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PREDICTION OF BWR PERFORMANCE UNDER THE INFLUENCE OF ISOLATION CONDENSER-USING RAMONA-4 CODE**

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by

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Abstract :

The purpose of the Boiling Water Reactor (BWR) Isolation Condenser (IC) is to passively control the reactor pressure by removing heat from the system. This type of control is expected to reduce the frequency of opening and closing of the Safety Relief Valves (SRV).

A comparative analysis is done for a BWR operating with and without the influence of an IC under Main Steam Isolation Valve (MSIV) closure. A regular BWR, with forced flow and high thermal power, has been considered for analysis. In addition, the effect of ICs on the BWR performance is studied for natural convection flow at lower power and modified riser geometry. The IC is coupled to the steam dome for the steam inlet flow and the Reactor Pressure Vessel (RPV) near the feed water entrance for the condensate return flow.

Transient calculations are performed using prescribed pressure set points for the SRVs and given time settings for MSIV closure. The effect of the IC on the forced flow is to reduce the rate of pressure rise and thereby decrease the cycling frequency of the SRVs. This is the primary objective of any operating IC in a BWR (e.g. Oyster Creek). The response of the reactor thermal and fission power, steam flow rate, collapsed liquid level, and core average void fraction are found to agree with the trend of pressure. The variations in the case of an active IC can be closely related to the creation of a time lag and changes in the cycling frequency of the SRVs.

An analysis for natural convection flow in a BWR indicates that the effect of an IC on its transient performance is similar to that for the forced convection system. In this case, the MSIV closure has resulted in a lower peak pressure due to the magnitude of reduced power. However, the effect of reduced cycling frequency of the SRV due to the IC , and the time lag between the events, are comparable to that for forced convection. This phenomena is expected to be more pronounced in the case of the simultaneous operation of multiple ICs. SRV opening can be completely avoided with the availability of a sufficient number of ICs.

INTRODUCTION

Isolation Condensers (IC) are important components for the safety systems of the new generation Simplified Boiling Water Reactors (SBWR). Active usage of Isolation Condensers can also be found in a few of the current operating reactors, e.g., Oyster Creek , Millstone etc. Applications of these components include passive operation for reactor pressure regulation (as well as in decay heat removal). Anticipated Transient Without Scram (ATWS) is an important transient to be simulated by current computer codes. Main Steam Isolation Valve (MSIV) closure is one of the most important ATWS events that is investigated. RAMONA-3B (1) has been applied for MSIV closure prediction for current BWRs (2).

In this study, MSIV closure ATWS events will be analyzed in order to investigate the effect of the ICs on BWR performance. The Neutronic data for the analyses were obtained for the Browns Ferry Unit 3 (BWR4) reactor near the end of cycle 5. BF3 neutronic data were processed by the BLEND (3) code to obtain the 77 group cross section sets. RAMONA-3B was originally developed for reactor transient analysis. The code is based on a three dimensional neutron kinetics model which is coupled to a multichannel, nonhomogeneous, nonequilibrium thermal hydraulics model. Traditionally, point kinetics have been used in other codes (4) for neutronics calculations. RAMONA-3B utilizes a more realistic 3D kinetics. Hence the effect of void fraction variation due to MSIV closure is accounted through the void reactivity feedback. The RAMONA-4 code is being developed from RAMONA-3B by incorporating a drift flux formulation, flow reversal capabilities, and the implementation of SBWR specific components.

The Isolation Condenser model incorporated into RAMONA-4 represents the GE design for this component. Effectiveness of the ICs will be measured through their influence on the frequency of operation of the Safety Relief Valves (SRVs) and thereby, contributing to the reactor pressure control. The condensate liquid from the ICs are returned to the downcomer region, while steam flow into the ICs are taken from the steam dome. Effect of increasing the number of active ICs will be discussed. In the SBWR, the Emergency Core Cooling System (ECCS) has been replaced by a passive system by eliminating the High Pressure Core Injection (HPCI) and Reactor Core Isolation Cooling (RCIC) systems. The reactor performance, with operating ICs, has been investigated in the absence of these components.

TRANSIENT PROBLEM DEFINITION

Closure of only one MSIV in the steam line is permitted for special testing purposes of the reactor. The reactor is scrammed if three or more steam line isolation valves are less than 90% open and the reactor pressure is above 600 psig. However, the type of ATWS event considered here is conservative, as MSIVs in all four steam lines have been assumed to be closed, resulting in a sharp rise in pressure up to 8.9 MPa. During this period the reactor voids collapse, resulting in a power increase, and the SRVs open at their pressure setpoints. After the initial part of the transient, which lasts for about 40 seconds, the cyclic operation of the SRVs controls the reactor pressure. Early shutdown of the incoming feedwater flow causes a decrease in the level, which initiates the HPCI, at the low water level set point developing at 42 seconds. The ICs are activated by a 10% closing of the MSIV or a by reactor pressure level of 7.9 MPa.

Specific data related to the RAMONA 4 input deck are given in the following section. Several cases are analyzed, with identical transient events but different combinations of functional components.

Table 1. Test Matrix for MSIV Closure

Case No.	Number of ICs	HPCI	Recirc. Pump	Observation
1	0	Active	Active	Effect of IC
2	1	Active	Active	"
3	1	Inactive	Active	Effect of HPCI
4	3	Inactive	Active	"
5	0	Active	Inactive	Natural Convection
6	1	Active	Inactive	"

Table 2. The initial and boundary conditions used in this analysis

Reactor Operating Conditions

System Operating Pressure	:	69.154 10^5 Pa.
Reactor Thermal Power	:	3.293 10^9 Watts.
Feed Water Flow Rate	:	1637 Kg/sec
Inlet Subcooling	:	11.53 C
Feedwater Temperature	:	191.0 C
Total Core Flow Rate	:	1.304 10^4 Kg/sec
Core Bypass Flow Rate	:	130.4 Kg/sec

MSIV closure test on time

Begins	:	0.0 sec
Delay	:	0.5 sec
90% opening	:	1.85sec
Complete closure	:	4.0 sec

HPCI initiation on level

Low water level	:	-1.485 m below downcomer entrance
High Water level	:	1.207 m above downcomer entrance
Flow Capacity	:	359.72 kg/sec
Temperature	:	21.11 C
Delay Time	:	25 sec

Feedwater Disturbance

Flow rate	:	Linear coastdown in 3.5 secs
Feedwater temperature	:	Linear coastdown in 3.5 secs

SRV settings for 4 banks

Valve bank 1

Number of Valves	:	4
Opening pressure setting	:	7.2213 Mpa.
Closing pressure	:	7.3774 MPa.
Steam flow capacity	:	108.64 Kg/sec

Valve bank 2

Number of Valves	:	4
Opening pressure setting	:	7.9108 MPa.

Closing pressure	:	7.4463 MPa.
Steam flow capacity	:	108.64 Kg/sec

Valve bank 3

Number of Valves	:	4
Opening pressure setting	:	7.86 MPa.
Closing pressure	:	7.515MPa.
Steam flow capacity	:	81.48 Kg/sec

Valve bank 4

Number of Valves	:	4
Opening pressure setting	:	8.721 MPa.
Closing pressure	:	8.377 MPa.
Steam flow capacity	:	54.32 Kg/sec

ISOLATION CONDENSER INPUT

Initiation	:	MSIV closure by 10%
	:(or	Reactor pressure equals 7.9 MPa)
Initial Condition		
IC System Pressure	:	6.96 MPa
Initial Quality	:	10%
Geometric Dimensions	:	GE design for SBWR
IC pool temperature	:	27 C
Condensate return flow	:	Calculated from momentum balance between the IC and downcomer .
Steam Inflow	:	Calculated from momentum balance between Steam Dome and IC.
Heat removal rate	:	Calculated from mass and energy balance in IC with condensation, conduction and pool boiling heat transfer coefficients. (5)

NATURAL CONVECTION SYSTEM:

System Pressure	:	6.91 MPa
System Themal Power	:	1600 MW
Feed Water Flow Rate	:	800 Kg/sec
Riser Height (for SBWR)	:	5 meters

RAMONA MODEL

The RAMONA code was originally developed to simulate BWR transients. The components of this code and the corresponding input parameters are, therefore, applicable to current BWR design.

A Detailed description of the code's modeling and formulations can be found elsewhere (1). Figure 1 shows the nodalization of the reactor pressure vessel as used by RAMONA-4. The reactor vessel consists of a downcomer region where the feedwater inlet and IC condensate return ports are located. The lower part of the downcomer is separate, and it accounts for the reduced area representing the jet pump and recirculation loops. The lower plenum regions lead to the core, which consists of multiple parallel channels and a bypass channel. The riser section constitutes the upper plenum, steam separators, and the chimney section (in case of SBWR analysis). The topmost part of the vessel constitutes the steam dome connected to the steam line. The steam line includes the main steam isolation valve, and four banks of the safety relief valves. The steam entering the isolation condenser is taken from a short stub connected to the steam dome. In the present analysis the neutronic cross sections, prepared for Browns Ferry unit 3 near the end of cycle five were used. For the present calculations, the core is divided into 25 parallel channels, each with 24 axial nodes, utilizing the 1/8th core symmetry. RAMONA-4 uses a four equation, nonequilibrium drift flux formulation with liquid mass balance, vapor mass balance, mixture momentum balance and mixture energy balance equations coupled with a 3D neutron kinetics model for a 3D power distribution.

RESULTS AND DISCUSSIONS:

A regular BWR operating without any isolation condenser has been used as the base case for comparison of the results. Several modifications to the input have created other significant cases of interest. Table 1 shows the test matrix used to isolate the separate effects in each modification. Cases 1 and 2 refer to a BWR operating without and with one isolation condenser respectively. Cases 3 and 4 refer to the results obtained for the operation of 1 and 3 ICs without HPCI. Lastly, cases 5 and 6 model the effect of isolation condenser on a natural circulation system achieved by removing the recirculation pump system. These two cases refer to a regular

BWR operating without and with one isolation condenser in the absence of any active component. The operating conditions and boundary conditions are as described in Table 2. The results will be separated into two parts. In the first part we focus on the forced convection system, while the second part is related to the natural convection system.

Effects on Forced Convection System:

Figure 2(a), 2(b), 2(c) and 2(d) show the prediction of transient pressure response for cases 1 through 4 respectively. MSIV closure results in a rapid increase of pressure to 8.9 MPa within the first 10 seconds. During this period all the SRV banks have reached their relief pressures, and therefore opened sequentially. Consequent release of steam has resulted in reactor pressure decrease after attaining the peak pressure of 8.9 MPa. This peak pressure has remained fixed for all four cases analyzed. A periodic behavior of the transient pressure can be observed following the initial peak. According to the SRV pressure set points (Table 2), it is clear that the SRV bank 3 is periodically opening and closing to produce this profile. The SRV banks 1 and 2 are open for the entire period of the transient, while the valves in bank 4 has closed within the first 20 seconds.

The cyclic frequency of operation of the SRVs is reduced when an active isolation condenser is used in case 2, where one IC is operating in the presence of HPCI. However, the effect of IC is reduced after 90 seconds into the transient, as seen from Figure 2 (a) and 2(b). This is due to the actuation of the HPCI system, as initiated by the low level in the reactor at 45 seconds. As observed from Figure 3(a), the HPCI supplies a constant flow of 369 kg/sec during the rest of the transient. Figure 3(b) shows the combined mass flow rate of the feed water, HPCI flow, and the condensate flow returning from the IC. The feedwater flow reduces rapidly within the first 5 seconds, based on an external calculation, which has been prescribed here as a boundary condition to RAMONA. The condensate return from the IC is in response to several factors, including system pressure, IC pressure, IC cooling capacity, and the liquid levels inside the downcomer and IC (5). The resulting flow of condensate is showed to fluctuate around 30 kg/sec, as will be discussed later. Therefore, the net external liquid input to the reactor vessel is largely dominated by the HPCI flow rate. And after the activation of the HPCI, the effect of the IC is negligible. According to Figure 3(b), there is no net inflow between 25 to 42 seconds. During this period, the IC activation conditions are satisfied. However, the momentum balance between the IC and the condensate return port has prevented any downflow of the liquid. As observed from figure 3(b), the HPCI activation has been delayed by 20 seconds due to the operation of the IC. As will be discussed in the next section, this delay has been caused by the modified collapsed liquid level during the transient.

In the new design of the SBWR, the ECCS systems are not available in the present form. In order to eliminate the effect of the HPCI, cases 3 and 4 are presented, which include one and three active ICs respectively.According to Figures 2(c) and 2(d), the effect of removing the HPCI has resulted in much reduced cycling of the SRVs, although the system pressure is maintained within the same range. It is also observed that increasing the number of ICs reduced the cycling frequency further.

The periodicity of the pressure profile is directly related to the steam flow rates shown in Figures 3(a) through 3(d). As a consequence of the pressure rise to 8.9 MPa, during the early transients of 5 seconds, there is a core wide collapse of voids, as seen in Figures 4(a) to 4(d). Due to the effect of negative void reactivity feedback, the reactor thermal power increases during the first 5 seconds, as shown in Figures 5(a) and 5(b). These processes reverse later on when the system pressure is reduced, causing the void fraction to increase and resulting in a decrease in the thermal power within 40 seconds. The periodic behavior during the transient is also evident from the void fraction and thermal power profiles. Removal of the HPCI has resulted in much fewer peaks in the cases 3 and 4. Therefore, the ICs are found to be more effective in the absence of the HPCI, which is the case of the SBWR design.

The effectiveness of the Isolation Condenser as a passive pressure regulating component has thus been demonstrated. The effects of an IC on the collapsed liquid level are presented in Figures 6(a) and 6(b) for the cases without and with one IC respectively. The HPCI is initiated by the low collapsed liquid level of -1.485 meter below the entrance to the downcomer. Condensate return from the isolation condenser changed the transient profile of the collapsed liquid level. As observed from Figures 6(a) and 6(b), the low level required for HPCI initiation has been delayed from 42 secs to 62 secs by the operating IC.

The condensate return to the reactor from the IC is closely related to the system pressure. Figures 7(a) and 7(b) show the condensate return flow rate from the IC for cases 2 and 3 respectively. The periodicity of system pressure has resulted in fluctuation of the liquid return by 5 kg/sec. After the initial fluctuation of the flow during the early transient, the flow rate has stabilized at approximately 30 kg/sec. Figures 8(a) and 8(b) show the steam flow rates into the IC for these cases. Figures 9 and 10 show the steam quality and liquid level inside the IC during the transient for case 2. These results are dependent on the initial quality and the initial liquid levels. A quality of 10% at a pressure of 6.96 MPa has been assumed to be the initial condition for the IC, which is a user-specified input. In the case of multiple ICs, they are assumed to be identical in operation and design. MSIV closure is one of the major ATWS events for activation of the system ICs in the SBWRs.

Effects on Natural Convection System:

The effects of ICs on the forced convection system of regular BWRs was presented in the previous section. The overall effect on a natural convection system is quite similar to that on a forced convection. Due to the inherent nature of the natural convection system, the response time is longer, which results in relatively smoother transient events for the case of MSIV closure. Figures 11(a) and 11(b) show the transient pressure profiles for MSIV closure with inactivated recirculation pumps. Cases 5 and 6 shown in Table 1 represent performance without and with one IC respectively .

The total reactor power for this analysis has been reduced to 1600 MW , and the initial flow rate is 800 kg/sec . The feedwater flow is given as a boundary condition, such that it shuts down in 3.5, seconds while the HPCI activates on the low liquid level indicated earlier.

Due to the reduced power in the natural convection system, the high pressure peak observed in the short term transient is only 7.9 MPa, as compared to 8.9 MPa in the forced convection cases . This pressure peak is below the operation set points for the SRVs in banks 2 and 4 . Therefore, the total number of SRVs active in this natural convection system is reduced by half. The periodic behavior of the pressure is due to the repeated opening and closing of SRV bank 3, while SRV bank 1 remains open throughout the transient. According to Figures 11(a) and 11(b), the cyclic frequency of operation for the SRVs has been reduced significantly by the use of one Isolation Condenser. The steam flow rate in the steam line also shows the periodic behavior. Figures 12(a) and 12(b) show the thermal power during the transient. As compared to the forced convection cases, the amplitude of oscillation during the first 40 seconds of the transient is higher. The presence of one isolation condenser has reduced the thermal fluctuations during the transient, as shown in Figure 12(b).

CONCLUSIONS:

The effectiveness of Isolation Condensers as a passive pressure regulation system has been demonstrated. The cyclic frequency of opening and closing of the SRVs is reduced by the active use of the ICs. However, the effect is minimal in the case of simultaneous operation of the ECCS system. The mass flow rate from the ECCS system dominates the transient events. In the absence of the HPCI, the SRV operational frequency is further reduced. This is an important observation for the SBWR , since the effectiveness of the IC can not be fully achieved in the presence of the HPCI. The ECCS of the SBWR uses a passive system operating at low reactor pressure, and high pressure injection of liquid is prevented. Therefore the benefit recieved from the ICs as pressure regulating devices is maximized in this configuration.

In the case of a natural circulation system, the effectiveness of the IC as a pressure regulating device has also been confirmed. In this case the amplitude of pressure oscillation is found to be similar to that for the forced convection system, although the initial peak pressure is reduced due to the lower power of these systems. Therefore the total number of operating SRVs is already fewer than for the forced flow case. The oscillations noted in the transient thermal power profile were of higher amplitudes than the previous cases. The effect of the IC is to reduce such amplitudes. The response time in the natural circulation system is expected to be longer than for the forced convection system. Therefore, the transient events are expected to develop over an extended time period.

List of References

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3. L. D. Eisenhart and D. J. Diamond," Automatic Generation of Cross Sections Input of BWR Spatial Dynamics Calculations",BNL-NUREG-28796,1980.

4. RETRAN-02- A Program for Transient Thermal Hydraulic Analysis of Complex Fluid Flow Systems. EPRI NP-1850-CCMA Vol1,Rev 2. 1984.

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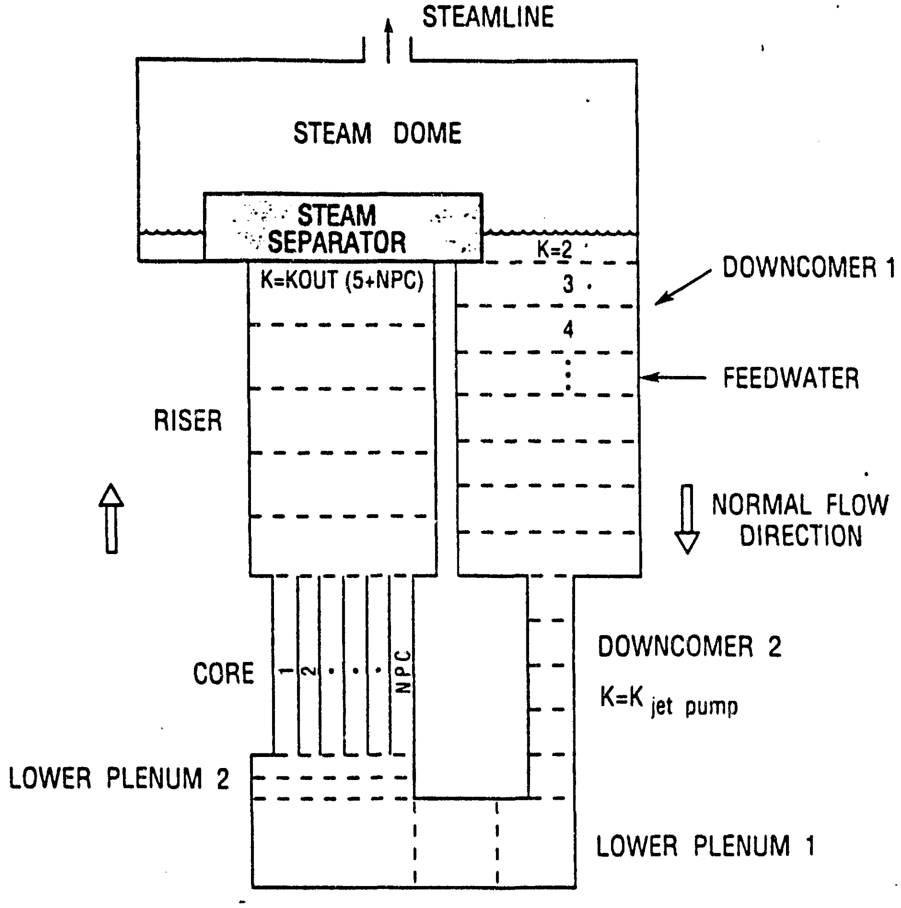

Figure 1 Nodalization used in RAMONA-4

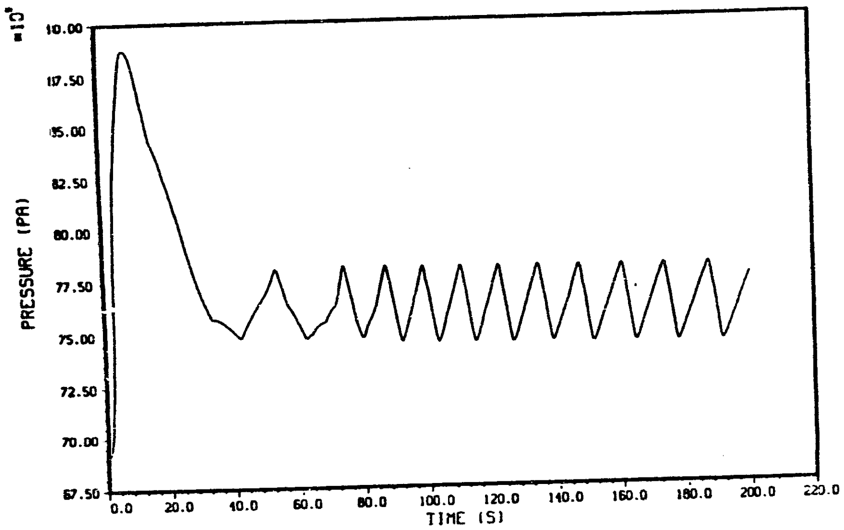

Figure 2(a) Transient Pressure Profile for case 1

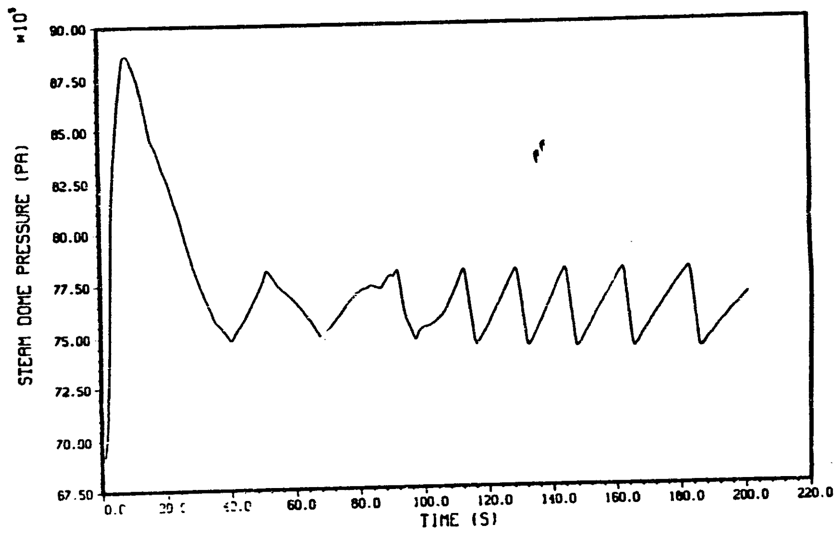

Figure 2(b) Transient Pressure Profile for case 2

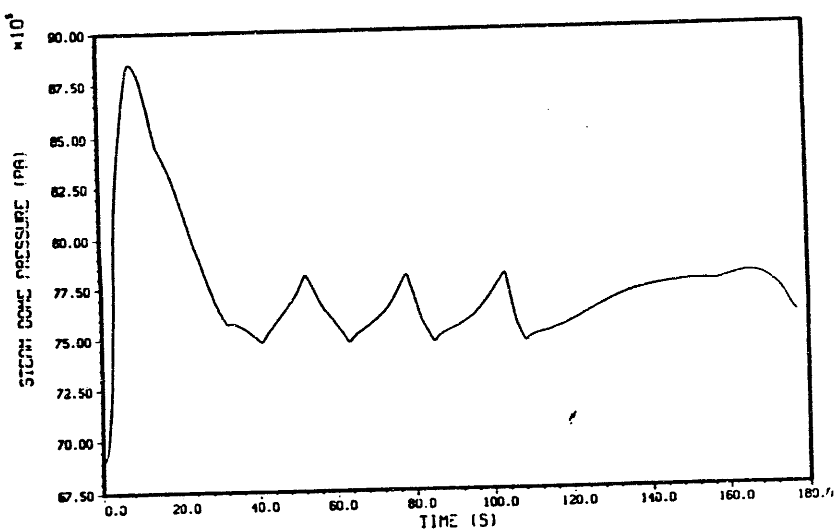

Figure 2(c) Transient Pressure Profile for case 3

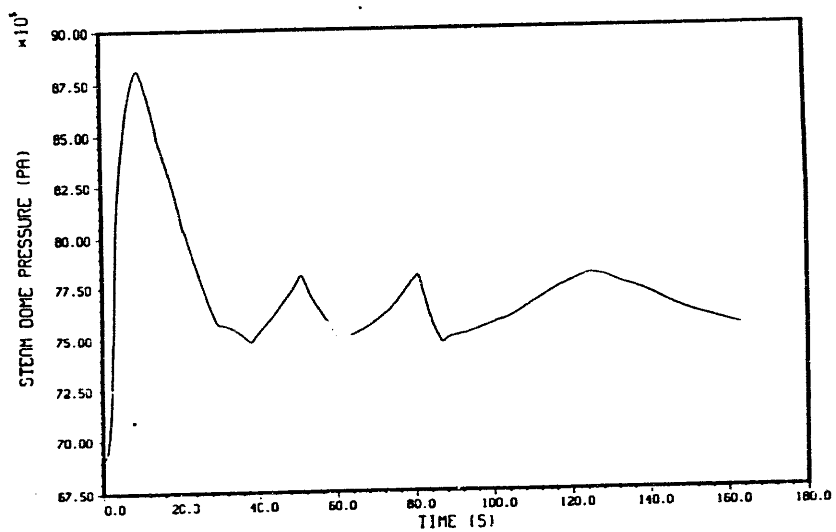

Figure 2(d) Transient Pressure Profile for case 4

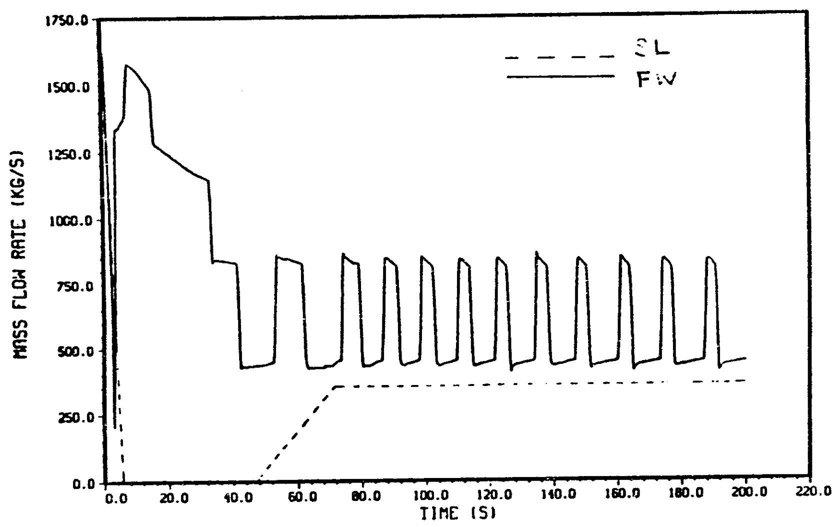

Figure 3(a) Steam & Feed Water Flow Rate for case 1

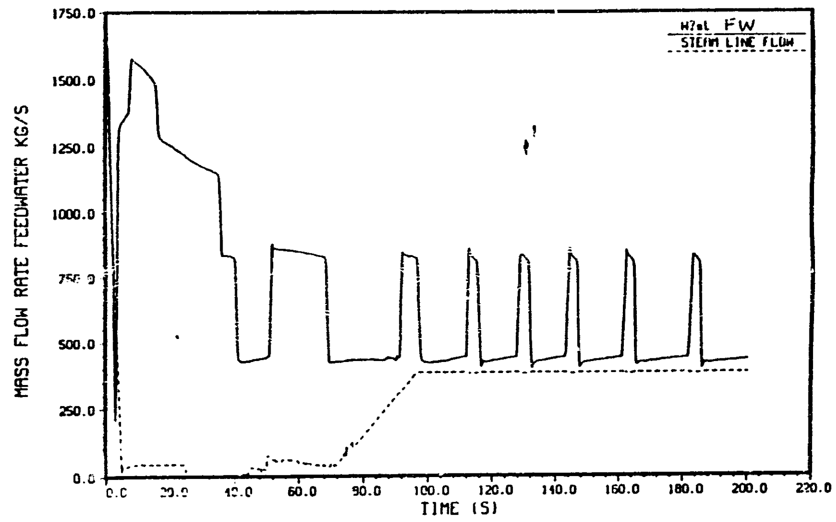

Figure 3(b) Steam & Feed Water Flow Rate for case 2

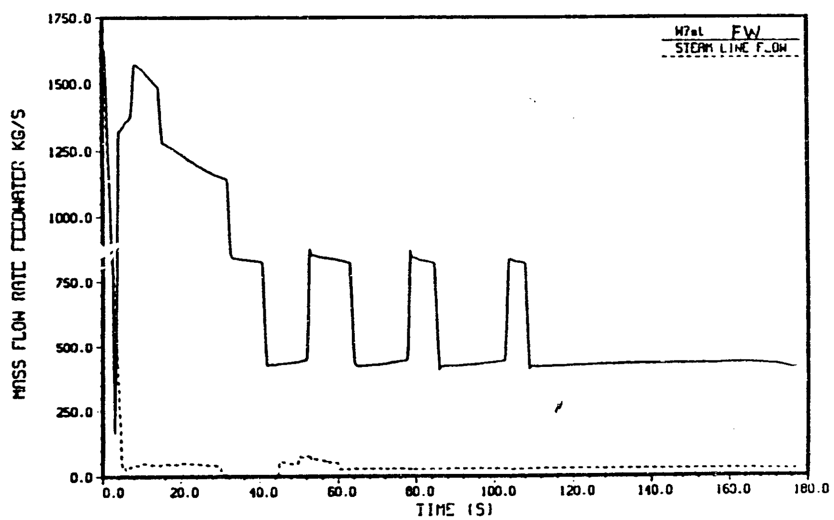

Figure 3(c) Steam & Feed Water Flow Rate for case 3

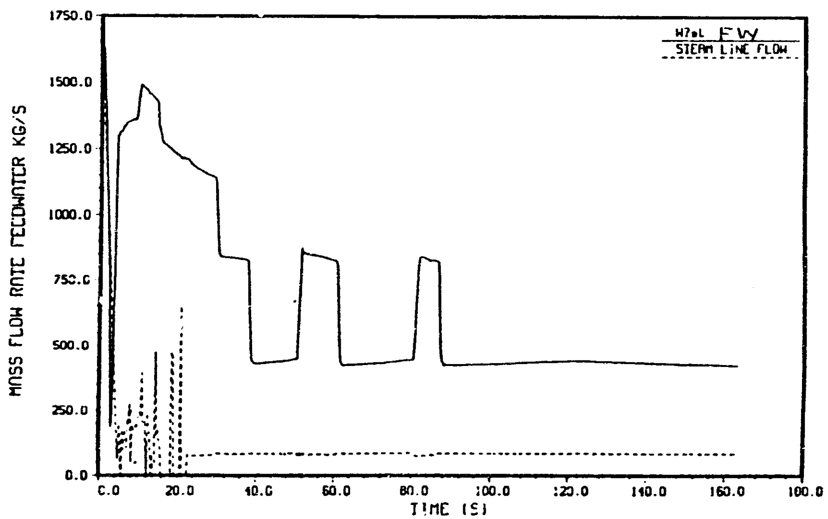

Figure 3(d) Steam & Feed Water Flow Rate for case 4

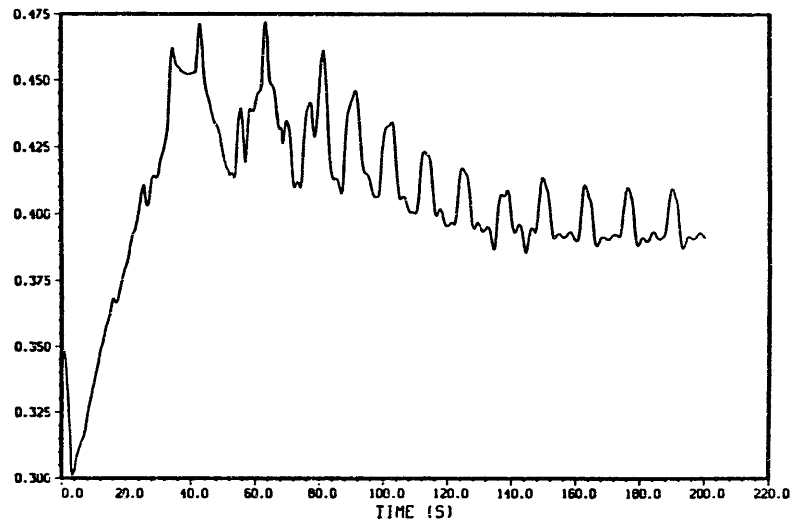

Figure 4(a) Transient Void Fraction Profile for case 1

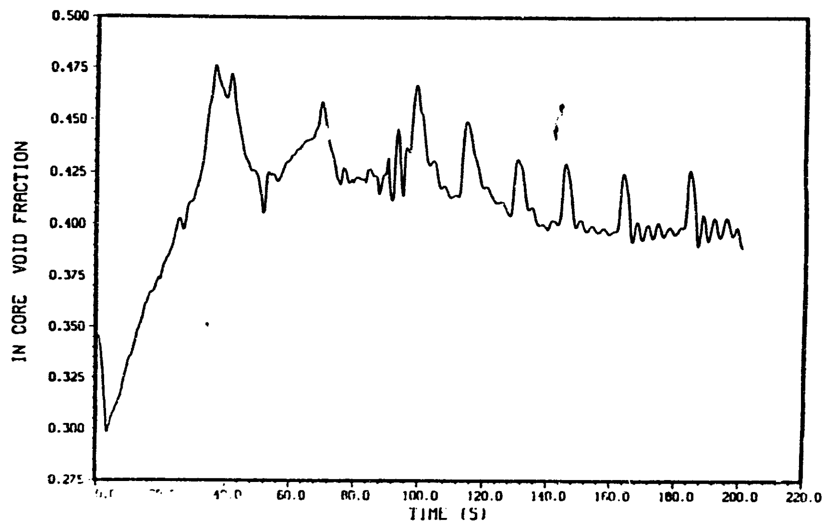

Figure 4(b) Transient Void Fraction Profile for case 2

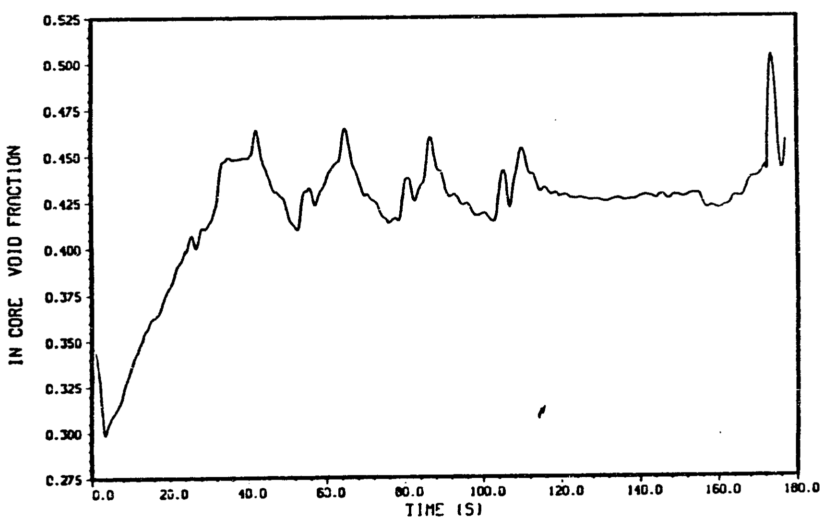

Figure 4(c) Transient Void Fraction Profile for case 3

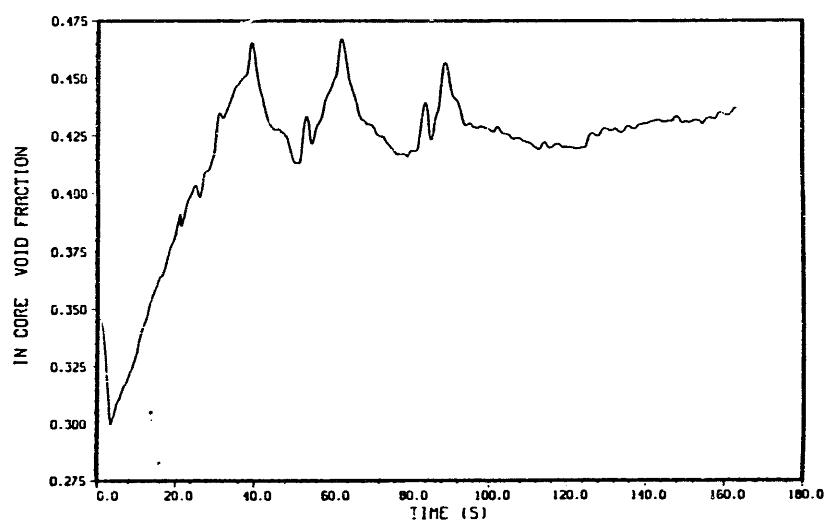

Figure 4(d) Transient Void Fraction Profile for case 4

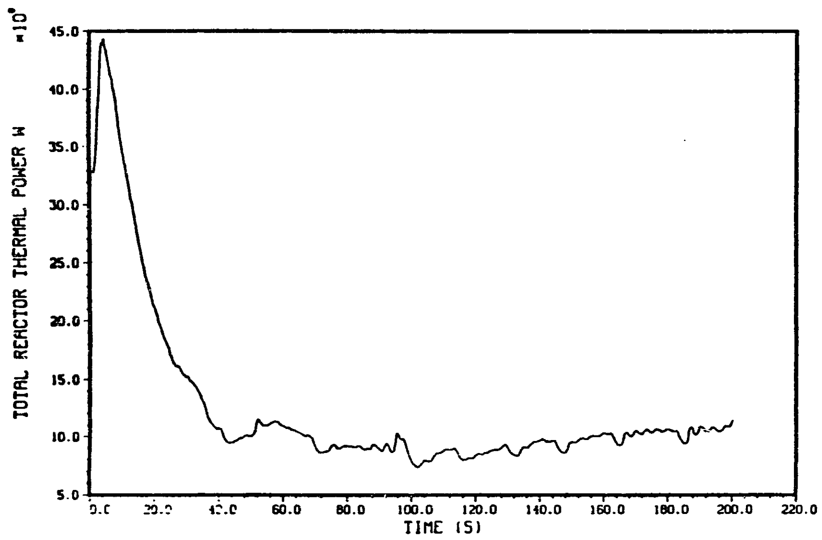

Figure 5(a) Thermal Power Profile for case 2

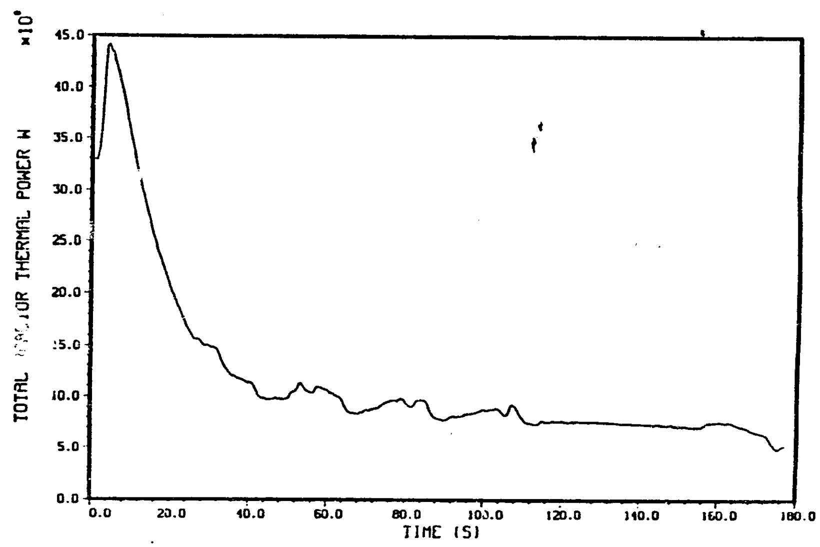

Figure 5(b) Thermal Power Profile for case 3

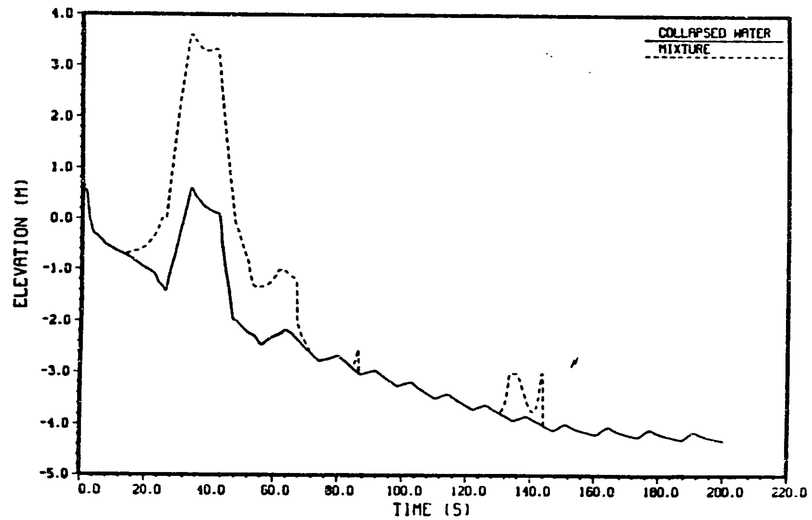

Figure 6(a) Collapsed Liquid Level for case 1

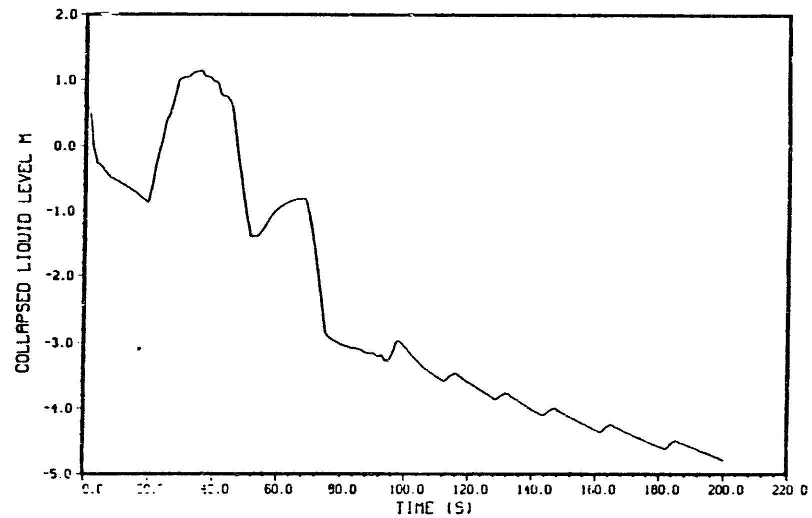

Figure 6(b) Collapsed Liquid Level for case 2

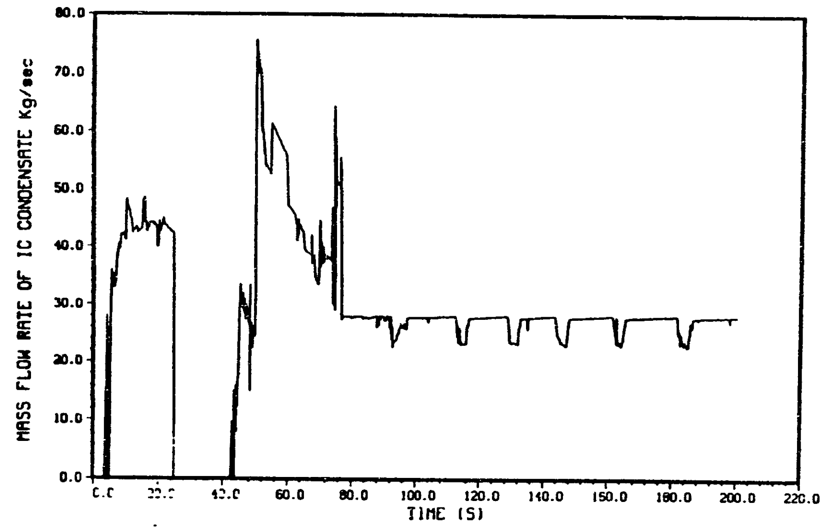

Figure 7(a) Mass Flow Rate of IC condensate for case 2

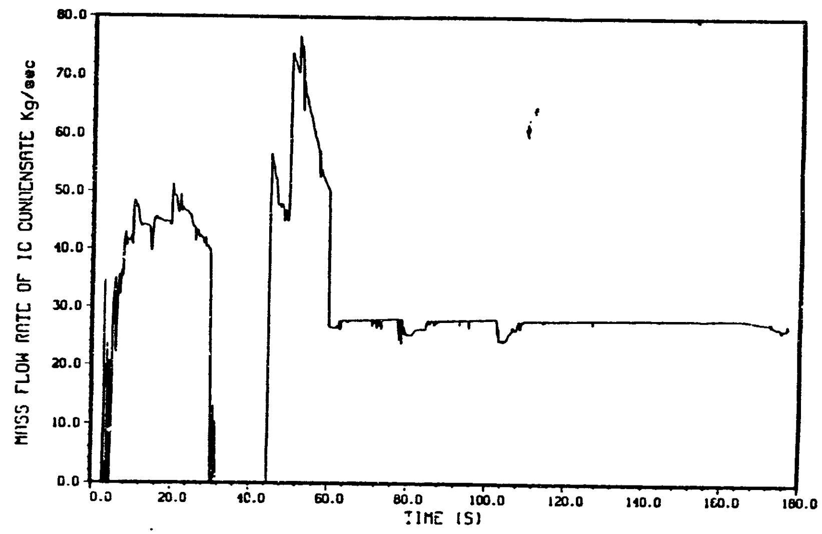

Figure 7(b) Mass Flow Rate of IC condensate for case 3

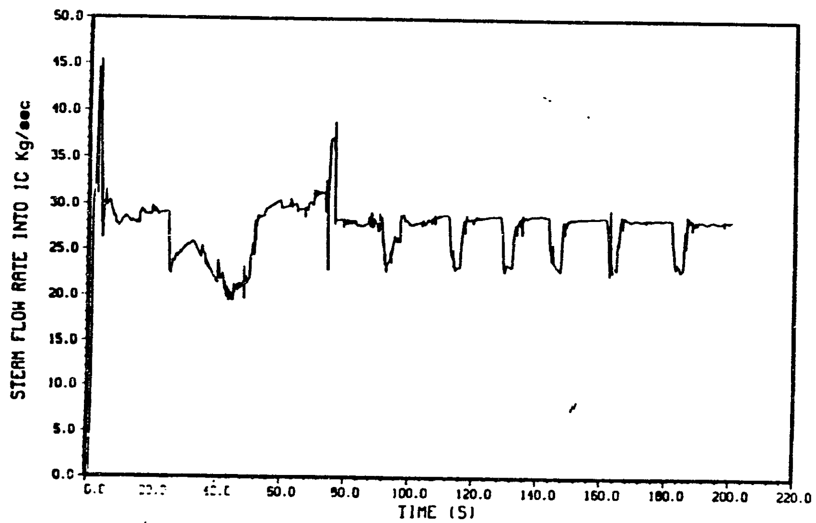

Figure 8(a) Steam Flow Rate into IC for case 2

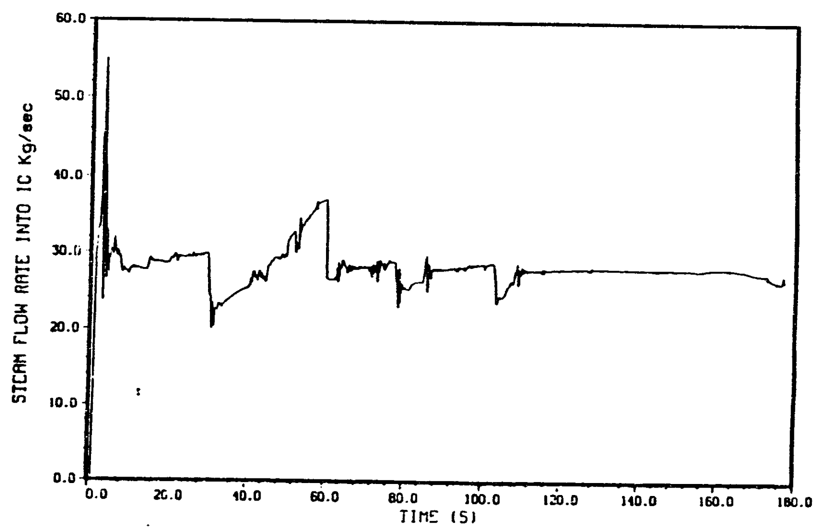

Figure 8(b) Steam Flow Rate into IC for case 3

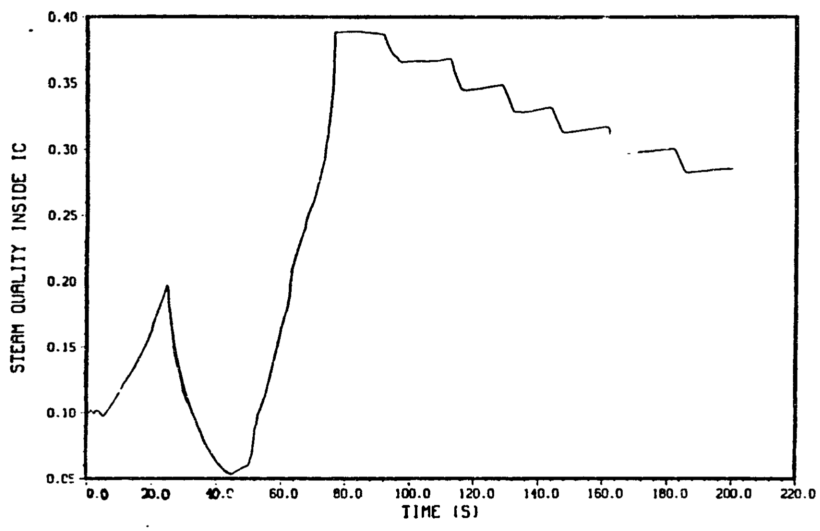

Figure 9 Steam Quality in IC for case 2

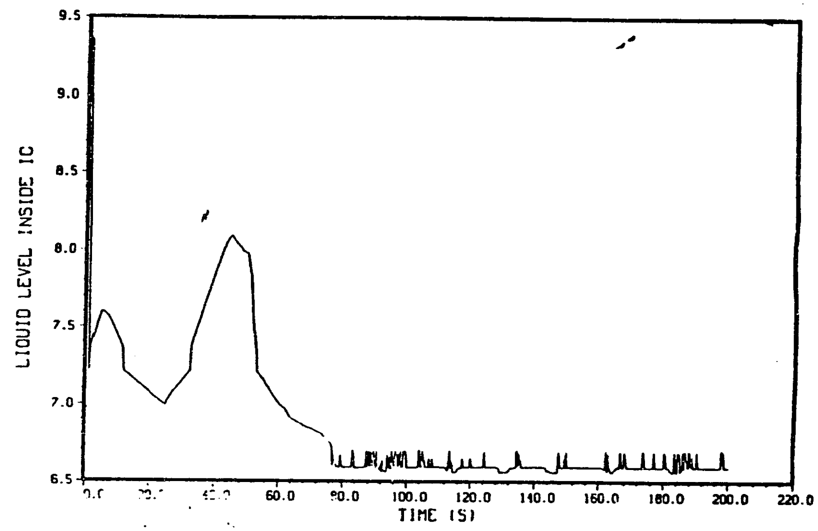

Figure 10 Liquid Level in IC for case 2

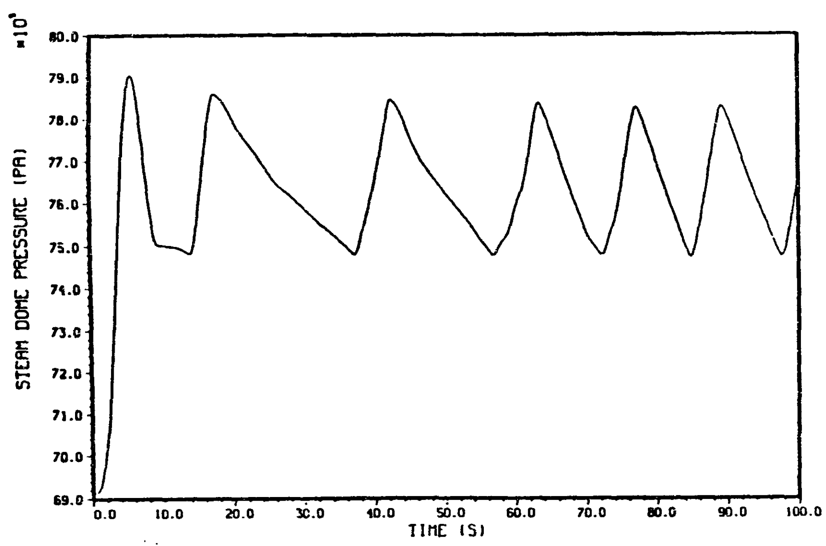

Figure 11(a) Transient Pressure Profile for Natural Convection Without Isolation Condenser (case 5)

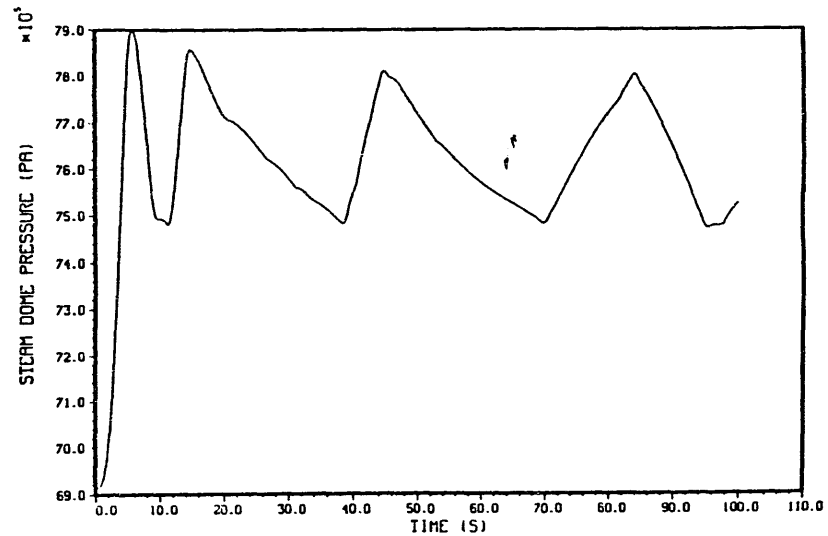

Figure 11(b) Transient Pressure Profile for Natural Convection With Isolation Condenser (case 6)

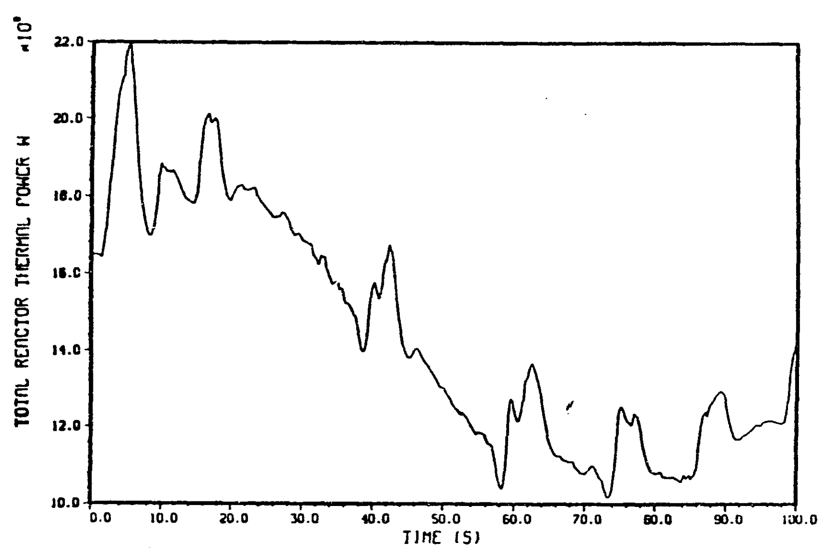

Figure 12(a) Thermal Power Profile for Natural Convection (case 5)

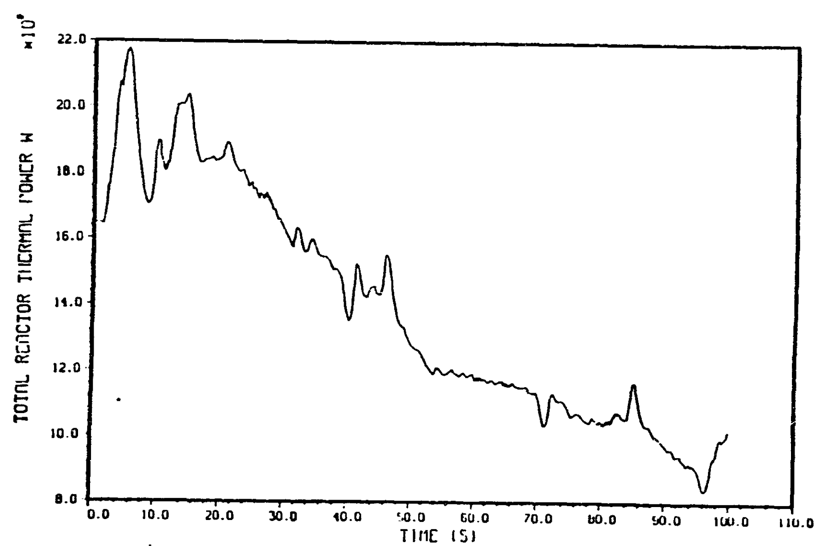

Figure 12(a) Thermal Power Profile for Natural Convection (case 6)

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