region.

The vapor entering the upper plenum from the core is less dense for two reasons. The first, of course, is that its temperature is higher. The second reason is that the fraction of the flow that is hydrogen is increasing. The importance of these mechanisms in driving flows will be examined by J. Dearing with his two-dimensional MELPROG flow module. Flow through the CRGTs was 5 kg/s or less and not important for energy transport. The flow directions with the CRGTs, as is indicated on Fig. 5, were similar to the flow pattern in the upper plenum, namely up the center radial pipe on the hot-leg side and down the other pipes. Flows in the CRGTs on the hot-leg side are given in Figs. 10 and 11.

The increase in mass flow associated with core slumping results in an altered flow pattern. The flow pattern at 8800 s is shown in Fig. 12. The convection cells persist but some of the vapor flows more directly to the hot leg. As the flow increases, so does the importance of the heat slabs. Figure 6 shows that the energy flow to the heat slabs becomes significant after 8760 s. The temperature of the heat slabs in Figs. 13 and 14 increases significantly following increased core outflow.

IV. CONCLUSIONS AND RECOMMENDATIONS

The important conclusions that result from these calculations are:

1. For the flows provided by Battelle Columbus, the vessel structures were not an important heat sink from the time of core uncovery until the time of core slumping;
2. Flow driven by differences in density between the vapor exiting the core and vapor present in the vessel resulted in mixing and lower temperature vapor exiting the vessel;
3. Flow areas of the connections between the upper plenum, upper head, and downcomer are too small to be of any importance to the energy flows; and
4. The vessel structures become more important as heat sinks when the core outlet flow increases following slumping.

I believe that a coupled multi-dimensional analysis of this accident that included the core region would produce higher flow from the core region thereby increasing the importance of above-core structures. I therefore recommend that this calculation be re-run when such a capability exists. This accident sequence will provide an excellent test for the multi-dimensional version of TRAC/MELPROG.

REFERENCES

1. Safety Code Development Group, "TRAC-PF1, An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Analysis," Los Alamos National Laboratory report LA-9944-MS (NUREG/CR-3567), February 1984.

2. Roger O. Wooton, Battelle Columbus Laboratories, private communication March 27, 1984.

3. Peter Cybulskis, Battelle Columbus Laboratories, private communication October 1983.

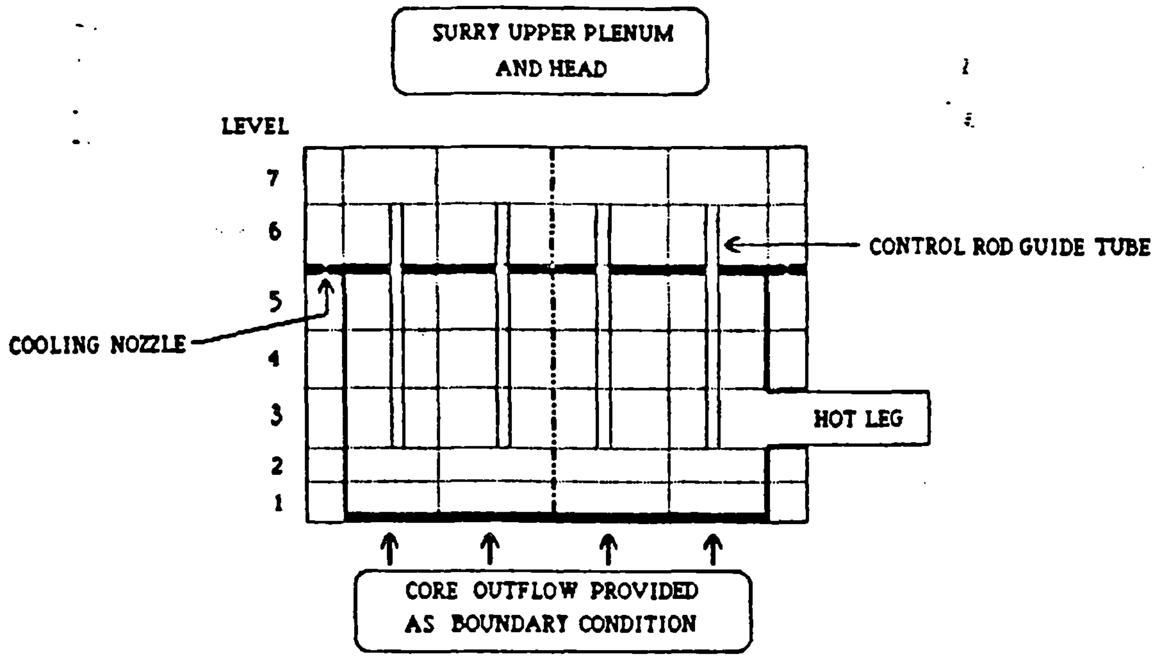

Fig. 1.
TRAC noding diagram for Surry upper vessel.

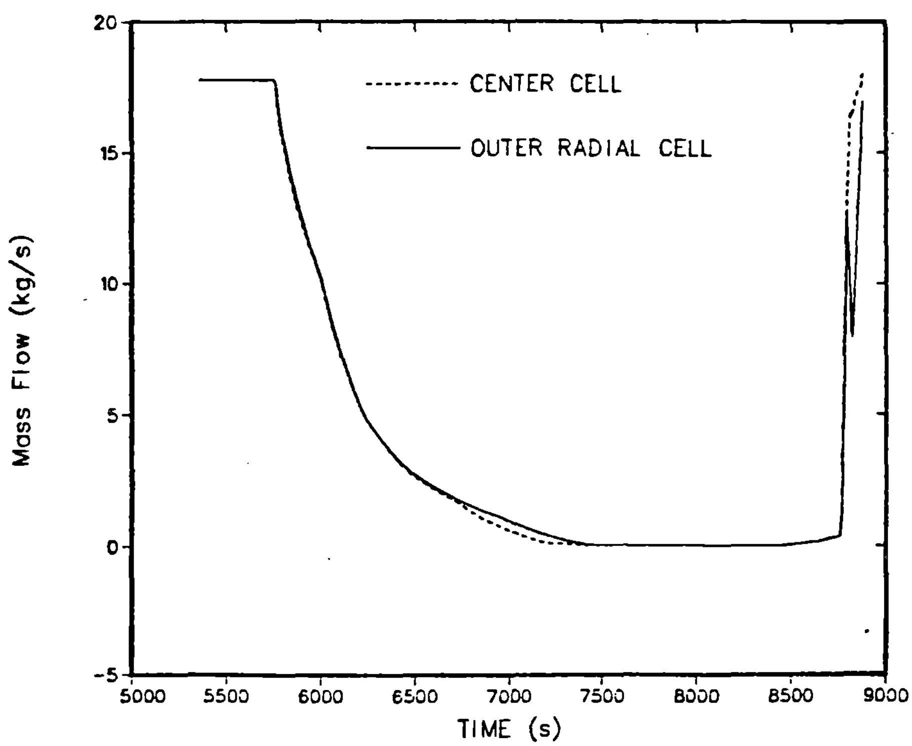

Fig. 2.
Outlet mass flow for the two radial regions in the core. The flows are azimuthally symmetric.

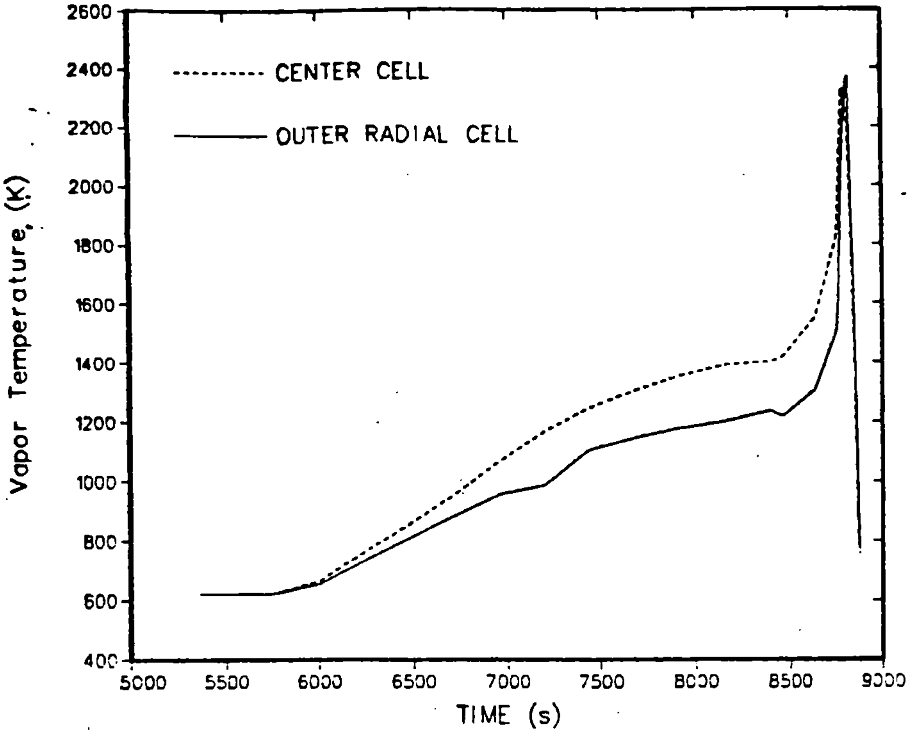

Fig. 3.
Outlet vapor temperatures for the two radial regions in the core.

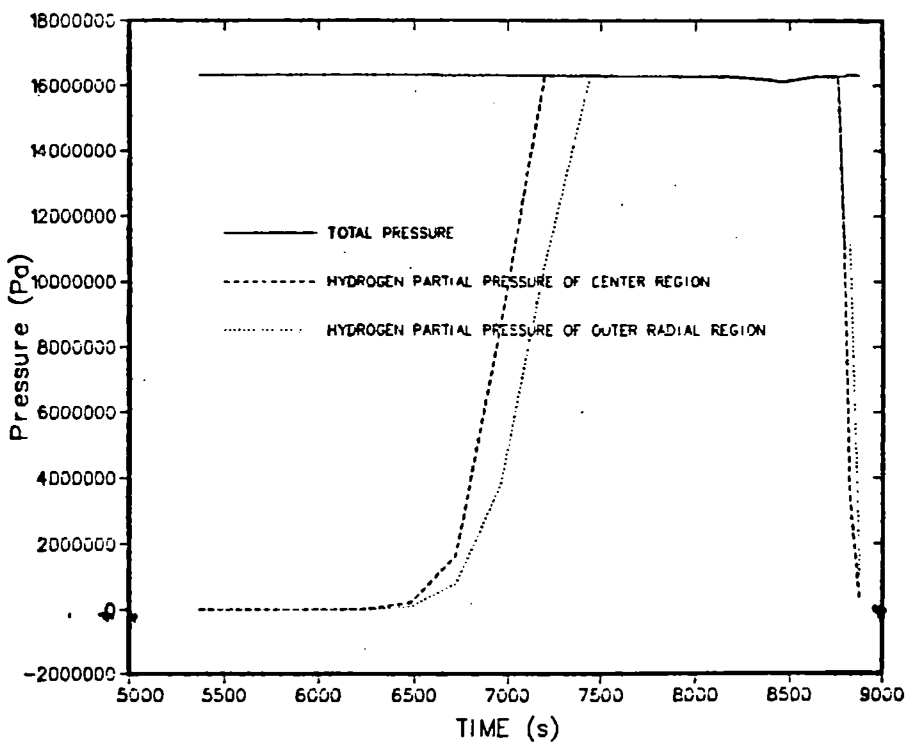

Fig. 4.
Total pressure and partial pressures of hydrogen at the core outlet. Pressure drops through the system are small, so the total pressure throughout the primary remain near this pressure.

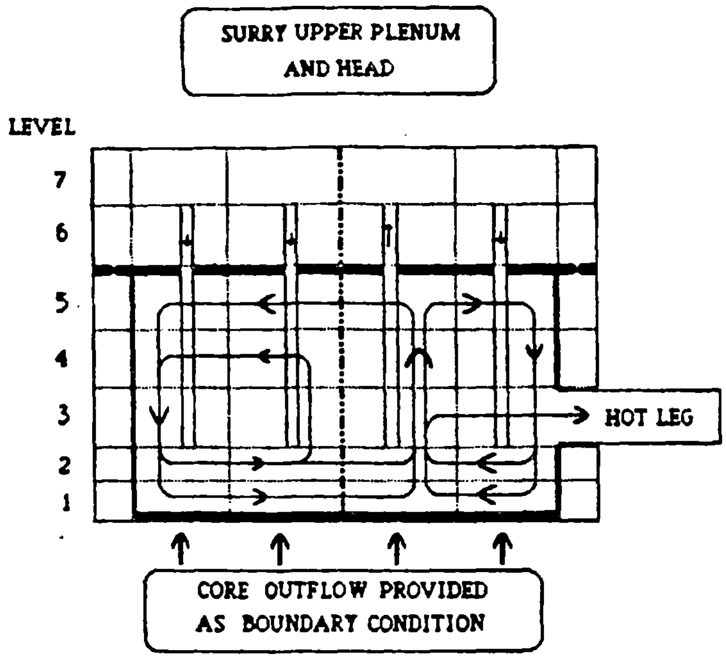

Fig. 5.
Flow pattern in the upper plenum for TMLB' sequence from core uncovery to core slumping. This flow is driven mainly by density differences between vapor exiting the core and vapor already present in the vessel. The vessel heat slabs are of little importance because of the limited core outflow in this time regime. Flow in the CRGTs was limited and of little importance.

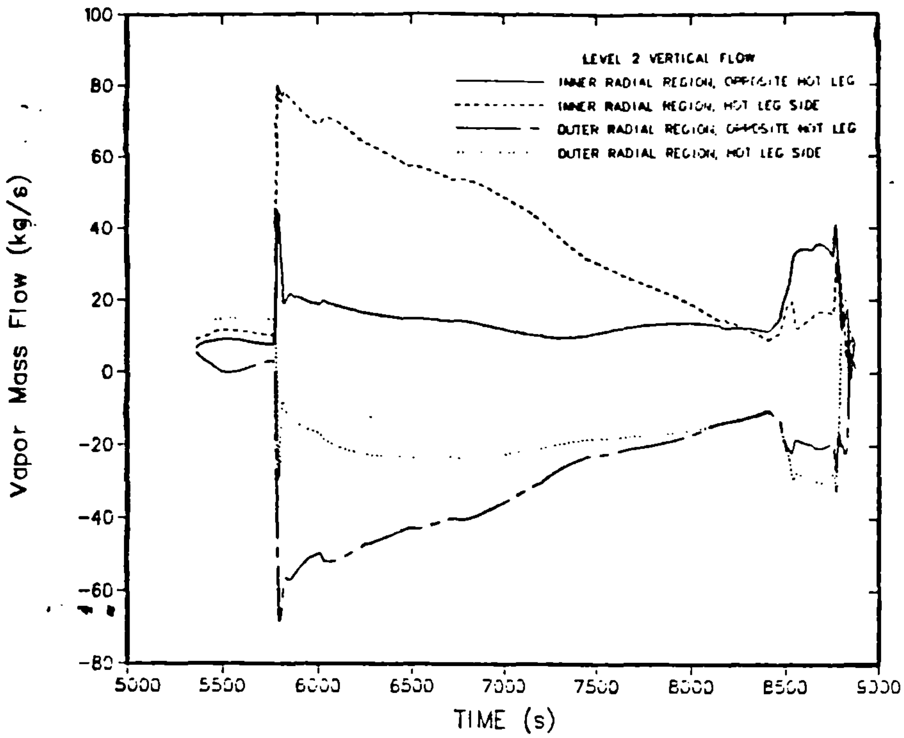

Fig. 6.
Vapor mass flows for the four segments within the core barrel at the top of axial level 2. This figure shows that the vapor flows up the center cells and down the outside cells as depicted in Fig. 5.

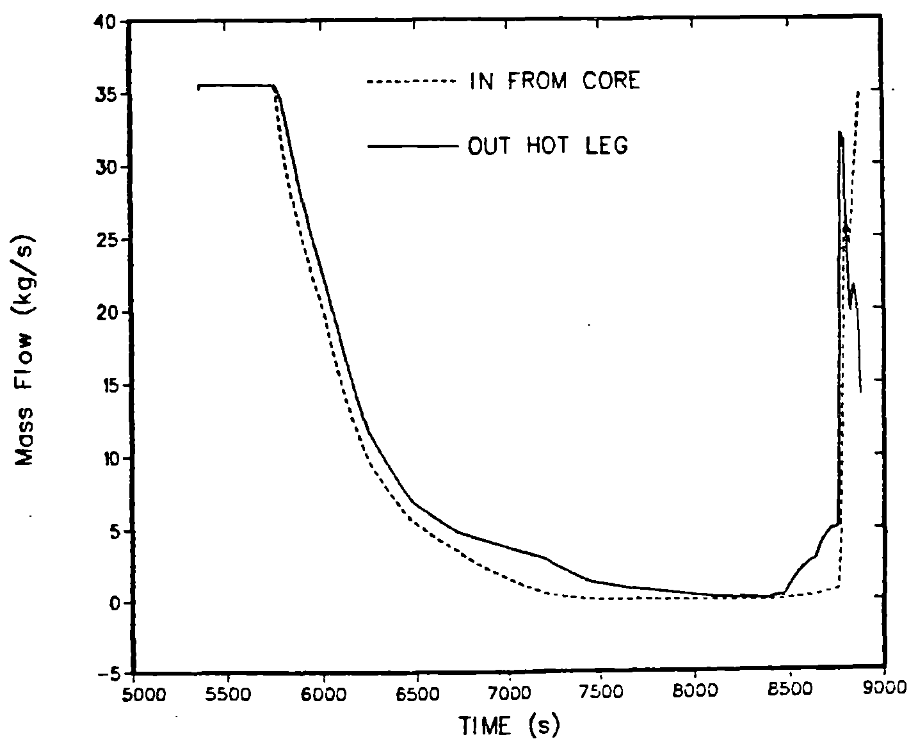

Fig. 7.
Mass flows entering the upper plenum from the core and exiting through the hot leg for the TMLB′ transient.

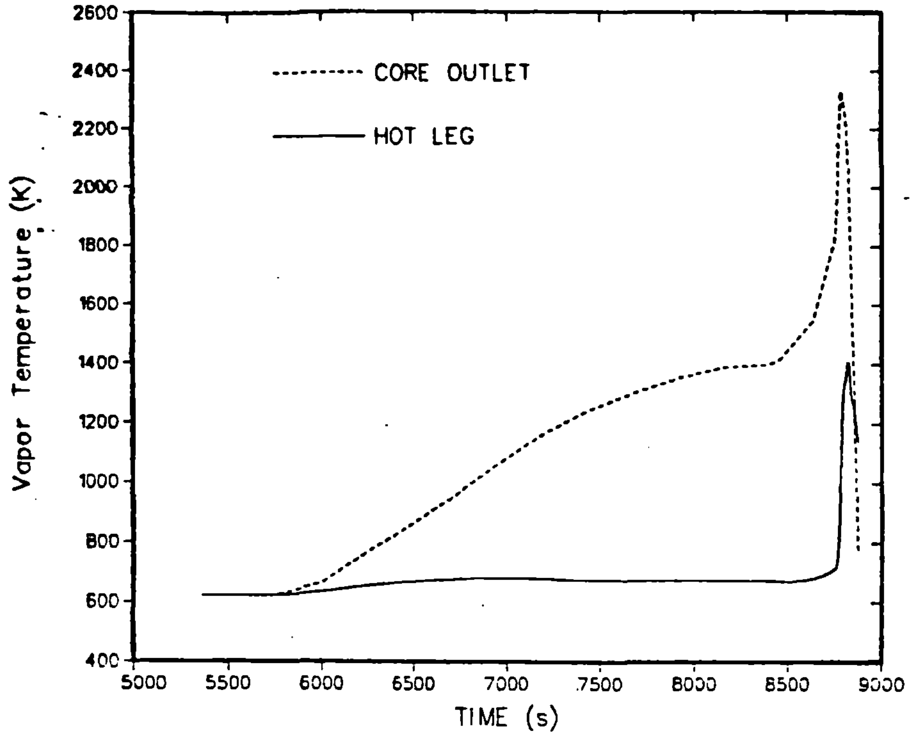

Fig. 8.
Core exit and hot-leg vapor temperatures for the TMLB′ transient. The vapor temperature in the hot leg does not increase significantly until the core slumps at 8760 s.

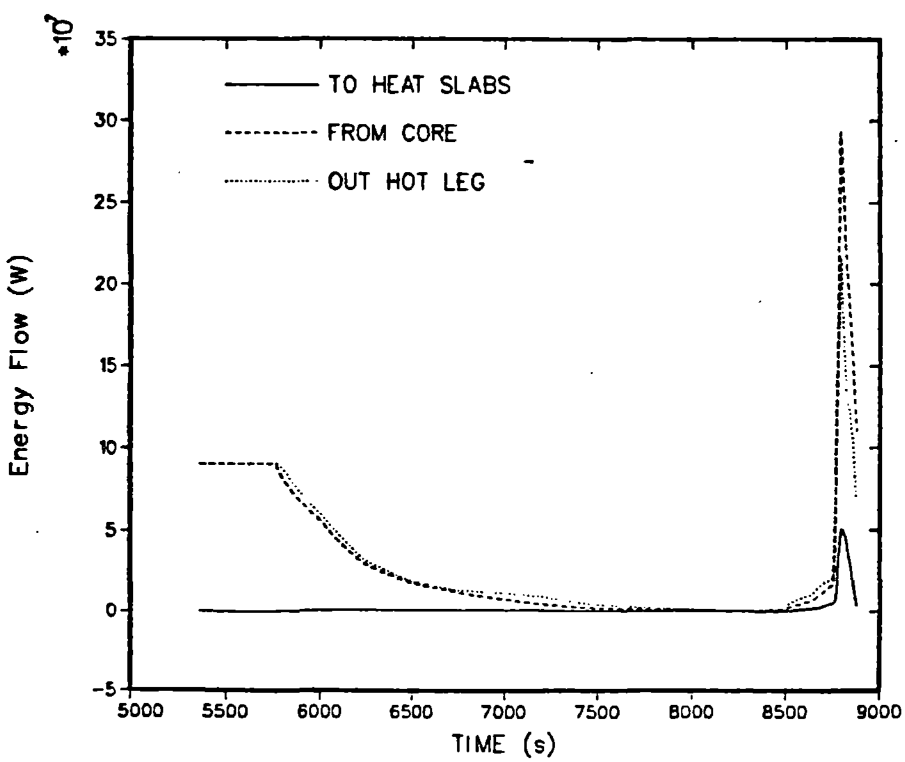

Fig. 9.
Energy flows from the core, out the hot leg and to the vessel heat slabs for the TMLB′ transient. The heat slabs are not important until the core slumps and the mass flow from the core region increases.

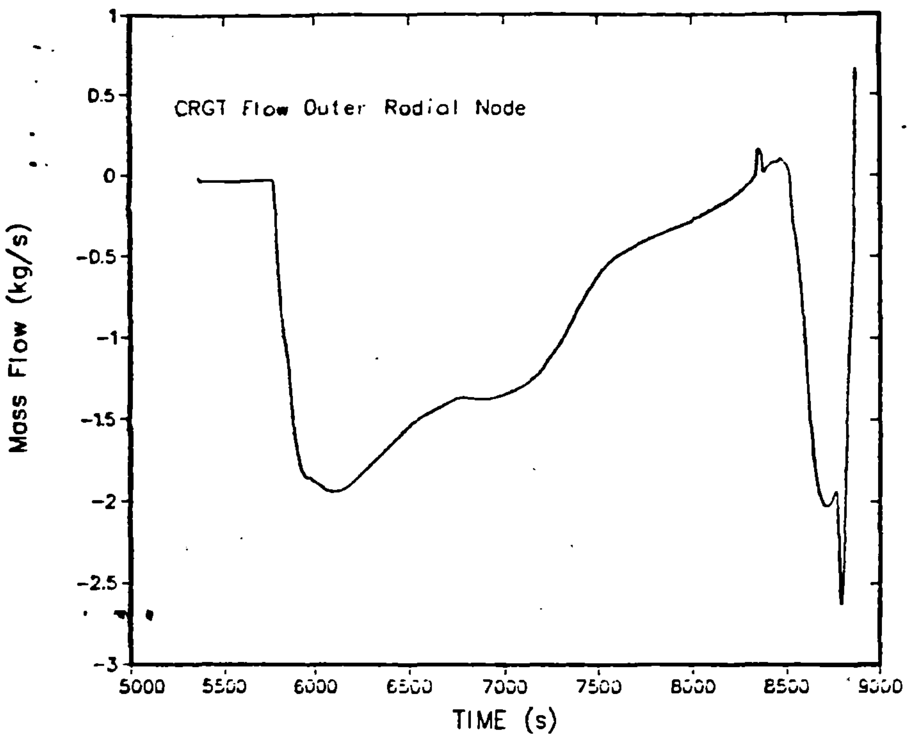

Fig. 10.
Flow in the CRGT in the center on the hot-leg side.

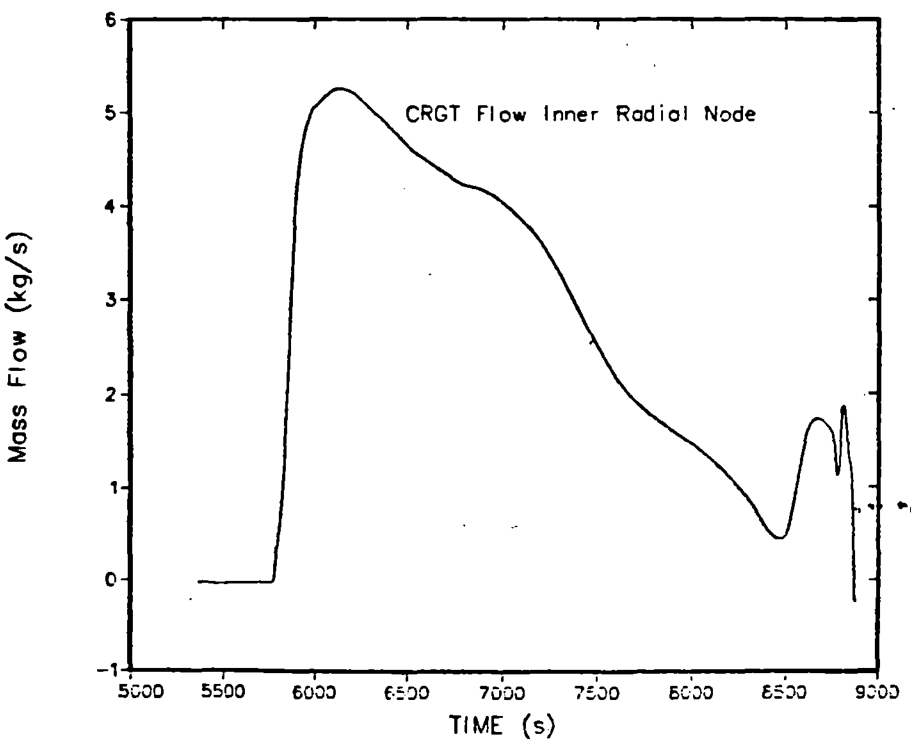

Fig. 11.
Flow in the CRGT in the outer radial node on the hot-leg side.

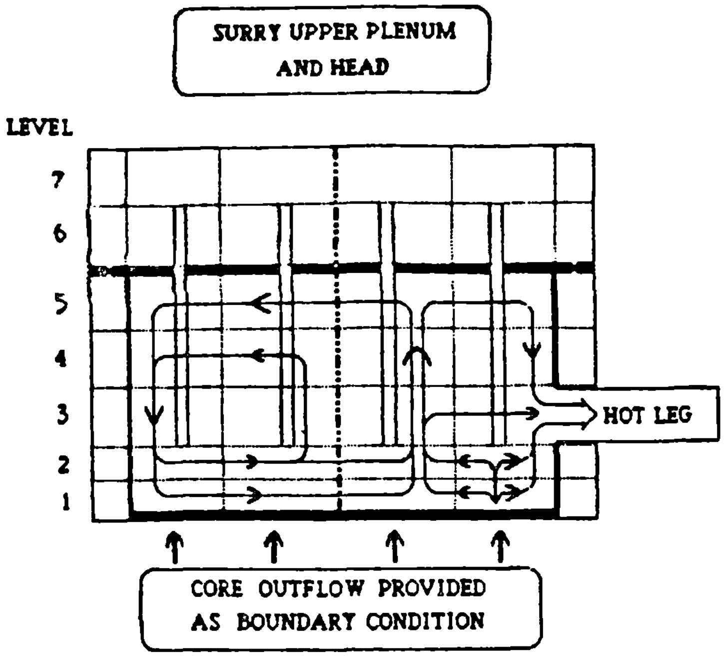

Fig. 12.
Flow pattern in the vessel at 8800 s. Some of the vapor from the core exits directly to the hot leg.

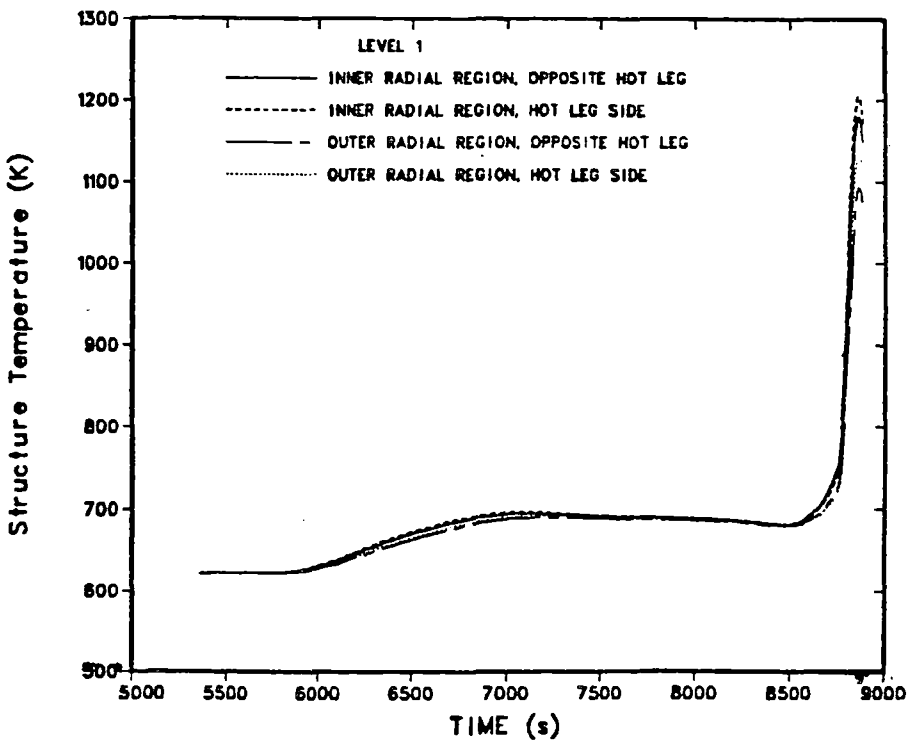

Fig. 13.
Surface temperatures of the heat slabs in level 1 for the two radial regions within the core barrel.

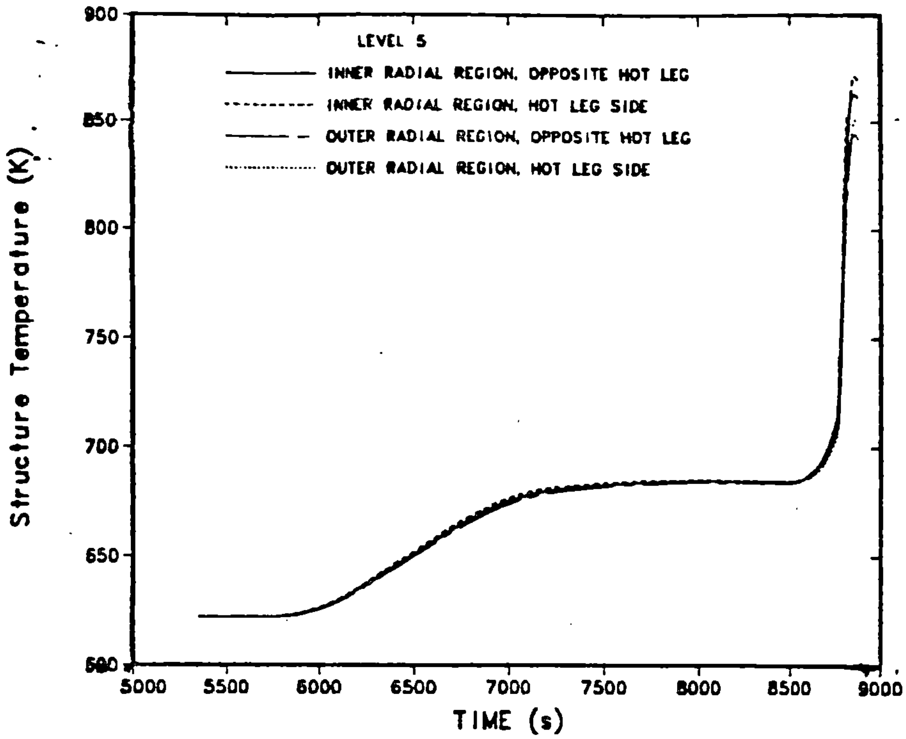

Fig. 14.
Surface temperatures of the heat slabs in level 5 for the two radial regions within the core barrel.