PDR

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September 22, 1983

Mr. P. E. Litteneker, Acting Chief
Reactor Research and Technology Branch
Reactor Operations and Programs Division
Idaho Operations Office - DOE
Idaho Falls, ID 83401

TRANSMITTAL OF PRELIMINARY RESULTS OF NATURAL CIRCULATION ANALYSES FOR MCGUIRE AND NORTH ANNA - TRC-90-83

Dear Mr. Litteneker:

Transmitted as attachments to this letter are the preliminary results of natural circulation analyses for the November 11, 1981 transient at the McGuire Nuclear Power Station and the July 5, 1980 natural circulation low power test at the North Anna Nuclear Power Station. The RELAP5 analyses were performed for the Office for Analysis and Evaluation of Operational Data.

Attachment 1 presents the results of the McGuire analysis. The November 11, 1981 transient was caused by a loss of stator winding cooling to the reactor coolant pumps. The plant's four primary pumps were sequentially tripped, two before the manual reactor scram and two after the scram. The comparison between data and calculation showed good agreement and led to the following conclusions:

1. The sequence of events as reported in the LER was the true sequence of events. There was no indication of any other unreported actions or inactions which could have affected the course of the transient.

2. Temperature readings gave a positive indication that a stable natural circulation condition was established. A significant difference existed between narrow range and wide range cold leg temperature measurements, which could adversely affect interpretation of transient events, particularly during posttransient analysis.

Attachment 2 presents the results of the North Anna analysis. The July 5, 1980 low power test was performed to verify the ability of the plant to establish a natural circulation condition. During the test, which was initiated by the simultaneous trip of all three reactor coolant pumps, the power operated relief valve (PORV) unexpectedly cycled several times. The calculation and data agreed extremely well up to the opening of the PORV, and measured and calculated temperatures were converging at the time the calculation was terminated. The following conclusions were reached:

1. The PORV opened due to an increase in system T_{ave} which occurred because of the reactor coolant pump trip. It did not represent any type of anomolous system behavior.

2. Natural circulation was established and could be confirmed by system temperature measurements.

Transmittal of these results constitutes completion of Node 67-03 (McGuire) of A6234. Transmittal of the North Anna calculation is ahead of schedule.

Very truly yours,

T. R. Charlton

T. R. Charlton, Manager
Reactor Simulation and
Analysis Branch

JDB:sb

Attachment:
As Stated

cc: W. D. Lanning, NRC ✓
R. W. Kiehn, EG&G Idaho (w/o Attach.)

Attachment 1

ANALYSIS OF MCGUIRE LOSS OF STATOR WINDING COOLANT ACCIDENT (NOVEMBER 11, 1981)

The purpose of this interim report is to present the results of a RELAP5 analysis performed for the Office for the Analysis and Evaluation of Operational Data (AEOD) of a transient that occurred at the McGuire Nuclear Power Station on November 11, 1981. The analysis was performed in an effort to improve understanding of natural circulation phenomena.

McGuire is a 3411 MWt, four loop, Westinghouse pressurized water reactor (PWR). McGuire, located at Cornelius, North Carolina, is owned and operated by Duke Power Company. On November 11, 1981, while the plant was operating at 48% power, a fuse failed, cutting off cooling water to the reactor coolant pump (RCP) motor coolers. Responding to a high temperature alarm from the D loop RCP stator winding, reactor operators began reducing power to a level (~40%) where the pump could be tripped. Upon tripping the B loop RCP, an unexpected high water level trip occurred in one of the steam generators, causing a turbine trip and taking the main feedwater pump and the turbine-generator off line. Reactor power was reduced below 10% and the D loop RCP was tripped. The decision was made to manually scram the reactor and trip the remaining two pumps to establish natural circulation cooling in the plant while the problem with the RCP motor coolers was identified and resolved. Reference 1 contains additional information about the transient.

The RELAP5/MOD1.5 computer code was used to calculate the expected plant thermal hydraulic response during the transient. A model developed for the Westinghouse RESAR-3S plant (Seabrook) was utilized for the analysis (Reference 2). This model was selected based on its availability. The model was used as originally developed with one major exception. The original small break model used a two loop configuration, with one loop simulating three actual plant loops: the McGuire deck modelled all four loops individually.

The use of the RESAR-3S model for this analysis involved one significant compromise. The RESAR-3S steam generators were modeled after the Westinghouse Model F steam generator, which is characterized by a high feedwater inlet ring above the U-tube bundle. The McGuire station actually has Model D-2 steam generators using a low feedwater inlet and a preheater baffle section. The differences between the two steam generator designs are substantial, limiting the ability of the analysis to study secondary behavior during the transient. However, the compromise was considered acceptable since the focus of the analysis was on the natural circulation flow in the primary system, and the exact response of the secondary side was not considered to be crucial to the analysis.

For analytical purposes the transient was assumed to start at the time the first pump was tripped. All four steam generator secondary pressures were driven with time dependent volumes to match the measured secondary transient data as closely as possible. A power decay curve was used to simulate the ramp down in power from 39% power (the condition at the time the first pump was tripped) to 3.5% power (the condition immediately preceeding the reactor scram), and the decay heat for the remainder of the transient.

Data from the transient was available in the form of transient monitor printouts, with data points taken every 15 s starting ~45 s prior to the initial pump trip. The key parameters for this analysis were hot and cold leg temperatures, primary mass flow, and primary and secondary pressures. Comparisons were made with the calculated values for all key parameters, except secondary pressure which was used as a model boundary condition.

The calculation was run for 1500 s at which time natural circulation had been established and the system stabilized. The sequence of events is listed in Table 1.

Figures 2 through 4 show the comparisons with data for mass flow in Loops D, A, and C, respectively; Figure 1 shows only the calculated mass flow for Loop B as the data available were insufficient to provide a meaningful comparison. Figure 5a presents a comparison of all four

calculated loop flows with Figure 5b detailing the portion of the transient where natural circulation was occurring. As seen in Figure 5a, as long as a single pump remained in operation flow in the passive loops reversed, flowing from the vessel inlet annulus to the vessel upper plenum through the steam generators. This reverse flow decreased as the number of active pumps decreased and mass flow in the active loops increased with each pump trip. Plant flow instrumentation, registering percent nominal flow did not register this reverse flow phenomena, although the loop ΔT did show a negative value representing reversed flow. Once the C loop RCP was tripped all the loops began to steady out at a natural circulation flow rate of 150 kg/s (330.7 lb/s). Flow in C loop was slower to converge to the natural circulation flow because the pump was coasting down normally. The other pumps locked their rotors early due to the development of reverse flow.

Primary system temperature comparisons with data are presented in Figures 6 through 9, with Figures 6a through 9a comparing hot leg temperatures and Figures 6b through 9b comparing cold leg temperatures. Figure 10 shows a comparison of all four calculated hot leg temperatures and Figure 11 shows all four calculated cold leg temperatures. The most pronounced temperature effect is seen in Loop B, since it was the first to experience a pump trip at a high power level. Following an immediate increase in the hot leg temperature as flow decreased, corresponding to a drop in core flow, the hot leg temperature rapidly fell below the cold leg temperature as reverse flow was established. This negative ΔT was much less evident in the remaining loops due to the decrease in power and the reactor scram which occurred during the transient. In general, both hot and cold leg temperatures showed excellent agreement with data.

The comparison of loop cold leg temperatures, shown in Figures 6b through 9b, also include a comparison between data taken by the plant wide range instruments and the narrow range instruments. As seen, wide range temperature readings differed from the narrow range readings in the separate cold legs during the development of natural circulation. This observation was made in all four loops, with the most divergent readings occurring in A and B loops. This divergence is a result of the location of the instruments. The narrow range instruments are located in the loop

bypass manifolds, which will see the correct loop temperatures during forced flow. During natural circulation, however, there is not enough pressure difference to force fluid through the manifolds and the narrow range instruments' temperature readings begin to diverge. Wide range loop temperature instrumentation is located in the loops and is capable of tracking loop coolant temperatures throughout the natural circulation phase of the transient. Plant operators should be aware of this difference to ensure that the correct readings are used when determining proper plant recovery procedures following a transient. Analysts studying the transient after the fact should also be aware of the difference when determining the nature of the incident.

Coolant flow instrumentation in McGuire is not sensitive enough to register established natural circulation flow once all four pumps are tripped, therefore hot leg temperatures and ΔT measurements were needed to verify the existence of the flow. Figures 12 through 15 present the comparisons with data of the loop ΔTs. Beyond 600 s, after the last pump is tripped, the loop ΔTs rise, then turn over to stabilize out. The comparison of all four calculated loop ΔTs, provided in Figure 16, illustrates a significant difference between the ΔT response in Loop C and the ΔT responses of the other three loops. The Loop C ΔT began increasing immediately upon C loop's RCP trip. However, the other three loops' ΔTs did not begin increasing until 100 s later. The reason for this offset between loops was the reverse flow developed in Loops A, B, and D. Once C RCP was tripped it took ~100 s for flow in these loops to again reverse and begin flowing hot leg to cold leg. Once the reversal had occurred, the three hot legs began to heat up. Once all loops were experiencing heatup, temperature turn over occurred between 170 and 180 s after the final pump trip. This temperature turnover was the key indicator that a steady natural circulation flow had been established. Based on the temperature turnaround criteria, plant data indicated that a slightly longer period of time (~60 s) was required to achieve a steady natural circulation condition. Previous studies (References 3 and 4) have found that the calculated time to establish natural circulation was quite sensitive to the pump coastdown information used in the model. Altering pump data in the model could have narrowed the difference between calculated and observed times for natural circulation establishment.

During the transient calculation, primary pressure (Figure 17) increased initially after the B loop RCP was tripped, due to the decrease in core flow which caused a system heatup. As the reactor was brought down in power and finally scrammed, system pressure decreased continuously until the C loop RCP was tripped at 600 s. The pressure increased, following hot leg temperature, as natural circulation established itself then stabilized. Measured plant data indicated repressurization was initiated around 400 s, peaking as natural circulation stabilized. The reason for the measured early repressurization was the additional energy provided by the pressurizer heaters, which were left on automatic control during the transient. The depressurization due to pump trips and the decrease in power prior to and immediately following the scram overwhelmed the ability of the heaters to control pressure. However, at 400 s, the plant cooldown had slowed, converging hot leg and cold leg temperatures, and the heaters were able to regain control and repressurize the plant. A sensitivity study confirmed this hypothesis as shown in Figure 18. For the study 1800 kW of simulated pressurizer heaters were added to the base model, with the power controlled by primary pressure. As seen the calculated pressure began increasing ~360 s, confirming the cause of the plants repressurization. Comparison of measured and calculated pressure showed similar trends, but the absolute values differed. This difference was due primarily to the absense in the model of several other pressure control systems, such as pressurizer spray and charging systems.

An evaluation of the entire transient as calculated provided several conclusions.

1. The sequence of events as reported in the LER was the true sequence of events. There was no indication of any other unreported actions or inactions which could have affected the course of the transient.

2. Temperature readings gave a positive indication that a stable natural circulation condition was established. A significant difference existed between narrow range and wide range cold leg temperature measurements, which could adversely affect interpretation of transient events, particularly during posttransient analysis.

REFERENCES

1. Incident Investigation Report No. 81-239. Duke Power Company, McGuire Nuclear Station Unit 1 Reactor Trip of November 11, 1981.

2. J. E. Blakeley and J. M. Cozzuol, Best Estimate Analysis of a Small Break LOCA in a RESAR-3S Pressurized Water Reactor, EGG-NTAP-6032, September 1982.

3. P. D. Bayless, Analysis of the June 24, 1980 Loss of Off-Site Power Transient at Arkansas Nuclear One Unit 2 (Draft), EGG-NTAP-6309, June 1983.

4. C. B. Davis, Analysis of the April 7, 1980 Loss of Off-Site Power Transient at Arkansas Nuclear One Unit 1 (Draft), EGG-SAAM-6381, August 1983.

TABLE 1. SEQUENCE OF EVENTS

Event	Time	
	Data	Calculation
Pump B Tripped	0	0
Pump D Tripped	142.0	142.0
Reactor Trip	234.0	234.0
Pump A Tripped	300-365	332.0
Pump C Tripped	601.0	597.0
Natural Circulation Established	950-1000 s	875 s

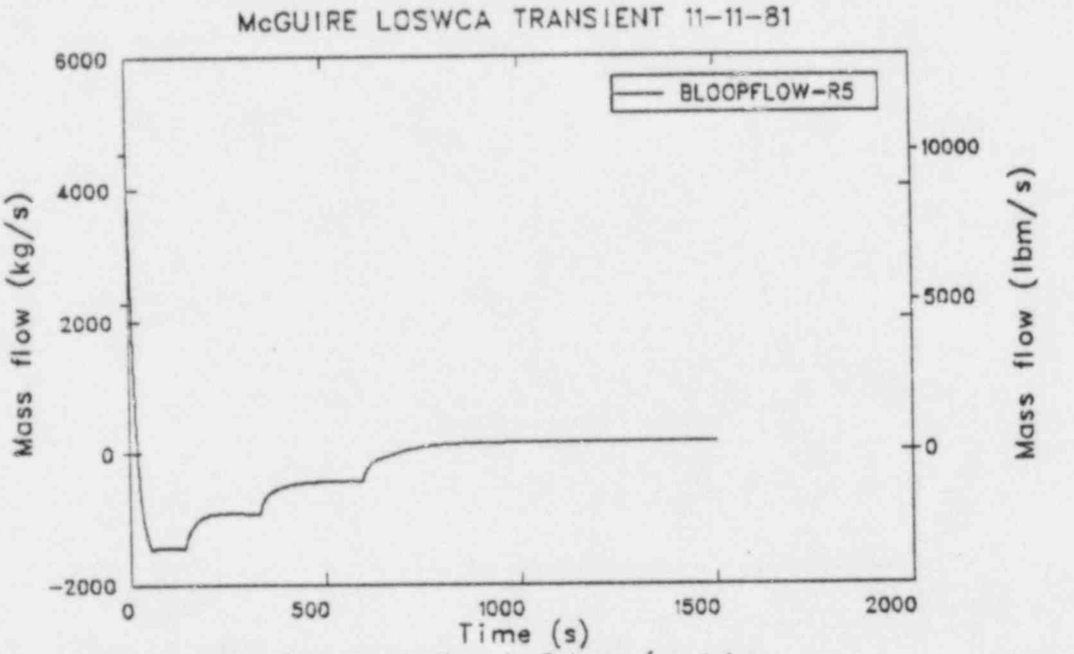

Figure 1. Mass flow versus time in B Loop. (no data comparison)

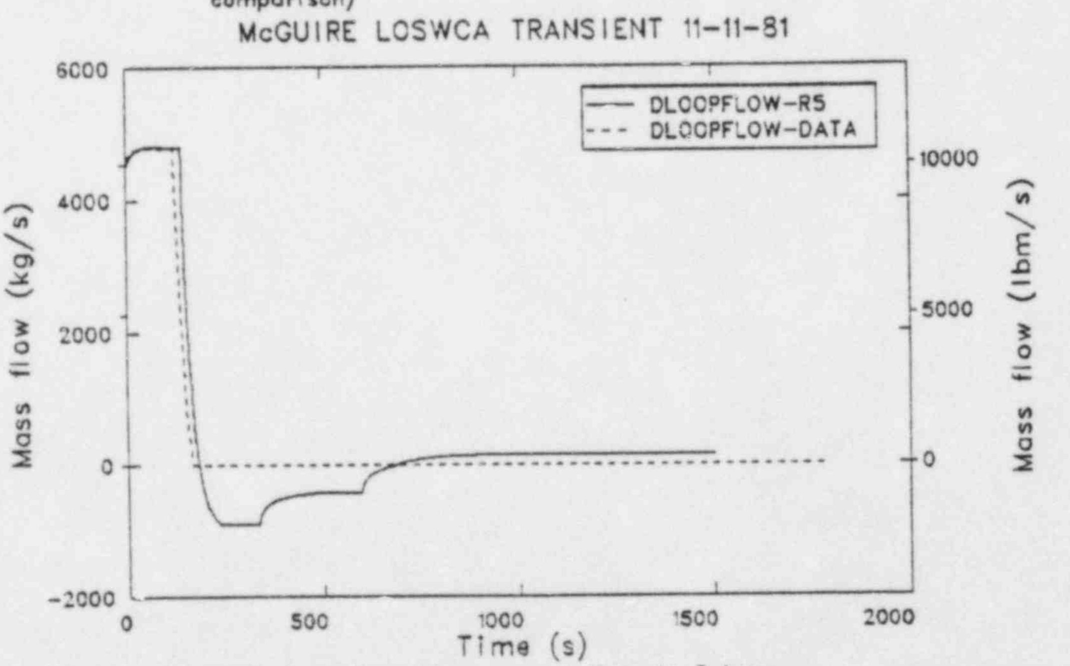

Figure 2. Mass flow comparison versus time in D Loop.

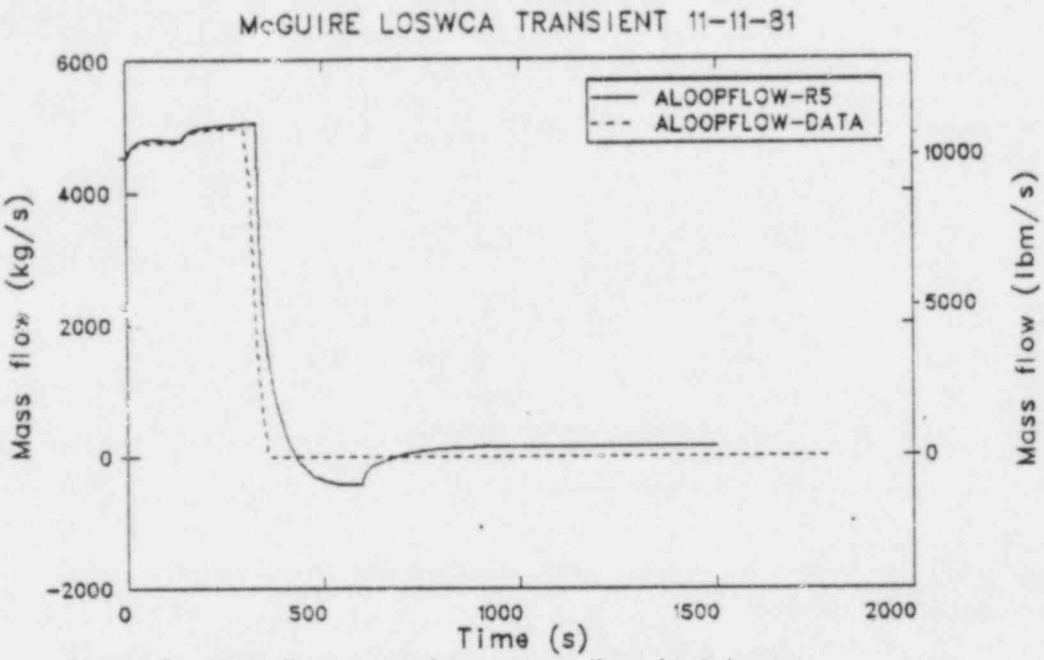

Figure 3. Mass flow comparison versus time in A Loop.

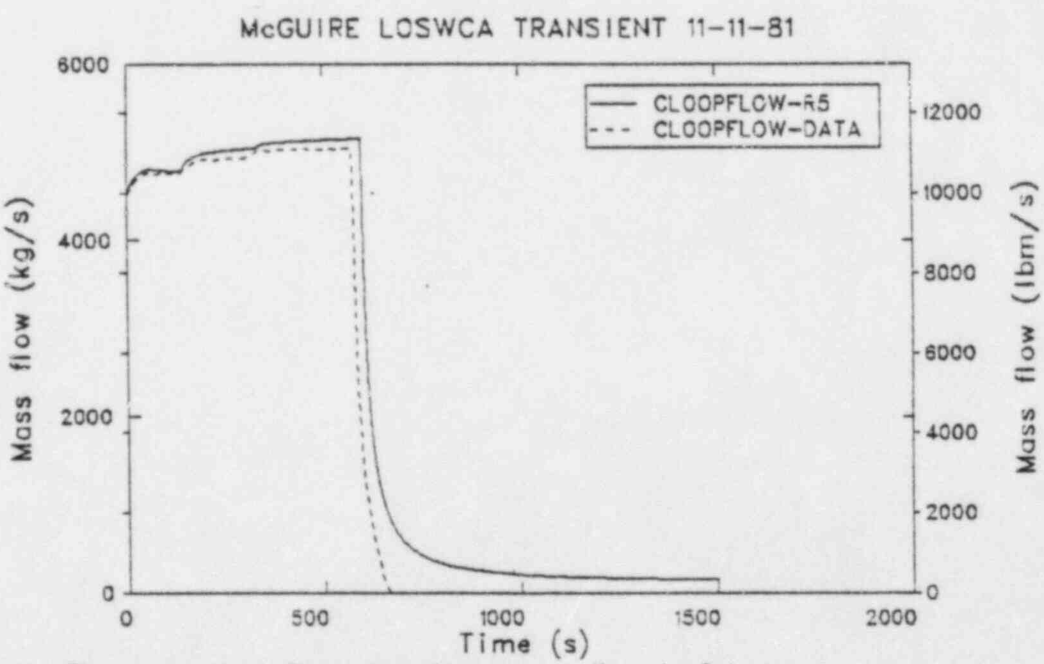

Figure 4. Mass flow comparison versus time in C Loop.

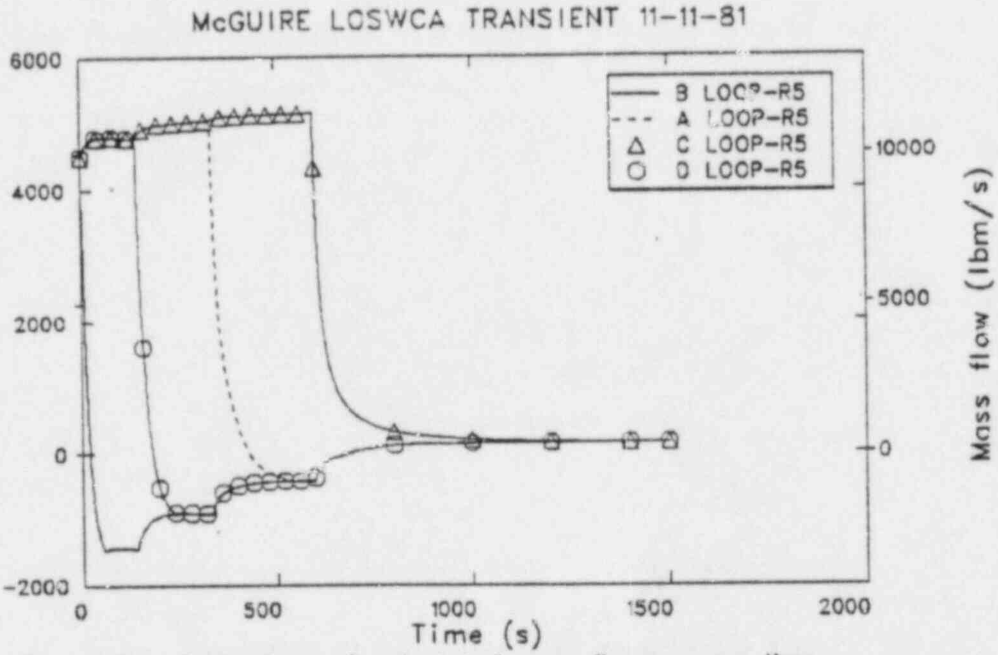

Figure 5a. Comparison of calculated mass flows versus time for all loops.

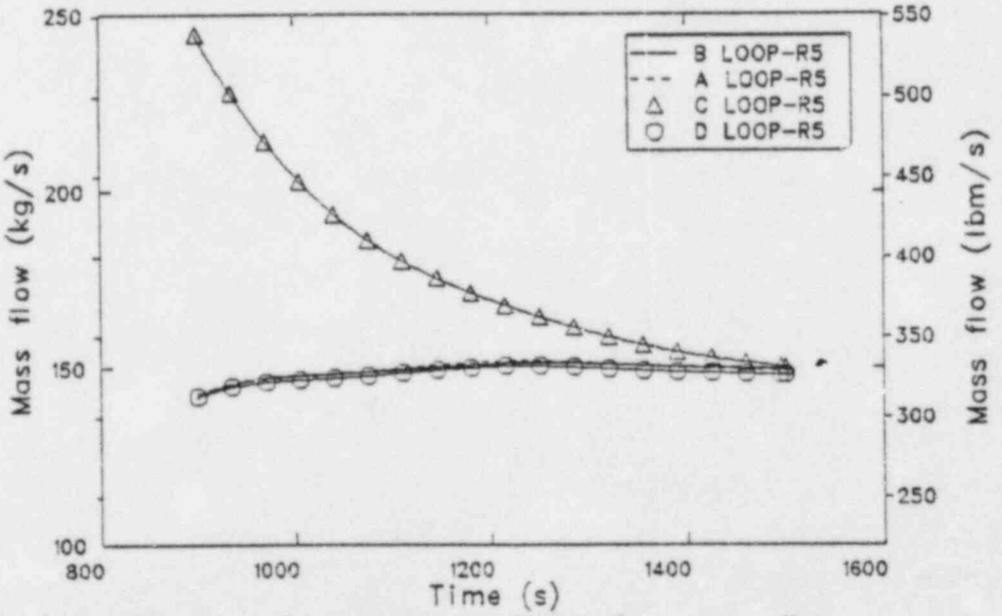

Figure 5b. Comparison of calculated mass flows versus time for all loops. (900 - 1500s).

McGUIRE LOSWCA TRANSIENT 11-11-81

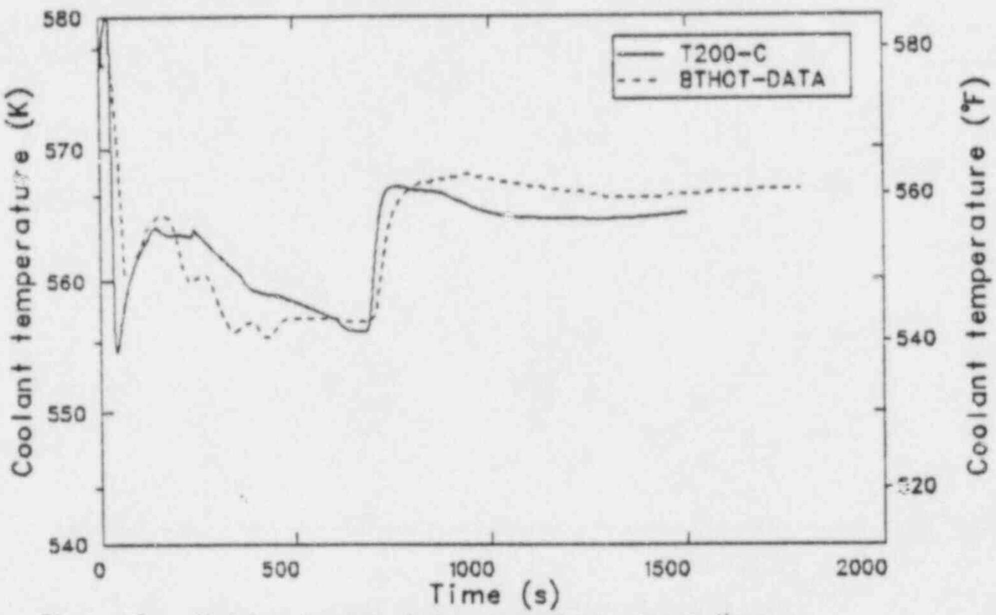

Figure 6a. Hot leg temperature comparison versus time for B Loop.

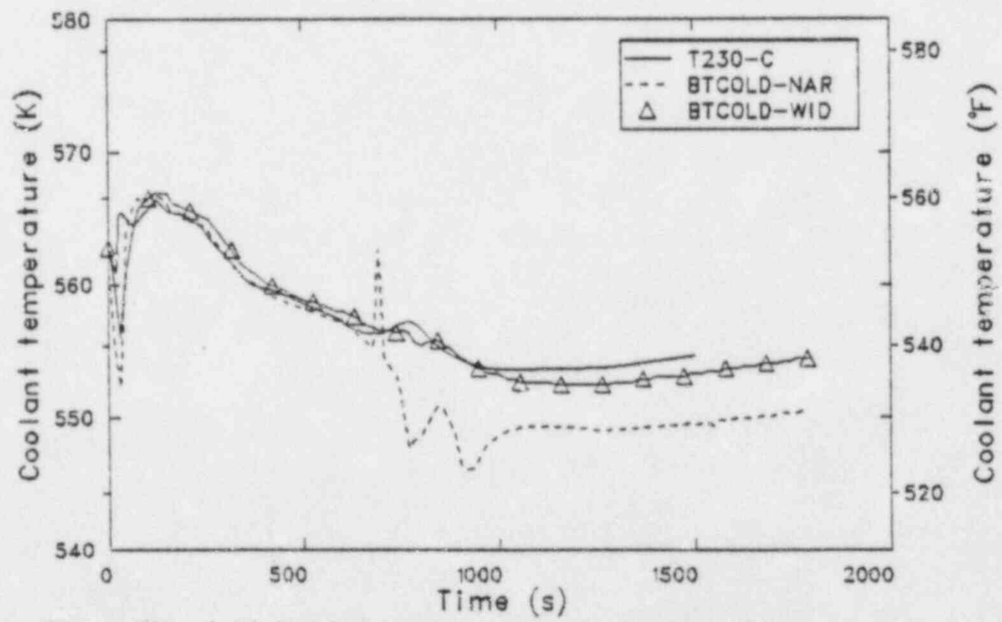

Figure 6b. Cold leg temperature comparison versus time for B Loop.

McGUIRE LOSWCA TRANSIENT 11-11-81

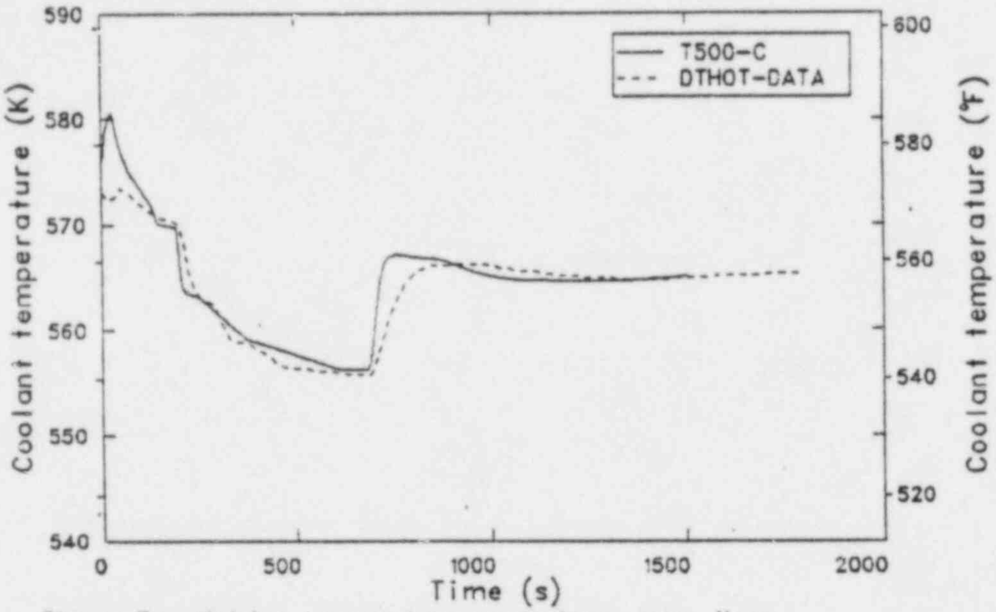

Figure 7a. Hot leg temperature comparison versus time for D Loop.

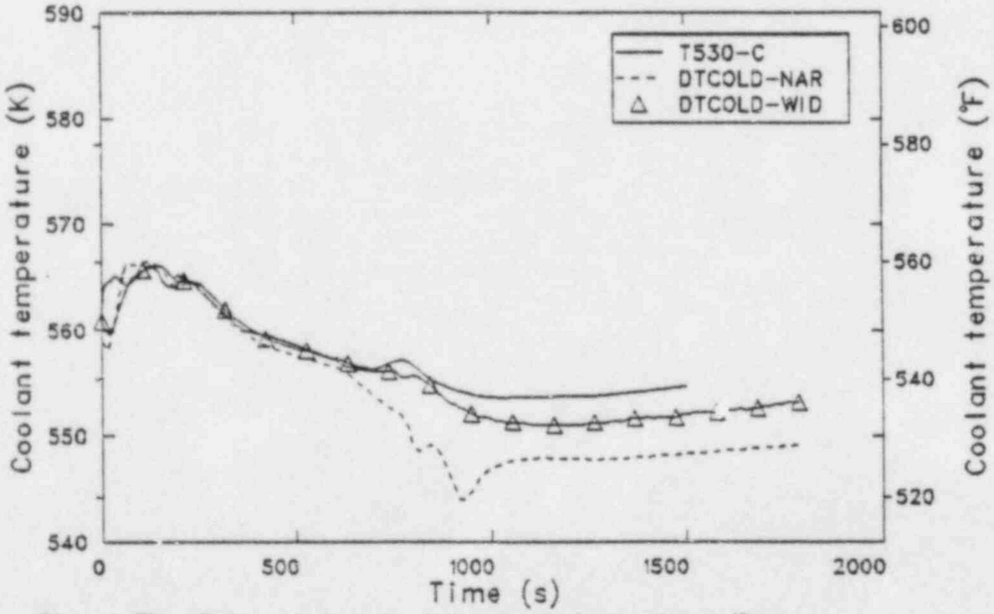

Figure 7b. Cold leg temperature comparison versus time for D Loop.

McGUIRE LOSWCA TRANSIENT 11-11-81

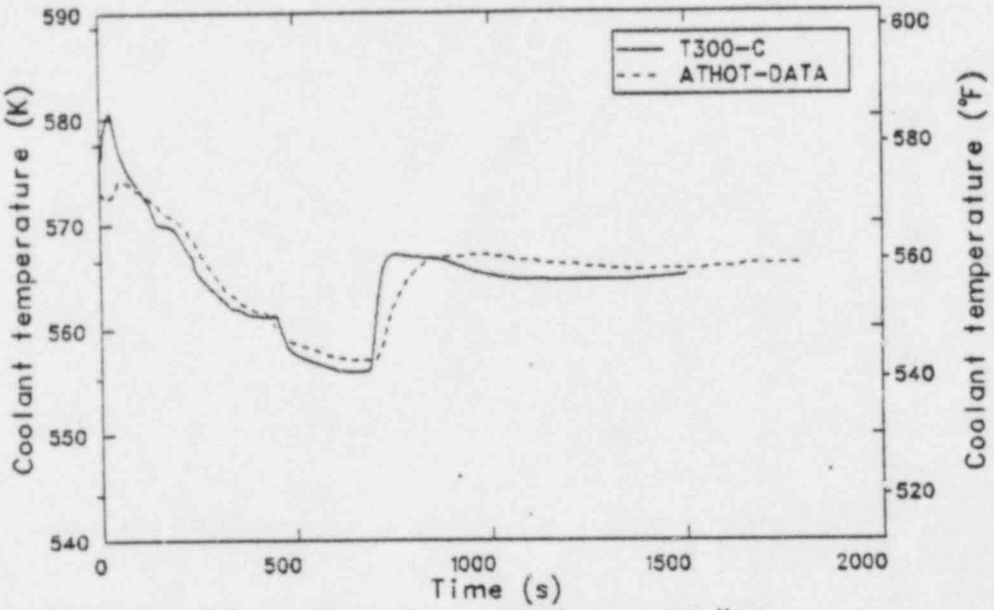

Figure 8a. Hot leg temperature comparison versus time for A Loop.

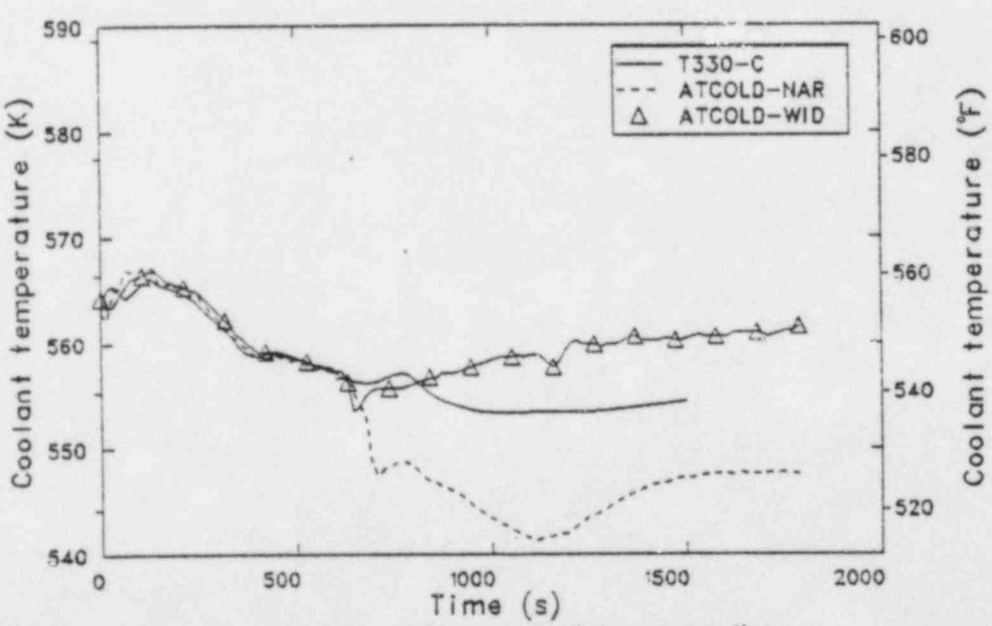

Figure 8b. Cold leg temperature comparison versus time for A Loop.

McGUIRE LOSWCA TRANSIENT 11-11-81

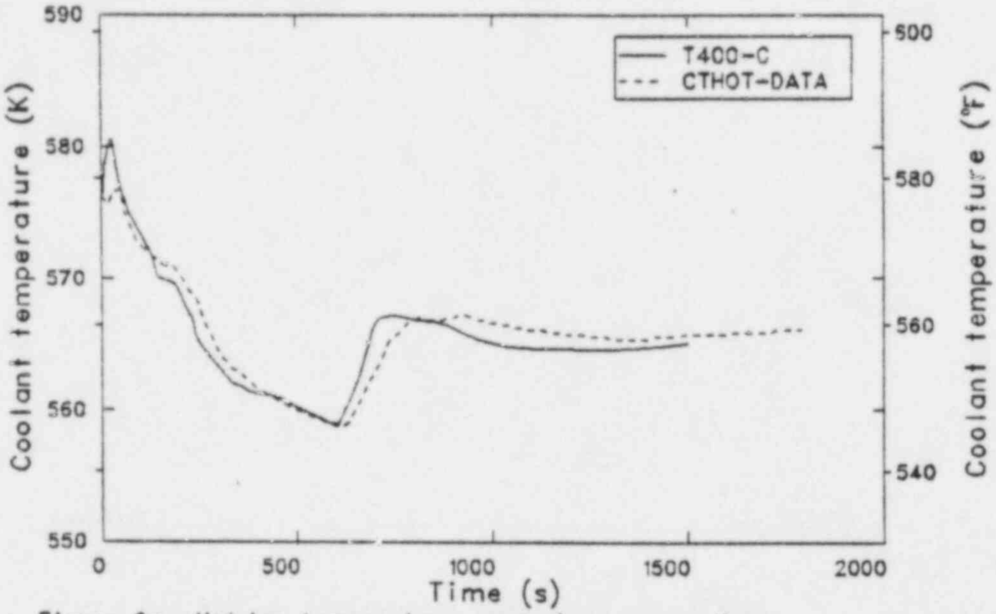

Figure 9a. Hot leg temperature comparison versus time for C Loop.

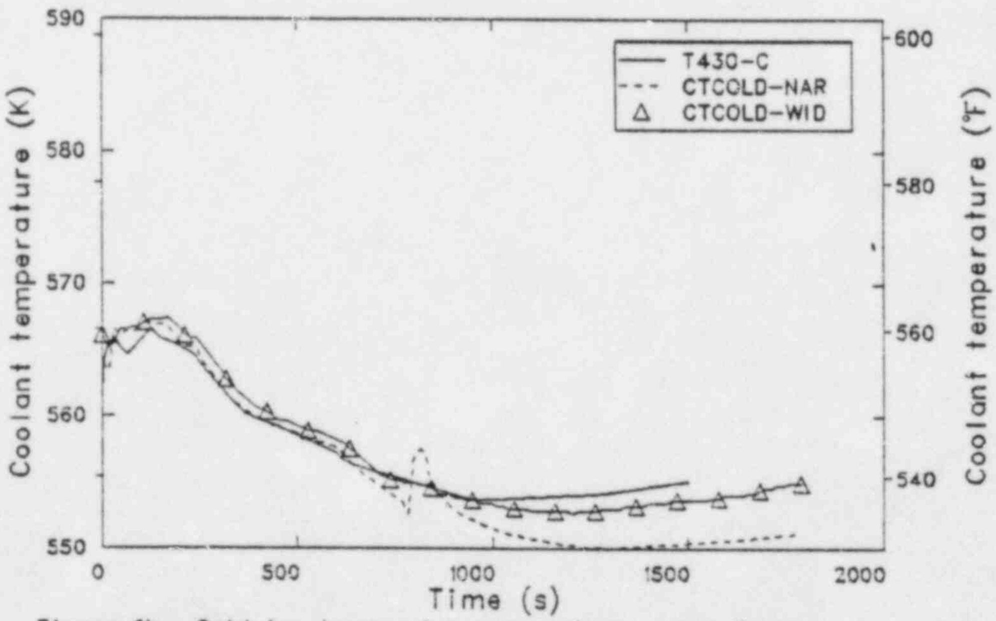

Figure 9b. Cold leg temperature comparison versus time for C Loop.

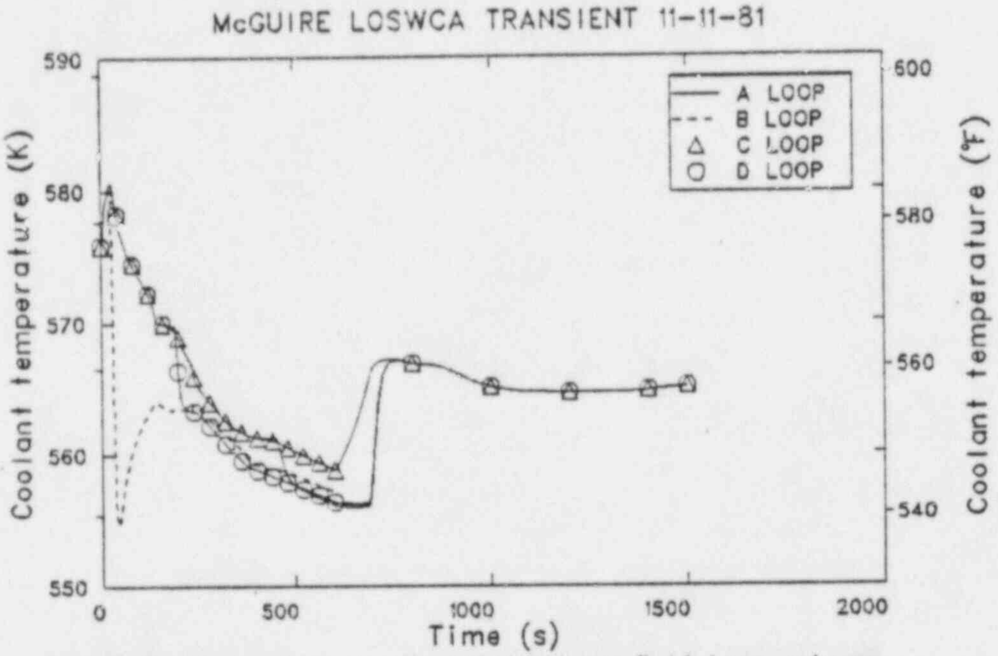

Figure 10. Comparison of calculated hot leg fluid temperatures versus time for all loops.

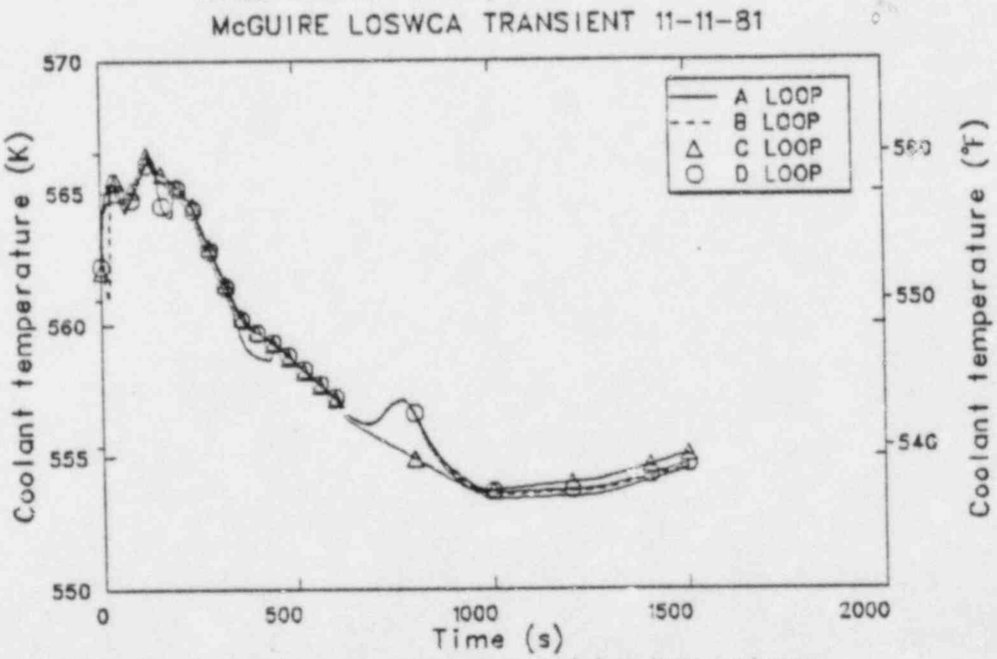

Figure 11. Comparison of calculated cold leg temperatures versus time for all loops.

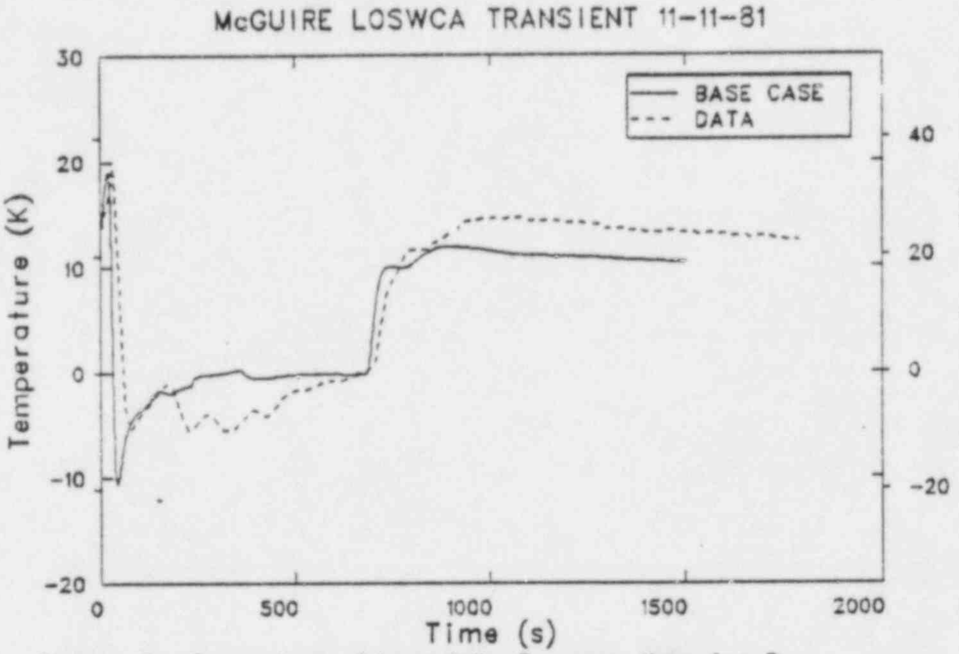

Figure 12. Comparison of loop delta T versus time for B Loop.

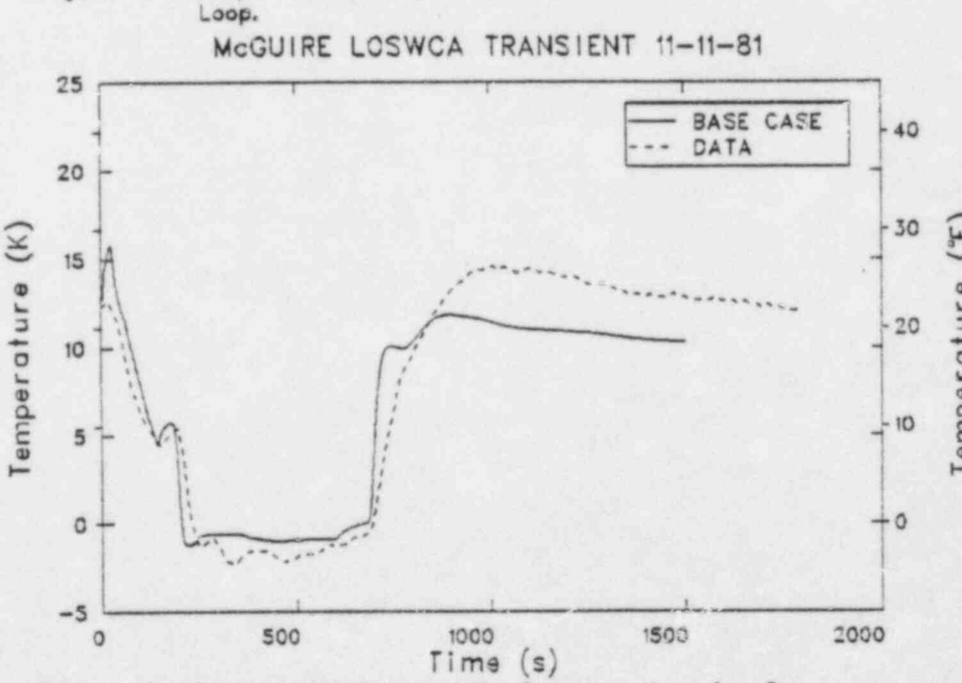

Figure 13. Comparison of loop delta T versus time for D Loop.

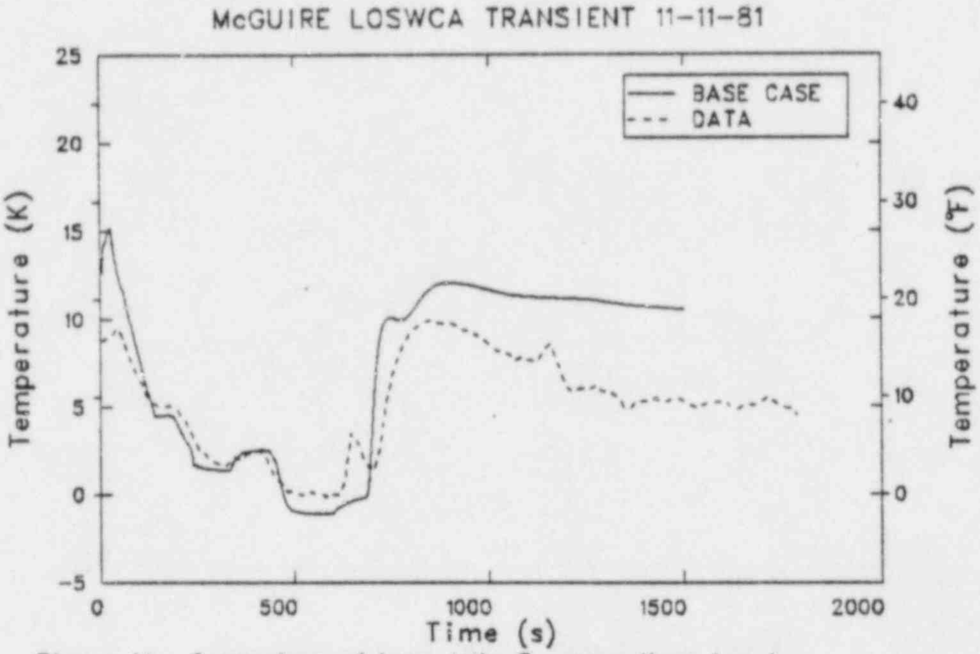

Figure 14. Comparison of loop delta T versus time for A Loop.

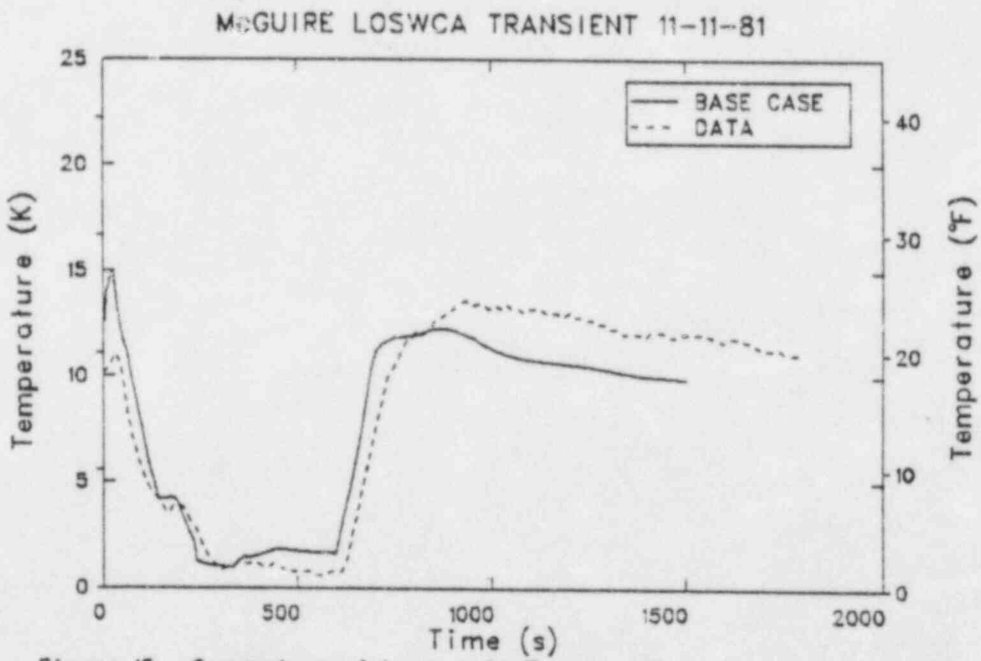

Figure 15. Comparison of Loop delta T versus time for C Loop.

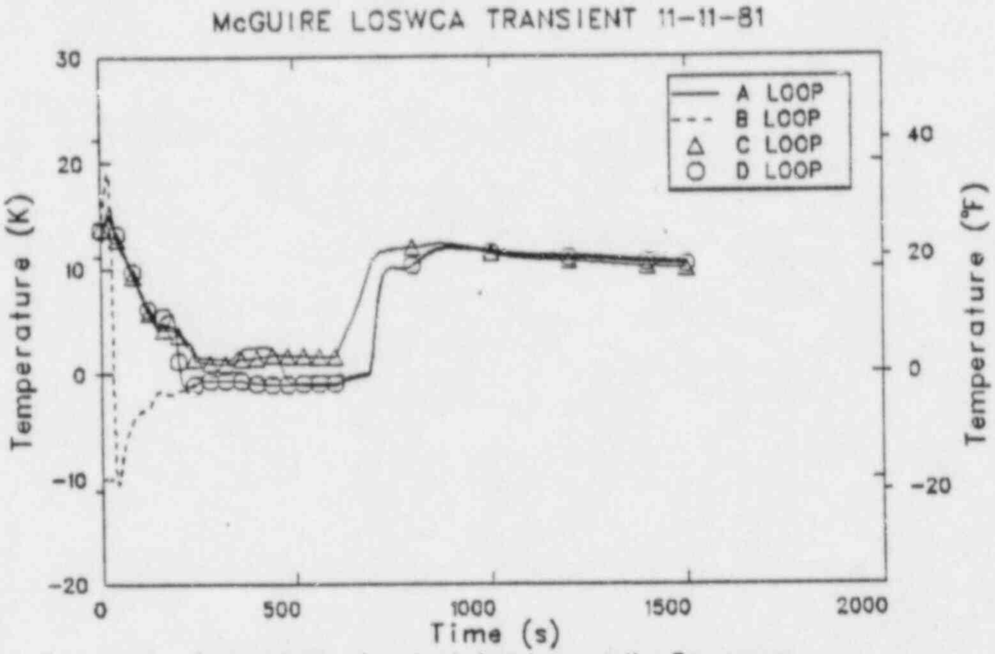

Figure 16. Comparison of calculated Loop delta Ts versus time for all loops.

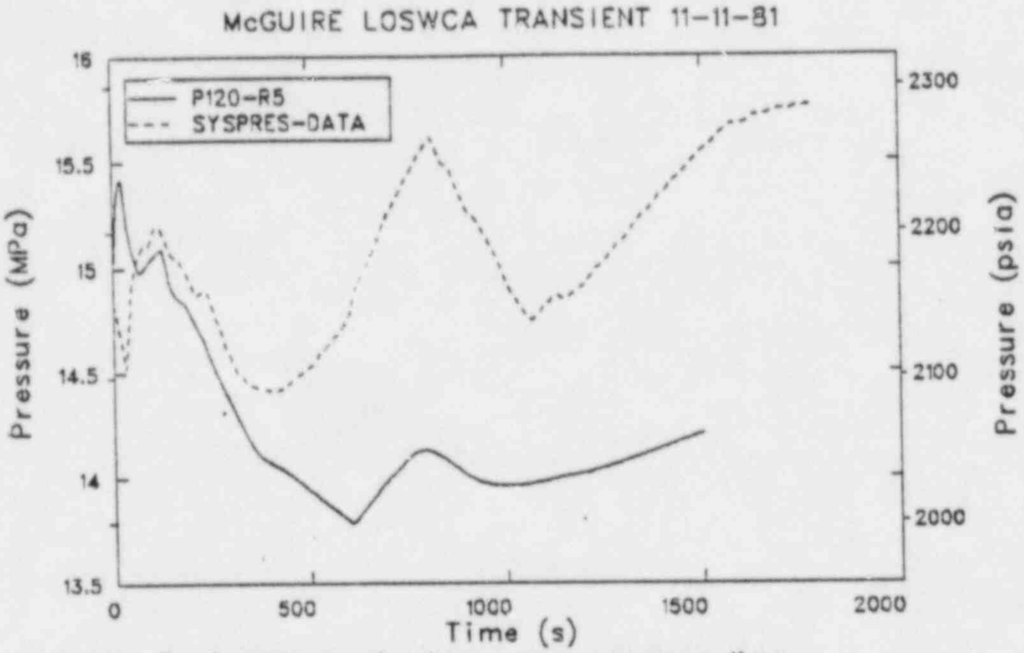

Figure 17. Comparison of primary pressure versus time.

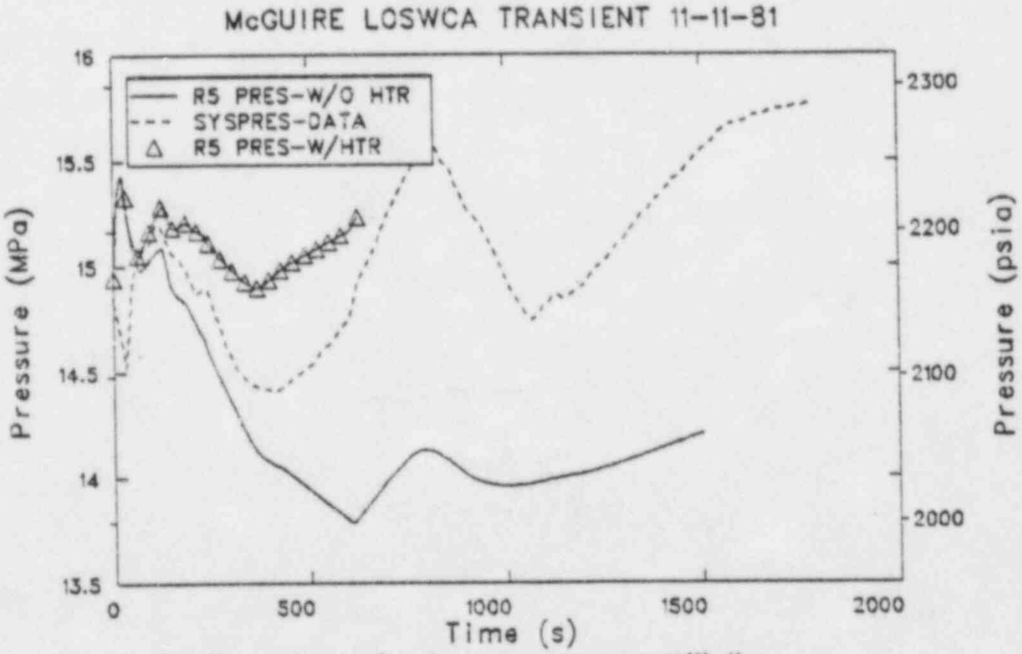

Figure 18. Comparison of primary pressure sensitivity calculations versus time.

ATTACHMENT 2

ANALYSIS OF THE NORTH ANNA, UNIT 2, NATURAL CIRCULATION VERIFICATION TEST (JULY 5, 1980)

The purpose of this interim report is to present the results of a RELAP5 analysis performed for the Office for the Analysis and Evaluation of Operational Data (AEOD) of a low power natural circulation test performed at the North Anna Power Station on July 5, 1980. The analysis was performed as part of a task aimed at studying natural circulation phenomena in nuclear steam supply systems.

North Anna, Unit 2, is a 2775 MWt, three loop Westinghouse pressurized water reactor. The plant is located in Mineral, Virginia and is owned and operated by Virginia Electric and Power Company (VEPCO). In July, 1980, as part of the low power start up tests for the unit, a series of natural circulation tests was performed. The first test of the series, designated 2-ST-8, performed on July 5, 1980, involved holding the reactor at a constant 3% power and tripping all three reactor coolant pumps simultaneously. Some 3 minutes into the test the Power Operated Relief Valve (PORV) on the pressurizer lifted unexpectedly in response to high primary system pressure. Over the next 240 s, the PORVs lifted at least 3 more times before the pressure stabilized below the setpoint. Reference 1 contains additional information about this test.

The RELAP5/MOD 1.5 computer code was used to calculate the expected plant thermal hydraulic response during the test. The model used in the analysis was a version of the model developed to study main steam line breaks at the North Anna plant (Reference 2). The original model used a dual channel vessel/core and two loops, with one model loop simulating the two unaffected plant loops. For the natural circulation calculation the vessel/core was modeled as a single channel and all 3 primary loops were modeled.

The test data available in reference 1 for comparison purposes was quite poor. The data for 2-ST-8 were available only in 12-hour plots, making the digitization of the initial 1800 s (30 min) very uncertain. Additional pressure data were provided by VEPCO (Reference 3), but were in the form of single points at staggered intervals (30 s minimum, 120 s maximum). The result is a large degree of uncertainty within the data and, therefore, with the comparisons.

For the analysis, the model was initialized at 3% power (83.25 MWt) and the transient was initiated by tripping all 3 reactor coolant pumps. The secondary pressure was controlled by time dependent pressure volumes, designed to match data measurements. The calculation was terminated after a steady natural circulation condition in the plant was established.

Figure 1 shows the comparison of calculated pressurizer pressure with the pressure data. Following the pump trip at time zero, both calculated and actual primary pressure increased rapidly to the PORV setpoint of 16.2 MPa (2350 psia) and the valve lifted at virtually the same time. Pressure behavior after this initial valve opening diverged between calculated and measured response due to the modeling of the PORV itself. In the plant the PORV blowdown allowed a decrease in pressure to its reseat value, approximately 15.4 MPa (2235 psia). Once the PORV reseated, measured pressure increased to the setpoint again and the valve reopened. This oscillation occurred at least 3 times, according to North Anna personnel, although the data would suggest the PORV cycled four times. It is worth noting that the high pressure setpoint appeared to drift downward for cycle after cycle, indicating a reseating problem with the valve or a drift due to the valve heating up. Once the PORV cycling ended, measured pressure stabilized at 15.35 MPa (2226 psia). In the RELAP5 analysis, the PORV was modeled as a trip valve, opening or closing as the pressure exceeded or dropped below the 16.2 MPa (2350 psia) setpoint. This modeling was used due to the absence of good PORV data such as pressure setpoints and blowdown characteristics. In the calculation, the PORV cycled four times before the pressure stabilized at 16.1 MPa (2335 psia). Had the actual reseating logic been available, the calculated pressure response would have been more in line with the data.

The cycling of the PORV was an unexpected event in 2-ST-8. The cause of the pressure increase was the increase in hot leg temperature and, therefore, T_{ave} due to the reduced core flow (Figure 2). With a constant power source and a constant energy removal, there were no compensating phenomena to keep the pressure down. In contrast, a reactor coolant pump trip in a plant operating at 100% power will react differently. The increase in hot leg temperatures due to low flow will attempt to pressurize the plant. However, the reduction in power caused by the resulting reactor scram will tend to decrease system pressure by lowering T_{ave}. The result is an overall decrease in pressure and no challenge to the PORVs.

Figures 3 and 4 show comparisons between calculated and measured loop hot leg temperatures and cold leg temperatures, respectively. The hot leg temperatures, both measured and calculated begin to increase immediately upon reactor coolant pump trip. The rate of increase seen in the RELAP5 curve is much faster than that in the data. There can be several reasons for this difference, all of which are based on the model used in the calculation. Information obtained on the actual plant conditions during the test is sketchy and several systems, such as the charging/letdown system, could have had an effect. These systems were not modeled. Perhaps the most significant reason would be the PORV action discussed previously. The higher system pressure, coupled with the limited depressurization provided by the model's PORV could have forced more system energy into the temperature increase. Despite the initial difference, both calculated and measured hot leg temperatures converge. Cold leg temperatures followed the controlled secondary condition, rising and falling with the secondary pressure.

Figure 5 presents the comparison of loop ΔT between the data and the calculation. The early rapid rise in calculated hot leg temperature is reflected in the rapid rise in calculated ΔT. But while the data, given the uncertainties in it, increased more slowly, the measured ΔT ultimately parallelled the calculations to within a degree or two. The turnover in the ΔT represented the establishment of a steady natural circulation flow. The calculated time to establishing this condition was between 300 and 500 seconds; the data appeared to indicate a delay in

establishment of natural circulation to 750 s, but there is a large uncertainty in this time. Of more importance, given the differences between the model and plant was that the final calculated ΔT closely matched the final measured ΔT. This agreement indicates that both the RELAP5 model and the plant reached the same natural circulation flow condition.

Figure 6 shows a comparison of the calculated loop flows as a function of time. All three loops showed a normal coastdown and a steady flow of ~256 kg/s (566 lb/s) following the establishment of natural circulation. The slight fluctuations in temperature due to the changing secondary pressure had no observable effect on natural circulation flow.

The conclusions that can be drawn from this limited analysis are:

1. The PORV opened due to an increase in system T_{ave} which occurred because of the reactor coolant pump trip. It did not represent any type of anomolous system behavior.

2. Natural circulation was established and could be confirmed by system temperature measurements.

REFERENCES

1. B. R. Sylvia ltr to H. R. Denton, "North Annal Power Station Unit 2 Lower Power Tests Report", Serial No. 648, July 22, 1980.

2. J. D. Burtt, "Audit Calculations for a Main Steam Line Break in North Anna, Unit 2 Using the RELAP5 Computer Code", EGG-NTAP-6082, November 1982.

3. W. L. Stewart ltr to H. R. Denton, "North Anna Power Station Unit No. 2 Response to the Additional Request for Information concerning Low Power Natural Circulation Testing", Serial No. 427A, August 25, 1983.

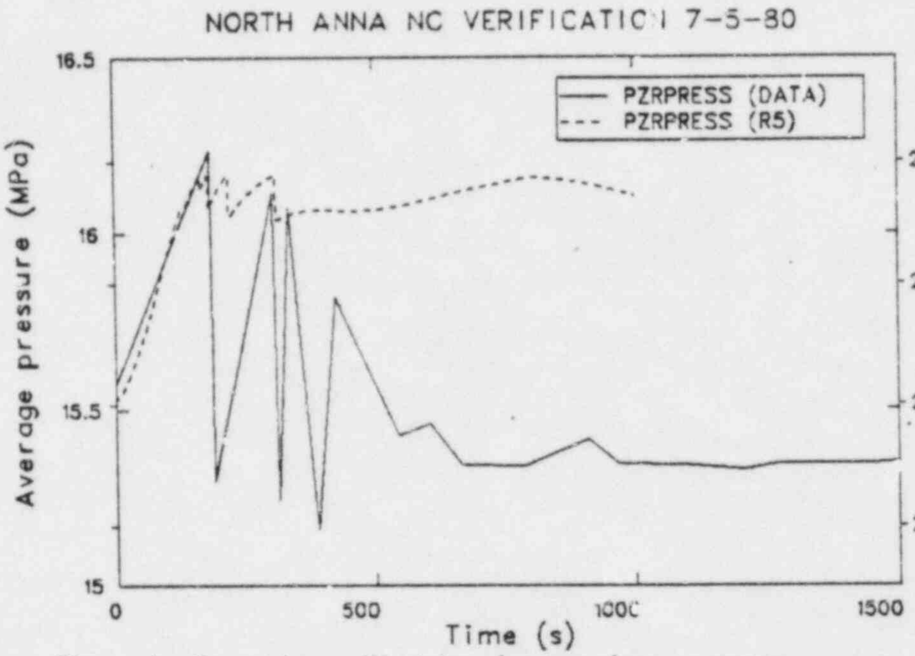

Figure 1. Comparison with data of pressurizer pressure versus time.

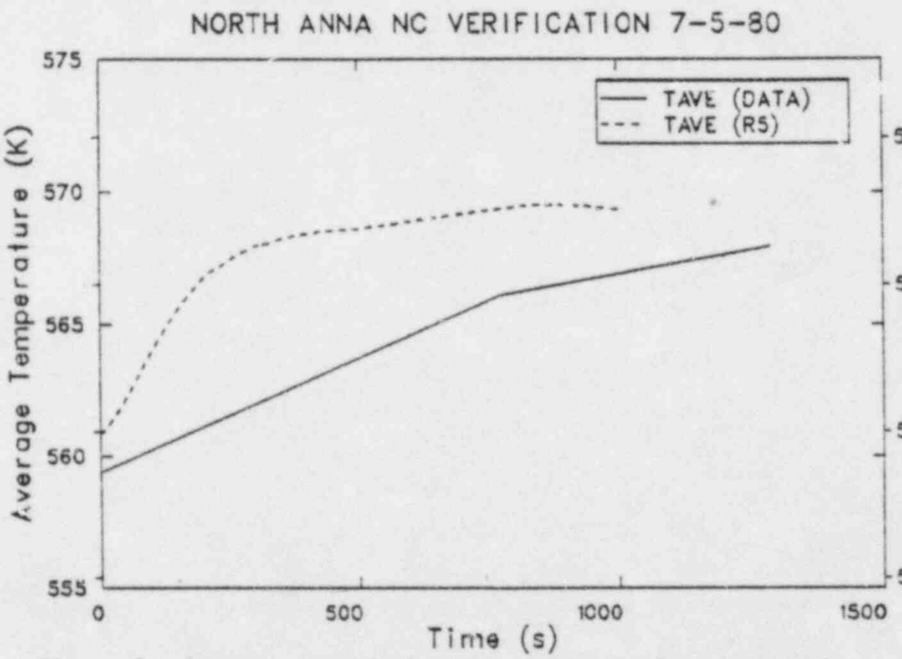

Figure 2. Comparison with data of average system temperature versus time.

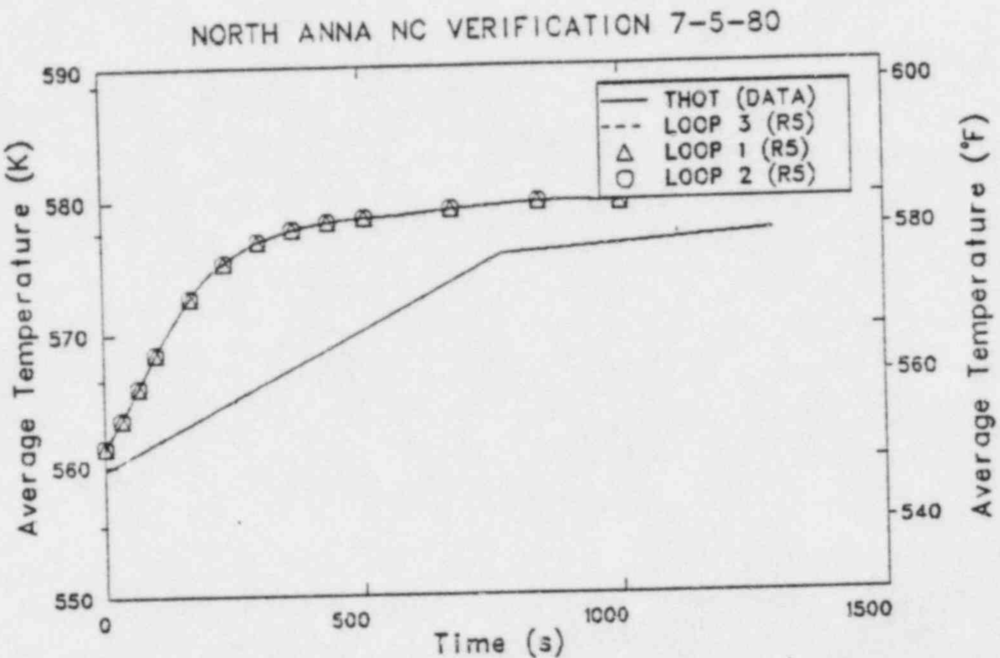

Figure 3. Comparison with data of loop hot leg temperatures versus time.

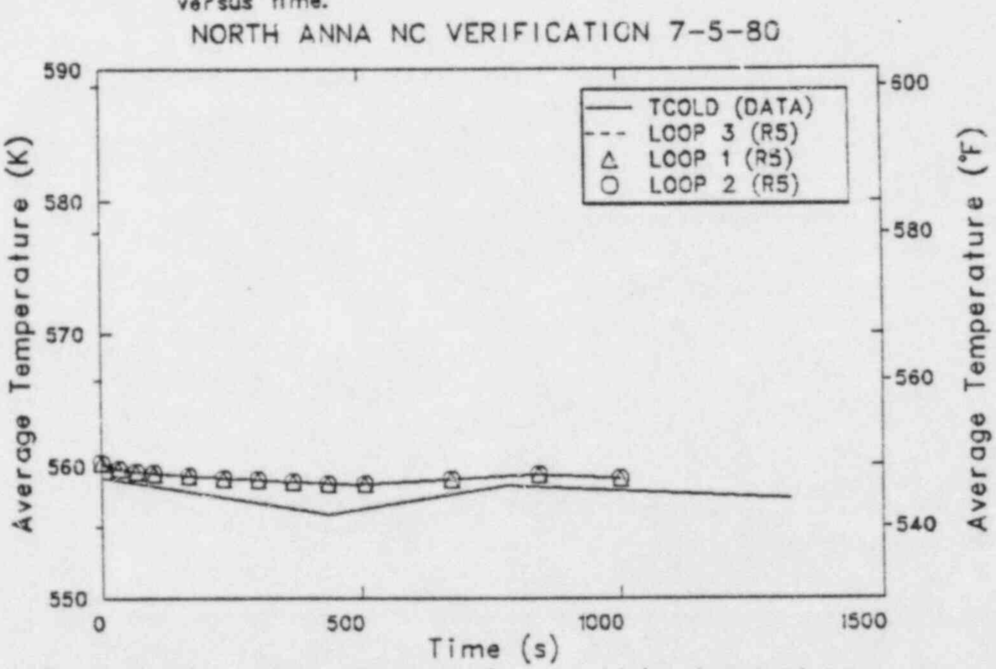

Figure 4. Comparison with data of loop cold leg temperatures versus time.

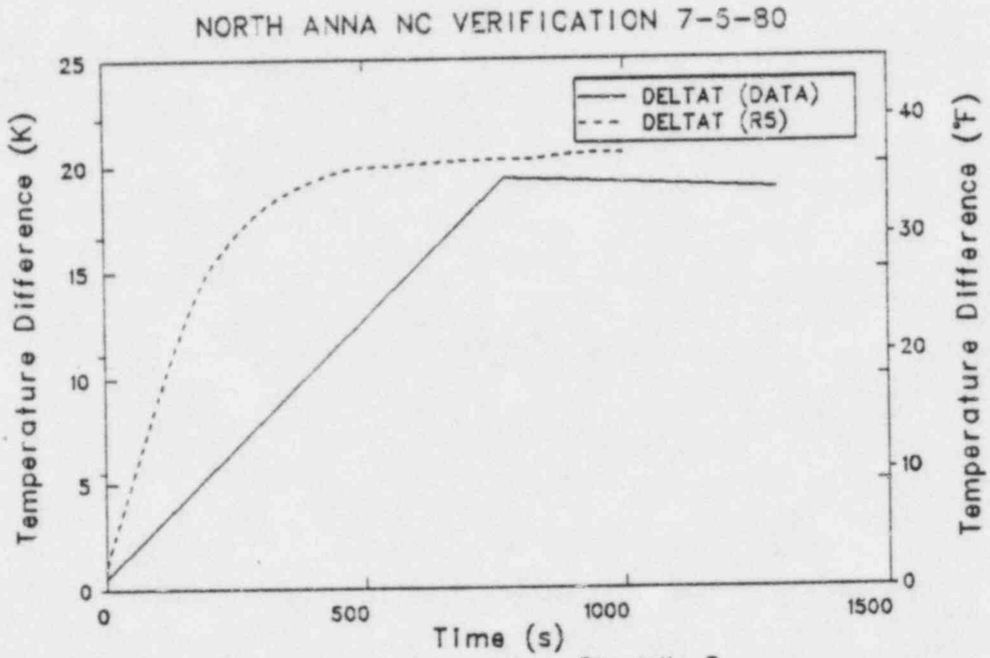

Figure 5. Comparison with data of loop 3's delta T.

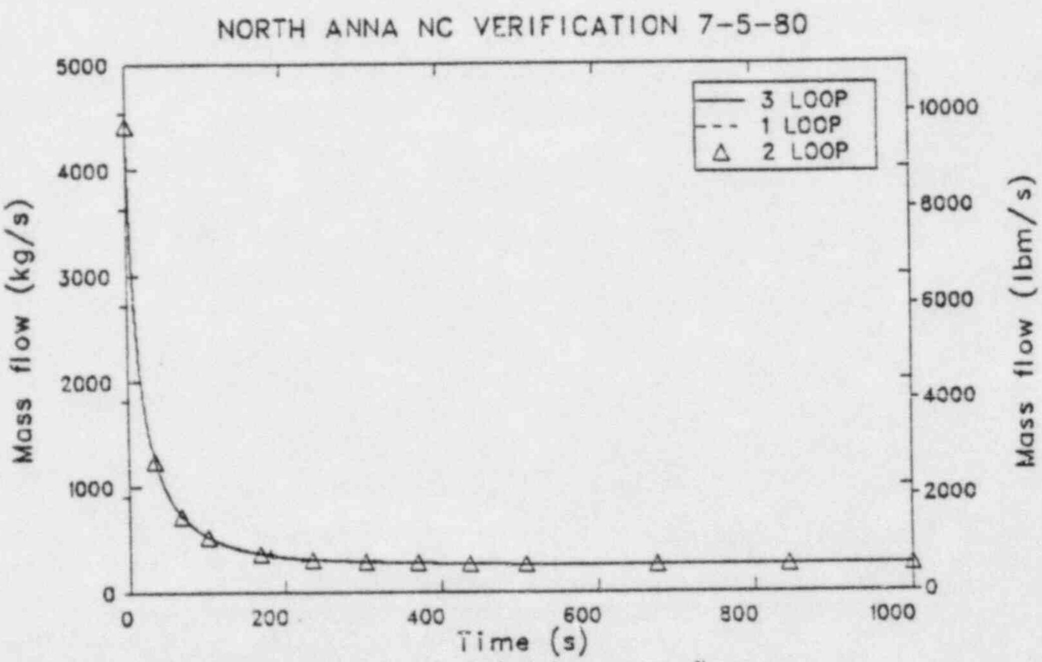

Figure 6. Comparison of calculated loop mass flows.