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TITLE **PWR SHUTDOWN DECAY-HEAT REMOVAL ANALYSES IN SUPPORT OF TAP A-45**

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PWR SHUTDOWN DECAY HEAT REMOVAL ANALYSES IN SUPPORT OF TAP A-45

by

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INTRODUCTION

The primary method for removal of decay heat from pressurized water reactors (PWRs) is via the steam generators to the secondary system using either the main feedwater or auxiliary feedwater systems. The probabilistic risk assessment reported in WASH 1400, later reliability studies, and related experience from the Three Mile Island Unit 2 accident have reaffirmed that the loss of capability to remove heat through the steam generators is a significant contributor to the possibility of core damage.

The US Nuclear Regulatory Commission (NRC) currently considers the adequacy of shutdown decay heat removal to be an unresolved safety issue (USI A-45). The purpose of Task Action Plan (TAP) A-45[1] is to "evaluate the adequacy of current licensing design requirements, to ensure that nuclear power plants do not pose an unacceptable risk because of failure to remove shutdown decay heat." A major part of TAP A-45 is concerned with the transition from reactor trip to hot shutdown. Also of interest is the transition from hot shutdown to cold shutdown and maintaining cold shutdown conditions. Although a limited number of alternative means for removal of shutdown decay heat from PWRs are being examined by the NRC, this paper focuses on activities at the Los Alamos National Laboratory to investigate the application of the "feed and bleed" concept as a diverse alternative method of removing decay heat that does not rely on the use of the steam generators.

ANALYSIS ACTIVITIES

An extensive program of decay heat removal analysis using the TRAC-PF1 code[2] is in progress at Los Alamos National Laboratory. Thermal-hydraulic analyses of accidents involving loss of all secondary cooling are being performed. These studies are evaluating the capability of Babcock and Wilcox (B&W), Combustion Engineering (CE), and Westinghouse (W) plants to remove decay heat using a "feed-and-bleed" operation. Audited plant models for specific plants have been developed and are in use. The specific plants are Oconee-1 (B&W), Calvert Cliffs-1 (CE), and Zion-1 (W). A common set of transient analyses has been identified and are being performed for each plant. The set of transients consists of 1) a loss-of-offsite power (LOSP) induced loss-of-feedwater (LOFW) event, 2) a LOFW event, 3) a combined main-steamline break (MSLB) and LOFW event, 4) a combined single-tube steam-generator tube rupture (SGTR) and LOFW event, and 5) a combined main-feedwater-line break (MFLB) and LOFW. For each of the five events in the common set, a minimum of three transients are calculated. First a base-line transient is calculated for which there is no actuation of the safety injection (SI) system and no operator intervention. This transient, which leads to core dryout, establishes the timing of critical events such as steam-generator dryout, primary system saturation, containment overpressure, and the start of core heatup. The second transient evaluates plant thermal-hydraulic performance considering "feed" only operation after the safety-injection (SI) system signal, usually containment overpressure. We define "feed" only as a limited mode of "feed and bleed" cooling that occurs when the operator does not open the power-operated relief valves (PORVs) to reduce the primary pressure. The "feed" of the emergency core coolant (ECC) is at a primary system pressure determined by the PORV setpoint. The third transient evaluates the effectiveness of a "feed and bleed" procedure conducted according to the appropriate operator emergency guidelines. "Feed and bleed" cooling is effected by starting ECC injection (feed) and by opening (bleed) the PORVs on top of the pressurizer to reduce primary system pressure. An additional transient is calculated using a LOFW initiator to determine the effectiveness of a "feed and bleed" procedure in cooling and depressurizing the plant to the design operating conditions of the residual heat removal (RHR) system.

STATUS AND RESULTS TO DATE

The status and results obtained to date are presented in the following for each plant type. It should be noted that the results are for the specific plant models indicated and do not apply to all reactors manufactured by the vendor. However, efforts are in progress to extend the conclusions to similar plants of the same vendor.

Oconee-1 (B&W)

All calculations in the common transient set have been completed[3-5] with the exception of the combined SGTR/LOFW transient. Compared to CE and W reactors, steam-generator-secondary dryout occurs early in the transient because the once-through steam generators have less secondary liquid inventory. However, the Oconee-1 ECC flow capacity at the PORV setpoint is large and the plant can successfully maintain a stable operation in the "feed" mode until the water supply is exhausted. If two high-pressure injection (HPI) pumps are actuated before 1600 s for the LOSP transient and 900 s for the LOFW transient subcooling can be maintained. Operating in the "feed and bleed" mode aids cooling by lowering the primary pressure and increasing HPI output. Although the early (<1000 s) character of the combined MSLB/LOFW transient differs from the LOFW transient, after 1000 s the transients are similar and the conclusions for the LOFW transient apply. The combined MFLB/LOFW transient is similar to a LOFW transient with a compressed time scale to steam-generator-secondary dryout and a similar timescale thereafter. "Feed and bleed" cooling in a once-through mode can be maintained for approximately 9 h. Cooldown and depressurization to RHR system design conditions using only the contents of the refueling water storage tank can not be achieved. Either switching to the high-pressure recirculation mode, additional relief capacity, or an additional long-term once-through water supply is required.

Zion-1 (Westinghouse)

The LOSP, LOFW and combined MSLB/LOFW calculations[6-10] have been completed. The Zion-1 plant is characterized by a large PORV relief capacity and an ECC system incorporating centrifugal charging pumps that provide moderate flows at the PORV setpoint and high-head SI pumps that begin delivering at an intermediate pressure (< 1500 psig). The plant can successfully maintain a stable operation in the "feed" mode until the water supply is exhausted. The latest time at which injection can be started and still maintain subcooling has not been determined. Operating in the "feed and bleed" mode aids cooling by lowering the primary pressure and increasing ECC output. Cooldown and depressurization to RHR system design conditions using a "feed and bleed" procedure can be successfully accomplished. As with Oconee-1, the early character (< 3000 s) of the combined MSLB/LOFW transient differs from the LOFW transient. After dryout of the steam generators with intact steam lines at ~3100 s, the transients are similar and the conclusions for the LOFW transient apply.

Calvert Cliffs-1 (CE)

Only the LOSP and LOFW transients have been completed. The Calvert Cliffs-1 plant is characterized by an intermediate PORV relief capacity (larger than Oconee-1 and smaller than Zion-1), and a low SI capacity at the PORV setpoint. For the LOSP transient, the plant can maintain a stable operation when "feed" is initiated on containment overpressure. The plant can be maintained in this condition until the water supply is exhausted. For the LOFW transient, the plant cannot maintain a stable operation and cool the core when "feed" is initiated on containment overpressure. The limited SI capacity at the POPV setpoint is insufficient when the reactor coolant pumps (RCPs) are operating and adding ~17.5 MW(t) to the primary system. A "feed and bleed" operation will be required for this plant and is expected to be successful.

REFERENCES

1. Task Action Plan A-45, "Shutdown Decay Heat Removal Requirements," Rev. 1, US Nuclear Regulatory Commission (June 2, 1982).

2. Safety Code Development Group, "TRAC-PF1, an Advanced Best Estimate Computer Program for Pressurized Water Reactor Analysis," Los Alamos National Laboratory Report (to be published).

3. R. J. Henninger and N. S. DeMuth, "Loss-of-Offsite-Power-Initiated Loss-of-Feedwater Transients for B&W Plants," Los Alamos National Laboratory Report LA-UR-83-3001 (October 1983).

4. R. J. Henninger, "Loss-of-Feedwater Transients for Oconee-1," Los Alamos National Laboratory Report LA-UR-83-2894 (October 1983).

5. R. J. Henninger, "Combined Secondary-Side Break/Loss-of-Feedwater Transients for Oconee-1," Los Alamos National Laboratory Report LA-UR-83-2883 (October 1983).

6. N. S. DeMuth, D. Dobranich, and R. J. Henninger, "Loss-of-Feedwater Transients for the Zion-1 Pressurized Water Reactor, NUREG/CR-2656 (May 1982).

7. B. E. Boyack, "Loss-of-Offsite Power Transient for the Zion-1 PWR," Los Alamos National Laboratory Report LA-UR-83-1714 (June 1983).

8. B. E. Boyack, "Loss-of-Feedwater Transients for the Zion-1 PWR," Los Alamos National Laboratory Report LA-UR-83-2224 (June 1983).

9. B. E. Boyack, "Shutdown to Residual Heat Removal Cooling in the Zion-1 PWR Following a Severe Loss-of-Feedwater Transient," Los Alamos National Laboratory Report LA-UR-83-2684 (September 1983).

10. B. E. Boyack, "Combined Main-Steam-Line-Break/Loss-of-Feedwater Transient in the Zion-1 PWR," Los Alamos National Laboratory Report LA-UR-83-2787 (September 1983).

PWR
SHUTDOWN DECAY HEAT REMOVAL ANALYSES IN SUPPORT OF TAP A-45

SAFETY ANALYSIS GROUP
ENERGY DIVISION
LOS ALAMOS NATIONAL LABORATORY

PRESENTED TO

ELEVENTH WATER REACTOR
SAFETY INFORMATION MEETING

OCTOBER 25, 1983

Los Alamos

USI A-45

TASK

EVALUATE ADEQUACY OF CURRENT LICENSING DESIGN REQUIREMENTS FOR SHUTDOWN DECAY HEAT REMOVAL

APPROACH

1. DEVELOP ACCEPTANCE CRITERIA FOR DHRS
2. DEVELOP MEANS FOR DHRS IMPROVEMENT
3. ASSESS DHRS ADEQUACY IN EXISTING LWRs
4. IMPLEMENT NEW REQUIREMENTS AS NECESSARY

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CURRENT LOS ALAMOS ACTIVITIES

OBJECTIVE

EVALUATE CAPABILITY OF EXISTING PWRs TO REMOVE DECAY HEAT USING "FEED & BLEED" FOLLOWING LOSS OF ALL SECONDARY COOLING

PLANTS TO BE ANALYZED

1. OCONEE-1 (B&W)
2. CALVERT CLIFFS-1 (CE)
3. ZION-1 (WESTINGHOUSE)

ANALYSIS TOOL

TRAC-PF1

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TRANSIENT SET

		B&W	CE	W
LOSP	BASE	●	●	●
	FEED	●	●	●
	FEED&BLEED	●	◒	●
LOFW	BASE	●	●	●
	FEED	●	●	●
	FEED&BLEED	●	◒	●
	SHUTDOWN TO RHR	●	○	●
LOFW + MSLB	BASE	●	○	●
	FEED	●	○	●
	FEED&BLEED	●	○	●
LOFW + SGTR	BASE	◒	○	○
	FEED	○	○	○
	FEED&BLEED	○	○	○
LOFW + MFLB		●	○	○

● COMPLETED ◒ IN PROGRESS ○ TO BE DONE

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TRANSIENT SET RATIONALE

BASE CASE

ESTABLISH TIMING OF CRITICAL EVENTS
1. STEAM-GENERATOR-SECONDARY DRYOUT
2. PRIMARY SYSTEM SATURATION
3. CONTAINMENT OVERPRESSURE
4. CORE HEATUP

FEED CASE

ADEQUACY OF ECC AT PORV SETPOINT

FEED & BLEED CASE

COMPATIBILITY OF PORV AND ECC FLOW CAPACITIES

SHUTDOWN TO RHR DESIGN CONDITIONS

ATTAINMENT OF LONG-TERM CONTROL

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PLANT SIZING

	OCONEE	CALVERT CLIFFS	ZION
STEADY-STATE POWER (Mwt)	2584	2700	3250
TOTAL SG SECONDARY INVENTORY (kg)	35000	124700	173840
NUMBER OF PORVS	ONE	TWO	TWO
RATED PORV CAPACITY (kg/s)	12.8	38.7	53.0
ECC FLOW (kg/s) AT PORV SETPOINT	27.2	8.3	15.6

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BASE CASE LOFW EVENTS (NO HPI)

	TIME(s)		
	B&W	CE	W
SG ARVs OPEN	14	23*	91
SG SECONDARY DRYOUT	200	1250	3080
PORV OPENS	140	1680	3110
CONTAINMENT OVERPRESSURE	900	3000	4095
PRIMARY SYSTEM SATURATION	1200	2900	4875
CORE HEATUP BEGINS	2200	4200	6280

* AUTOMATIC OPEN ON REACTOR AND TURBINE TRIP

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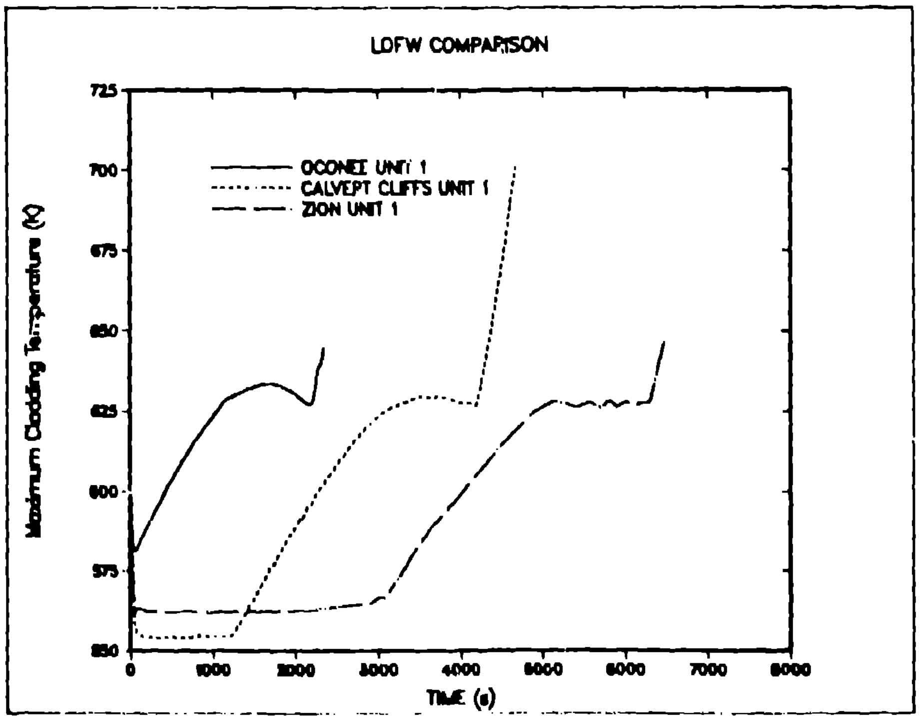

OCONEE-1 SUMMARY

FEED MODE

1. ECC CAPACITY SUFFICIENT TO COOL CORE
2. 2 HPI BEFORE CONTAINMENT OVERPRESSURE MAINTAINS SUBCOOLING

FEED AND BLEED MODE

1. ENHANCES COOLING BY LOWERING PRESSURE AND INCREASING HPI OUTPUT
2. AVOIDS CYCLING PORV

SHUTDOWN TO RHR USING FEED AND BLEED

1. UNABLE TO REACH RHR SYSTEM DESIGN CONDITIONS WHEN SYSTEM LIQUID FULL USING ONLY RWST CAPACITY
2. INCREASED PORV CAPACITY ALLOWS SUCCESSFUL FEED AND BLEED PROCEDURE

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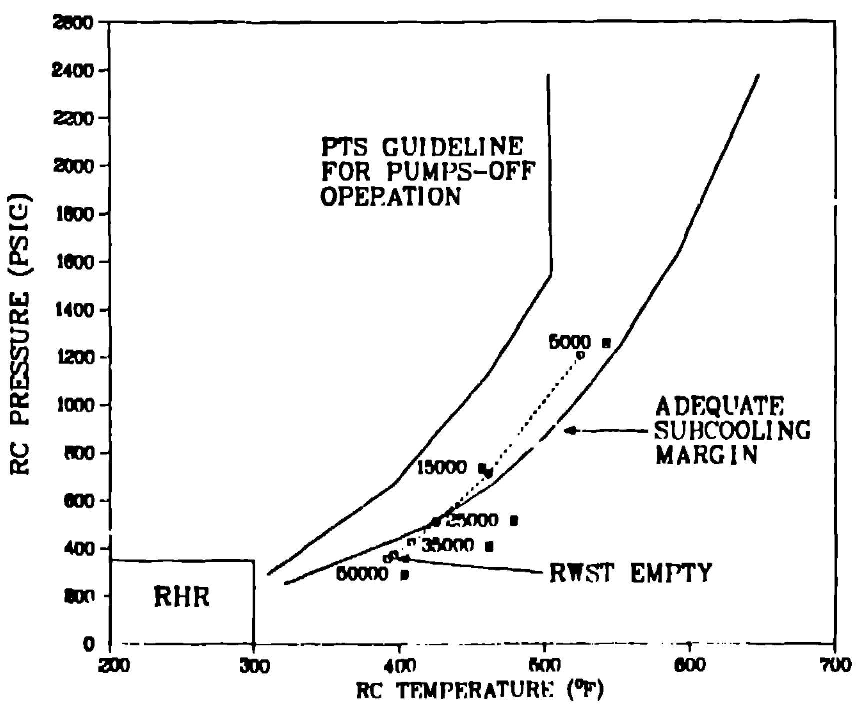
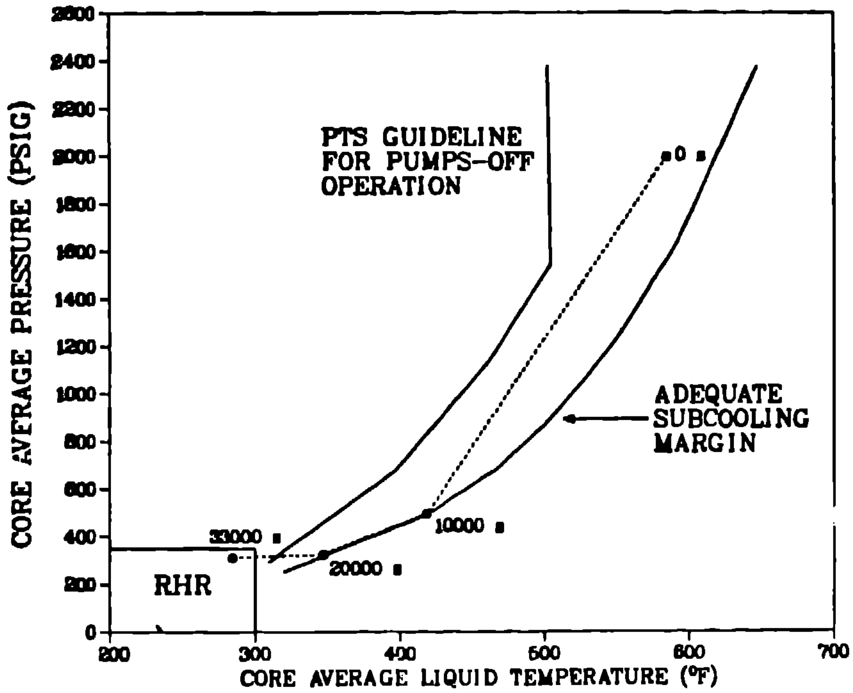
OCONEE UNIT 1 - SHUTDOWN TO RHR
LOSP INDUCED LOFW





CALVERT CLIFFS-1 SUMMARY

FEED MODE

1. THREE CPs* ON CONTAINMENT OVERPRESSURE COOL CORE FOR LOSP TRANSIENT
2. THREE CPs ON CONTAINMENT OVERPRESSURE NOT SUFFICIENT TO PREVENT CORE VOIDING AND HEATUP FOR LOFW TRANSIENT

FEED AND BLEED MODE

WORK IN PROGRESS

SHUTDOWN TO RHR USING FEED AND BLEED

WORK IN PROGRESS

* CHARGING PUMPS

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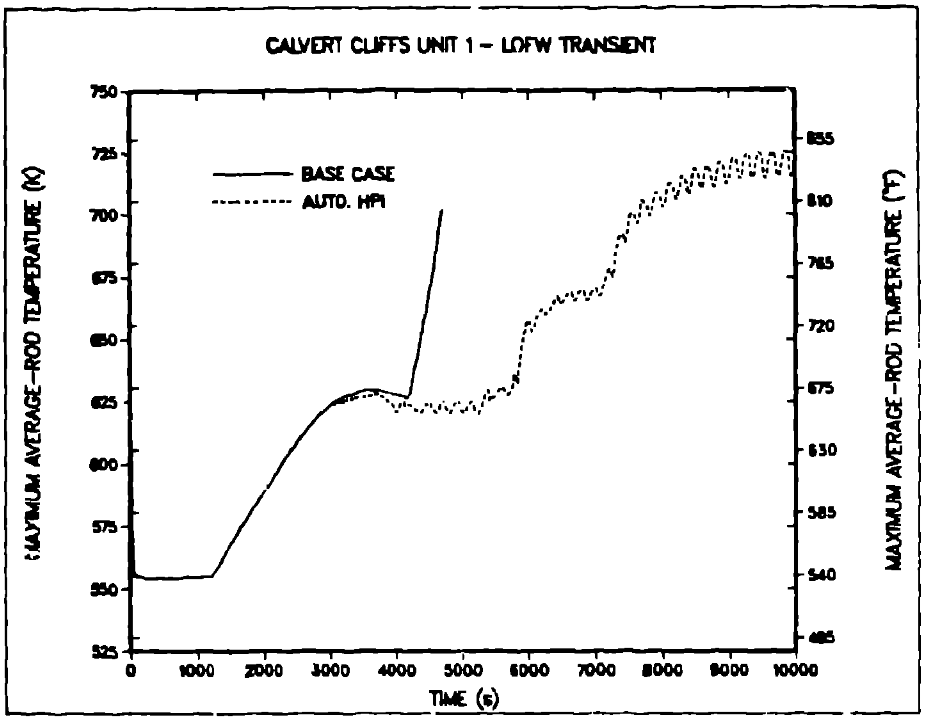

ZION-1 SUMMARY

FEED MODE

1. ECC CAPACITY SUFFICIENT TO COOL CORE
2. 2 CCP BY 2000 s (PERHAPS LATER) MAINTAINS SUBCOOLING

FEED AND BLEED MODE

1. ENHANCES ALREADY ACCEPTABLE COOLING BY INCREASING HPI OUTPUT
2. AVOIDS CYCLING PORV

SHUTDOWN TO RHR USING FEED AND BLEED

COOLS AND DEPRESSURIZES PRIMARY TO RHR SYSTEM DESIGN CONDITIONS WITH MARGIN

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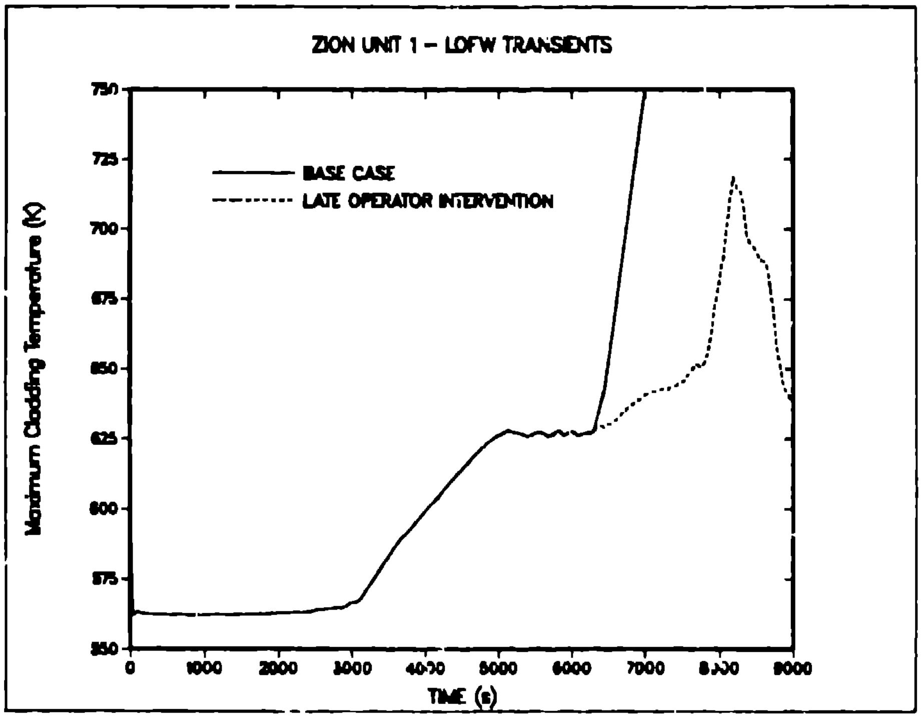
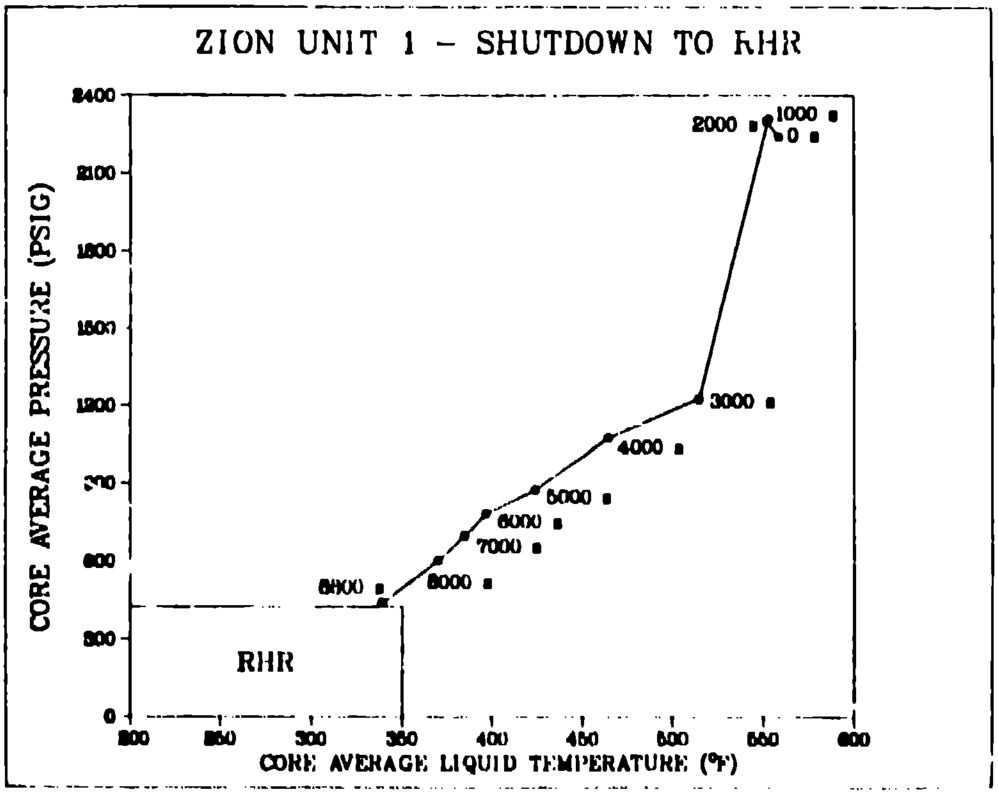

ZION UNIT 1 – LOFW TRANSIENTS
Maximum Cladding Temperature (K)
TIME (s)
BASE CASE
LATE OPERATOR INTERVENTION
550
575
600
625
650
675
700
725
750
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


ZION UNIT 1 – SHUTDOWN TO RHR
CORE AVERAGE PRESSURE (PSIG)
CORE AVERAGE LIQUID TEMPERATURE (°F)
RHR
0
300
600
1200
1800
2100
2400
200
250
300
350
400
450
500
550
600
1000
0
2000
3000
4000
5000
6000
7000
8000