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TRAC-PF1/MOD1 ANALYSIS OF A 200% COLD-LEG BREAK IN A US/JAPANESE PWR WITH FOUR LOOPS AND 15×15 FUEL*

by

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ABSTRACT

This report presents the results of a TRAC-PF1/MOD1 calculation that simulated a 200% double-ended cold-leg-break loss-of-coolant accident in a generic US/Japanese pressurized water reactor. This is a best-estimate analysis using conservative boundary conditions and minimum safeguards. The calculation shows that the peak cladding temperature (PCT) occurs during blowdown and that the core reheat is minimal during reflood. The results also show that for an evaluation-model peak rod linear power of 15.85 kW/ft, a PCT of 1084 K is reached at 3.5 s into the blowdown transient, which is ~394 K below the design basis limit of 1478 K.

INTRODUCTION AND SUMMARY

This report presents the results of a 200% doubled-ended cold-leg-break loss-of-coolant accident (LOCA) in a generic US/Japanese pressurized water reactor (PWR) with four loops and 15×15 fuel. The calculation was performed with the TRAC-PF1/MOD1 code (Ref. 1), which is a best-estimate, multidimensional, nonequilibrium, thermal-hydraulic computer code developed for the US Nuclear Regulatory Commission (USNRC) by Los Alamos National Laboratory. The boundary and initial conditions represent the minimum safeguards conditions that may occur at an actual plant as opposed to the most probable conditions; therefore, the basis for the minimum safeguards conditions is taken from the worst time in the plant life, in which the power peaking and stored energy are highest and offsite power is lost.

The calculation used an input deck similar to that of a previously reported calculation[2] for a UK-Sizewell reactor with 17×17 fuel. Therefore, the accumulator models were changed to simulate the US/Japanese typical design and the core model was modified to simulate 15×15 fuel in the core. The upper head simulated in this calculation was a top-hat design; therefore, there was less fluid in the upper head in this vessel model as compared to the model in reference 2.

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* Work performed under the auspices of the US Nuclear Regulatory Commission.

The important conclusions of this analysis are:

1. A PCT of 1084 K for the highest powered evaluation-model (EM) rod (peak linear power 15.85 kW/ft) occurred during blowdown at 3.5 s.
2. A PCT of 920 K for the highest-powered best-estimate (BE) rod occurred during blowdown at 3.5 s.
3. A PCT of 897 K for the highest averaged power rod (peak linear power 9.13 kW/ft) occurred during blowdown at 3.5 s.
4. The maximum cladding temperature of the BE rods remained below 850 K during the refill and reflood phases of the transient.
5. The maximum cladding temperature of the EM rods remained below 1050 K during the refill and reflood phase of the transient.
6. Blowdown ended at 26 s.
7. ECC liquid entered the core at 39 s.
8. Accumulator nitrogen began to flow into the cold legs at ~45 s, producing an increase in cold-leg pressure and a surge of liquid into the core.
9. Accumulators in the intact loops emptied at ~49 s.
10. End of accumulator flow was followed by a slow filling of the core. All of the BE rods were quenched by 170 s.
11. By 180 s the EM rods cooled to below 780 K. Quenching of the EM rods is estimated to occur before 220 s.

RESULTS

The sequence of events for this transient is given in Table I. The low-pressure set point in the pressurizer (12.41 MPa) is tripped at 1.85 s. A comparison of Figs. 1 and 2 shows that the pressurizer pressure is lagging behind the upper-plenum pressure during the early phases of the blowdown. This behavior can be attributed to the high flow resistance and to the flashing of liquid in the pressurizer surge line. The reactor-coolant system pumps are tripped by the low-pressure trip signal from the pressurizer; therefore, pump coastdown begins at 1.85 s.

It is assumed that a 0.1-s delay occurs between initiation of scram and tripping of the low-pressure set point in the pressurizer. Therefore, reactor scram is initiated at 1.95 s. Figure 3 shows that reactor power begins to drop before the reactor is scrammed. This behavior is caused by the point reactor-kinetics model option in TRAC that allows a reactor-kinetics calculation rather than user input of power versus time (used in previous calculations [2,3]) to determine reactor power. The rapid core voiding that occurs during the first few seconds of the blowdown (Fig. 4) results in reduced neutron moderation in the core, which in turn causes the power to drop as the core voids.

As can be seen from Fig. 4, the core starts to refill again at ~3 s into the transient. This refilling will increase the neutron moderation in the core; however, Fig. 3 shows that the reactor power continues to decrease. This behavior is caused because scram occurrs before core refill, therefore, neutron moderation has no effect on core power. The transient power given in Fig. 3 and calculated by TRAC included the effects of void reactivity feedback.

moderator temperature feedback, Doppler feedback, time-dependent scram reactivity, and the 1979 ANS decay-heat power,[1] assuming infinite operating period with ^{235}U fuel.

Figure 5 shows that the PCT in the average hot rod location (9.13 kW/ft) of 897 K occurs at ~3.5 s. The core heatup caused by voiding during the first seconds of the blowdown is terminated by the refill that starts at ~3 s. The core refill from ~3 to ~15 s illustrated in Fig. 4 is caused by the core flow turning positive as the three intact-loop flows exceed the broken-loop two-phase flow. This behavior has been observed in LOFT experiments[5] and other TRAC transient plant calculations.[2,3] As the blowdown continues, core dryout occurs again. However, steam flow rates through the core are high enough to prevent significant heatup until refill begins at ~25 s.

At the end of blowdown and at the beginning of refill, steam flows through the core are insufficient for adequate cooling, and core heatup occurs again from ~20 to ~40 s. This second core heatup is terminated by the beginning of core recovery that occurs at ~39 s. A very rapid core cooldown occurs from ~40 to ~55 s as the intact accumulators empty and nitrogen gas from the accumulators enters the cold legs and the top of the downcomer. This nitrogen gas has the effect of reducing the condensation rate in the intact cold legs and pressurizing the intact cold legs and downcomer. As can be seen from Fig. 4, this results in a core refill to ~70% liquid full just before 50 s. From ~55 to ~170 s, the core slowly cools and quenches with no other significant heatups in the average rods. From Figs. 4 and 6 it can be seen that late in the reflood some manometer-like oscillations occur between the core and downcomer.

Figures 7 and 8 show typical rod surface temperature plots for an average hot rod (9.13 kW/ft peak linear power) and a peak best-estimate rod (10.59 kW/ft peak linear power). The peak zone best-estimate rods exhibit similar behavior to the average rods. However, the PCT is slightly higher and the time to quench is longer.

Figure 9 shows typical rod-surface temperatures for an EM rod (15 85 kW/ft peak linear power). For the EM rod, the maximum cladding temperature during blowdown is higher than those of the average rod and the peak BE rod. In addition, a third heatup occurs at ~60 s in the upper half of the rod. This third heatup in the EM rods is terminated at ~90 s when the core has again filled to ~50% full of liquid. From Fig. 10, which is the maximum cladding temperature of all the EM, it can be seen that during reflood the third EM rod heatup is terminated at ~1030 K. The quench time for the EM rods can be estimated from Fig. 10 to be within 200 s, although the calculation was stopped at about 180 s.

CONCLUSIONS

TRAC-PF1/MOD1 has been applied to analysis of a US/Japanese PWR with four loops and 15 × 15 fuel during a large-break LOCA. The results indicate that even with very conservative boundary conditions, the PCT reached is 1084 K, leaving a margin of ~394 K below the design basis limit of 1478 K. Also, the best-estimate rod temperature for an average rod in the core remained below 850 K throughout the transient. The injection of accumulator nitrogen caused an increase in cold-leg pressure and a resultant surge of liquid to flow into the core. This had a major effect on the core reflood, and helped terminate the core heatup.

REFERENCES

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2. P. I. Coddington and F. Motley, "TRAC-PF1/MOD1 Analysis of a Minimum Safeguards Large-Break LOCA in a 4-loop PWR with 17×17 Fuel," UK–Winfrinth document AEEW-R 1772, February 1985.
3. R. K. Fujita, F. Motley, K. A. Williams, "TRAC-PF1 Analysis of a Best-Estimate Large-Break LOCA in a Westinghouse PWR with Four Loops and 17×17 Fuel," Los Alamos National Laboratory document LA-UR-85-858 (March 1985).
4. American Nuclear Society Proposed Standard, "Decay Heat Power in Light Water Reactors," ANSI/ANS-5.1-1979.
5. "TRAC-PD2 Independent Assessment," Los Alamos National Laboratory draft report (May 1984).

TABLE I

SEQUENCE OF EVENTS FOR US/JAPANESE PWR LOCA CALCULATION

Event	Time (s)
Transient started	0.0
Low-pressure set point in the pressurizer tripped	1.85
RCS pumps tripped	1.85
Reactor scram initiated	1.95
Average rod PCT reached (~897 K)	3.5
Broken loop accumulator flow initiated	5.0
SG feedwater flow terminated	6.85
Pressurizer empty	13.0
Intact-loop accumulator flows initiated (loops 1, 2, and 4)	14.6
End of blowdown	25.0
Broken-loop (3) accumulator empty	37.0
Beginning of core recovery	39.0
Intact-loop (1, 2, 4) accumulator empty	49.0
Core completely quenched	170.0

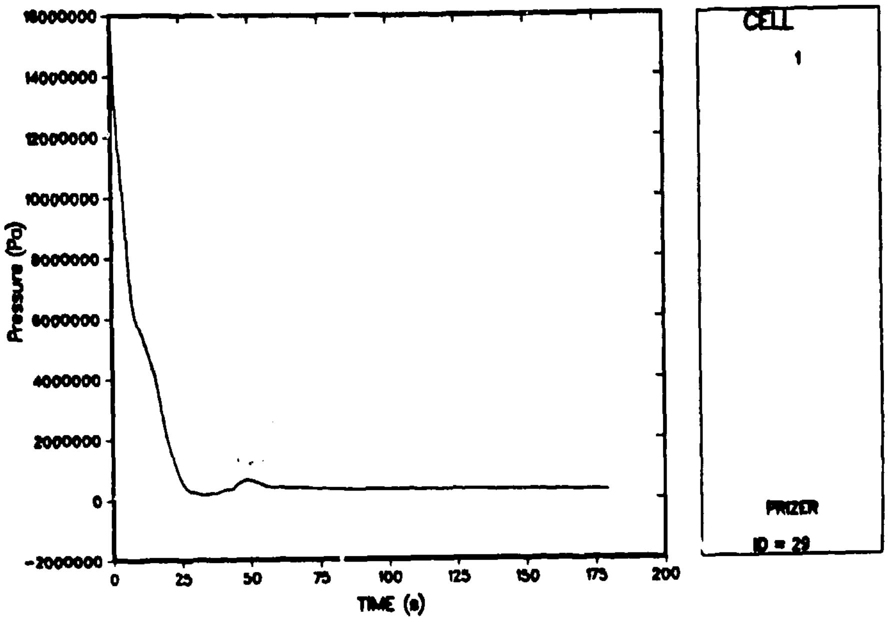

Fig. 1.
Pressurizer pressure.

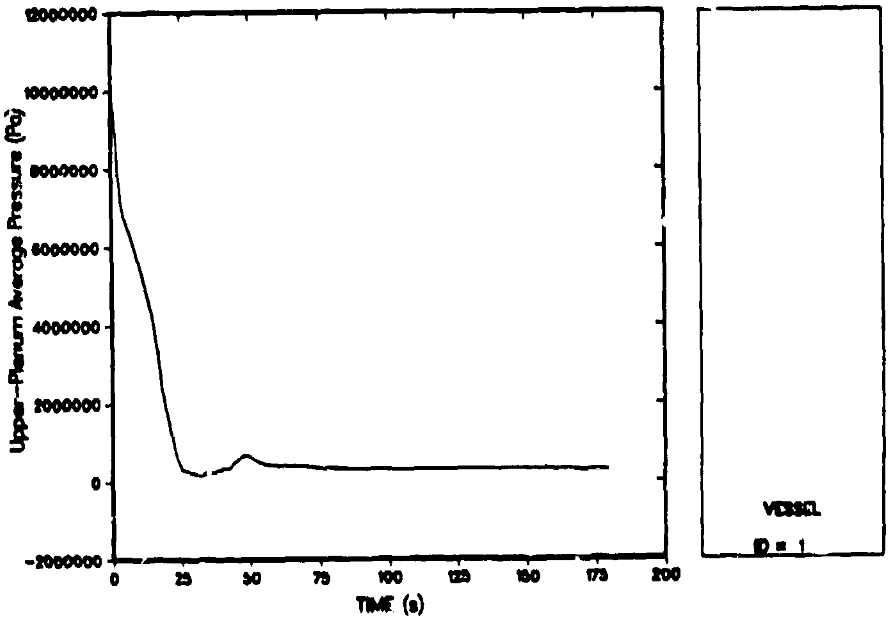

Fig. 2.
Upper-plenum average pressure.

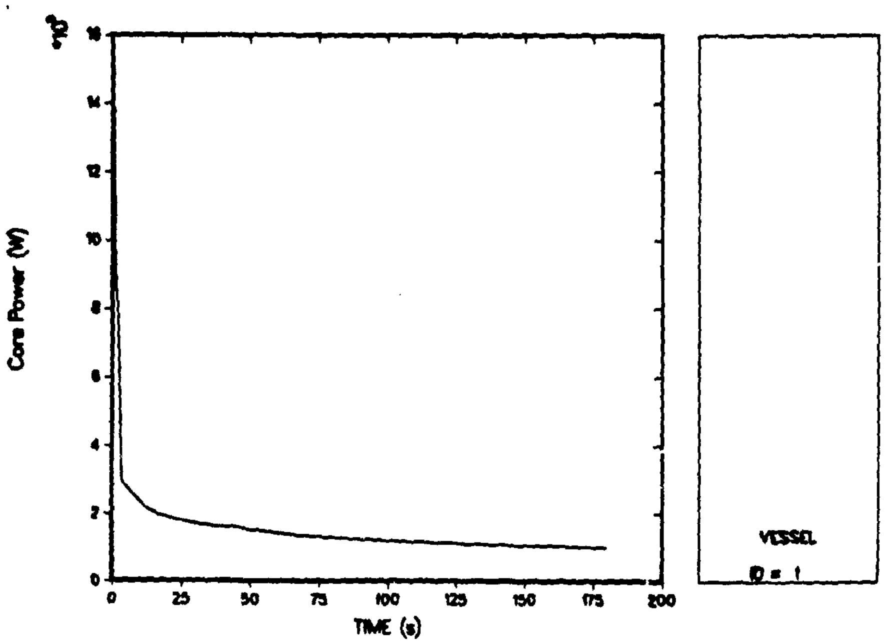

Fig. 3.
Reactor power.

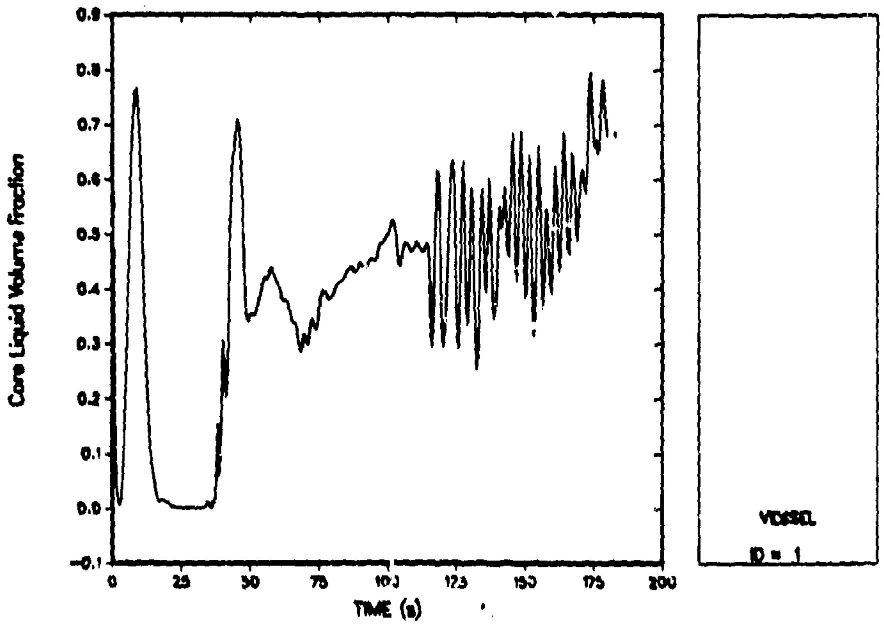

Fig. 4.
Core liquid volume fraction.

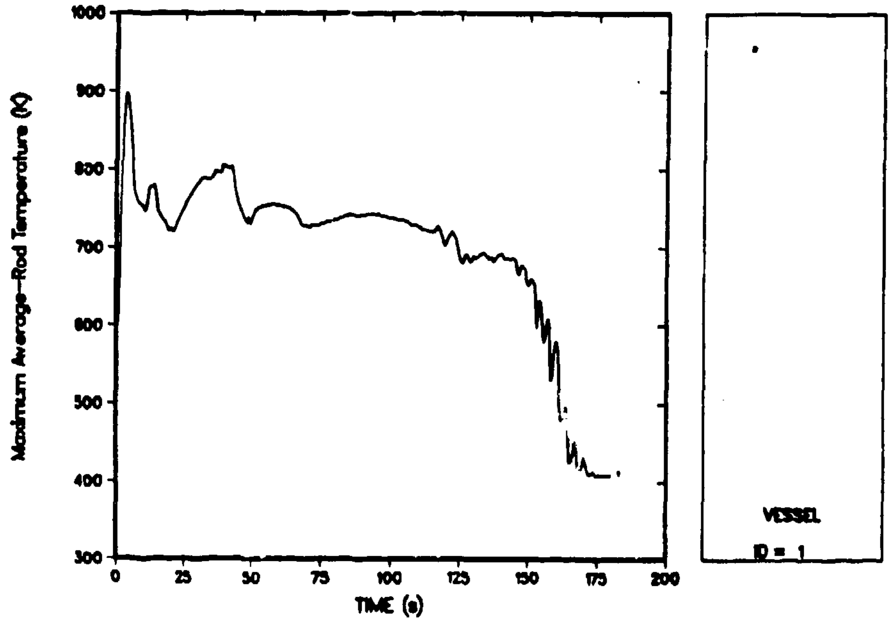

Fig. 5.
Maximum average rod temperature.

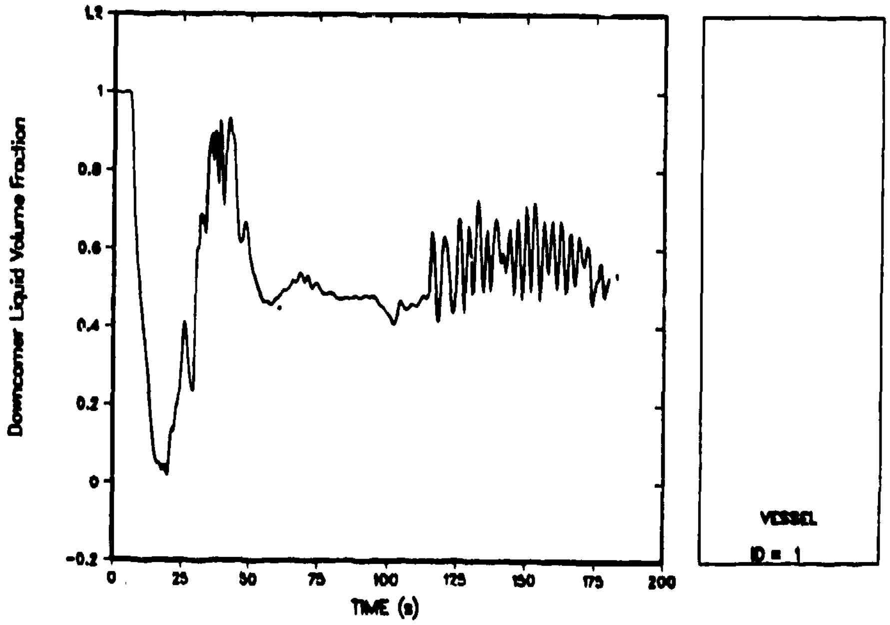

Fig. 6.
Downcomer liquid volume fraction.

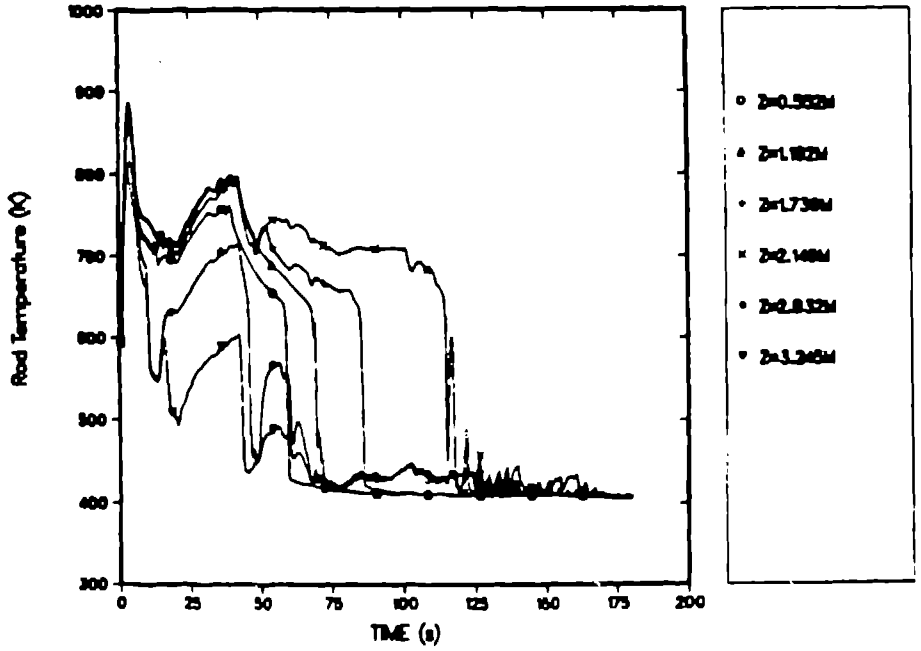

Fig. 7.
Rod 1 surface temperature.

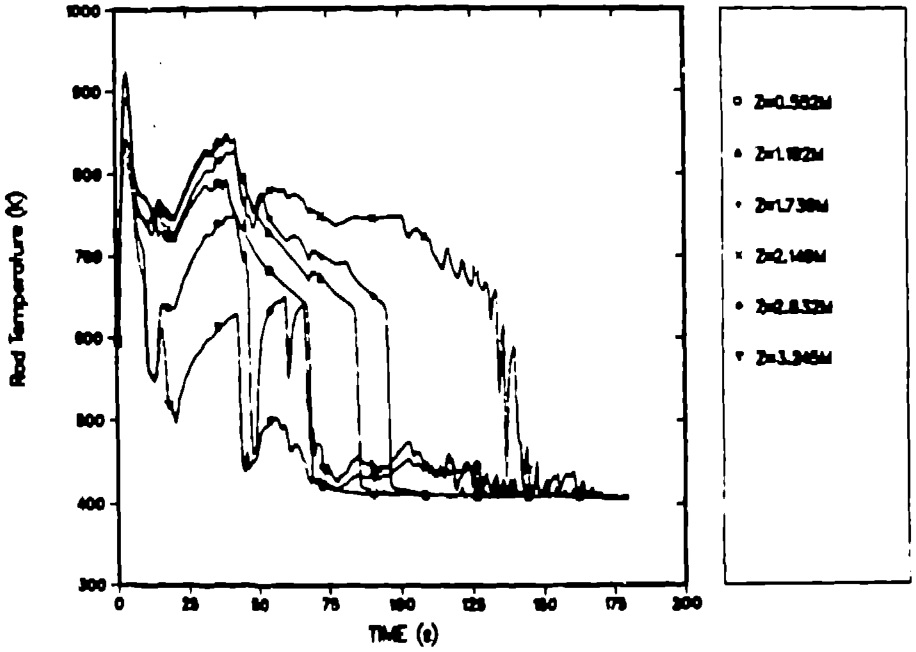

Fig. 8.
Rod 17 surface temperature.

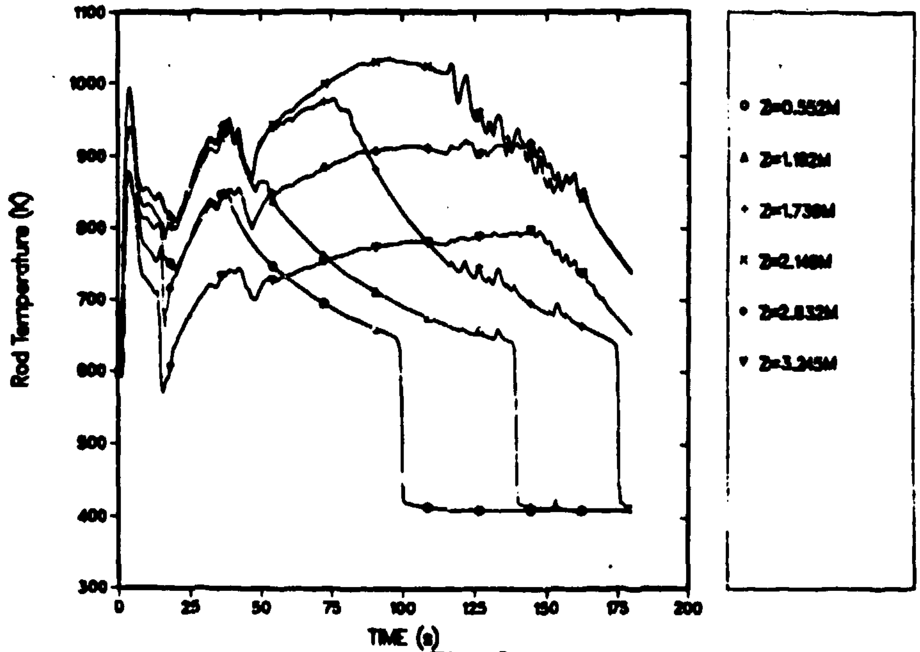

Fig. 9.
Rod 36 surface temperature.

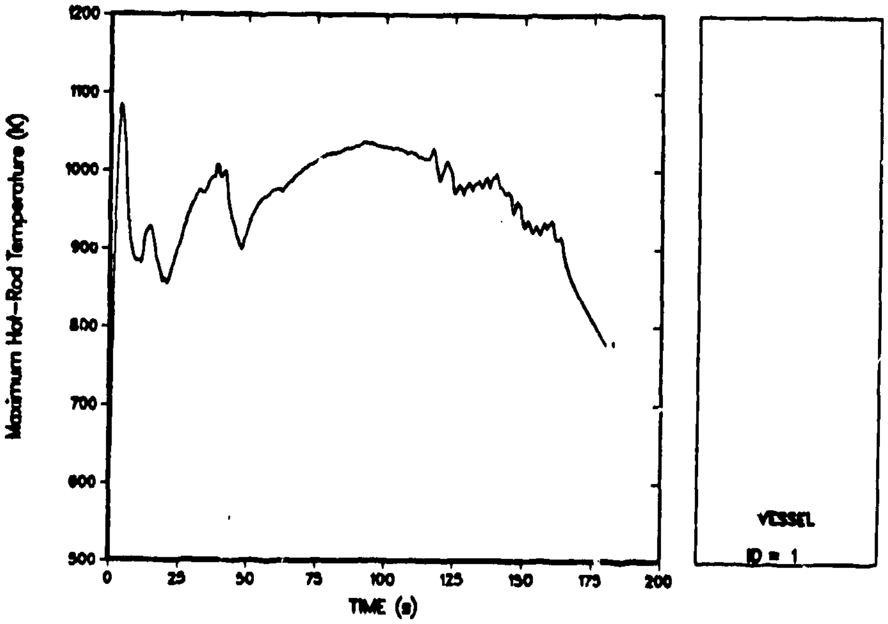

Fig. 10.
Maximum EM rod temperature.