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Millstone Unit 2 Uncontrolled CEA Bank Withdrawal from Subcritical/Startup Analysis

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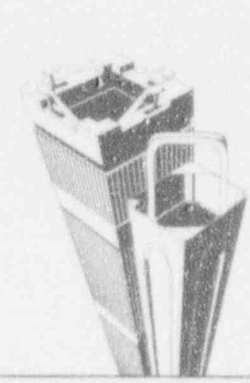

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Nuclear Division

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Millstone Unit 2 Uncontrolled CEA Bank Withdrawal from Subcritical/Startup Analysis

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1. Introduction

This report describes an analysis of the Uncontrolled Control Element Assembly (CEA) Bank Withdrawal from a Subcritical or Low Power Startup Condition event for the Millstone Unit 2 nuclear power plant. This event and its acceptance criteria are defined in Section 15.4.1 of the USNRC's Standard Review Plan.[1]

The analysis scope includes the following calculations:

- Coupled thermal-hydraulic/kinetics analysis of the plant response to the event
- Neutronics analysis of the axial and radial power distributions which can occur during the event, as well as the applicable CEA bank reactivity worths
- Flow/enthalpy distribution analysis of the core and departure from nucleate boiling (DNB) analysis of the peak-power fuel assembly at the time of maximum fuel rod heat flux
- Thermal analysis of the peak-power fuel pellet at the time of maximum fuel temperature

As discussed in Reference 2, the original licensing-basis Uncontrolled CEA Bank Withdrawal from Subcritical/Startup analysis performed for Millstone Unit 2 took credit for a Startup Rate reactor trip. Thus, cases initiated from subcritical conditions became nonlimiting, and the case initiated from a critical condition became limiting. However, as discussed in Reference 3, the Startup Rate trip was physically removed from the Millstone Unit 2 Reactor Protection System (RPS) in 1978.

Siemens Power Corporation (SPC) began supplying reload fuel and performing licensing analyses for Millstone Unit 2 in 1988 (Cycle 10). The Uncontrolled CEA Bank Withdrawal from Subcritical/Startup analysis performed by SPC for Millstone Unit 2 at that time is described in Section 15.4.1 of Reference 4. That analysis did not take credit for a Startup Rate trip. The plant response calculations of that analysis used a conservatively low initial power level to bound cases initiated from both subcritical and low-power conditions.

The analysis described in this report is based on the current licensing-basis plant response results (described in Section 15.4.1 of Reference 4 and repeated here for completeness). This analysis also includes a neutronics evaluation of a wider range of axial and radial power distributions for the event than was previously considered, as well as DNB and peak fuel temperature calculations based on those power distributions. The analysis bounds operating conditions for Cycles 10 through 13.

2. Summary

The analysis results (presented in Section 7) demonstrate that the fuel does not experience DNB or centerline melt during the event:

- The minimum DNB ratio[a] (MDNBR) is well above the 95/95 safety limit of the DNB correlation.
- The maximum fuel centerline temperature is well below the fuel melting point.

Thus, the Uncontrolled CEA Bank Withdrawal from Subcritical/Startup acceptance criteria are satisfied for operation of Millstone Unit 2 during Cycles 10 through 13 (and future cycles bounded by the conditions of this analysis) without the Startup Rate trip.

(a) The DNB ratio is defined as the ratio of the DNB heat flux to the operating heat flux.

3. Event Description

The Uncontrolled CEA Bank Withdrawal from Subcritical/Startup event is initiated from a subcritical or low-power startup condition[a] by a malfunction in the reactor control or CEA control systems which causes the uncontrolled withdrawal of one or more wired-in-common CEA banks.

As the CEAs are withdrawn, reactivity rises. When the reactor conditions approach prompt-criticality, the power level begins to rise rapidly.

When the power level reaches the Variable Overpower RPS trip setpoint, a scram signal is issued. As the scram signal is being transmitted, the power level continues to rise rapidly.

Before scram CEA insertion actually begins, rising fuel temperatures--together with the negative Doppler reactivity coefficient--arrest the power rise. After scram CEA insertion begins, the power level begins to drop rapidly. Although the peak power level is much higher than the rated power level, the brevity of the power spike precludes excessive energy deposition.

The DNB acceptance criterion is challenged by this event because of pronounced axial and radial power peaking (associated with the range of CEA insertion configurations as the CEAs withdraw). For Millstone Unit 2, the DNB acceptance criterion is also challenged by reduced Reactor Coolant System (RCS) pressure (allowed by the Technical Specifications[5] for a Mode 3 initial condition [as discussed in Section 5.1.2 of this report]).[b]

The fuel melt acceptance criterion is challenged by this event because of the power spike and the pronounced axial and radial power peaking.

(a) The most limiting scenario (as described in this section) is preceded by an extended shutdown. The extremely low neutron population under such conditions delays the power rise as the CEAs withdraw until a significant amount of positive reactivity has been added. This maximizes the subsequent power excursion.

(b) The increases in the core-average fuel rod heat flux and RCS temperatures which occur during this event provide less of a challenge to the DNB acceptance criterion than do the corresponding values for normal operation at rated power.

4. Analytical Methods

The methods used to perform the analysis are described in References 6 through 8.

The PTSPWR2 code[9] has been used to perform a coupled thermal-hydraulic/kinetics analysis of the plant response to the event. The input parameters have been conservatively biased in accordance with Section 15.4.1 of Reference 6 (as described in Section 6 of this report).

The XTGPWR code[10] has been used to perform neutronics analyses of the axial and radial power distributions which can occur during the event, as well as the applicable CEA bank reactivity worths (as discussed in Section 6.1 of this report).

Based on the PTSPWR2-calculated overall core conditions at the time of the maximum core-average fuel rod heat flux and a range of XTGPWR-calculated axial and radial power distributions which can occur during the event, the XCOBRA-IIIC code[11] has been used to perform flow/enthalpy distribution analyses of the core and DNB analyses of the peak-power fuel assembly. The XNB DNB correlation used in the analyses is described in Reference 12.

Also, based on the PTSPWR2-calculated maximum centerline temperature of the core-average fuel rod and the XTGPWR-calculated maximum total power peaking, a calculation of the peak-power fuel pellet's maximum temperature has been performed.

5. Disposition and Justification

5.1 *Operating Modes*

5.1.1 Modes 4 Through 6

The Technical Specifications require that the CEA drives be de-energized in Modes 4 through 6 whenever the RCS boron concentration is less than that required for refueling. Thus, an uncontrolled CEA bank withdrawal from these modes either is impossible (if the CEA drives are de-energized) or cannot result in criticality (if the RCS boration satisfies the refueling requirement).[a]

5.1.2 Modes 3 and 2

The Technical Specifications allow the CEA drives to be energized in Mode 3 (with no restriction on RCS boration) if all of the following criteria are satisfied:

- Four reactor coolant pumps are operating.
- The RCS temperature is greater than 500°F.
- The RCS pressure is greater than 2000 psia.
- The Variable Overpower trip is operable.

Thus, an uncontrolled CEA bank withdrawal from Mode 3 under these conditions must be considered in the analysis.

The Technical Specifications allow the CEA drives to be energized in Mode 2 (with no restriction on plant conditions). However, the Technical Specifications require that the CEAs be withdrawn to (or above) the zero-power CEA insertion limit in Mode 2. Thus, an uncontrolled CEA bank withdrawal from Mode 2 with the CEAs at or above the zero-power CEA insertion limit must also be considered in the analysis.

The Uncontrolled CEA Bank Withdrawal from Subcritical/Startup event consequences are most limiting when the event is initiated from the lowest possible power level (which maximizes the power overshoot), the most limiting CEA insertion configuration (which maximizes the axial and radial power peaking and the CEA bank reactivity worths), and the

(a) The refueling boration requirement is sufficient to preclude criticality even if all CEAs are fully withdrawn.

lowest possible RCS pressure (which minimizes the margin to DNB). Thus, initiation from Mode 3 is more limiting than initiation from Mode 2:

- The power levels of Mode 3 (subcritical) are lower than those of Mode 2 (critical).
- The CEA insertion configurations of Mode 3 bound those of Mode 2.
- The Technical Specifications minimum RCS pressure of Mode 3 is lower than that of Mode 2.

5.2 *Mode 3 Uncontrolled CEA Bank Withdrawal Scenarios*

In Mode 3 there is no Technical Specifications CEA insertion limit. The following Mode 3 uncontrolled CEA bank withdrawal scenarios must therefore be considered:[a]

- Starting with all CEAs fully inserted, a single failure could cause the uncontrolled withdrawal of one or both shutdown CEA banks to the fully withdrawn position. However, the total reactivity inserted by the withdrawal of both shutdown CEA banks is less than the Technical Specifications shutdown margin requirement (including the RCS overboration for a potentially stuck-out CEA). Thus, criticality cannot occur for this scenario.
- Also, starting with all CEAs fully inserted, a single failure could initiate the uncontrolled withdrawal of one or more regulating CEA banks. However, the CEA Motion Inhibit feature (described in Section 7.4.2 of the Millstone Unit 2 Final Safety Analysis Report)[13] does not allow regulating CEA banks to be withdrawn unless both shutdown CEA banks are already fully withdrawn. This would stop the uncontrolled withdrawal of the faulted regulating CEA bank(s). Thus, criticality cannot occur for this scenario, either.
- Starting with both shutdown CEA banks fully withdrawn and all regulating CEA banks fully inserted, a single failure could cause the uncontrolled withdrawal of one or more regulating CEA banks to the fully withdrawn position. This is the limiting uncontrolled CEA bank withdrawal scenario. (The consequences of this scenario, however, are limited by the CEA Motion Inhibit feature, which ensures that the faulted regulating CEA banks are withdrawn according to the normal withdrawal sequence and overlap requirements.)

(a) These uncontrolled CEA bank withdrawal scenarios were supplied by Northeast Utilities, as a result of a single-malfunction analysis of the reactivity control system, in accordance with 10 CFR 50 Appendix A, GDC 25.

6. Definition of Case Analyzed

The case analyzed is initiated from Mode 3 with both shutdown CEA banks fully withdrawn and all regulating CEA banks fully inserted. The event initiator is assumed to be a single failure which causes the uncontrolled withdrawal of all regulating CEA banks (in the normal withdrawal sequence and overlap) to the fully withdrawn position.

6.1 *Computational Procedure*

The computational procedure used in the analysis is described below:

- A PTSPWR2 analysis has been performed to evaluate the plant response to the event.

- A set of XTGPWR analyses have been performed to evaluate the axial and radial power distributions which can occur during the supercritical phase of the event, as well as the applicable CEA bank reactivity worths. These analyses have been performed for various CEA insertion configurations, ranging from the critical configuration to the all-rods-out (ARO) configuration--with intermediate configurations at regular intervals.

- Based on the PTSPWR2-calculated overall core conditions at the time of the maximum core-average fuel rod heat flux and the set of XTGPWR-calculated axial and radial power distributions, a set of XCOBRA-IIIC analyses have been performed to evaluate the lowest DNBR corresponding to each of the power distributions and thereby determine the MDNBR to be reported for the event.

- Also, based on the PTSPWR2-calculated maximum centerline temperature of the core-average fuel rod and the largest of the XTGPWR-calculated total power peaking factors for the set of power distributions, a fuel pellet thermal analysis has been performed to evaluate the maximum temperature of the peak-power fuel pellet.

6.2 *Initial Conditions*

Initial conditions used in the analysis are described below:

- The initial power level has been set to a conservatively low power level for Mode 3 (10^{-9} of the 2700 MW_t rated power). The analysis also assumes that the event is preceded by an extended shutdown (which maximizes the power overshoot) and occurs at a beginning-of-cycle (BOC) condition (which minimizes negative Doppler feedback).

- The initial RCS pressure has been set to the Technical Specifications minimum for Mode 3 with the CEA drives energized and the shutdown margin requirement met, minus measurement uncertainty (2000 psia – 24 psi).

- The initial core inlet coolant temperature has been set to the programmed value for zero power, plus measurement uncertainty (532°F + 2.25°F).
- The number of reactor coolant pumps operating has been set to the Technical Specifications minimum for Mode 3 with the CEA drives energized and the shutdown margin requirement met (four pumps).
- The initial RCS flow has been set to the Technical Specifications minimum for four-pump operation (360,000 gpm).[a]

6.3 *Other Key Parameters*

Other key parameters used in the analysis are described below:

- The reactivity insertion rate due to the uncontrolled CEA bank withdrawal has been set to the maximum differential worth of the various regulating CEA banks from the critical configuration to the ARO configuration (31.1 pcm/in.) times a conservatively rapid CEA withdrawal rate (50 in./min).
- The moderator temperature coefficient has been set to the Technical Specifications maximum for zero power (+7 pcm/°F).
- The Doppler feedback has been specified as a table of Doppler reactivity versus fuel temperature. The values in the table are based on temperature-dependent BOC Doppler coefficients times a factor of 0.80.
- The delayed neutron fraction (β) has been set to a BOC value (0.0063).
- The conductance of the gap between the fuel pellets and cladding has been set to a conservatively large value (9453 BTU/[hr·ft^2·°F]).[b]
- The Variable Overpower trip setpoint has been set to the Technical Specifications value for a zero-power initial condition, plus uncertainty (14.6% of the rated power + 5% of the rated power).
- The Variable Overpower trip delay has been set to a conservatively large value (0.4 sec).

(a) Measurement uncertainty has already been subtracted from the Technical Specifications minimum RCS flow.

(b) Maximizing the pellet/clad gap conductance minimizes the effect of negative Doppler feedback on arresting the power excursion--which dominates the plant response. This reduces margin to both the DNB limit and the fuel melt limit. Also, maximizing the pellet/clad gap conductance maximizes the fuel rod heat flux. This exacerbates the reduction of margin to the DNB limit but partially offsets the reduction of margin to the fuel melt limit. The overall effect of maximizing the pellet/clad gap conductance, however, is adverse to both the DNB and fuel melt acceptance criteria.

- The CEA holding coil release time has been set to a conservatively large value (0.5 sec).

- The peak-power fuel assembly DNBR calculations have been performed using the axial and radial power peaking factors which correspond to regulating CEA bank configurations ranging from critical to ARO. The XTGPWR-calculated maximum radial peaking factor for the ARO configuration has been augmented to the Technical Specifications unrodded F_r limit for zero power, with allowances for measurement uncertainty and CEA position uncertainty (1.837 × 1.06 × 1.02). The resulting XTGPWR-to-Technical-Specifications augmentation factor has also been applied to the XTGPWR-calculated maximum radial peaking factors for the other CEA insertion configurations. (The XTGPWR-calculated maximum radial peaking factor for the DNBR-limiting CEA insertion configuration is $F_r = 2.28$, and the corresponding axial power distribution is a bottom-skewed shape with an axial shape index (ASI)[a] of 0.485 ASIU and a maximum axial peaking factor of $F_z = 1.88$.) In addition, a factor to bound cycle-to-cycle variations (1.02) has been applied to the augmented radial peaking factors.

- The peak-power fuel assembly DNBR calculations and the peak-power fuel pellet maximum temperature calculation have been performed using a conservatively large fuel rod heat flux multiplier (1.03), which is an allowance for fuel rod dimensional uncertainties due to manufacturing tolerances and in-reactor densification.

- The peak-power fuel pellet maximum temperature calculation has been performed using the maximum XTGPWR-calculated total power peaking factor for the range of regulating CEA bank configurations from critical to ARO ($F_q = 4.43$), plus the Technical Specifications allowance for total peaking uncertainty (7%) and the XTGPWR-to-Technical-Specifications augmentation factor (discussed above). In addition, a factor to bound cycle-to-cycle variations (1.10) has been applied to the augmented total peaking factor.

(a) The ASI is defined using the power levels of the lower and upper halves of the core, as follows:

$$ASI = \frac{\dot{q}_{lower} - \dot{q}_{upper}}{\dot{q}_{lower} + \dot{q}_{upper}}$$

7. Analysis Results

The analysis results, given in Table 7.1 and Figures 7.1 through 7.6, may be summarized as follows:

1. As the CEAs are withdrawn, reactivity rises (see Figure 7.1).

2. When the reactor conditions approach prompt-criticality, the power level begins to rise rapidly (see Figure 7.2). At 23.4 seconds after CEA withdrawal initiation, the power level reaches the Variable Overpower trip setpoint (19.6% of the rated power), and a scram signal is issued. As the scram signal is being transmitted, the power level continues to rise rapidly. Before scram CEA insertion actually begins, rising fuel temperatures--together with the negative Doppler reactivity coefficient--arrest the power rise. The power level peaks at 252.1% of the rated power. After scram CEA insertion begins (at 24.3 seconds), the power level begins to drop rapidly. The brevity of the power spike precludes excessive energy deposition.

3. The core-average fuel rod heat flux continues to rise until 24.7 seconds (see Figure 7.3), peaking at 75.3% of the rated-power value.

4. The MDNBR, which also occurs at 24.7 seconds, is 1.50. This MDNBR is well above the 95/95 safety limit of the XNB DNB correlation.

5. The peak-power fuel pellet centerline temperature continues to rise until 25.7 seconds, peaking at 2521°F. This peak fuel temperature is well below the fuel melting point.

6. The RCS hot leg coolant temperature continues to rise until 26.6 seconds (see Figure 7.4), peaking at 564°F. This peak value is below the RCS hot leg coolant temperature at normal rated-power operation.

The MDNBR and fuel temperature results demonstrate that the Uncontrolled CEA Bank Withdrawal from Subcritical/Startup acceptance criteria are satisfied for operation of Millstone Unit 2 during Cycles 10 through 13 (and future cycles bounded by the conditions of this analysis) without the Startup Rate trip.

Table 7.1 Sequence of Events

Time	Event	Value
0.0 sec	CEA withdrawal begins	—
23.4 sec	Core power reaches Variable Overpower trip setpoint	19.6% of rated
24.3 sec	Insertion of scram CEAs begins	—
24.3 sec	Core power peaks	252.1% of rated
24.7 sec	Core-average fuel rod heat flux peaks	75.3% of rated
24.7 sec	MDNBR occurs	1.50
25.7 sec	Peak-power fuel pellet centerline temperature peaks	2521°F
26.6 sec	RCS hot leg coolant temperature peaks	564°F

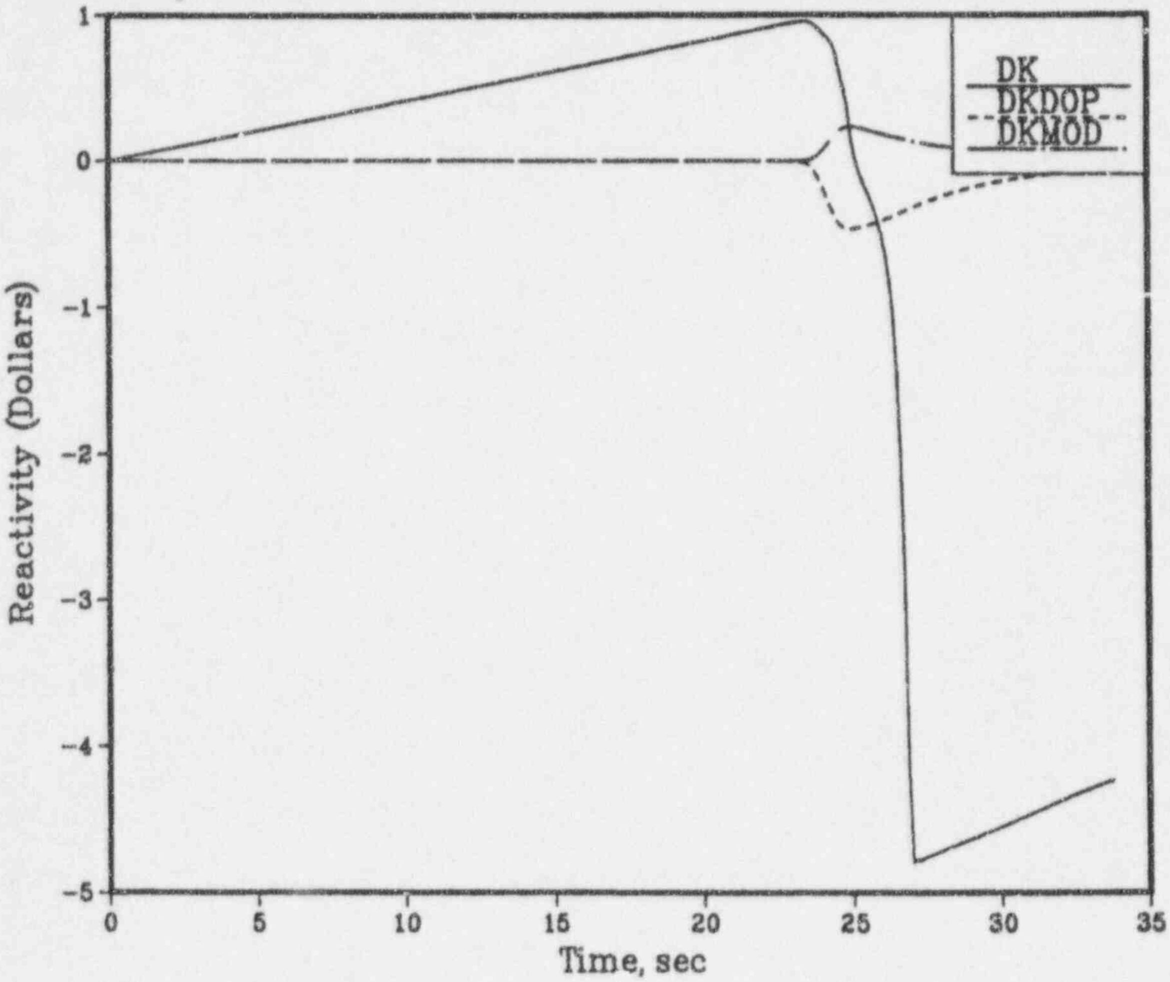

Figure 7.1 Reactivities

DK = total reactivity
DKDOP = Doppler-feedback reactivity
DKMOD = moderator-feedback reactivity

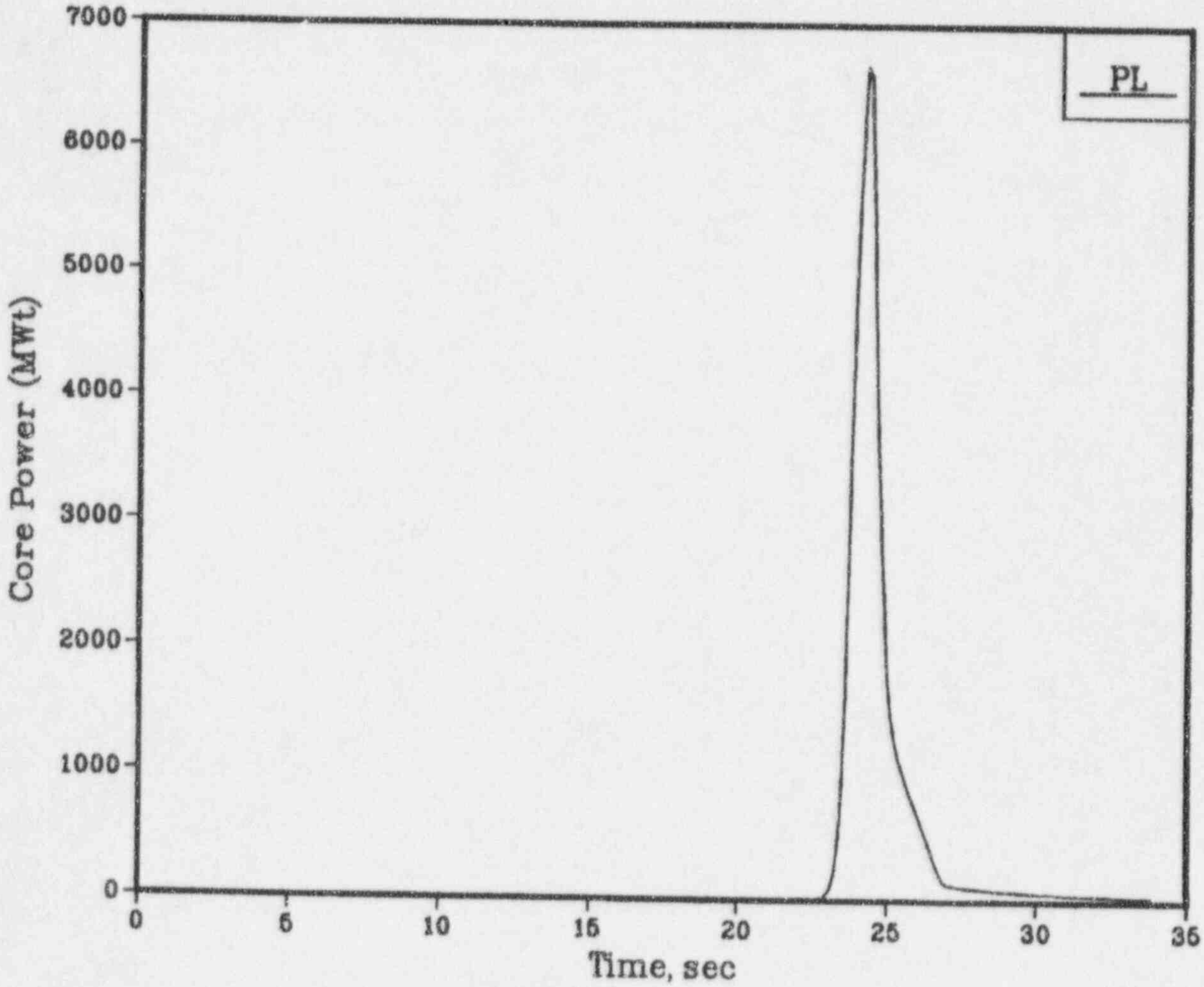

Figure 7.2 Core Power

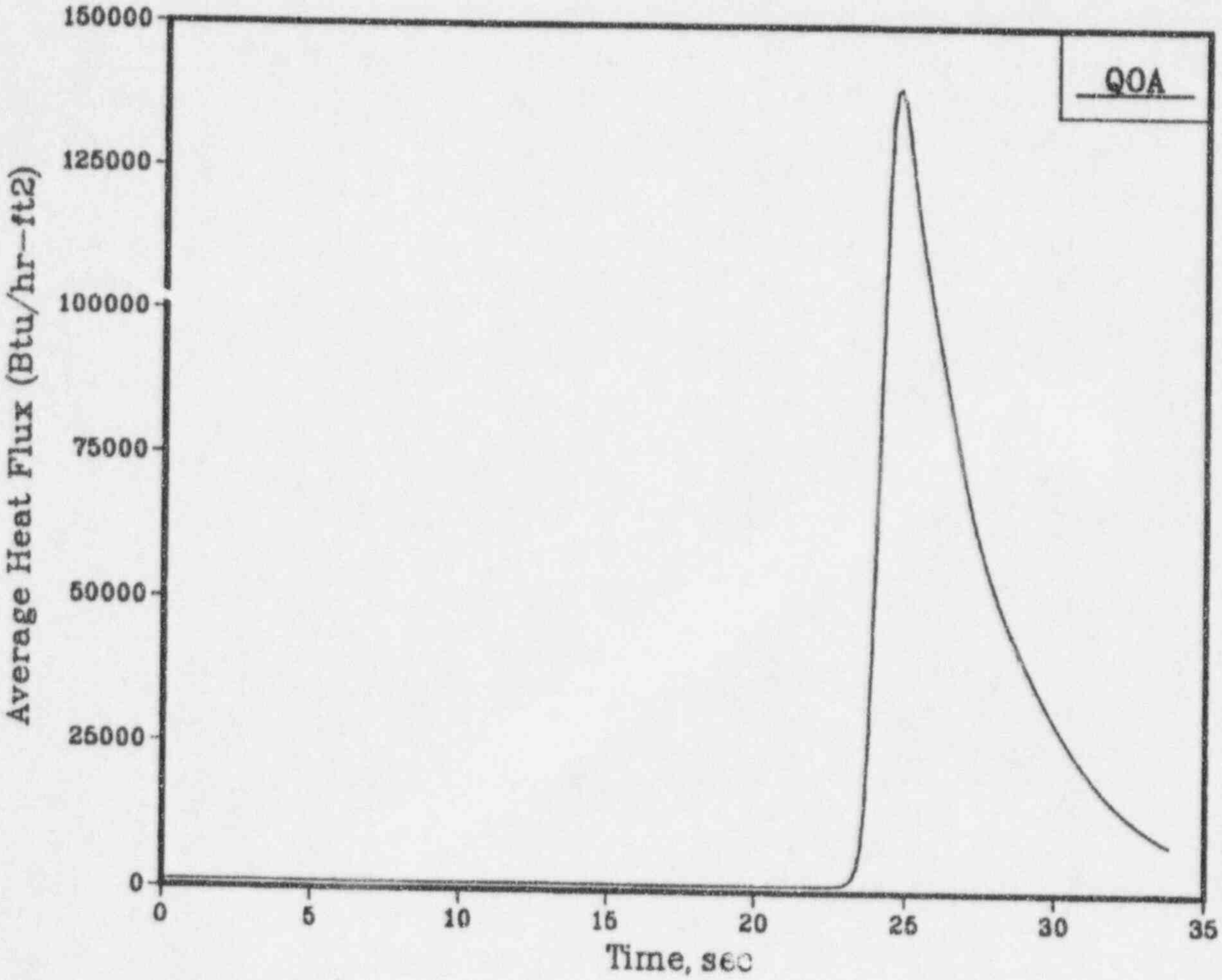

Figure 7.3 Core-Average Fuel Rod Heat Flux

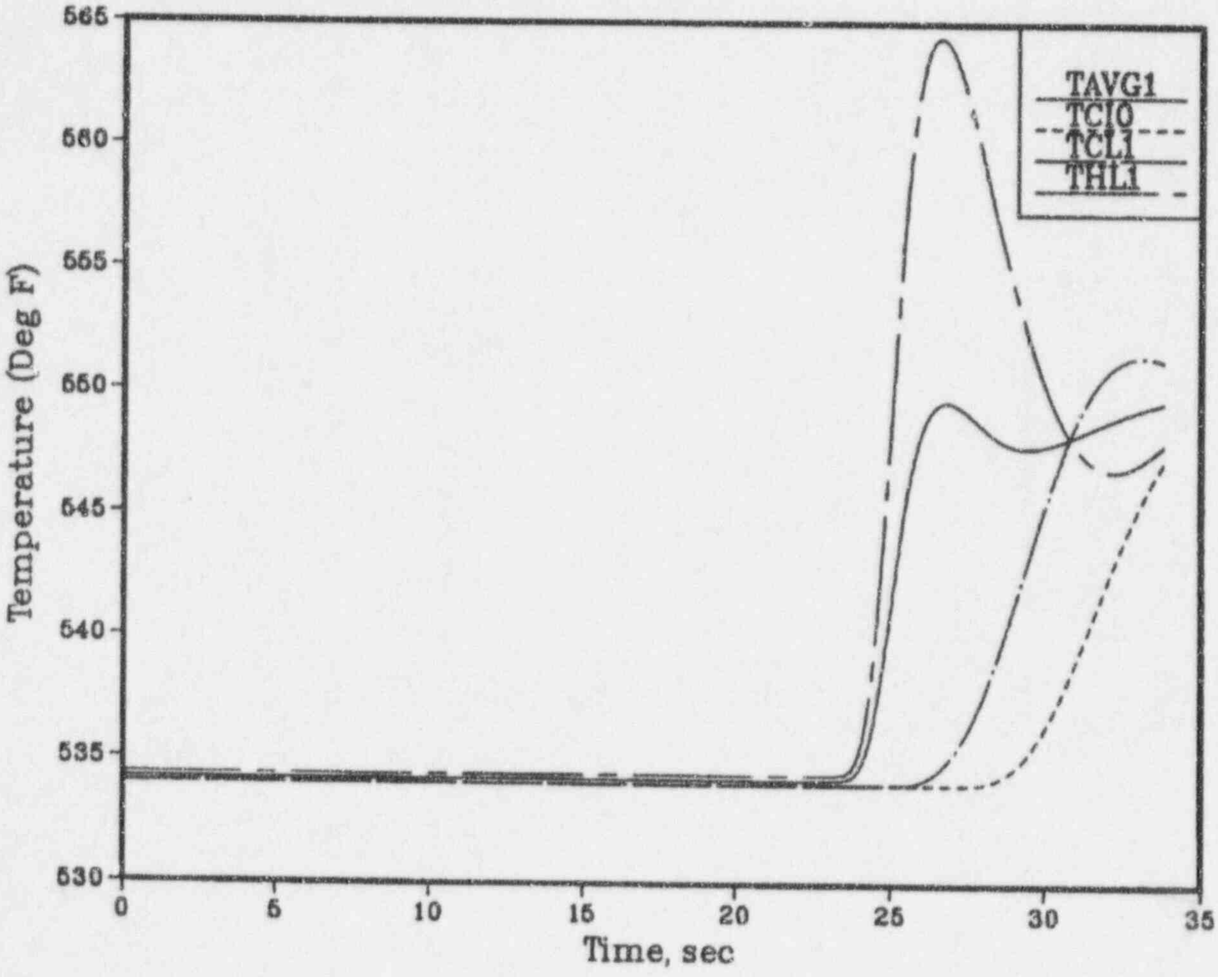

Figure 7.4 RCS Temperatures

TAVG1 = average RCS coolant temperature (average of TCL1 and THL1)
TCIO = core inlet coolant temperature
TCL1 = RCS cold leg coolant temperature
THL1 = RCS hot leg coolant temperature

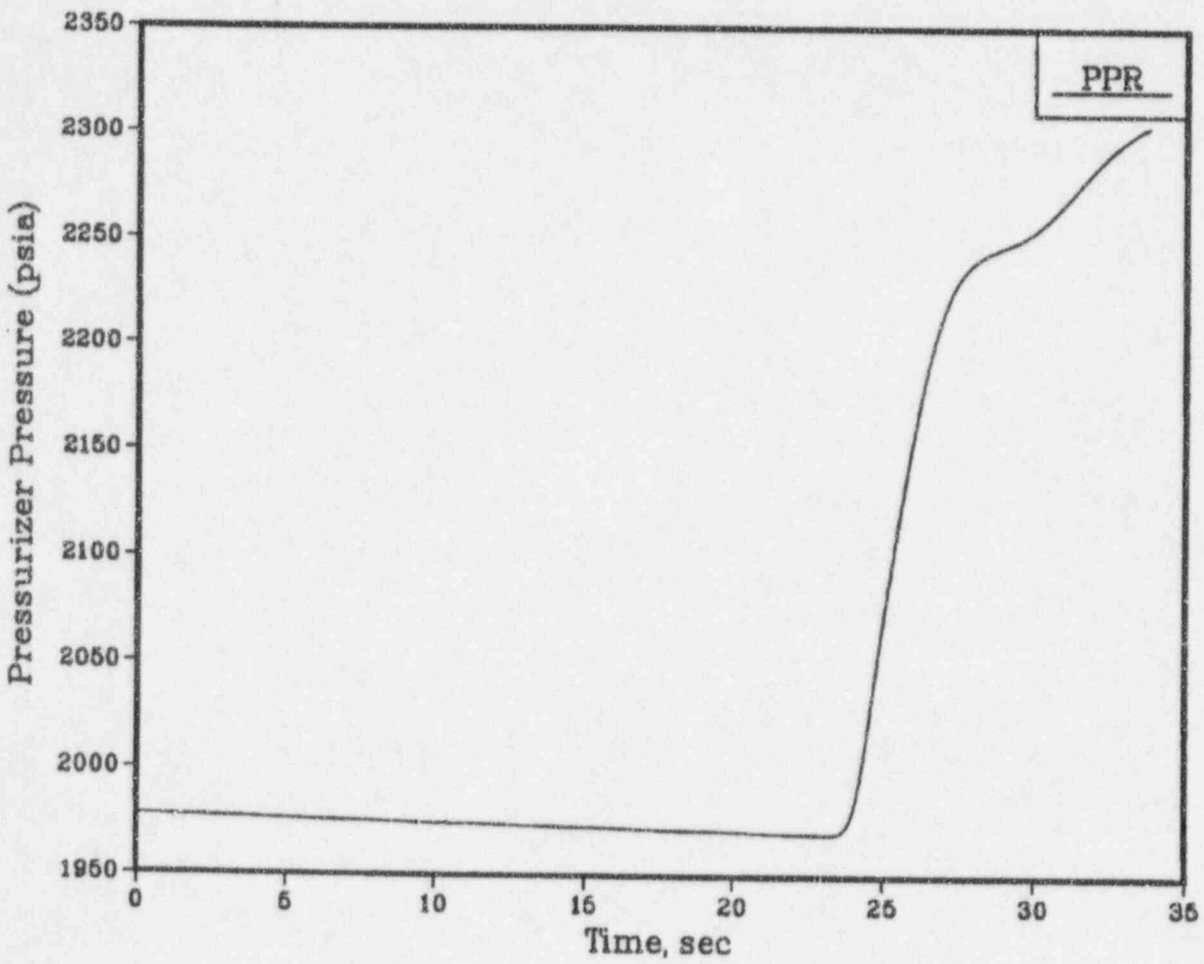

Figure 7.5 Pressurizer Pressure

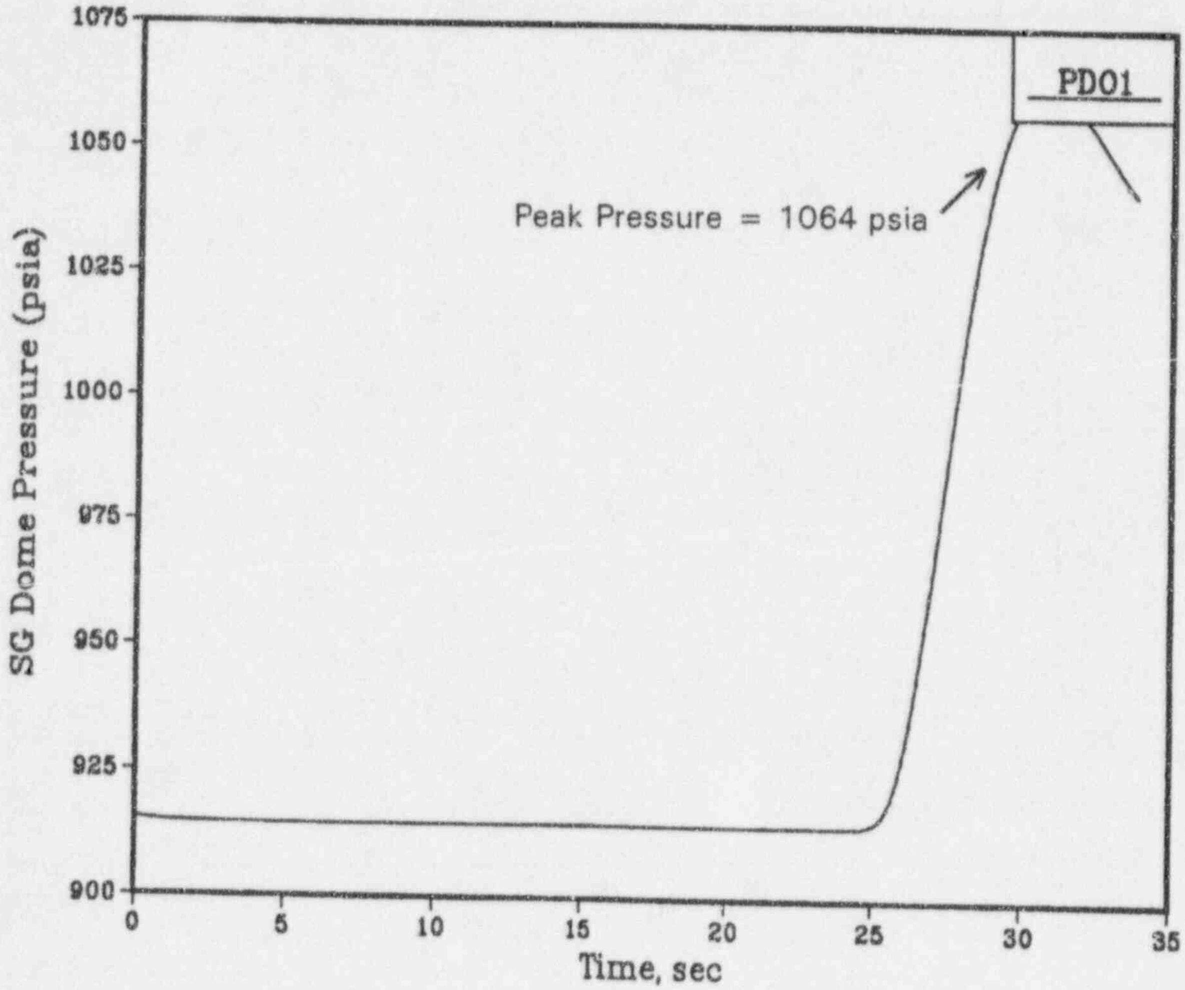

Figure 7.6 Secondary Pressure

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