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WESTINGHOUSE CLASS 3

WCAP-8904-A

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W EMERGENCY CORE COOLING SYSTEM EVALUATION MODEL FOR ANALYZING (N-1) LOOP OPERATION OF PLANTS WITH LOOP ISOLATION VALVES

R. M. Kemper

APPROVED: T. M. Anderson, Manager
Nuclear Safety Department

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WESTINGHOUSE ELECTRIC CORPORATION
P. O. BOX 355
PITTSBURGH, PA. 15230

[redacted]

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

FEB 2 8 1979

RECEIVED
MAR 5 1979
T. M. Anderson, Manager
Nuclear Safety Department

Mr. Thomas M. Anderson, Manager
Nuclear Safety Department
Westinghouse Electric Corporation
P. O. Box 355
Pittsburgh, Pennsylvania 15230

Dear Mr. Anderson:

SUBJECT: SAFETY EVALUATION OF WCAP-8904

The Nuclear Regulatory Commission has completed its review of Westinghouse Electric Corporation Topical Report WCAP-8904 (Non-proprietary) entitled "Westinghouse Emergency Core Cooling Evaluation Model for Analyzing (N-1) Loop Operation of Plants With Loop Isolation Valves". Our safety evaluation is enclosed.

As a result of our review of WCAP-8904, we have determined that the evaluation model described therein is conditionally acceptable for loss-of-coolant accident analyses for large and intermediate sized breaks of Westinghouse 3-loop and 4-loop reactors that are operated with one reactor coolant loop isolated. The conditions of acceptance are (1) that at least two nodes are used for the postulated inactive loop break and (2) that momentum flux is accounted for by the methods described in WCAP-8341 (Proprietary) and WCAP-8342 (Non-proprietary) entitled "Westinghouse Emergency Core Cooling Evaluation Model - Sensitivity Studies".

Accordingly, topical report WCAP-8904 is acceptable for reference in license applications. Each license application that references the methods of WCAP-8904 must provide results of analyses for a postulated active loop break and an inactive loop break to assure that the postulated break location resulting in the maximum fuel cladding temperature has been considered.

In accordance with established procedure, it is requested that Westinghouse issue a revised version of this report within three months of receipt of this letter to include the NRC acceptance letter, the enclosed evaluation, and any changes resulting from the review.

We do not intend to repeat our review of this report when it appears as a reference in a particular license application except to assure that the material presented in this report is applicable to the specific plant involved.

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Should Nuclear Regulatory Commission criteria or regulations change, such that our conclusions concerning this report are invalidated, you will be notified and given an opportunity to revise and resubmit your topical report, should you so desire.

Sincerely,

John F. Stolz, Chief
Light Water Reactors Branch No. 1
Division of Project Management

Enclosure:
Safety Evaluation

cc: Mr. Dave Rawlins
Westinghouse Electric Corporation
P. O. Box 355
Pittsburgh, Pennsylvania 15230

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ENCLOSURE

TOPICAL REPORT EVALUATION

Report No. & Title:	WCAP-8904, "Westinghouse Emergency Core Cooling System Evaluation Model for Analyzing (N-1) Loop Operation of Plants with Loop Isolation Valves."
Originating Organization:	Westinghouse Electric Corporation
Reviewed By:	Analysis Branch

Summary of the Topical Report

Westinghouse designed Nuclear Steam Supply Systems (NSSS), containing recirculation loop isolation valves, can be operated with one recirculation loop out of service. These valves isolate the steam generator and reactor coolant pump from the primary system, thereby permitting continued reactor operation at reduced power. Topical report WCAP-8904 documents how the computer programs, SATAN and WREFLOOD, will be used in modeling a loss of coolant accident for Westinghouse designed PWRs equipped with loop isolation valves, and operating under (N-1) loop configuration. The topical report presents system sensitivity studies and discussions of modeling assumptions for a Westinghouse 4-loop (15x15) and a Westinghouse 3-loop (17x17) power plant.

Regulatory Evaluation

LOCA analyses performed on plants operating under (N-1) loop configuration require no modification to the analytical models approved for the SATAN and WREFLOOD computer programs. Only minor noding changes are required to reflect the modified primary system configuration.

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The SATAN blowdown calculations for normal plant analyses (all loops in operation) model the primary system with 46 nodes. When modeling an active or an inactive loop break under (N-1) loop configuration, Westinghouse proposes to describe the primary system utilizing three additional nodes. One node models the valved off hot leg, the second node models the valved off cold leg, and the third node models the accumulator that is connected to the valved off cold leg. Thus, when modeling a break in the inactive loop, Westinghouse proposed to model the broken leg as one node.

When modeling the cold legs, the one-dimensional SATAN code does not account for the momentum flux pressure gradient between the downcomer and the adjacent cold legs. The momentum flux is not calculated at this location because the local fluid conditions in the downcomer, adjacent to the cold leg pipe, are unknown. This is due to the three dimensional behavior of the downcomer. Sensitivity studies conducted by Westinghouse showed that when modeling the break as two nodes (neglecting the momentum flux between the vessel and the cold leg, and considering the momentum flux between the two cold leg nodes), a slight increase in calculated peak clad temperature (13 deg. F) was observed. The use of two cold leg nodes to model the break is consistent with previous sensitivity studies (Ref. 3). Thus, Westinghouse agreed to model the broken leg using a minimum of two nodes, and accounting for the momentum flux between the cold leg nodes, but not between the vessel and the broken leg.

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The WREFLOOD code analyzes the reflood phenomena occurring during a postulated LOCA. When modeling an active loop break, Westinghouse uses the same noding structure as previously approved for (N) loop operation, with the addition of one node connected to the downcomer which models the inactive loop accumulator. The dead-ended hot and cold leg volumes were not simulated. This is acceptable since the dead-ended nodes have no influence on the reflood transient.

When modeling an inactive loop break, the WREFLOOD noding structure is modified to account for the dead-ended hot leg piping. The dead-ended (valved shut) pipe was modeled as three consecutive nodes with decreasing areas and increasing loss coefficients. This is acceptable since it adequately models the function of the dead-ended hot leg pipe.

Sensitivity studies have been performed for postulated breaks in both the active and inactive loops. In the cases analyzed, the peak clad temperature occurred for the postulated active loop break. For the postulated inactive loop cold leg breaks, no steam venting from the dead-ended hot leg occurs, thereby increasing potential steam binding effects. However, this is offset by a prolonged blowdown negative core flow, which results from the single-ended cold leg break. The prolonged negative core flow during the blowdown phase provides sufficient cooling to reduce the stored energy in the core, thereby reducing

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the amount of steam generated during the reflood transient. The net effect results in a higher peak clad temperature for the active loop breaks. To assure that this trend is consistent for all applications, (N-1) loop plant analyses for both an active and inactive loop break should be performed.

For a postulated cold leg break in the inactive loop, a potential concern exists regarding cold leg and downcomer plugging during the reflood transient. The downcomer mixture level model in WREFLOOD assumes that the level does not rise above the bottom of the cold legs. Consequently, the code could not properly assess potential plugging of the steam venting path in the cold legs and around the downcomer while the accumulators are injecting into a filled downcomer. The plugging of this path has a potential for increasing steam binding and retarding the reflooding rate. Westinghouse conducted a series of sensitivity studies which artificially increased the system pressure losses such that the plugging behavior was conservatively bounded. The studies showed this concern to have a small (less than 10°F) influence on the calculated peak clad temperature. The sensitivity of the reflooding process to this effect was confirmed by independent staff calculations.

Regulatory Position

The NRC staff has completed its review of WCAP-8904 which describes the models used to evaluate LOCAs for Westinghouse designed PWRs with isolation valves segregating one loop from the primary system. We conclude, with the stipulation of modeling the inactive loop break with a

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minimum of two nodes and proper accounting of the momentum flux effects, that the methods stipulated in WCAP-8904 are acceptable for ECCS performance evaluation for Westinghouse designed 3-loop (17x17) and 4-loop (15x15) PWRs with loop isolation valve. In addition, specific applicants should verify that the limiting peak clad temperatures occur for postulated active loop failures. This report may be referenced in related licensing applications as an acceptable analytical model.

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References

1. Letter from C. Eicheldinger, Manager, Nuclear Safety Department, Westinghouse Electric Corporation, to Mr. John F. Stolz, Chief, LWR Project, NRR, dated June 27, 1977.

2. Letter from C. Eicheldinger, Manager, Nuclear Safety Department, Westinghouse Electric Corporation, to Mr. John F. Stolz, Chief, LWR Project, NRR, dated September 7, 1977.

3. WCAP-8341, "Westinghouse Emergency Core Cooling System Evaluation Model - Sensitivity Studies, July, 1974.

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ABSTRACT

This report describes an analytical model to be used for performing Appendix K ECCS analyses for a loss-of-coolant accident, which occurs during operation in the (N-1) configuration in a plant equipped with loop isolation valves. The analytical results for ECCS analyses using this model are presented for a Westinghouse 4 loop (15 x 15) plant and for a Westinghouse 3 loop (17 x 17) plant. Sensitivity studies and a discussion of the effect of modeling assumptions are also documented.

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I. Introduction

During the lifetime of a nuclear power plant the owner-utility may desire, under certain circumstances, to operate with one reactor coolant loop out of service. To facilitate operation in an (N-1) loop configuration, several Westinghouse 3 and 4-loop plants are equipped with valves in the hot and cold legs which isolate an inactive loop from the reactor vessel. This report describes a model to be used for performing Appendix K ECCS analyses for a loss-of-coolant accident which occurs during operation in the (N-1) configuration in a plant equipped with loop isolation valves. Minimal changes have been made to the nodalization scheme approved for N-loop 10 CFR 50.46 ECCS analyses; all calculations are performed utilizing Westinghouse Evaluation Model versions of the applicable computer codes (References 1-4) modified as specified by the NRC in Reference (5).

The calculations presented in Section III of this report describe the ECCS performance of a 4-loop plant with 15 x 15 fuel operating under steady-state conditions in a 3-loop configuration at 75 percent of the licensed power level. A power peaking factor envelope calculated specifically for this mode of operation was utilized; all analyses performed were based on a cosine power distribution with a maximum total peaking factor of 2.413. The cosine power distribution was found to be the worst power shape in terms of peak clad temperature based on sensitivity studies reported in Chapter 5 of Reference (6) and Section F.7 of Reference (7). In addition, all analyses assumed the loss of one low head ECCS pump for the worst single failure and loss of offsite power coincident with the loss of coolant accident (LOCA). The bases for these assumptions are presented in Section 3.6 of Reference (7).

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In Section IV results are presented which describe the ECCS performance of a 3-loop plant with 17 x 17 fuel operating at steady-state in a 2-loop configuration at 65% of the licensed power level. The power shape utilized for the 3-loop case is a cosine power distribution with a maximum total peaking factor of 2.436. All analyses assume the loss of a low head ECCS pump as the worst single failure and the loss of offsite power coincident with the LOCA.

Sensitivity studies reported previously demonstrate that double-ended cold leg guillotine (DECLG) breaks are limiting compared to other break types and locations [References 8, 9, 10]. In this study, DECLG breaks in both the active and inactive loops were evaluated at various values of discharge coefficient (C_D); the active loop break location is established as the limiting case.

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II. Modeling

Three nodes have been added to the N-loop, 46-element SATAN nodal network presented in Reference (1) in order to model in detail the (N-1) loop LOCA blowdown transient. Figure 1 presents the 49-element model for an active loop break location. Element 47 represents the inactive loop hot leg pipe segment on the reactor vessel side of the loop isolation valve, element 48 represents the inactive loop cold leg pipe segment, and element 49 is the inactive loop accumulator. Physically, the accumulator and safety injection delivery lines enter each cold leg pipe on the vessel side of the loop isolation valves. Figure 2 depicts the 49-element SATAN model as applied to an inactive loop DECLG break.

The (N-1) active loop break case is modeled as shown in Figure 3A in the WREFLØØD code basically as described in Reference (3) with the active, intact reactor coolant loop(s) represented by the "unbroken loop." The inactive loop accumulator is attached to element 10, the downcomer; all safety injection flow is assumed to feed into element 8 of the unbroken loop. No elements are added to simulate the hot and cold leg pipe stubs. The WREFLØØD model employed in analyzing the inactive loop break case is shown in Figure 3B. The 11-element unbroken loop representation is identical with the unbroken loop modeling from the N-loop operation case, element 11 being the broken cold leg pipe stub. A 3-element sequence with successively lower flow areas and successively higher loss coefficients comprises the broken loop input to WREFLØØD. Such input permits code execution to be achieved.

The CØCØ and LØCTA models remain unchanged for the analysis of a LOCA occurring during (N-1) loop operation. The containment data used in these studies are presented as Tables 3 and 3A.

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III. 4-Loop Plant Results

Results obtained for a spectrum of 4-loop plant cold leg breaks are presented in Tables 1 and 2. It is apparent that the active loop is the limiting break location and the C_D = 0.4 case the limiting break size. A comparison of core flow rates during blowdown for active and inactive loop DECL breaks (C_D = 0.6) is presented in Figure 4. The two core flows are similar throughout the initial 15 seconds of the transient; after 15 seconds the inactive loop break exhibits much greater negative core flow. Since no blowdown mass can leave the RCS through the valved off hot leg pipe stub, a much higher system pressure (840 psi vs. 590 psi) and roughly 50,000 lbs of additional mass exist in the RCS in the inactive loop break than the active loop break case at 15 seconds. This water must flow through the core, cooling the fuel rods, in order to reach the break, so a significant benefit in peak clad temperature relative to the active loop break case is realized.

The core reflooding transient for the limiting case is described in Figure 5, a plot of core inlet velocity as a function of time. As shown in Figure 5, V_{in} is less than one inch per second throughout most of reflood; values of V_{in} are lower than the comparable 4-loop case core flooding rates. This degradation of reflood performance in the (N-1) loop condition is balanced by the lower core power level associated with (N-1) loop operation; overall, a high value of F_Q (2.413) is permissible in the (N-1) loop configuration with loop isolation valves closed. Figure 6 presents the peak clad temperature transient for the limiting case break (active loop DECLG, C_D = 0.4).

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IV. 3-Loop Plant Results

Results obtained for several 3-loop plant cold leg breaks are presented in Tables 4 and 5. It is apparent that the active loop is the limiting break location and the $C_D = 0.4$ case the limiting break size. A comparison of core flow rates during blowdown for active and inactive loop DECL breaks ($C_D = 0.4$) is shown in Figure 7. A significant difference in negative core flow again exists in the 3-loop plant analysis, causing the calculated peak clad temperature to be lower for the inactive loop break case.

The core reflooding transient for the limiting case is described in Figure 8, a plot of core inlet velocity as a function of time. As shown in Figure 8, V_{in} is less than one inch per second throughout all of reflood; values of V_{in} are lower than the comparable (N) 3-loop case core flooding rates. This degradation of reflood performance in the (N-1) loop conditions is balanced by the lower core power level associated with (N-1) loop operation, so that a low peak clad temperature is calculated as shown in Figure 9.

V. Comparative Studies

Capability exists in the (N-1) loop model to consider the pressurizer as being attached to either an active or an inactive loop. The sensitivity to pressurizer location was determined for the C_D = 0.6 DECLG 4-loop plant active loop break by attaching the pressurizer to element 47, the inactive hot leg pipe segment. Results of an analysis based on this configuration are compared in Table 6 with the results obtained using the standard nodalization scheme of Figure 1. Figure 10 compares the core flows during blowdown calculated in the two runs and demonstrates the insensitivity of core flow to pressurizer location. The slightly improved performance achieved with the pressurizer located in the inactive loop may be attributed to an earlier end-of-bypass time.

Core flow rate and core differential pressure plots for the 4-loop plant limiting case C_D = 0.4 active loop DECL break are shown in Figures 11 and 12. These plots are very similar to those obtained in the Reference (11) 10 CFR 50.46 ECCS performance analysis because of the physical similarity between a 3-loop plant and a 4-loop plant with loop isolation valves operating in the (N-1) configuration. The similarity between these cases is again evident in the emergence of the C_D = 0.4 case as the limiting break. Similarly, the C_D = 0.4 case is the limiting case break for both 2-loop plants (Reference 10) and 3-loop plants operating in the (N-1) condition. From these results one is able to conclude that any (N-1) active loop break (with loop isolation valves closed) will exhibit a similar hydraulic transient to that N-loop case with the same number of active loops. Because of this it is unnecessary to perform additional sensitivity studies for the (N-1) loop operation case; the parametric sensitivities for any (N-1) case are indicated by available N-loop studies already performed with the appropriate number of active loops.

A lumped inactive loop 46-element SATAN model has been derived in which the hot leg and cold leg inactive volumes are incorporated into the upper plenum and upper downcomer nodes respectively. The limiting case (C_D = 0.4) DECLG break 4-loop plant (N-1) loop operation ECCS performance was calculated utilizing this lumped model, in which the inactive loop accumulator is attached directly to element 11, the upper downcomer. The calculated peak clad temperature obtained utilizing the lumped model is 2052°F, 9°F less than the 49-element model result reported in Table 2. Thus, little difference exists between the two models' predictions of ECCS performance for the C_D = 0.4 DECLG.

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VI. Sensitivity to Upper Head Fluid Temperature

Reference (12) has documented recent operating plant and model test results which indicate that the reactor vessel upper head fluid temperatures exceeds the design value of cold leg temperature (T_{cold}). The most significant sensitivity to upper head fluid temperature which might occur in an (N-1) loop operation ECCS analysis is a switch in the worst case break location from the active to the inactive loop. The effect of upper head fluid temperature has been established by reanalyzing the 3-loop plant limiting case active loop break (DECLG, C_D = 0.4) assuming the fluid in the upper head of the reactor vessel is at the hot leg temperature (T_{hot}) rather than T_{cold}. Table 7 provides a summary of the sequence of events for the T_{hot} cases, and Table 8 presents the results. The active loop break case incurs a greater penalty from having the upper head at T_{hot} than the inactive loop break and remains the limiting case. Figure 13 and 14 show the peak clad temperature transients for the active and inactive loop break T_{hot} cases. It is concluded that the active loop is the limiting case break location regardless of upper head fluid temperature conditions.

VII. Summary

The Westinghouse ECCS evaluation model for (N-1) loop operation of a plant with loop isolation valves incorporates a 49-element SATAN model and slightly modified WREFLØØD models and satisfies the requirements of Appendix K to 10 CFR 50. The active loop cold leg is the limiting break location.

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TABLE 1

4-LOOP PLANT TIME SEQUENCE OF EVENTS

	Active Loop DECLG, C_D=1.0 (Sec)	Active Loop DECLG, C_D=0.6 (Sec)	Active Loop DECLG, C_D=0.4 (Sec)	Inactive Loop DECLG, C_D=0.6 (Sec)
START	0.0	0.0	0.0	0.0
Reactor Trip Signal	0.66	0.67	0.68	0.68
S. I. Signal	0.66	0.67	0.68	0.68
Acc. Injection	12.6	15.7	19.7	22.6
End of Blowdown	28.1	31.3	35.0	33.5
Bottom of Core Recovery	40.7	44.4	45.3	49.1
Acc. Empty	56.1	58.9	63.9	65.8
Pump Injection	25.66	25.67	25.68	25.68
End of Bypass	25.0	28.5	30.4	33.5

TABLE 2

4-LOOP PLANT RESULTS

	Active Loop DECL, C_D=1.0	Active Loop DECL, C_D=0.6	Active Loop DECL, C_D=0.4	Inactive Loop DECL, C_D=0.6
Results				
Peak Clad Temp. °F	1880	1996	2061	1748
Peak Clad Location Ft.	7.5	6.5	6.5	8.0
Local Zr/H_2O Reaction (max)%	2.7	4.1	5.1	1.5
Local Zr/H_2O Location Ft.	7.5	7.5	8.0	8.0
Total Zr/H_2O Reaction %	<0.3	<0.3	<0.3	<0.3
Hot Rod Burst Time sec	35.4	31.2	32.1	103.6
Hot Rod Burst Location Ft.	6.0	5.75	6.0	6.5
Calculation				
Core Power Mwt (75% of licensed Power) 102% of		2437		
Peak Linear Power (kw/ft) 102% of		12.6		
Peaking Factor (at 75% of licensed Power Rating)		2.413		
Accumulator Water Volume (ft^3 each)		900		

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TABLE 3

<u>4-LOOP PLANT CONTAINMENT DATA</u>

(DRY CONTAINMENT)

NET FREE VOLUME	2.736×10^6 ft^3
INITIAL CONDITIONS	
Pressure	14.7 psia
Temperature	90°F
RWST Temperature	62°F
Service Water Temperature	33°F
Outside Temperature	-10°F
SPRAY SYSTEM	
Number of Pumps Operating	3
Runout Flow Rate	3600 gpm each
Actuation Time	18 secs
SAFEGUARDS FAN COOLERS	
Number of Fan Coolers Operating	5
Fastest Post Accident Initiation of Fan Coolers	38 secs

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TABLE 3 (Continued)

STRUCTURAL HEAT SINKS

Thickness, In.	Area, Ft^2
.25 steel, 12 concrete	74309
.25 steel, 12 concrete	18783
18 concrete	15500
.25 steel, 12 concrete	2000
12 concrete	36000
9 concrete	7000
.25 steel, 12 concrete	16000
.25 steel	54860
.375 steel	121300
.625 steel	1060
1 steel	2932
5.25 steel, 12 concrete	1147
.64 steel, 12 concrete	1400
10.51 steel, 12 concrete	186
24.25 steel, 12 concrete	54
.75 steel, 12 concrete	440
8.5 steel, 12 concrete	18
7.25 steel, 12 concrete	586
10.25 steel, 12 concrete	14
12.25 steel, 12 concrete	117

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TABLE 3A

<u>3-LOOP PLANT CONTAINMENT DATA</u>

(DRY CONTAINMENT)

Net Free Volume	1.89×10^6 ft^3
Initial Conditions	
Pressure	9.5 psia
Temperature	90°F
RWST Temperature	40°F
Outside Temperature	35°F
Spray System	
Number of Pumps Operating	2
Runout Flow Rate (each)	2200 gpm
Actuation Time	55 sec

Structural Heat Sinks

Thickness, in.	Area, ft^2
6 concrete	6972
12 concrete	77,446
18 concrete	36,848
24 concrete	17,010
36 concrete	8632
.408 steel	152,508
.375 steel, 54 concrete	18,270
.375 steel, 54 concrete	32,445
.5 steel, 30 concrete	26,250
24 concrete, .375 steel, 120 concrete	13,125
.825 stainless steel	3270
1.0 steel	2932.5

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TABLE 4

3-LOOP PLANT TIME SEQUENCE OF EVENTS

	Inactive Loop DECLG $(C_D=0.4)$ (Sec)	Active Loop DECLG $(C_D=0.6)$ (Sec)	Active Loop DECLG $(C_D=0.4)$ (Sec)
START	0.0	0.0	0.0
Reactor Trip Signal	.51	.48	.49
S. I. Signal	3.36	1.87	2.29
Acc. Injection	24.0	10.6	14.8
End of Blowdown	37.2	24.5	29.8
Bottom of Core Recovery	52.1	36.0	39.9
Acc. Empty	59.0	45.5	49.6
Pump Injection	28.36	26.87	27.29
End of Bypass	37.2	22.3	26.4

[redacted]

TABLE 5

3-LOOP PLANT RESULTS

	Inactive Loop DECLG (C_D=0.4)	Active Loop DECLG (C_D=0.6)	Active Loop DECLG (C_D=0.4)
Results			
Peak Clad Temp. °F	1799	1754	1814
Peak Clad Location Ft.	9.0	9.0	9.0
Local Zr/H_2O Rxn(max)%	2.44	1.25	2.27
Local Zr/H_2O Location Ft.	9.0	9.0	9.0
Total Zr/H_2O Rxn %	<0.3	<0.3	<0.3
Hot Rod Burst Time sec	216.8	185	134.5
Hot Rod Burst Location Ft.	7.5	7.5	6.75

Calculation	
Core Power Mwt (65% of licensed Power) 102% of	1725
Peak Linear Power (kw/ft) 102% of	8.25
Peaking Factor (At 65% of licensed Power Rating)	2.436
Accumulator Water Volume, Ft^3 each	1025

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TABLE 6

COMPARISON OF RESULTS OBTAINED
BY VARYING PRESSURIZER LOCATION

4-Loop Plant, C_D=0.6 DECLG Active Loop Break

	Pressurizer In Broken Loop	Pressurizer In Inactive Loop
Accumulator Injection	15.7 sec	15.6 sec
End of Bypass	28.5 sec	25.1 sec
Bottom of Core Recovery	44.4 sec	39.8 sec
Peak Clad Temperature, °F	1996	1988
Peak Clad Location, ft	6.5	7.0
Local Zr/H_2O Reaction, %	4.1	4.1

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[redacted]

TABLE 7

3-LOOP PLANT UPPER HEAD AT T_{hot}

TIME SEQUENCE OF EVENTS

	Active Loop Break C_D=0.4 DECLG	Inactive Loop Break C_D=0.4 DECLG
START	0.0	0.0
Reactor Trip Signal	.49	.51
S. I. Signal	2.27	3.33
Acc. Injection	14.0	23.2
End of Blowdown	27.8	36.2
Bottom of Core Recovery	38.2	49.6
Acc. Empty	48.4	57.9
Pump Injection	27.27	28.33
End of Bypass	24.9	35.1

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[redacted]

TABLE 8

3-LOOP PLANT UPPER HEAD AT T_{hot} RESULTS

	Active Loop C_D=0.4 DECLG	Inactive Loop C_D=0.4 DECLG
Results		
Peak Clad Temp. °F	1852	1813
Peak Clad Location Ft.	9.0	9.0
Local Zr/H_2O Rxn(max)%	3.0	2.41
Local Zr/H_2O Location Ft.	9.0	9.0
Total Zr/H_2O Rxn %	<0.3	<0.3
Hot Rod Burst Time sec	112.1	195.9
Hot Rod Burst Location Ft.	6.5	7.5
Calculation		
Core Power Mwt (65% of licensed Power) 102% of		1725
Peak Linear Power kw/ft 102% of		8.25
Peaking Factor (At 65% of licensed Power Rating)		2.436
Accumulator Water Volume, Ft^3 each		1025

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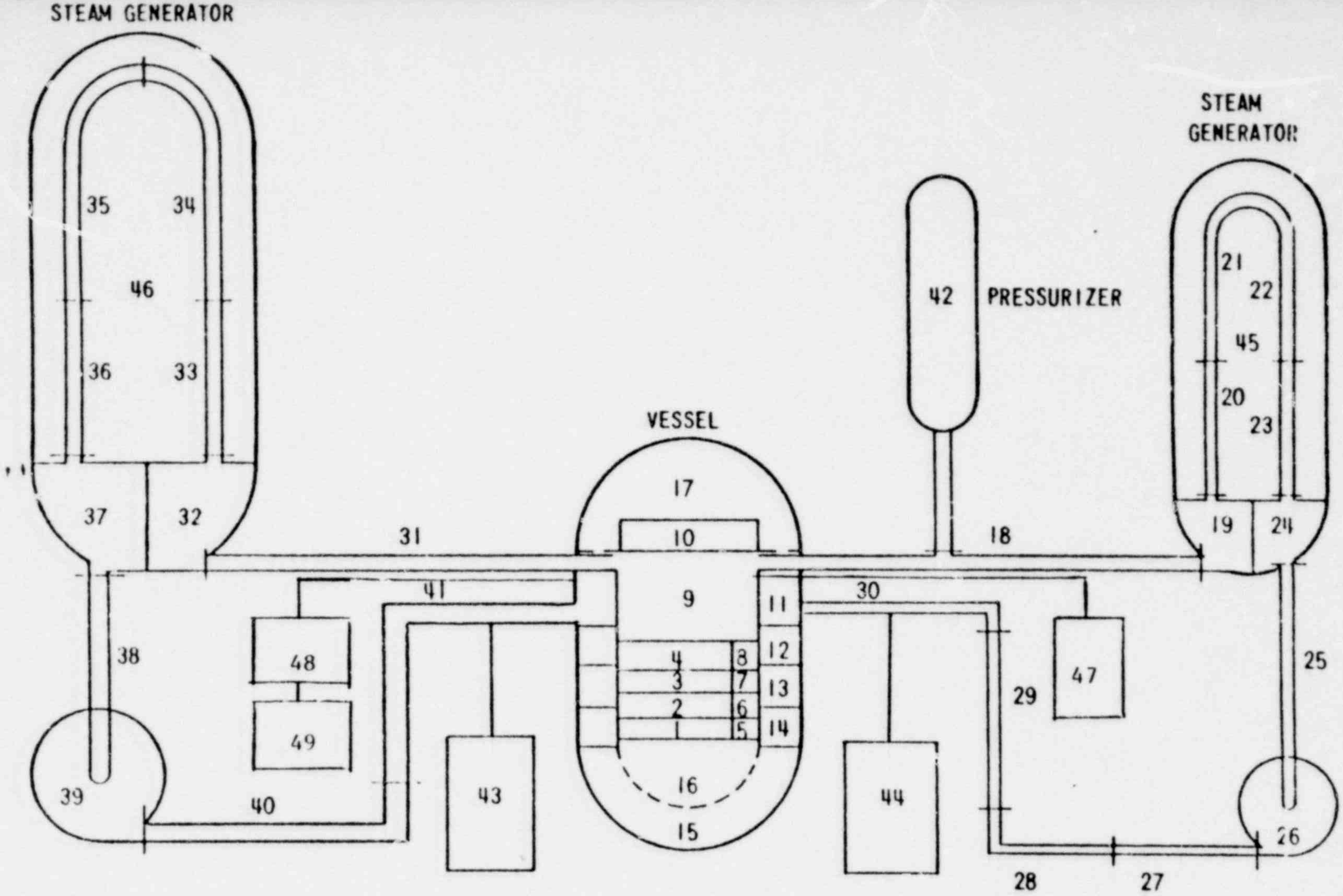

N-2 Intact Loops

Broken Loop

Figure 1 Typical SATAN Model for a PWR Active Loop Break (49 Elements)

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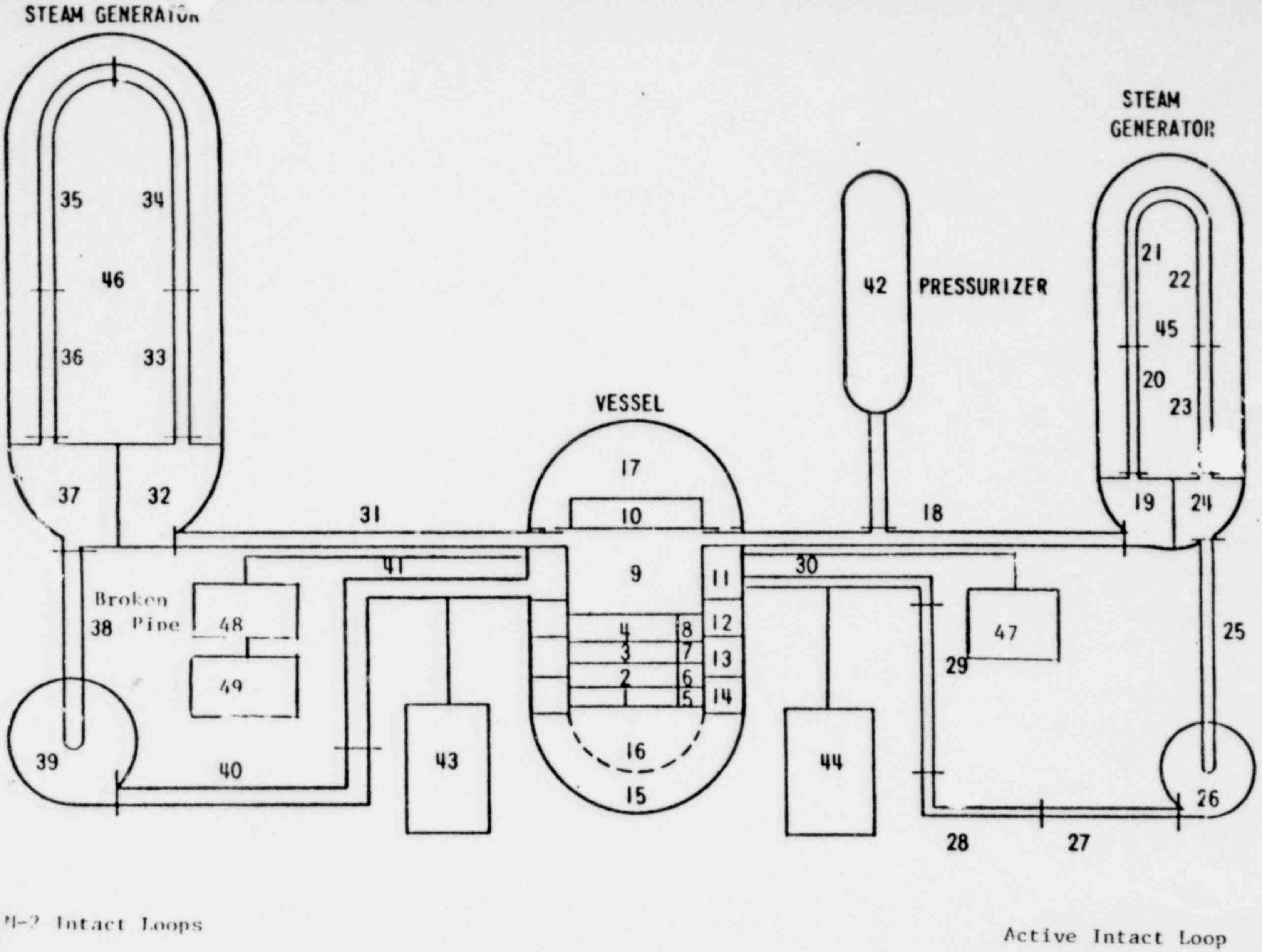

Figure 2 Typical SATAN Model for a PWR Inactive Loop Break (49 Elements)

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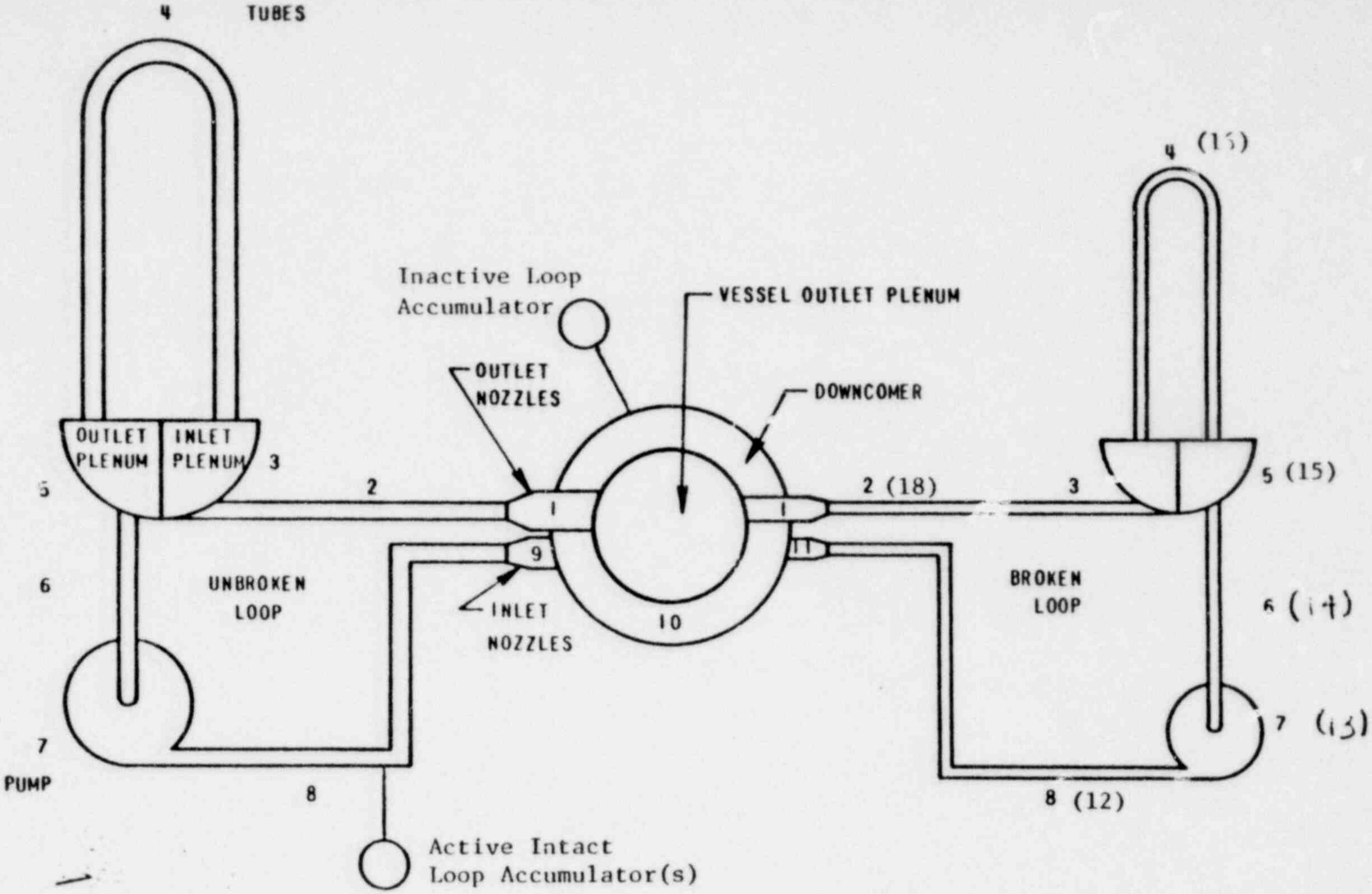

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Figure 3A Schematic of REFLOOD Code 19 Element Loop Model Active Loop Break

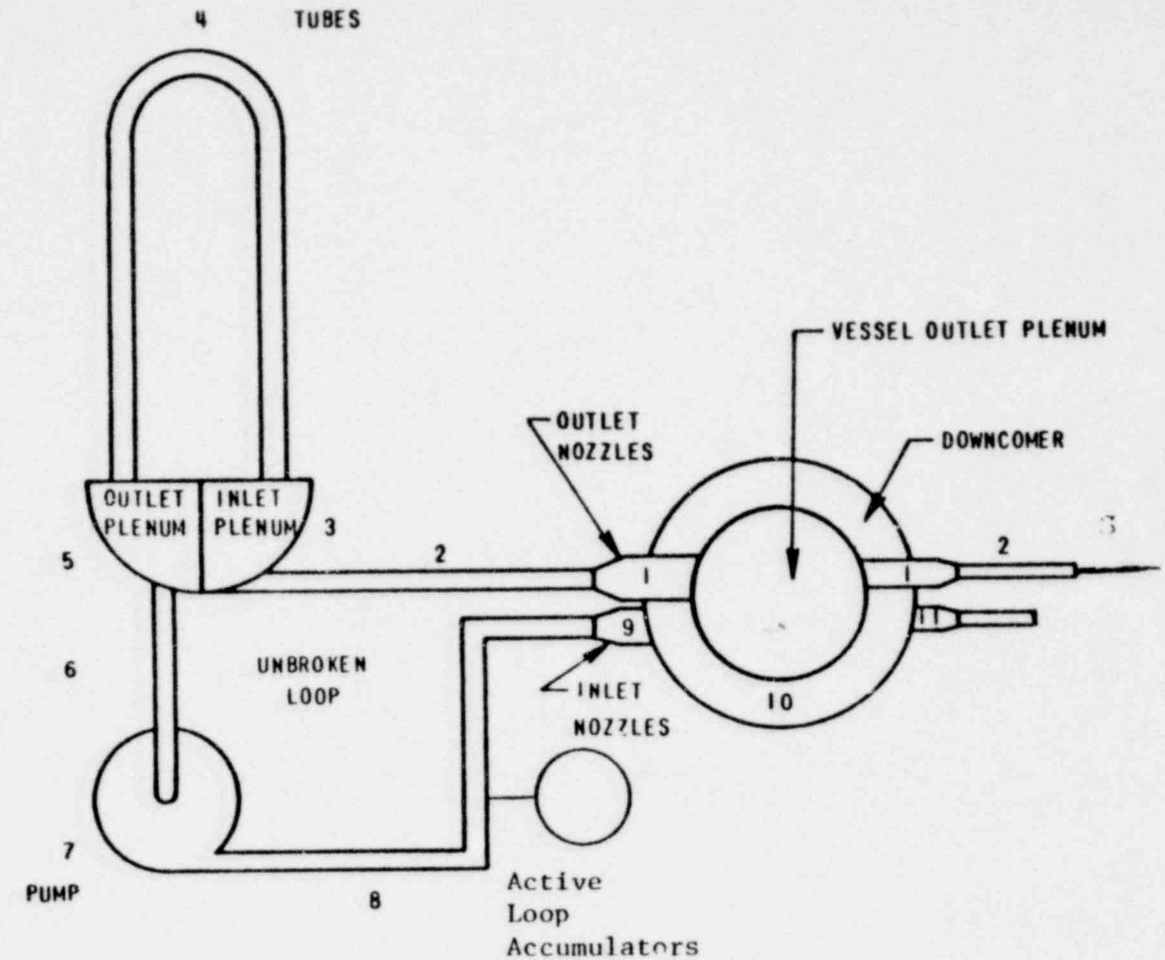

Figure 3B Schematic of REFLOOD Code 14 Element Loop Model Inactive Loop Break

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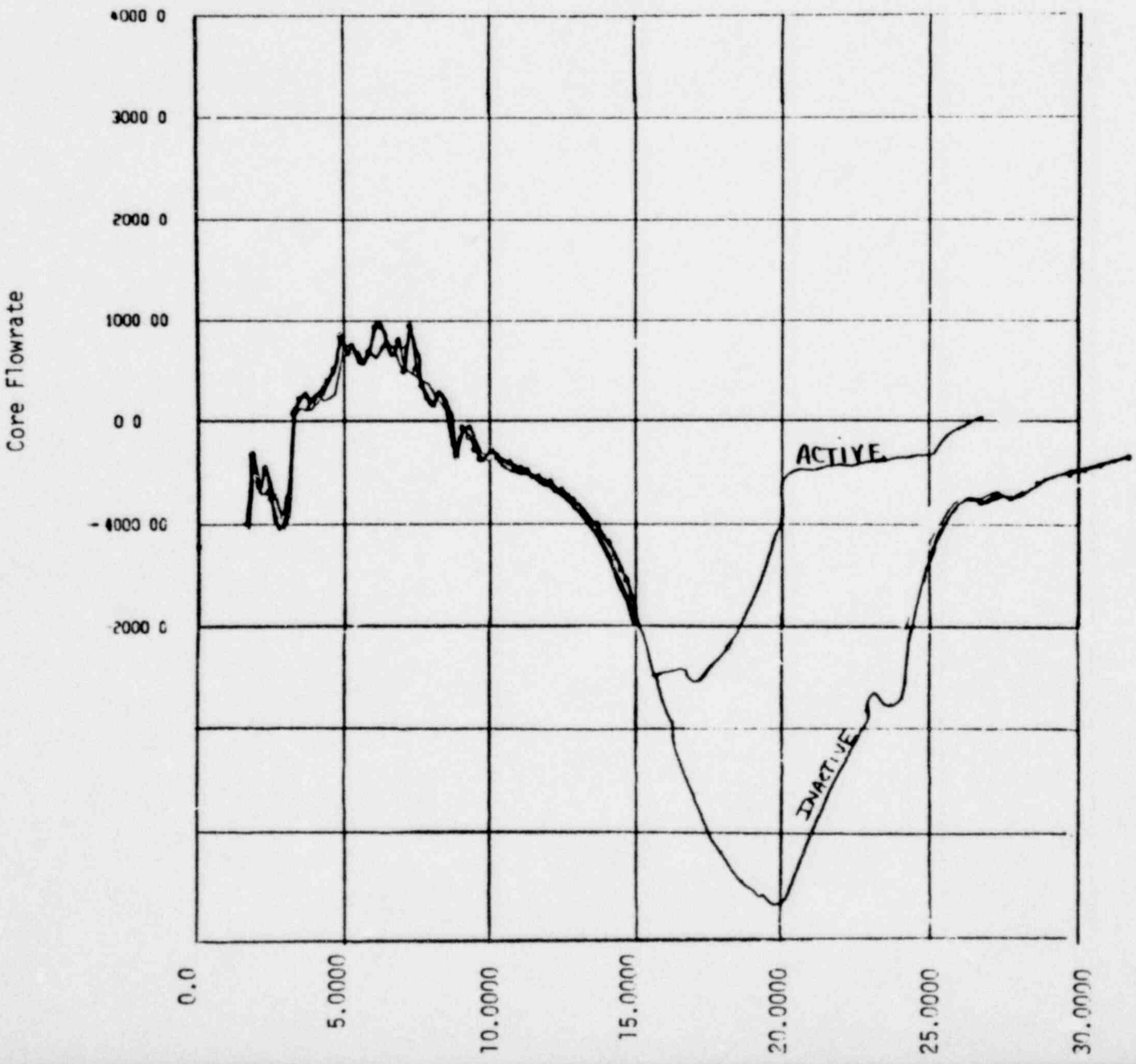
Figure 4 4-Loop Plant (N-1) ECCS Break LOCA Sensitivity: 0.6 DECLG Break in Inactive and Active Loops



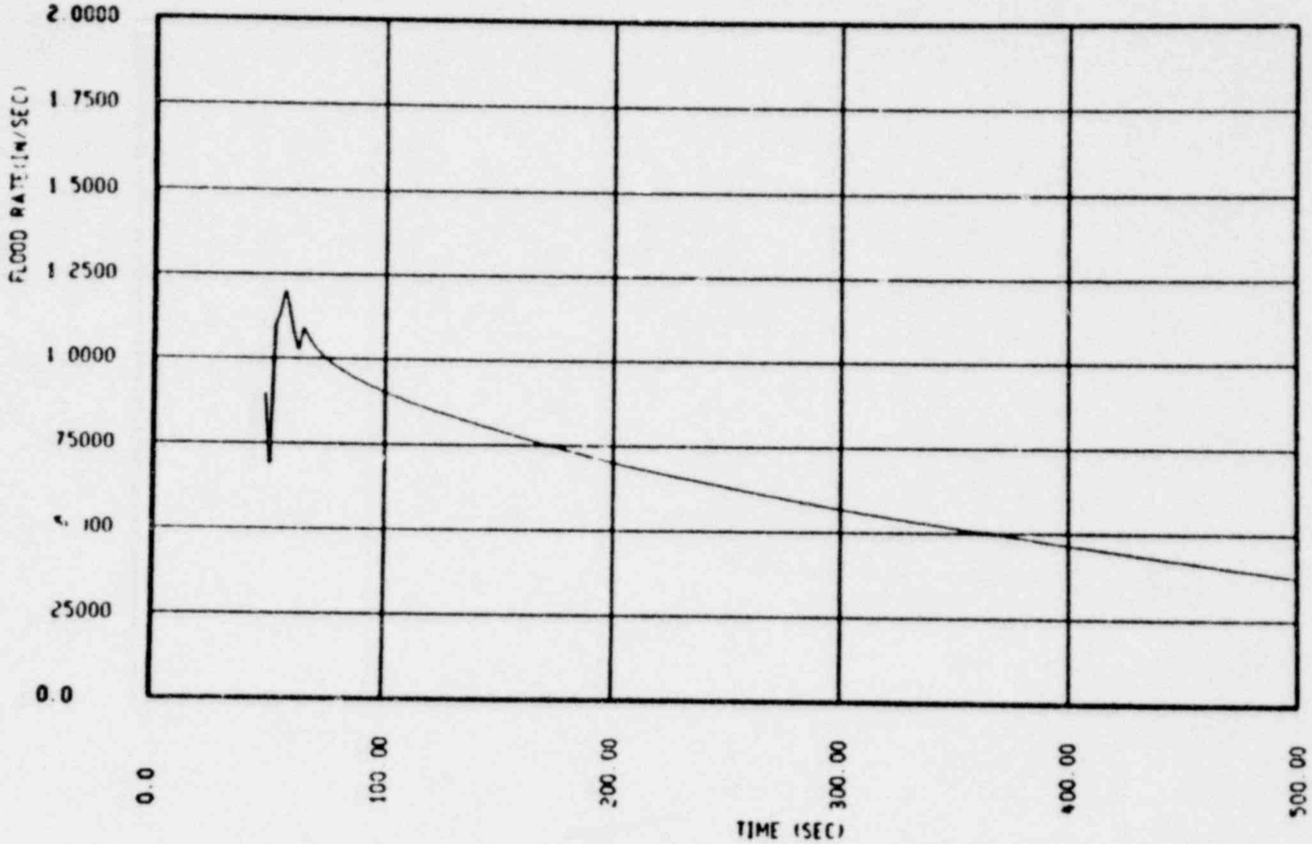


Figure 5 4-Loop Plant CD=0.4 Active Loop Break Flood Rate (In/Sec)

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[redacted]

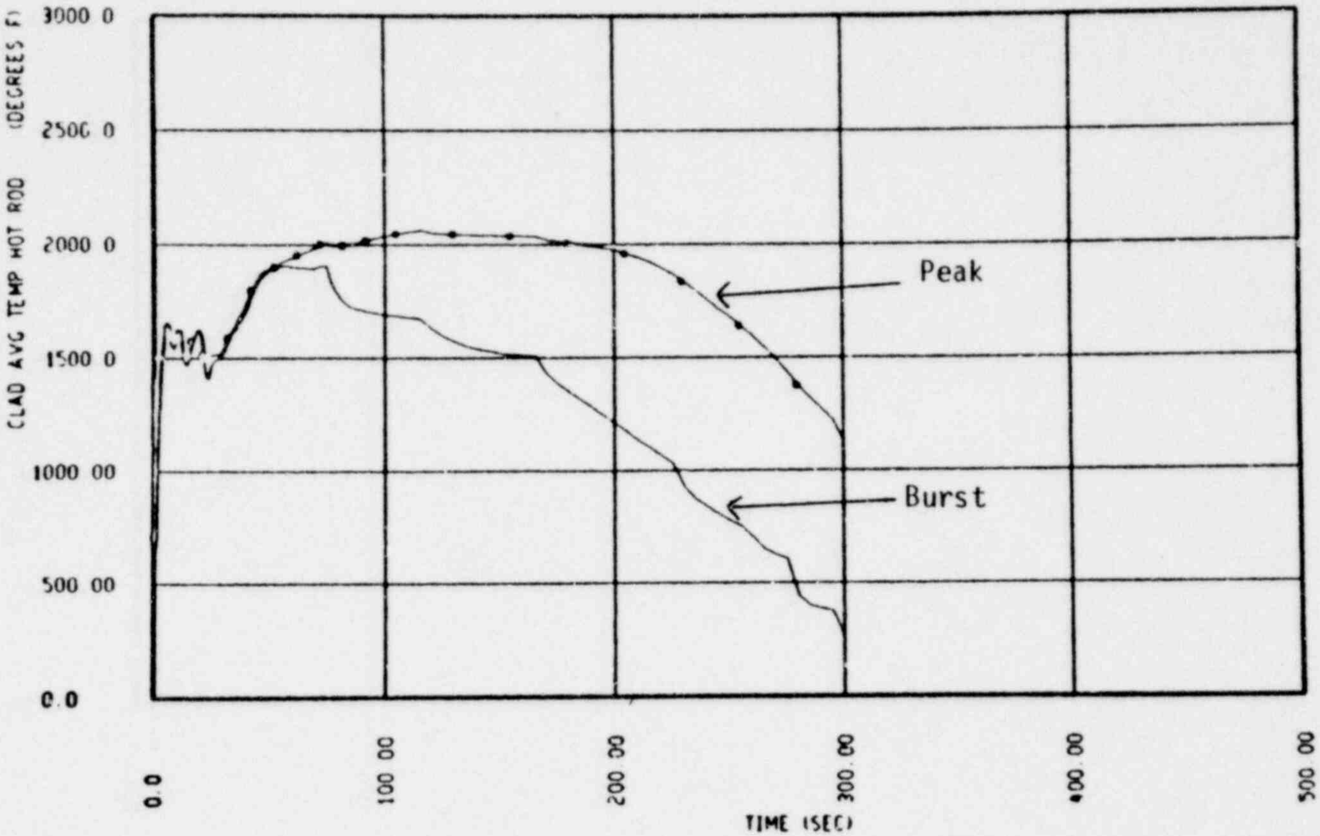

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Figure 6 4-Loop Plant CD=0.4 DECLG Active Loop Break Peak Clad AVG Temp. Hot Rod

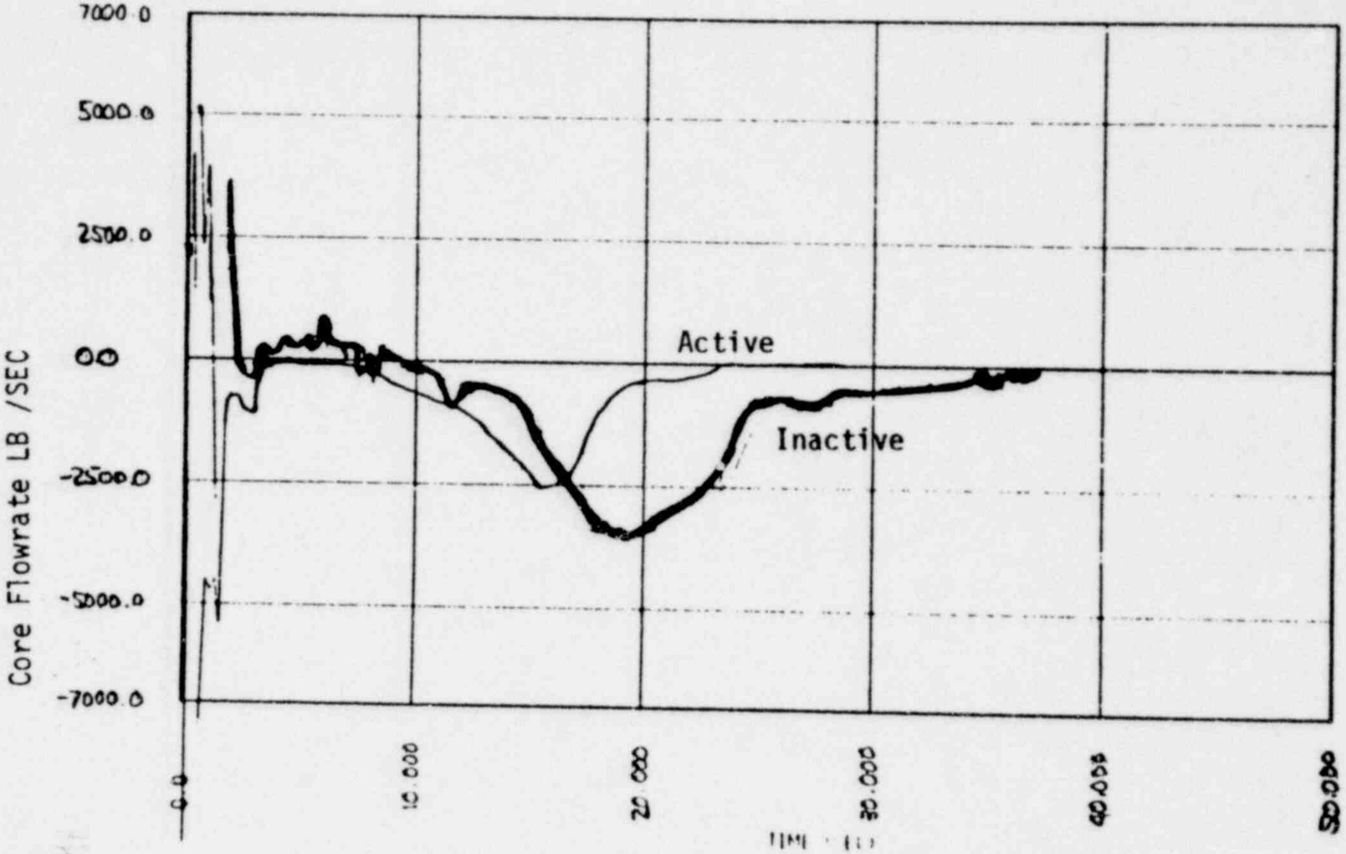

Figure 7 3-Loop Plant (N-1) ECCS Analysis: CD=0.4 DECLG Active Loop Break Core Flowrate

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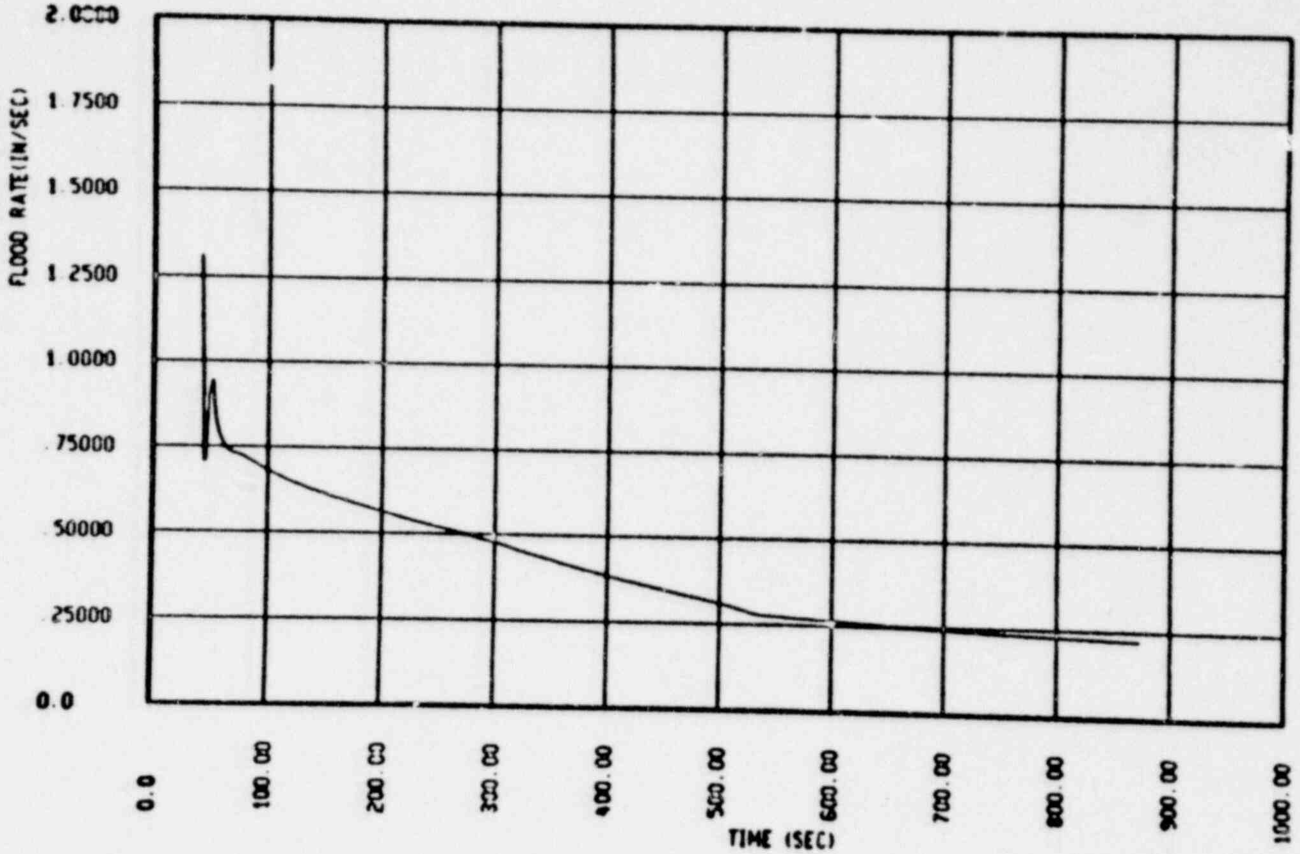

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Figure 8 3-Loop Plant CD=0.4 DECLG Active Loop Break Flood Rate (In/Sec)

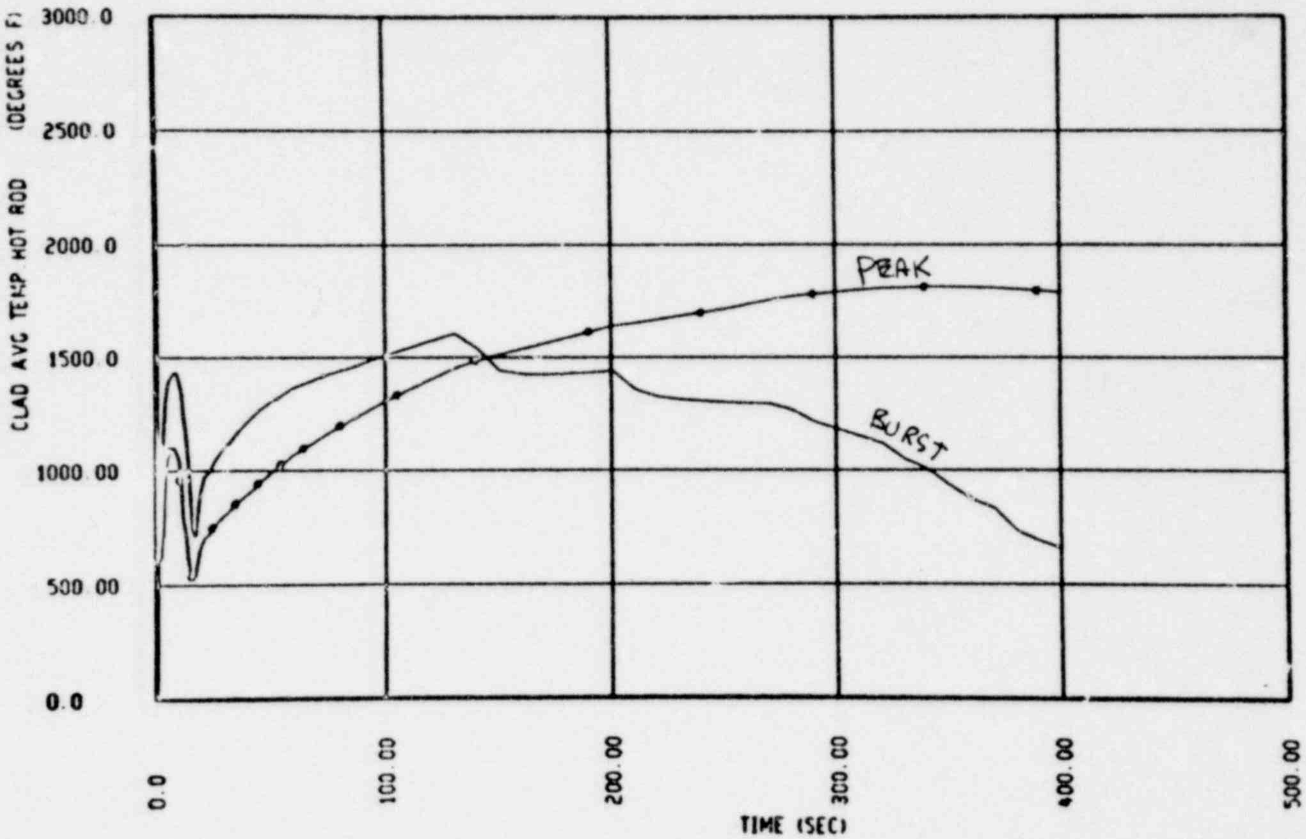


Figure 9 3-Loop Plant CD=0.4 DECLG Active Loop Break Peak Clad Avg. Temp. Hot Rod

1136 304

[redacted]

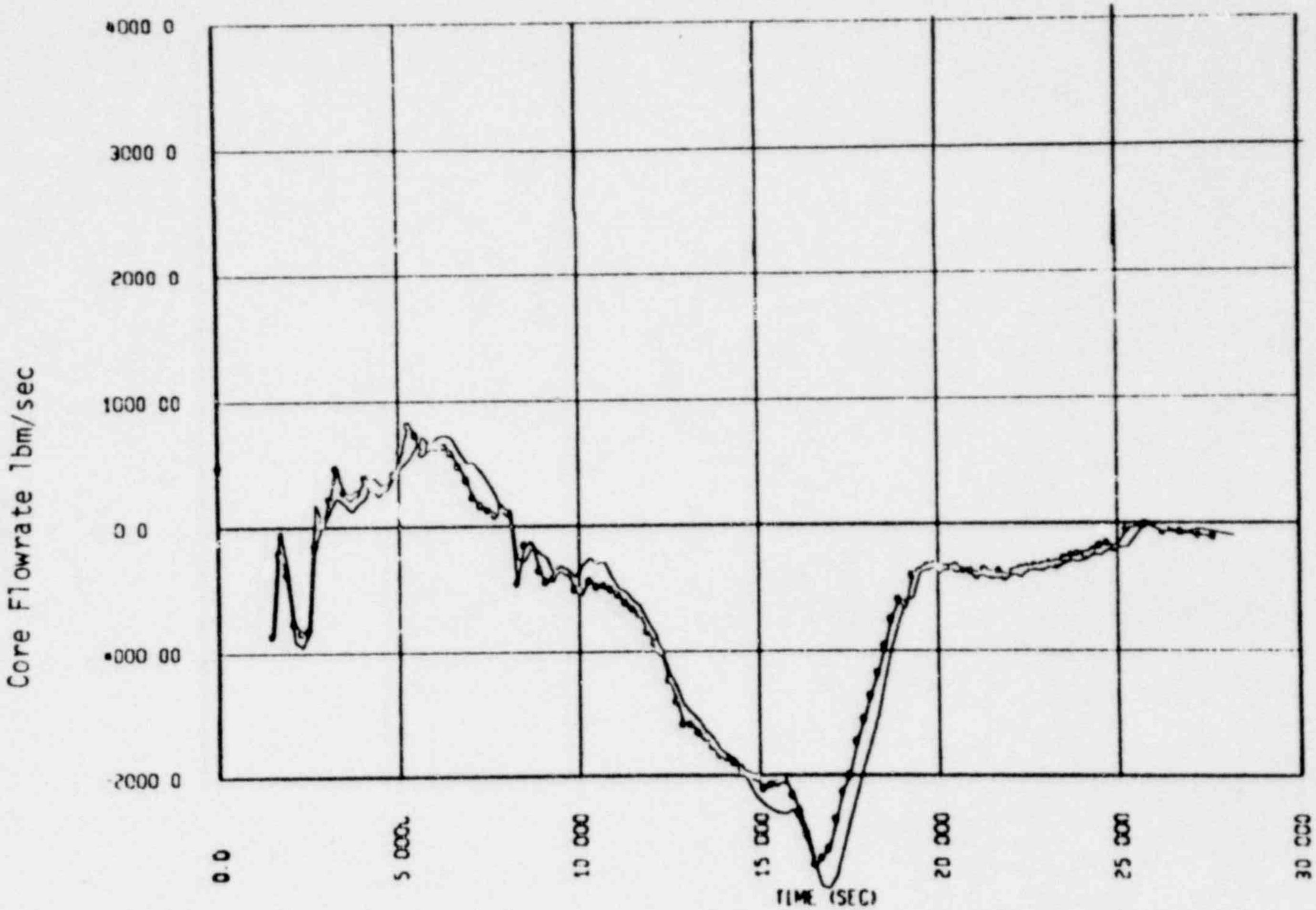
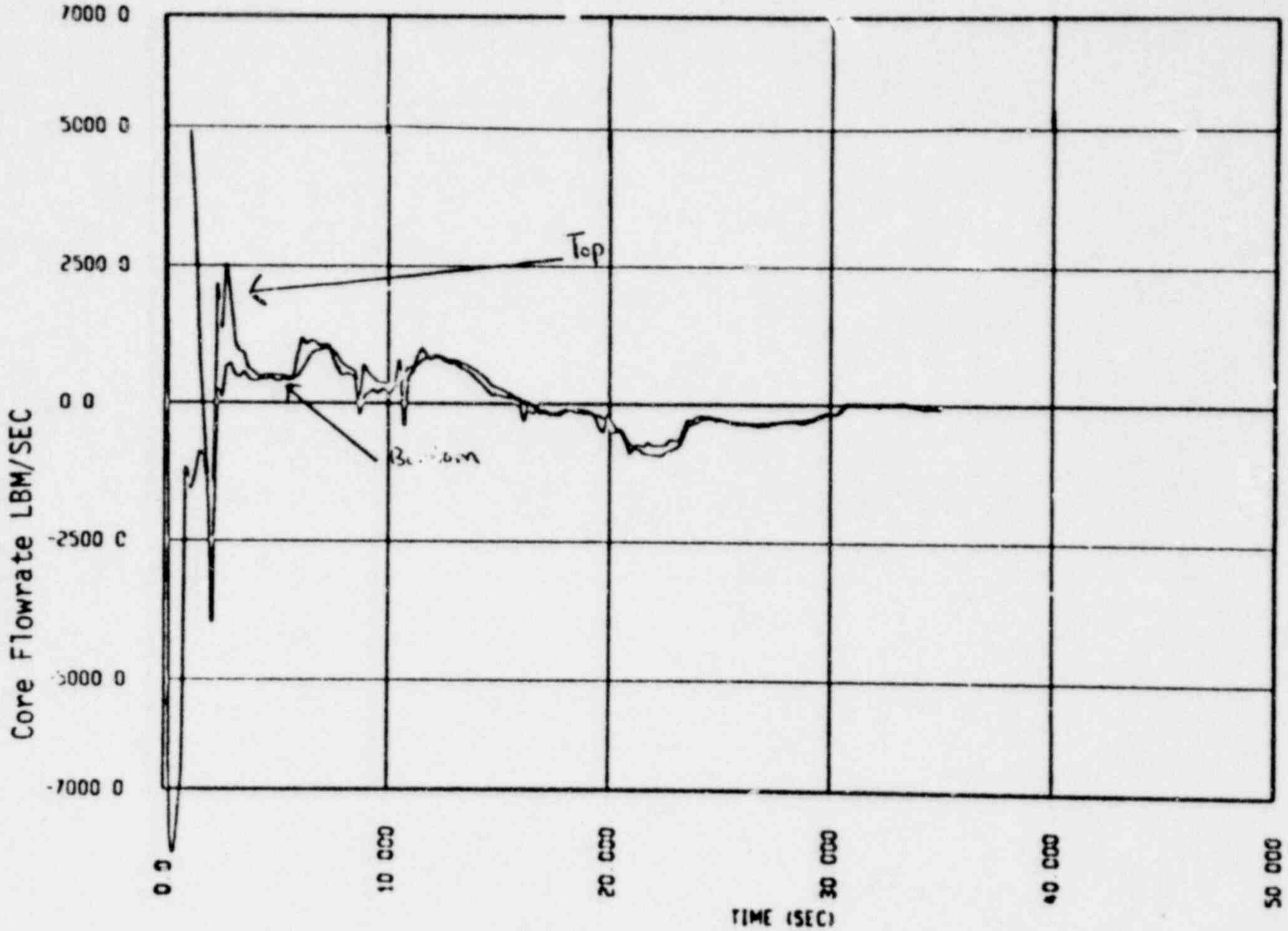


Figure 10 4-Loop Plant (N-1) ECCS Pressr. Location Sensitivity, 0.6 DECLG Active Loop Break: Standard Location (________) vs. Pressurizer in inactive loop (++++++++)

1136 305

[redacted]



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[redacted]

Figure 11 4-Loop Plant (N-1) Operation CD=0.4 DECLG Active Loop Break Core Flowrate

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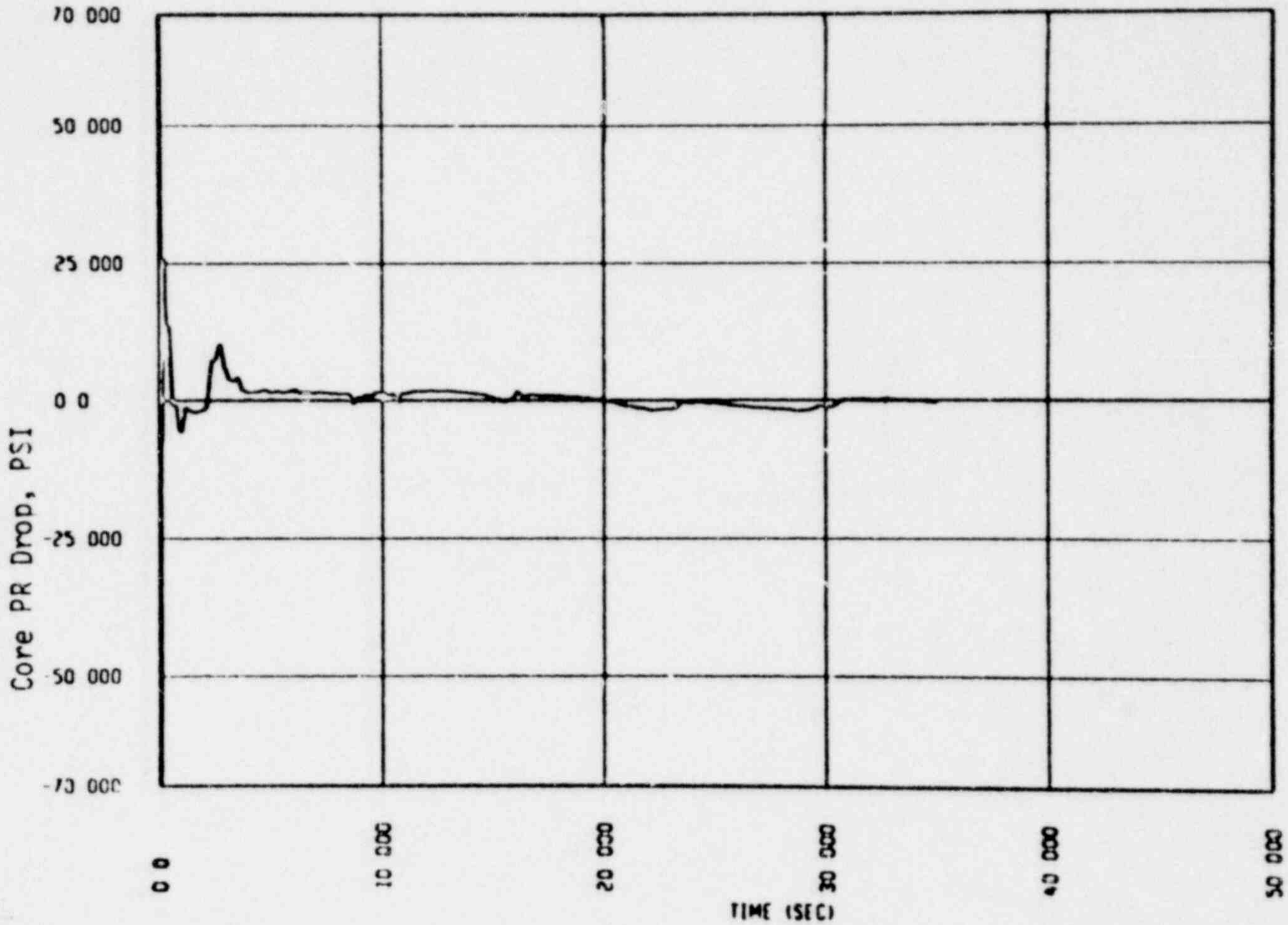

Figure 12 4-Loop Plant (N-1) Operation CD=0.4 DECLG Active Loop Break Core Pressure Drop

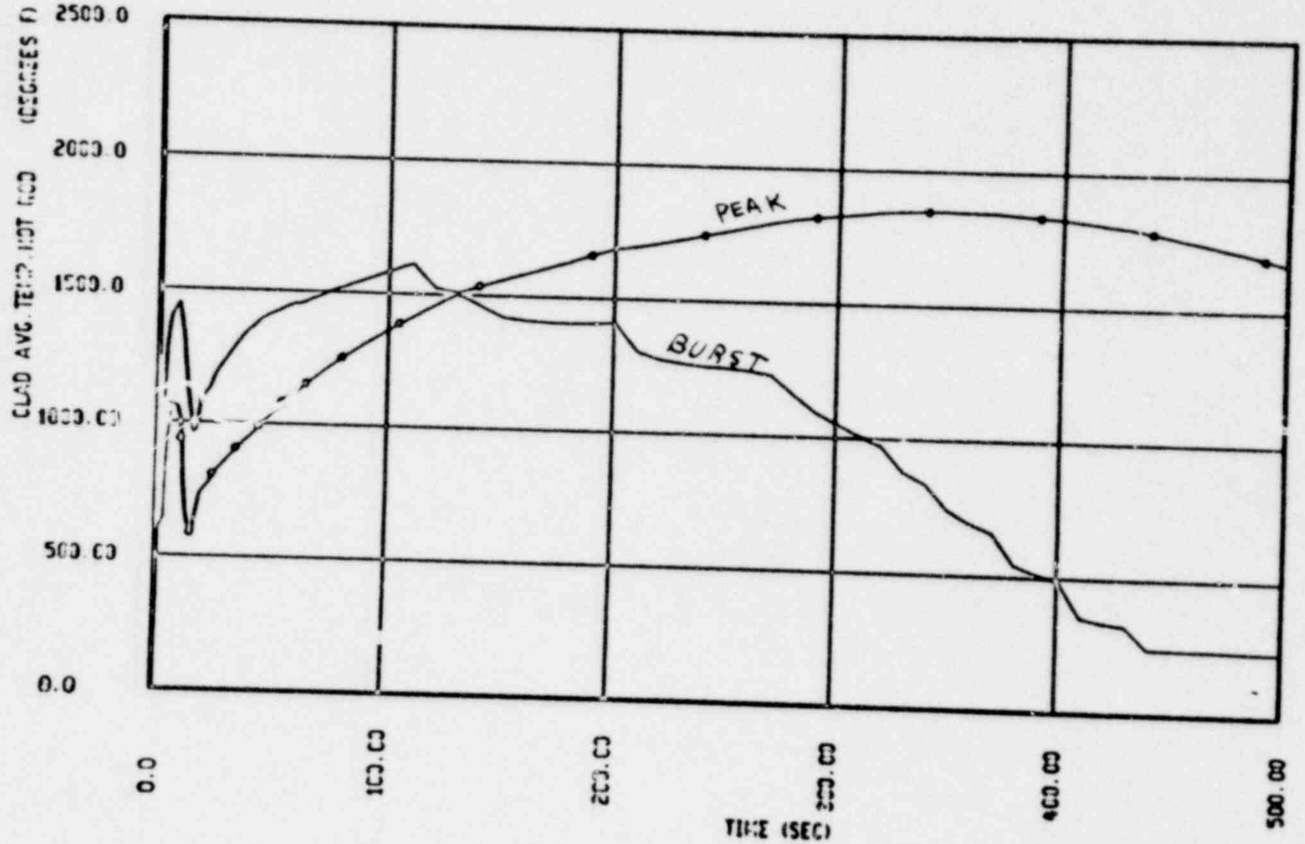

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Figure 13 3-Loop Plant CD=0.4 DECLG Active Loop Break Upper Head at Thot Peak Clad Avg. Temp. Hot Rod

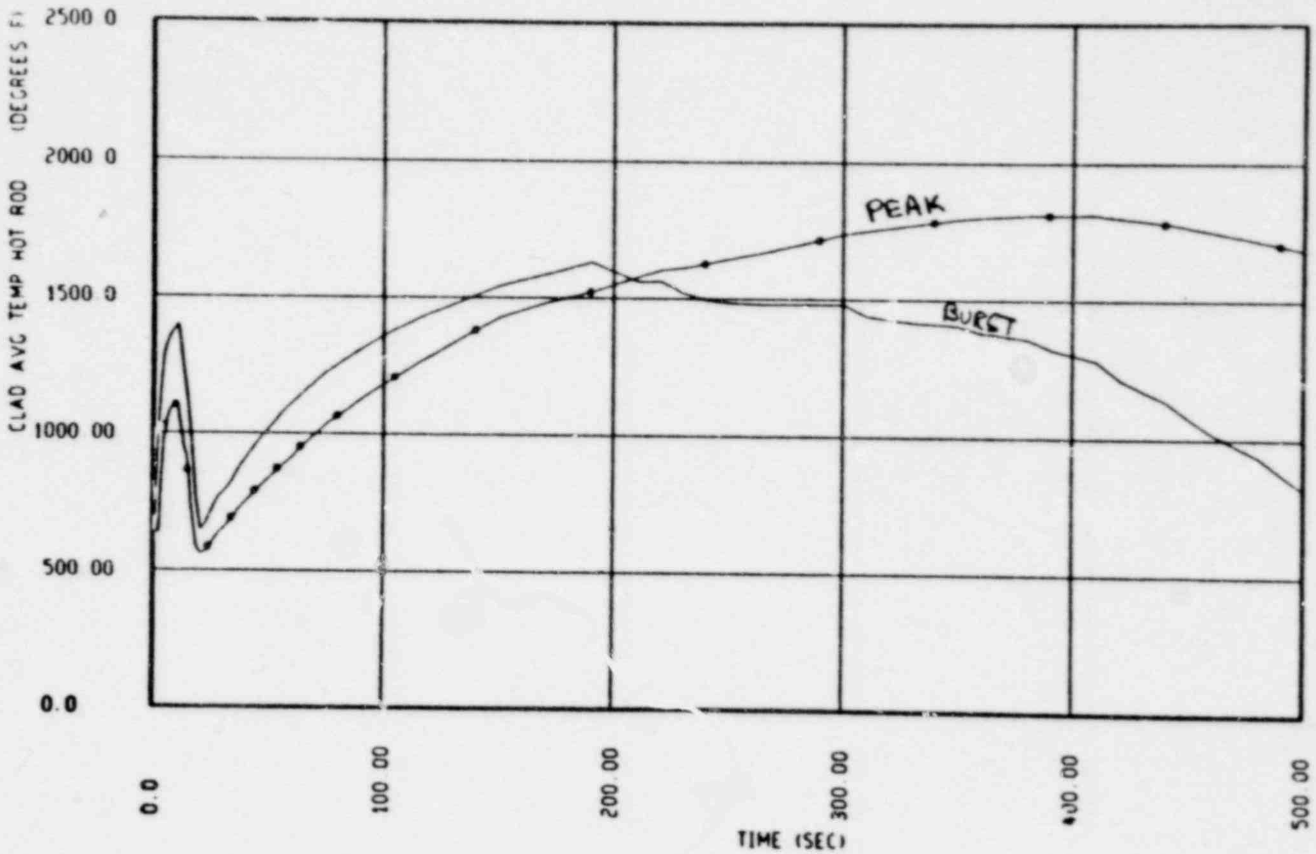

Figure 14 3-Loop Plant CD=0.4 DECLG Inactive Loop Break Upper Head at Thot

Peak Clad Avg. Temp. Hot Rod

1136 309

[redacted]

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1136 310

[redacted]

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12. Letter from C. Eicheldinger of Westinghouse Electric Corporation to V. Stello of the Nuclear Regulatory Commission. Letter No. NS-CE-1163 dated August 13, 1976.

13. Letter from C. Eicheldinger of Westinghouse Electric Corp. to J. F. Stolz of the Nuclear Regulatory Commission. Letter No. NS-CE-1540 dated September 7, 1977.

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[redacted]

QUESTION

1. Break noding studies for the Westinghouse LOCA model were reported in WCAP-8341. That study indicated that two nodes on each side of a postulated double ended failure were required. For the proposed (N-1) loop model, the vessel side of inactive loop broken leg is modeled with one node. Justify the use of a single node at that location in view of the study reported in WCAP-8341.

RESPONSE

To assess the effect of broken leg noding on the ECCS performance calculation for the inactive loop break location, the limiting inactive loop break cases for three and four-loop plants reported in WCAP-8904 were reanalyzed. Two nodes of equivalent length were used to model the length of pipe between the reactor vessel inlet and the break in the SATAN code; other input was held constant in order to obtain the sensitivity to break nodalization. Results of the analyses performed are presented in Tables 1 and 2. The peak clad temperature calculated for each case is within a few degrees of the previous result reported in WCAP-8904 (i.e. 1813 and 1748°F respectively for 3 and 4 loop plants), so the active loop break location remains limiting for both 3-loop and 4-loop plants.

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[redacted]

TABLE 1

INACTIVE LOOP BREAK LOCATION

TIME SEQUENCE OF EVENTS

	4-Loop Plant* C_D=0.6 DECLG (Sec)	3-Loop Plant** C_D=0.4 DECLG (Sec)
START	0.0	0.0
Rx Trip Signal	.68	.51
S. I. Signal	.68	3.33
Acc. Injection	22.7	23.2
End of Blowdown	40.4	36.2
Bottom of Core Recovery	52.7	50.4
Acc. Empty	66.0	57.9
Pump Injection	25.68	28.33
End of Bypass	35.9	35.7

* Upper head fluid temperature = T_{cold}.

** Upper head fluid temperature = T_{hot}.

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[redacted]

TABLE 2

INACTIVE LOOP BREAK RESULTS

Results	4-Loop Plant C_D=0.6 DECLG	3-Loop Plant C_D=0.4 DECLG
Peak Clad Temp. °F	1761	1821
Peak Clad Location Ft.	8.0	9.0
Local Zr/H_2O Rxn(max)%	1.57	2.74
Local Zr/H_2O Location Ft.	8.0	9.0
Total Zr/H_2O Rxn %	<0.3	<0.3
Hot Rod Burst Time sec	102	192
Hot Rod Burst Location Ft.	6.25	7.5

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QUESTION

2. Describe in detail why, during reflood, the inactive loop dead-ended pipe was modeled as three nodes with successively lower flow areas and successively higher loss coefficients.

RESPONSE

The WREFLØØD code loop model approved as part of the October 1975 version of the Westinghouse Evaluation Model consists of two parallel flow paths which connect the reactor vessel upper plenum with the break: a path through the broken loop and a path through the unbroken loops. For an inactive loop cold leg break during plant operation in the (N-1) configuration, no venting through the broken loop is possible if the loop isolation valves are closed. In order to use the October 1975 Model version of WREFLØØD in this inactive loop break application, it is imperative to set the flow resistance of the broken loop such that no significant flow occurs in the broken loop. Therefore, the inactive loop dead ended hot leg pipe was modeled as three nodes with successively lower flow areas [1, 0.1, 0.01 ft^2] and successively higher loss coefficients [1, 10, 100].

With this resistance network specified, code execution was achieved with minimal (less than 0.1 lb/sec) flow through the broken loop at all times. The path through the unbroken loops to the break was specified as in the N-loop break case.

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[redacted]

1. Describe any changes in the ECCS assumptions for (N-1) loop operation compared to N loop operation besides those identified for system noding.

No other changes in assumptions are made in performing an (N-1) loop operation ECCS performance analysis; changes in input parameters are made to properly represent (N-1) loop operating conditions. Initial reactor coolant system and secondary side fluid flow rates and enthalpies are computed for (N-1) loop steady-state operation, and a power peaking factor envelope based on (N-1) loop operation is specified. An additional steel heat sink representing the exposed metal of a reactor coolant pump motor is modeled in the containment backpressure calculation.

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[redacted]

2. For postulated breaks in the inactive loop, improved heat transfer during blowdown is expected since more primary system fluid must pass through the core to exit from the single break location. However, the core reflooding transient would be degraded since the flow path through the hot leg side of the normally assumed broken loop is closed by the loop isolation valve. Provide a comparison of core reflood rates for postulated cold leg breaks in the active and inactive loops.

The same number of flow paths are available to vent steam from the core for both active and inactive loop cold leg break cases. In the active loop break case (N-2) loops vent through the vessel downcomer and out the broken cold leg pipe, and the broken loop hot leg also vents to containment. In the inactive loop break case all (N-1) loops vent through the vessel downcomer. Consequently, a greater overall resistance to flow exists in the vent paths to containment available for a postulated inactive loop break than for an active loop break. The core refloodings of the $C_D = 0.4$ DECLG active and inactive loop break transients for a 3-loop plant operating in the (N-1) condition are compared below:

	Active Loop Break		Inactive Loop Break	
Core Water Level, ft (Zc)	Time at which Zc is reached, sec	Core inlet velocity at Zc, in/sec	Time at which Zc is reached, sec	Core inlet velocity at Zc, in/s
BOC	39.85		52.05	
2	59.3	.77	75.5	.64
3	102.7	.68	123.3	.66
4	157	.61	179	.59
5	219.6	.55	244.1	.52
6	291 8	.49	321.1	.45
7	381.[illegible]	.40	422.6	.37

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Higher steam venting rates achieved during the active loop break reflood transient permit a faster core reflooding than in the inactive loop break case.

[redacted]

3. Justify for a spectrum of break sizes that the active loop breaks always give higher peak clad temperature.

The spectrum of break sizes presented in WCAP-8904 has been extended to include additional inactive loop break cases based upon the same plant parameters as the corresponding cases reported in WCAP-8904. Inactive loop DECLG breaks during (N-1) loop operation have been analyzed for a 4-loop plant (C_D = 1.0, C_D = 0.4) and for a 3-loop plant (C_D = 0.6). The results are summarized in Tables 1 and 2.

For both 3-loop and 4-loop plants the active loop is confirmed to be the limiting break location, with the C_D = 0.4 DECLG case the limiting break size. It is interesting to note that for the C_D = 0.6 DECLG break in a 3-loop plant the inactive loop break location gives a higher peak clad temperature (1771°F) than does the active loop location (1754°F). A comparison of the core mass flows during blowdown is presented as Figure 1; it reveals a smaller difference exists between the 3-loop plant C_D = 0.6 DECLG active and inactive loop break core flows than has been the case for other break sizes. As a result a smaller relative reduction in PCT is obtained during blowdown for this inactive loop break than for other cases.

The PCT increase resulting from its lower core reflooding transient becomes sufficient to cause the inactive loop break location to exhibit a higher PCT than the active loop break location for a 3-loop plant C_D = 0.6 DECLG LOCA.

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TABLE 1

INACTIVE LOOP BREAK

TIME SEQUENCE OF EVENTS

	4-Loop Plant C_D = 1.0 DECLG (Sec)	4-Loop Plant C_D = 0.4 DECLG (Sec)	3-Loop Plant C_D = 0.6 DECLG (Sec)
START	0.0	0.0	0.0
Rx Trip Signal	.66	.70	.50
S. I. Signal	.66	.70	2.37
Acc. Injection	14.0	33.9	16.0
End of Blowdown	24.0	59.3	28.2
Bottom of Core Recovery	39.7	67.5	42.0
Acc. Empty	57.1	79.0	50.7
Pump Injection	25.66	25.70	27.37
End of Bypass	24.0	50.5	28.1

Table 2

Inactive Loop Break Results

Results	4 Loop Plant C_D = 1.0 DECLG	4 Loop Plant C_D = 0.4 DECLG	3 Loop Plant C_D = 0.6 DECLG
Peak Clad Temp. °F	1722	1707	1771
Peak Clad Location Ft.	8.0	8.0	9.0
Local Zr/H_2O Rxn (max)%	1.4	1.2	2.3
Local Zr/H_2O Location Ft.	8.0	7.5	9.0
Total Zr/H_2O Rxn %	<0.3	<0.3	<0.3
Hot Rod Burst Time sec	138.4	179.6	205.8
Hot Rod Burst Location Ft.	7.0	7.0	7.5

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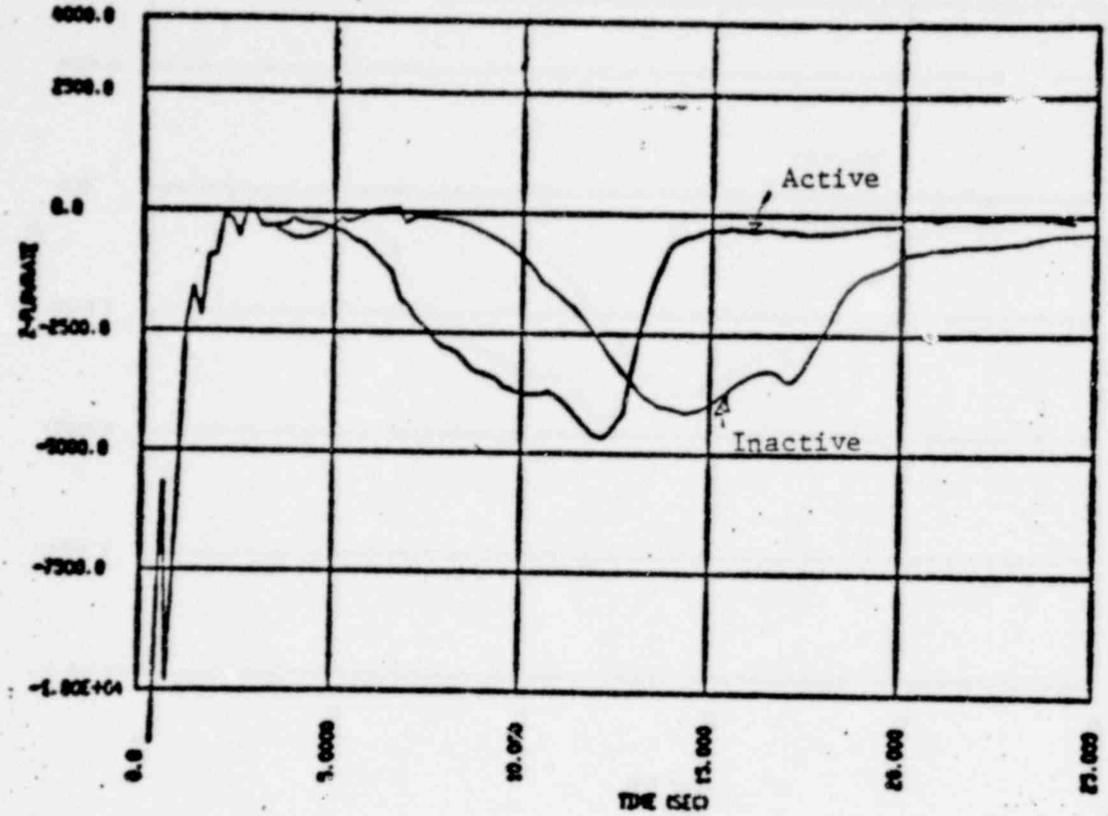

Figure 1: 3-Loop Plant (N-1) ECCS Analysis:

C_D = 0.6 DECLG Break Core Flow Rates

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4. Discuss the effect of (N-1) loop operation on small break calculations.

The peak clad temperature computed for any postulated loss of coolant accident is a direct function of the fuel peak linear power assumed and the core mass flow rates calculated. WCAP-8904 points out the great similarity between the large break transient core flow of a 3-loop plant and the core flow following a large break LOCA of a 4-loop plant possessing loop stop valves which is operating in the (N-1) condition. A comparable similarity will apply between the corresponding small break LOCA hydraulic transients. Because the entire core is uncovered and recovered during a large break accident, the ECCS performance computed for a large break case exhibits more sensitivity to core flow than small break cases do. The two cases are about equally sensitive to core power, and the reduced power level associated with (N-1) loop operation applies to both.

The power/flow relationship for plants in (N-1) loop operation with loop stop valves closed is shown in WCAP-8904 to be such that low peak clad temperatures are calculated for large break LOCAs at high power peaking factors. In fact, the PCT values presented for a 4-loop 15 x 15 plant operating in the (N-1) mode are significantly lower than those which have been calculated at much lower peaking factors for 3-loop 15 x 15 plants. Because the small break power/flow relationship in (N-1) loop operation is even more favorable than that of the large break, a plant operating in the (N-1) mode would also exhibit a lower PCT for small break than is calculated for N-loop operation in a comparable plant with the same number of active loops. Since all N-loop small break LOCA analyses show a great deal of margin to the regulatory limits, there is adequate assurance that small break LOCA analyses for plants operating in the (N-1) loop condition with loop stop valves closed will not be limiting.

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