SIEMENS

ANF-91-048(NP)
Supplement 1

BWR JET PUMP MODEL REVISION FOR RELAX

MAY 1996

Siemens Power Corporation

Nuclear Division

Siemens Power Corporation -- Nuclear Division

ANF-91-048(NP)
Supplement 1
Issue Date: 5/7/96

BWR Jet Pump Model Revision for RELAX

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Software Development Records and Engineering Calculation Notebooks supporting this report include:

SDR's

(1) SDR-119, Volume 8, RELAX Version UJAN96 on DECALPHA

(2) SDR-119, Volume 10, RELAX Version UAPR96 on DECALPHA

Engineering Calculation Notebooks

(3) E-Q766-N90-1, Justification of Jet Pump change

(4) E-6093-867-2, LaSalle LOCA Break Spectrum Analysis (all three break results shown are in this notebook).

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1.0 INTRODUCTION AND SUMMARY

This report presents a revision to the BWR jet pump model used in the RELAX code which is part of the Siemens Power Corporation EXEM/BWR LOCA ECCS evaluation model[1-2]. Applications of RELAX for BWR LOCAs (particularly SBLOCAs with breaks in the recirculation loop pump discharge piping) have revealed unrealistic behavior in the jet pump under reversed drive flow conditions. Calculated results show a sustained reversed flow from the jet pump mixing volume to the downcomer during the system blowdown calculation. In reality, following the initial recirculation pump coast down when the downcomer mixture level has fallen below the jet pump nozzle, the flow should be toward the broken loop drive line which is connected to the break. That is, the sustained flow should be forward from the downcomer into the jet pump and then into the drive line. The actual flow pattern is due to the pressure gradient which causes coolant to flow to the break. There is no sustained driving force to cause flow from the jet pump to the downcomer.

The calculated behavior is due to

accounts for the turbulence induced drag between the drive jet and suction flow in the mixing region of the jet pump. It is a secondary model parameter that optimizes the pump performance with forward drive flows including normal operating conditions. Fluid-fluid turbulent shear is significant when a large velocity difference exists between the two mixing fluid streams as in a jet pump under normal forward drive flow conditions. Fluid-fluid turbulent shear is minimal for reverse drive flow because there is no jet or mixing of two fluid streams with significantly different velocities. However, in the previous model, fluid-fluid shear is calculated for both the forward and the reversed drive flow. In the revised model described in this report, With this change, the flow at the jet pump suction reverses and sustained flow is toward the drive nozzle and the break.

Calculated peak cladding temperatures (PCT's) using the jet pump without the change to the fluid shear term are consistently higher (conservative) than the results with the more phenomenological jet pump model. The degree of conservatism depends on the break size and location. For limiting large breaks in the recirculation pump suction line, the delta PCT due to the change is not significant (< 50°F). For plants where the limiting break is the recirculation pump discharge location, PCT's are calculated to decrease

. For small break LOCAs in the discharge line where the calculated unrealistic behavior persists over an extended time, unrealistic and excessively conservative PCT's would be calculated. With the change, calculated SBLOCA PCT's are comparable to the LBLOCA results.

2.0 MODEL REVISION

The RELAX jet pump model development is presented in Reference 1. The 1/6th scale jet pump test data from EG&G[3] provides the validation and calibration basis for the jet pump model. The magnitude of the

. This value was established from the 1/6th scale EG&G jet pump data based primarily on normal flow direction operation. Because of the relative insensitivity of the term for that data base, it was assumed to apply globally for all flow conditions.

It should be noted that a drive jet does not exist in the mixing section when the jet pump drive is in reverse flow. There is no jet wake and the fluid-fluid turbulent shear in the mixing region is minimal or non-existent. The revision presented here acknowledges this situation.

3.0 JUSTIFICATION OF MODEL CHANGE

This section presents an evaluation and justification of the revision to the RELAX jet pump model. The evaluation was done by comparing the calculated and measured pressures for the drive and suction for the entire data base before and after the change. The measured flows and other operating conditions from the data base were used to define input to the RELAX jet pump model run by a stand-alone driver program. The comparisons confirmed that differences only occurred for reverse drive flow.

Figures 3.1 and 3.2 show the calculated versus measured pressure difference between the drive and exit (P_d-P_e) and suction and exit (P_s-P_e), respectively, for the reverse drive flow data only. The open symbols show the computed results with the revised jet pump model. The smaller solid symbols are for the original model. The revised model points are seen to be quite close to the original model computed results and all points are within the accuracy of the original calibration.

On the average, the drive and suction pressure differences are predicted slightly better with the model change. The changes are also in the range of uncertainty of the data as indicated in Figures 3.1 and 3.2.

Figure 3.3 shows a comparison of the calculated and measured pressures for a nominal reverse drive flow of -4.1 l/sec. This is the highest reverse drive flow from the EG&G 1/6 scale model jet pump tests and exhibits the greatest sensitivity to the fluid-fluid shear term. The open symbols show the computed results with the revised model. The smaller solid symbols are for the original model. The measured pressure is also shown by the nearby companion symbol.

The revised model points are seen to be quite close to the original model computed results and all points are consistent with the accuracy of the original calibration.

. While the EG&G data are the best available to qualify a jet pump model, the sensitivity to the reverse drive flow shear is significantly less in the model jet pump than in the full scale reactor jet pumps.

Therefore, the revision of the jet pump model:

1) Is physically based. There is no jet and the associated wake to produce turbulent shear in the mixing section as is the case for forward drive flow. The forward drive flow cases have a jet that interacts with the suction flow in the mixing section and fluid-fluid shear is modeled in that region. Reverse drive flow does not produce a jet in the mixing region.

2) Produces results that are consistent with the EG&G data base. The predictive performance relative to the data base is improved slightly with the model change.

Figure 3.1

Figure 3.2

Figure 3.3

4.0 EFFECTS OF MODEL CHANGE

Large Break LOCA Results

The effect of the jet pump model change on LOCA PCT was assessed for large break LOCA in the pump discharge line for a BWR-5. Two analysis calculations were performed, the first with the currently approved revised EXEM BWR model[2], and the second an identical case performed with a version of RELAX containing the proposed jet pump modification. A single break size is presented to show the effect. Because of the jet pump change, there is an impact on the inventory loss (as explained below in the sample application). Therefore, as required by Appendix K, the plant analyses will include a break spectrum for both suction and discharge breaks to assure the limiting break is analyzed. Figure 4.1 gives the basic nodalization used in the RELAX calculations. Significant results of the two calculations are shown as overlay plots in Figures 4.2 - 4.14. Table 4.1 shows a comparison of calculated event times for the two cases.

The system pressure transient during the LOCA is given in Figure 4.2 which plots the calculated upper plenum pressure versus time for the two cases. The difference in system pressure response due to the jet pump change is evident beginning when the jet pump suction nozzle uncovers at 14.8 seconds. With the old model, two-phase fluid is calculated to flow from the jet pump to the downcomer, and there is little change in depressurization rate when the jet pump suction nozzle uncovers. With the model change, steam begins flowing from the downcomer to the jet pump and then to the break at this time. The effect is a decrease in calculated break flow rate and an increase in system depressurization rate.

Figure 4.3 shows the calculated total flow at the recirculation pump discharge break. The calculated total break flow is reduced for the case with the change relative to the calculation without the change. The change affects the flow at the jet pump suction junction which has a

direct effect on the jet pump side break flow. The change also decreases liquid inventory in the downcomer as well as decreasing the system pressure both of which in turn cause a decrease in the flow at the vessel end of the break.

Overlays of the broken loop jet pump drive flow, suction flow, and discharge flow are given in Figures 4.4, 4.5, and 4.6, respectively. The revised jet pump model changes the broken loop jet pump suction flow which in turn affects the pressure head associated with the broken loop jet pump and ultimately the core flow. Calculated average core inlet and outlet flows are shown in Figures 4.7 and 4.8, and hot assembly calculated inlet and outlet flows are presented in Figures 4.9 and 4.10. The

Figure 4.11 shows the calculated liquid mass in the lower plenum for the two cases. As expected, the jet pump change results in less inventory loss through the break and more mass in the lower plenum.

The hot channel quality and heat transfer coefficient corresponding to the HUXY PCT plane are given in Figures 4.12 and 4.13. The results comparison shows improved cooling conditions associated with the increased core flow due to the code change. Final HUXY calculated PCT's for the two cases are given in Figure 4.14.

. When a break spectrum analysis is performed, this change may result in a different limiting break size or location.

Small Break LOCA Results

To demonstrate the calculated SBLOCA behavior with the code change, SPC performed a SBLOCA calculation for the BWR-5 assuming a 1.0 ft^2 break in the recirculation pump discharge line. The results of this calculation are given in Figures 4.15 - 4.27. Table 4.2 gives the calculated event times for the 1.0 Ft^2 small break LOCA.

The basic nodalization is the same as for the LBLOCA as given in Figure 4.1. The break is modeled as a split in the pump discharge line. Figure 4.15 shows the system pressure response in the upper plenum. The total break flow is given in Figure 4.16. The broken loop jet pump drive, suction, and discharge flows are shown by Figures 4.17, 4.18, and 4.19, respectively. Average core inlet and outlet flows are given in Figures 4.20 and 4.21, and hot assembly inlet and outlet flows in Figures 4.22 and 4.23. Figure 4.24 shows the lower plenum liquid mass versus time. The hot channel quality and heat transfer coefficient at the HUXY PCT plane are given in Figures 4.25 and 4.26. The final HUXY temperature results are shown in Figure 4.27.

The effects of the change in the small break are basically the same as given for the large break, except that the unrealistic behavior due to the shear term is integrated over a longer time resulting in unrealistic and excessively conservative results.

Table 4.1
Summary of Results, 1.0 DEG/PD Break

Event	Old Code Time, Sec	With Change Time, Sec
Low Mixture Level	12.5	10.8
Low Low Mixture Level	14.9	12.6
Jet Pump Suction Uncovers	17.4	14.8
Recirculation Suction Uncovers	27.8	22.6
Lower Plenum Flashes	21.9	27.1
HPCS Valve Opens	N/A	N/A
HPCS Pump at Rated Speed	N/A	N/A
HPCS Flow Starts	N/A	N/A
LPCS Pressure Permissive	71.5	74.5
LPCS Valve Opens	71.5	74.5
LPCS Pump at Rated Speed	61.9	60.0
LPCS Flow Starts	91.5	93.7
LPCI Pressure Permissive	71.5	74.5
LPCI Valve Opens	71.5	74.5
LPCI Pump at Rated Speed	61.9	60.0
LPCI Flow Starts	96.8	98.6
Time of Rated Spray	119.1	120.2
ADS Valve Opens	134.9	132.6
Time of Core Reflood	162.9	159.5
PCT Temperature, °F		
Time of PCT	162.9	159.5

Table 4.2
Summary of Results, 1.0 FT^2/PD Break

Event	With Change Time, Sec
Low Mixture Level	13.4
Low Low Mixture Level	16.1
Jet Pump Suction Uncovers	19.3
Recirculation Suction Uncovers	30.3
Lower Plenum Flashes	36.1
HPCS Valve Opens	N/A
HPCS Pump at Rated Speed	N/A
HPCS Flow Starts	N/A
LPCS Pressure Permissive	103.5
LPCS Valve Opens	103.5
LPCS Pump at Rated Speed	63.1
LPCS Flow Starts	134.9
LPCI Pressure Permissive	103.5
LPCI Valve Opens	103.5
LPCI Pump at Rated Speed	63.1
LPCI Flow Starts	139.5
Time of Rated Spray	162.1
ADS Valve Opens	136.1
Time of Core Reflood	201.8
PCT Temperature, °F	
Time of PCT	201.8

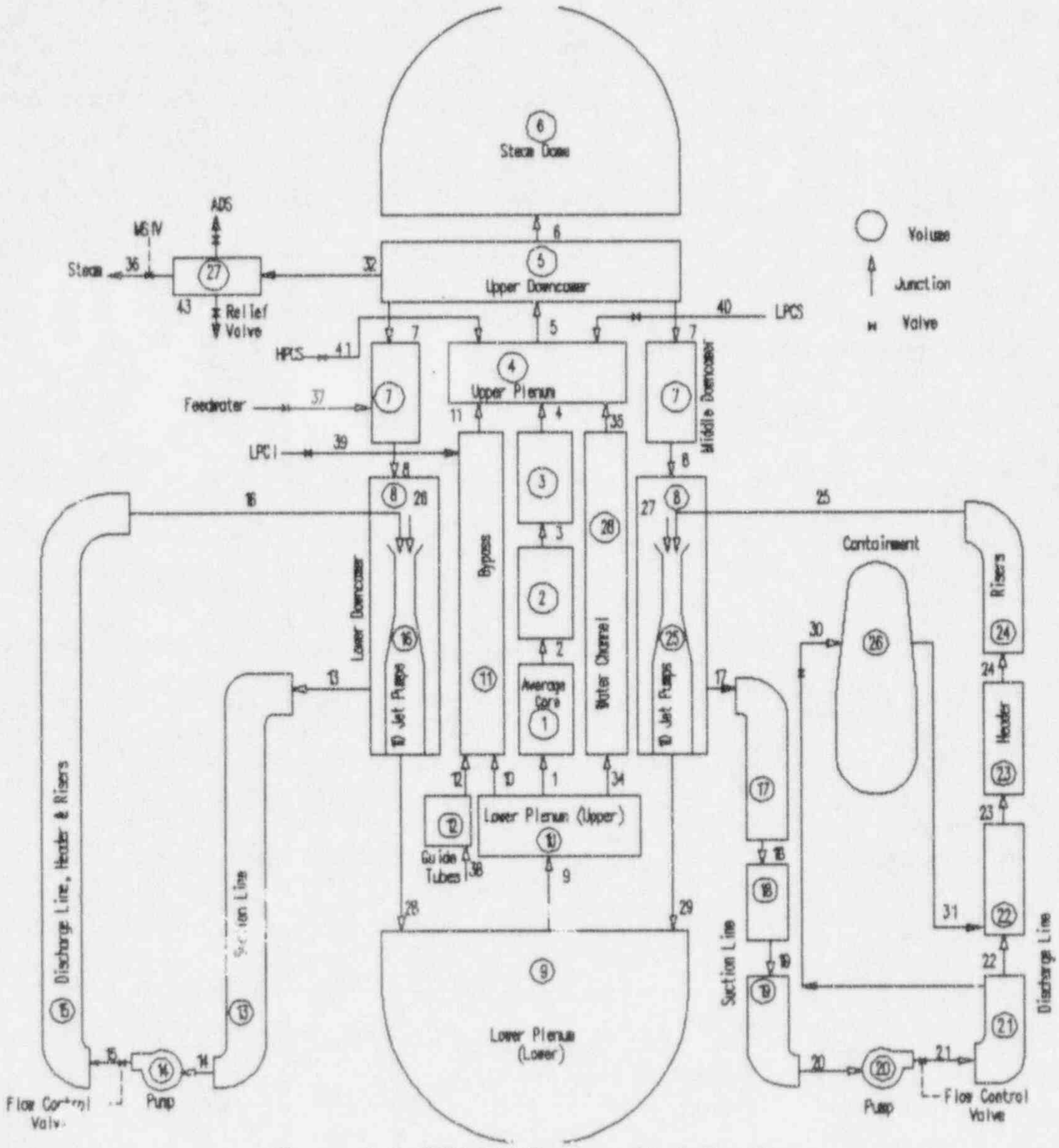

Figure 4.1 RELAX System Nodalization

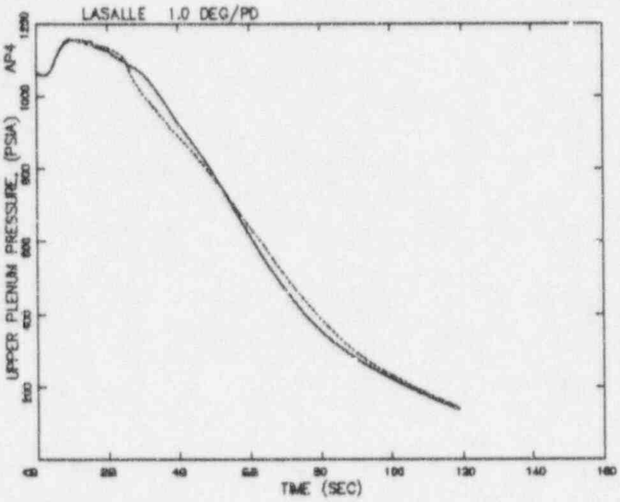

Figure 4.2 Upper Plenum Pressure vs Time, 1.0 DEG/PD Break
___ old code .... with changes

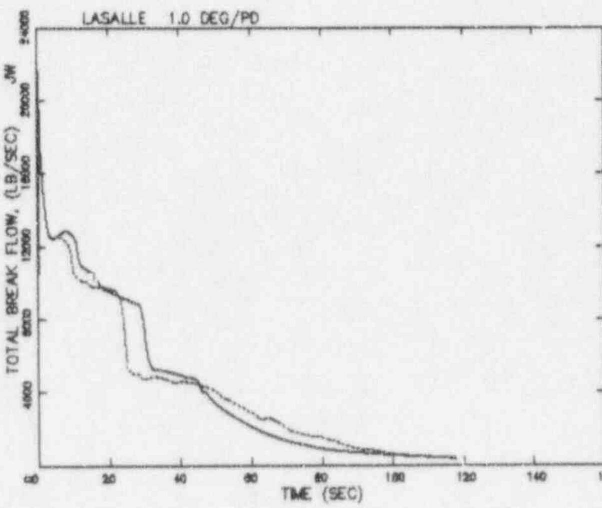

Figure 4.3 Total Break Flow vs. Time, 1.0 DEG/PD Break
___ old code .... with changes

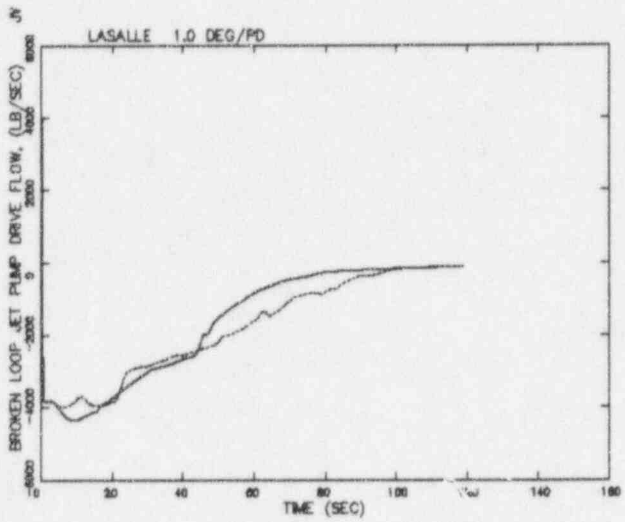

Figure 4.4 Broken Loop Jet Pump Drive Flow vs. Time, 1.0 DEG/PD Break
___ old code .... with changes

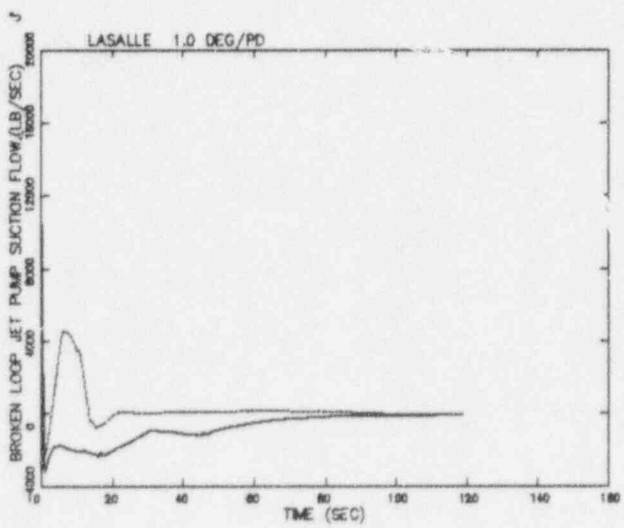

Figure 4.5 Broken Loop Jet Pump Suction Flow vs. Time, 1.0 DEG/PD Break
___ old code .... with changes

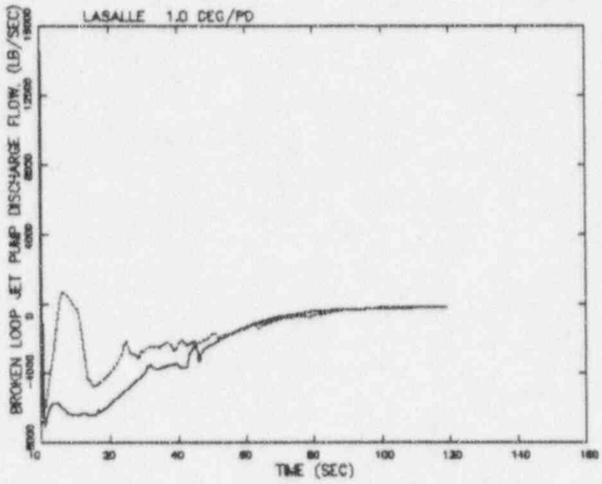

Figure 4.6 Broken Loop Discharge Flow vs. Time, 1.0 DEG/PD Break
___ old code .... with changes

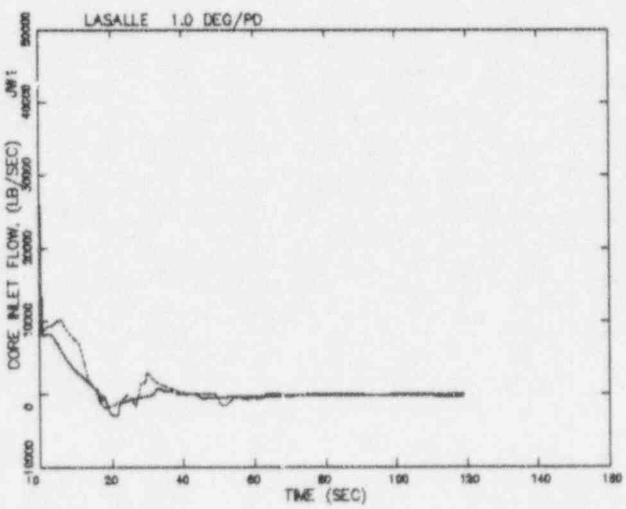

Figure 4.7 Average Core Inlet Flow vs. Time, 1.0 DEG/PD Break
___ old code .... with changes

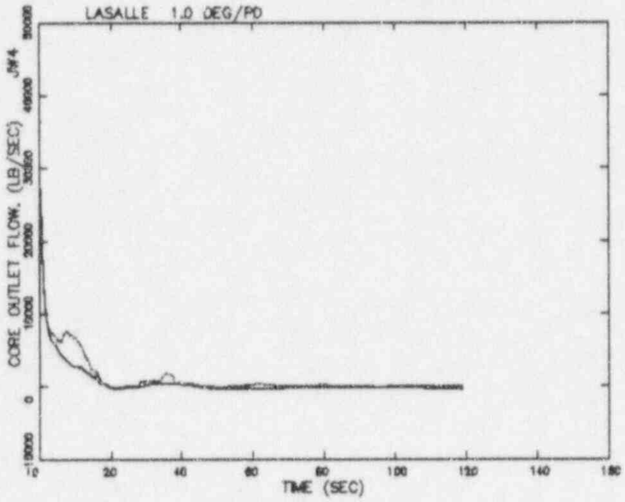

Figure 4.8 Average Core Outlet Flow vs. Time, 1.0 DEG/PD Break
___ old code .... with changes

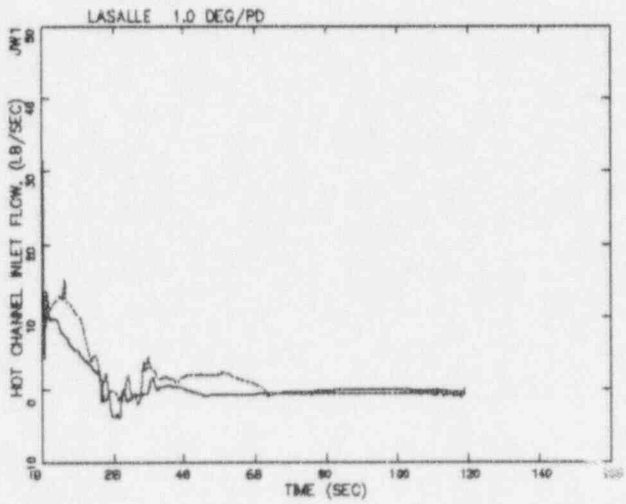

Figure 4.9 Hot Assembly Inlet Flow vs. Time, 1.0 DEG/PD Break
___ old code .... with changes

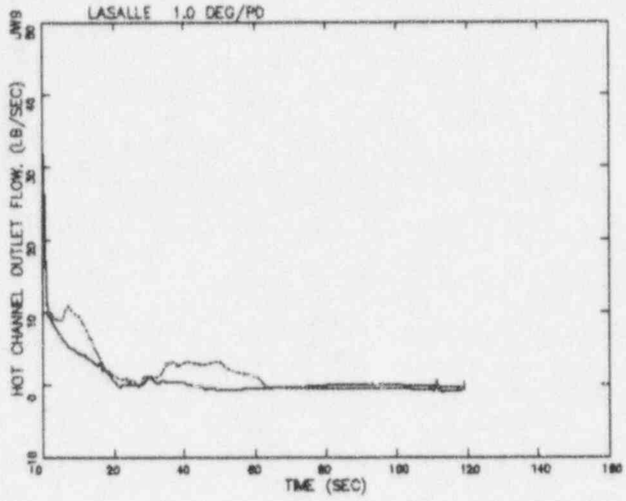

Figure 4.10 Hot Assembly Outlet Flow vs. Time, 1.0 DEG/PD Break
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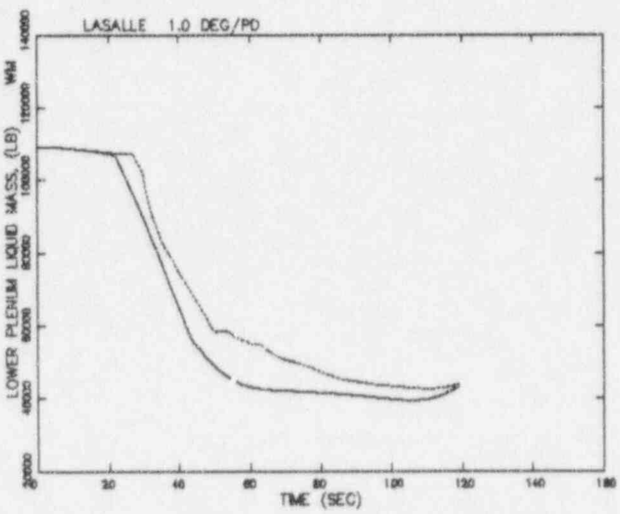

Figure 4.11 Lower Plenum Liquid Mass vs. Time, 1.0 DEG/PD Break
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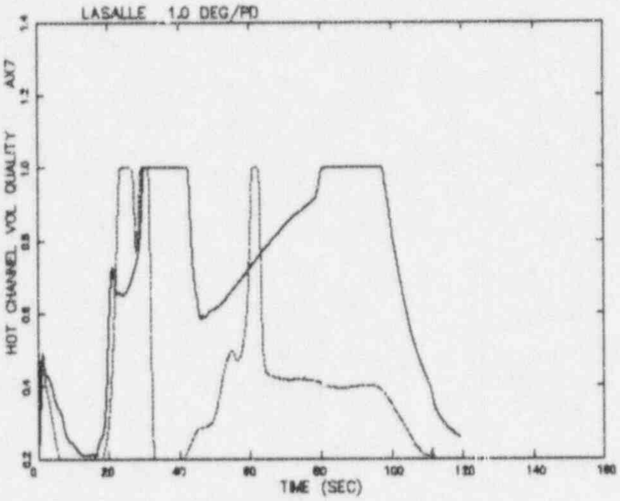

Figure 4.12 Hot Assembly PCT Node Quality vs. Time, 1.0 DEG/PD Break
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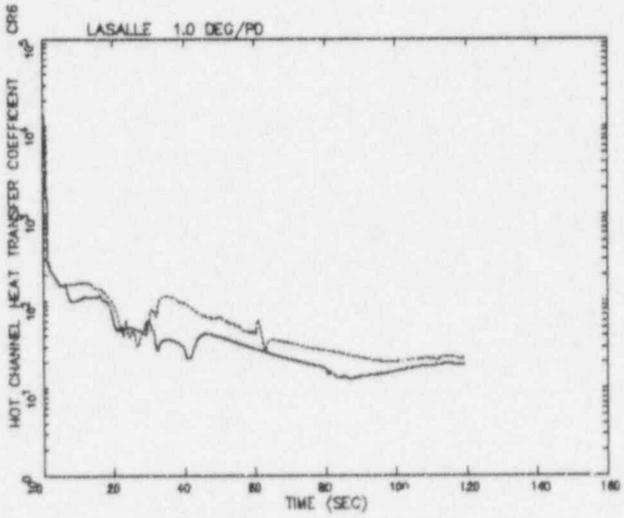

Figure 4.13 Hot Assembly PCT Node Heat Transfer coefficient vs. Time, 1.0 DEG/PD Break ___ old code .... with changes

Figure 4.14

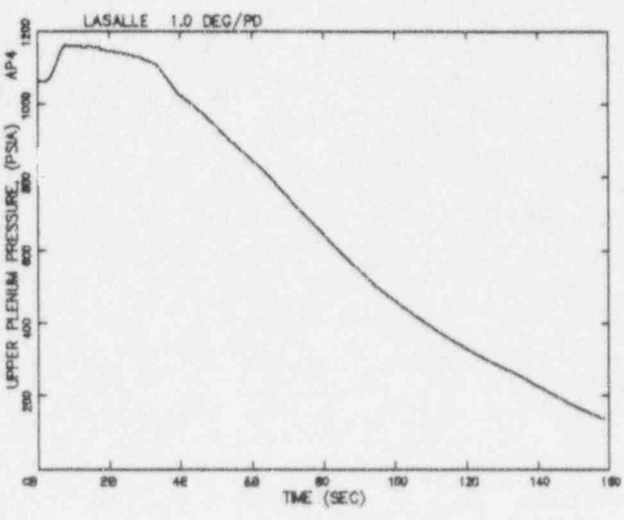

Figure 4.15 Upper Plenum Pressure, 1.0 Ft^2 Break

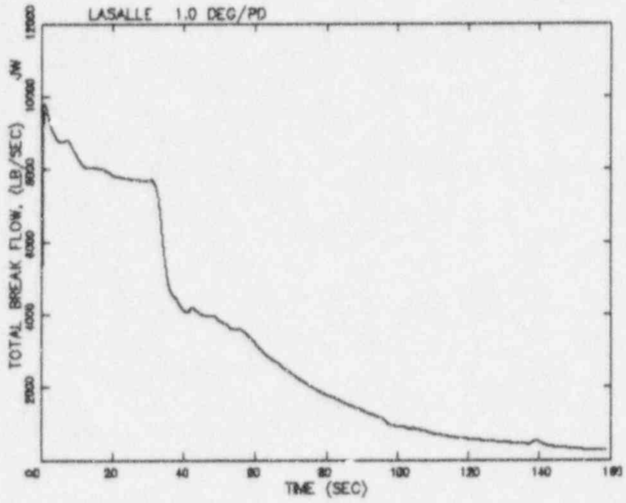

Figure 4.16 Total Break Flow, 1.0 Ft² Break

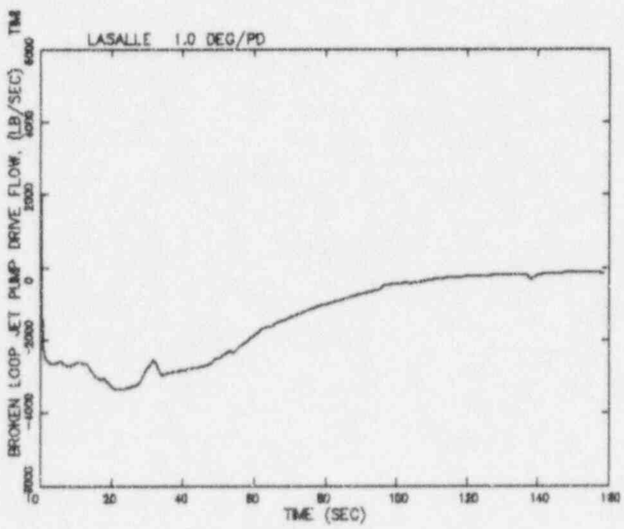

Figure 4.17 Broken Loop Jet Pump Drive Flow, 1.0 Ft² Break

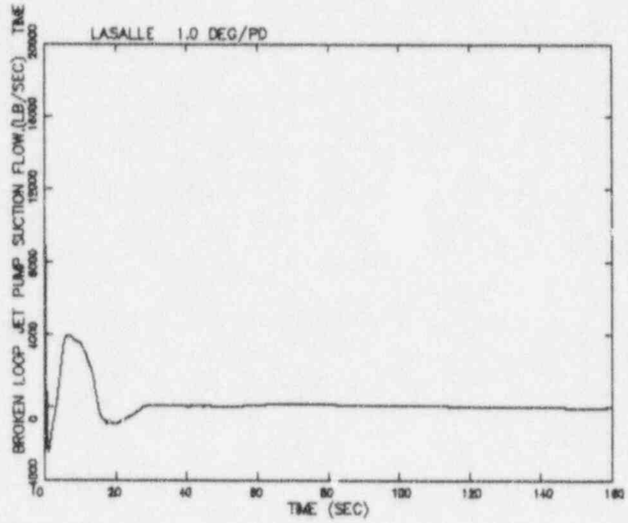

Figure 4.18 Broken Loop Jet Pump Suction Flow, 1.0 Ft^2 Break

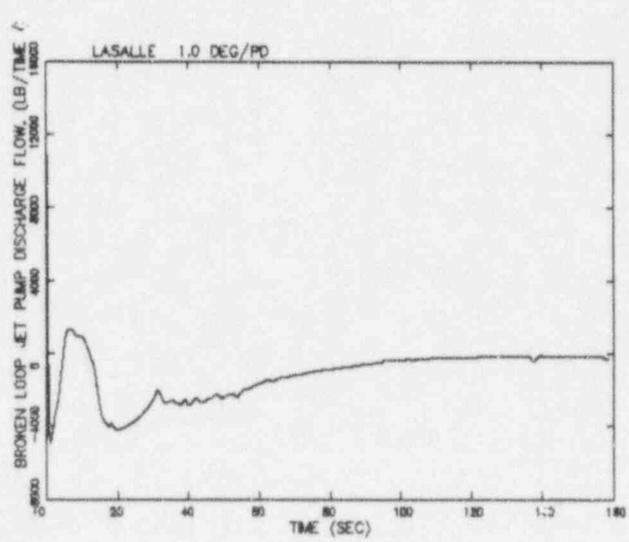

Figure 4.19 Broken Loop Jet Pump Discharge Flow, 1.0 Ft^2 Break

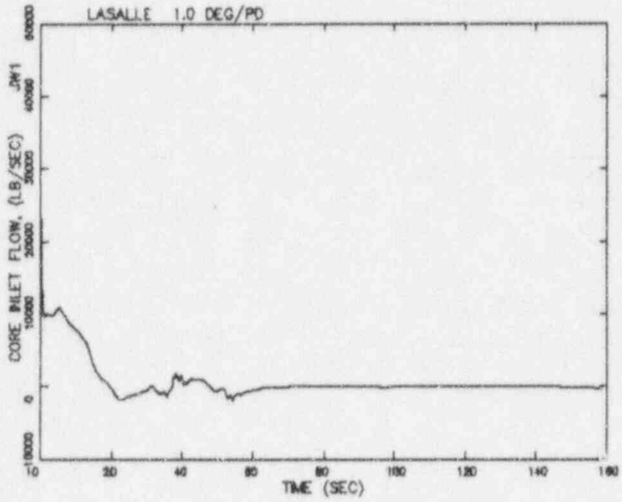

Figure 4.20 Average Core Inlet Flow, 1.0 Ft^2 Break

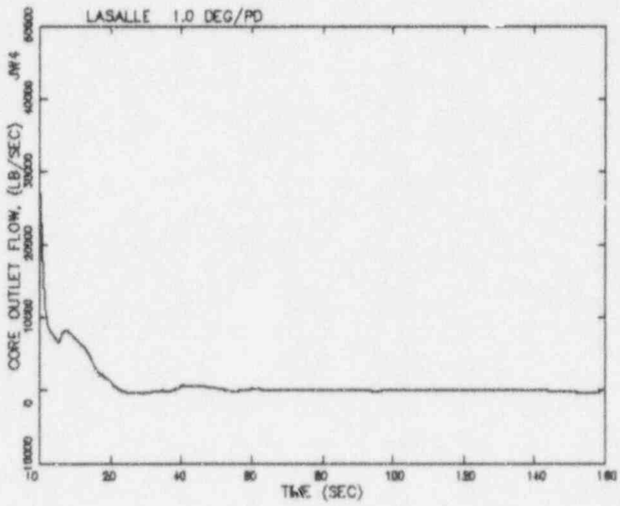

Figure 4.21 Average Core Outlet Flow, 1.0 Ft^2 Break

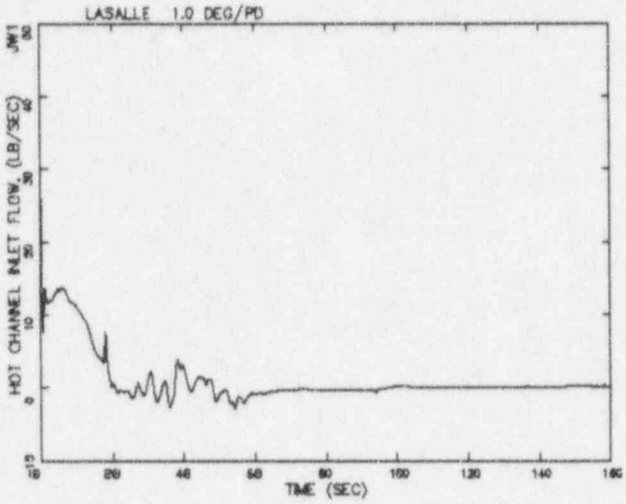

Figure 4.22 Hot Assembly Inlet Flow, 1.0 Ft^2 Break

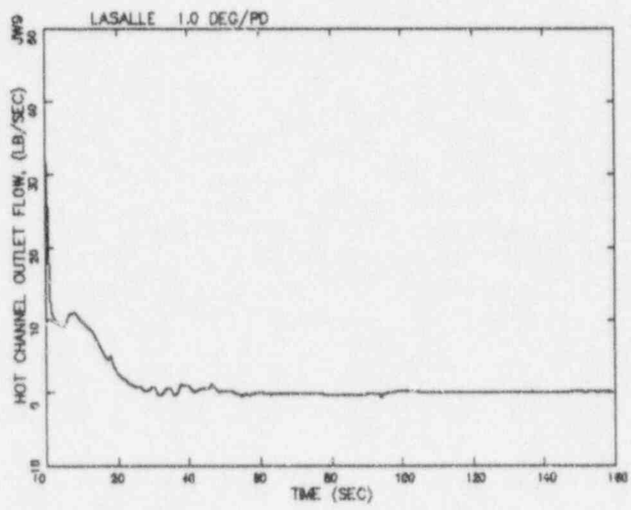

Figure 4.23 Hot Assembly Outlet Flow, 1.0 Ft^2 Break

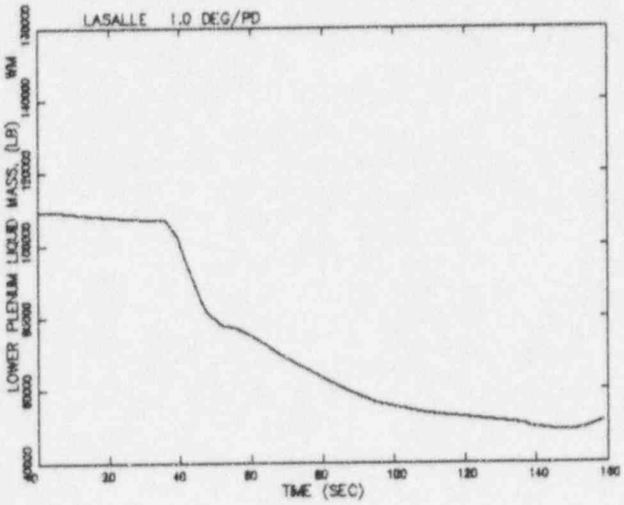

Figure 4.24 Lower Plenum Liquid Mass, 1.0 Ft^2 Break

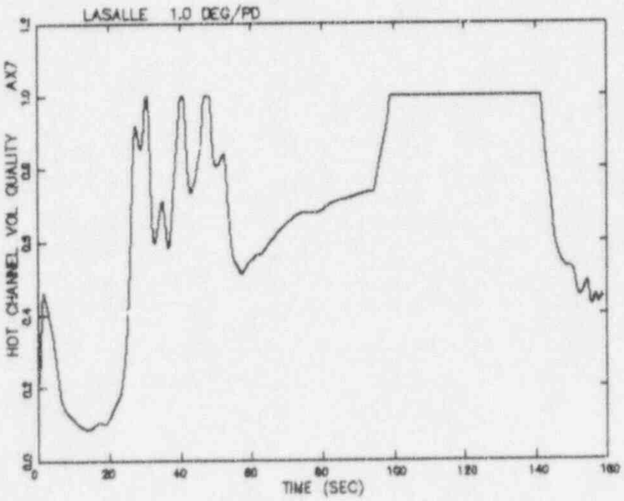

Figure 4.25 Hot Assembly PCT Node Quality, 1.0 Ft^2 Break

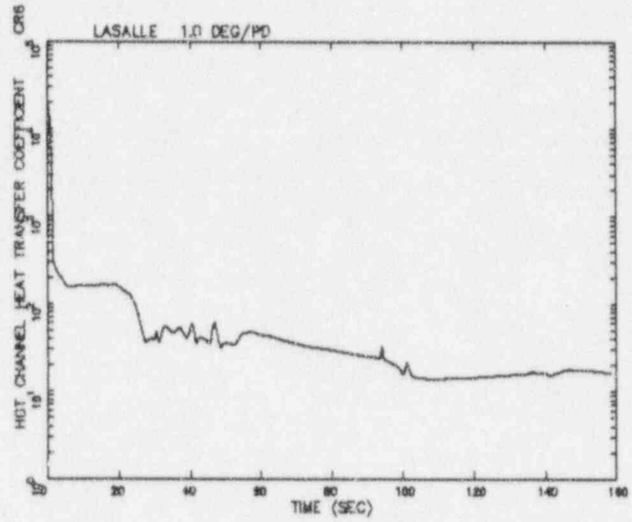

Figure 4.26 Hot Assembly PCT Node Heat Transfer Coefficient, 1.0 Ft² Break

Figure 4.27

5.0 REFERENCES

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ANF-91-048(NP)
Supplement 1
Issue Date: 5/7/96

BWR Jet Pump Model Revision for RELAX

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