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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

DEC 4 1981

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 126, "BWR SMALL-BREAK TESTS"

126

References:

(1) Letter from Denton to Levine, "TLTA Small-Break Tests (RR-NRR-79-27)" November 28, 1979.
(2) W. S. Hwang, "BWR Small-Break Simulation Tests With and Without Degraded ECC Systems-BWR Blowdown/Emergency Core Cooling Program," NUREG/CR-2230, March 1981.
(3) W. S. Hwang, "Analysis of TLTA Small-Break Test Results," NEDO-24823, August 1980.
(4) R. J. Dallman and W. D. Beckner, "Analysis of TLTA Small-Break Tests and Comparison of RELAP4/MOD6 Calculations," ANS Specialists Conference on Small-Breaks in LWRs, Monterey, California, August 25-27, 1981.

This memorandum transmits the results of initial testing and analysis of boiling water reactor (BWR) small-break loss of coolant accident (LOCA) simulations in the Two-Loop Test Apparatus (TLTA). This research was conducted under the Blowdown/Emergency Core Cooling program jointly sponsored by the U.S. Nuclear Regulatory Commission (NRC), the Electric Power Research Institute and the General Electric Company (GE). This research and the conclusions contained herein were reviewed by the BWR Blowdown Heat Transfer (BDHT) Research Review Group on September 18, 1981 and the Review Group's comments are included in this summary.

Reference 1 requested that small-break loss of coolant tests be conducted in the TLTA to aid in assessing calculational techniques used to analyze BWR transients and thus serve as input to operator guidelines for transient response. Reference 1 also requested that NRC conduct blind calculations of the tests to evaluate our own calculational techniques. Separately, NRC also required BWR owners to conduct pretest predictions of the tests.

Evaluation of the TLTA capability indicated that the TLTA, designed to test large-break LOCA's, could not adequately simulate small-break LOCA's. By forcing the boundary conditions, however, it was thought that the TLTA could be made to duplicate conditions similar to those expected in a BWR during a small-break accident. These tests should not be viewed as representative of what could happen in a BWR. However, they serve the intended purpose of assessing calculational techniques.

A summary of the tests and calculations is enclosed. The test data are reported in Reference 2 and the results of the calculations are reported in References 3 and 4.

The TLTA small-break tests were successful in their goal of providing data requested by NRR for assessment of calculational techniques. Blind calculations of the tests both by GE and by NRC-developed codes have enabled us to identify areas for improvement in the modeling. Lack of modeling of a countercurrent flow limit (CCFL) at the SEO (restriction at the bottom of the bundle) has been identified as a major shortcoming of the GE calculation. While not modeling CCFL at the SEO is conservative, the calculation may be misleading since an incorrect scenario is predicted. The NRC calculation, which did model SEO CCFL, did a much better job of predicting the data trends, but illustrated generic problems with handling subcooling and problems with subcooled CCFL in particular.

Future work in this area will involve both experimental and modeling improvements. The TLTA is being upgraded to improve its ability to simulate both small-break LOCAs and other BWR transients. The BWR-TRAC code currently being developed is a nonequilibrium code and improvements in modeling CCFL have been included in the code. These improvements address the major modeling deficiencies observed. The BWR-TRAC code is currently being assessed using TLTA data and will be used for pretest predictions of the upgrade TLTA facility.

Any questions concerning this report should be directed to William Beckner (427-4260).

Robert B. Minogue

Robert B. Minogue, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Summary of TLTA Small-Break LOCA Tests and Calculations
2. Reference 4

Enclosure 1

SUMMARY OF TLTA SMALL-BREAK LOCA TESTS AND CALCULATIONS

W. D. Beckner

Summary of TLTA Small-Break LOCA Tests and Calculations

This paper summarizes the results of initial testing and analysis of boiling water reactor (BWR) small-break loss-of-coolant accident (LOCA) simulations in the Two-Loop Test Apparatus (TLTA). This research was conducted under the Blowdown/Emergency Core Cooling (BD/ECC) program jointly sponsored by the Nuclear Regulatory Commission (NRC), the Electric Power Research Institute (EPRI), and the General Electric Company (GE). This research and the conclusions contained herein were reviewed by the BWR BDHT Research Review Group on September 18, 1981, and the Review Group's comments are included in this summary.

1.0 Background

Reference 1 requested that small-break loss-of-coolant tests be conducted in the TLTA to aid in assessing calculational techniques used to analyze BWR transients and thus serve as input to operator guidelines for transient response. Reference 1 also requested that NRC conduct blind calculations of the tests to evaluate our own calculational techniques. Separately, NRC also required BWR owners to conduct pretest predictions of the tests.

Evaluation of the TLTA capability indicated that the TLTA, designed to test large-break LOCAs, could not adequately simulate small-break LOCAs. By forcing the boundary conditions, however, it was thought that the TLTA could be made to duplicate conditions similar to those expected in a BWR during a small-break accident. Typical boundary condition changes included a variable-sized break to expell excess mass initially required to obtain correct levels and a larger-than-scaled automatic depressurization system (ADS) opening to obtain a more representative depressurization and level swell. Thus, these tests should not be viewed as representative of what could happen in a BWR. They should, however, serve the intended purpose of assessing calculational techniques.

Two tests were conducted in the TLTA simulating a small (.05 ft^2) break in a recirculation line. The first test simulated conditions with all emergency core cooling (ECC) systems functioning while the second test simulated the same break but with failure of all high pressure ECC systems. In the latter test, the ADS system depressurized the vessel to allow low pressure ECC systems to refill the vessel. This test was chosen since GE licensing calculations indicate that a small break of this size with failure of high pressure ECC systems will result in core uncovery and is one of the more severe small-break LOCAs.

Pretest predictions of both tests were conducted by GE independent of the BD/ECC program on behalf of the BWR owners group. These calculations were forwarded to NRC prior to the tests and are reported in Reference 2. Calculations of the tests were also conducted for NRC by Idaho National Engineering Laboratory (INEL) using RELAP4/MOD6. These calculations were blind calculations performed before release of the data but using actual test initial conditions. Comparison of the second test calculation with the data by the NRC project manager indicated that the ADS flow rate was significantly overpredicted by the code. Thus INEL repeated the second test calculation using the measured ADS flow versus pressure as a boundary condition. The repeat calculation was still blind and contained no changes other than the ADS flow.

2.0 Results

Data from both tests are reported in Reference 3 and are available through the NRC Data Bank at INEL.

The first test with fully functioning ECC systems resulted in a slow depressurization and drop in system inventory until pressure dropped to the point where ECC flow exceeded break flow. At this point the vessel filled and the bundle was never uncovered. This test was used to evaluate how well the level in the annulus, which is measured in a BWR, represents the level in the core. Reference 2 shows that while the level in the core was not always higher than the annulus level, the difference was within the allowable error calculated by GE.

While it was expected that the second test would be more severe and result in bundle uncovery and core heat-up, this did not occur. The calculations used by GE to plan the test were similar to the licensing model calculations reported in Reference 2. This code does not model a countercurrent flow limit (CCFL) at the bundle inlet side entry orifice (SEO). During the test CCFL at the SEO played an important role in preventing fluid from draining out of the bundle and thus the bundle never uncovered. The core heat-up predicted by the GE calculation did not occur during the test.

An independent analysis of the test data and of the INEL RELAP4/MOD6 calculation was performed by NRC and INEL staff and is reported in Reference 4 (attached). The major shortcoming of the RELAP4/MOD6 calculation of the first test is generic and is associated with a combination of coarse noding and the equilibrium nature of the code. The calculated depressurization rate shown in Figure 1 shows a discontinuity at 250 seconds as the level in the upper plenum approached the boundary of a node with ECC injection and allowed ECC fluid to condense steam. The coarse noding and problems with the equilibrium nature of the code also prevented draining of subcooled upper plenum fluid and thus resulted in a calculated upper plenum mass that was too high, as shown in Figure 2. This problem has been previously observed in large-break LOCA calculations.

Figure 3 illustrates some of the complex behavior observed in the lower plenum (LP) during the second test. At 286 seconds, the rapid depressurization caused by ADS opening caused LP and bundle liquid to swell into the upper plenum. The LP remained partially empty because CCFL at the SEO prevented draining of liquid back into the LP and a two-phase mixture remained in the bundle to keep it well cooled. At 550 seconds, CCFL above the bundle broke down and allowed accumulating ECC liquid in the upper plenum to fill the bundle. The resulting increase in hydrostatic head in the bundle forced LP liquid out of the jet pumps and depressed the LP level to the jet pump exit. At 610 seconds, CCFL at the SEO broke down and the LP refilled. These results show the importance of CCFL at the SEO in determining the course of the BWR small-break LOCA.

The repeat RELAP4/MOD6 calculation of the second test generally predicted the trends of the test well. Figure 3 also shows the calculated mass distribution. The complex behavior of the mass distribution is predicted but the timing is off. CCFL above the bundle breaks down too early and the timing of the resulting LP level depression and refill is off. Thus subcooled breakdown of CCFL is identified as an area where improved modeling is necessary.

3.0 Evaluation

The TLTA small-break tests were successful in their goal of providing data requested by NRR for assessment of calculational techniques. Blind calculations of the tests both by GE and by NRC developed codes that have enabled us to identify areas for improvement in the modeling. Lack of modeling of CCFL at the SEO has been identified as a major shortcoming of the GE calculation. While not modeling CCFL at the SEO is conservative, the calculation may be misleading since an incorrect scenario is predicted. The INEL calculation, which did model SEO CCFL, did a much better job of predicting the data trends but illustrated generic problems with handling subcooling and problems with subcooled CCFL in particular.

In addition to the TLTA scaling problems previously identified, one should remember that the TLTA is a single channel facility. Recent tests from the BWR 30° Steam Sector Test Facility (SSTF) have shown significant multichannel and multidimensional influences on CCFL behavior. Most, but not all, of these effects identified from SSTF tests appear to be beneficial. Therefore, we recommend that prior to either assuming that a model or computer code calculation is representative of a BWR transient or modifying evaluation models, the models should be assessed using both integral data from TLTA and SSTF separate effects data.

4.0 Future Research

Future work in this area will involve both experimental and modeling improvements. The TLTA is being upgraded to improve its ability to simulate both small-break LOCAs and other BWR transients. The BWR-TRAC code currently being developed is a nonequilibrium code and improvements in modeling CCFL have been included in the code. These improvements address the major modeling deficiencies observed. The BWR-TRAC code is currently being assessed using both TLTA and SSTF data and will be used for pretest predictions of the upgrade TLTA facility.

Any questions concerning this report should be directed to William Beckner (427-4260).

REFERENCES

1. Letter from Denton to Levine, "TLTA Small Break Tests (RR-NRR-79-27)," November 28, 1979.

2. W. S. Hwang, "Analysis of TLTA Small Break Test Results," NEDO-24823, August 1980.

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4. R. J. Dallman and W. D. Beckner, "Analysis of TLTA Small Break Tests and Comparison of RELAP4/MOD6 Calculations," ANS Specialists Conference on Small Breaks in LWRs, Monterey, California, August 25-27, 1981.

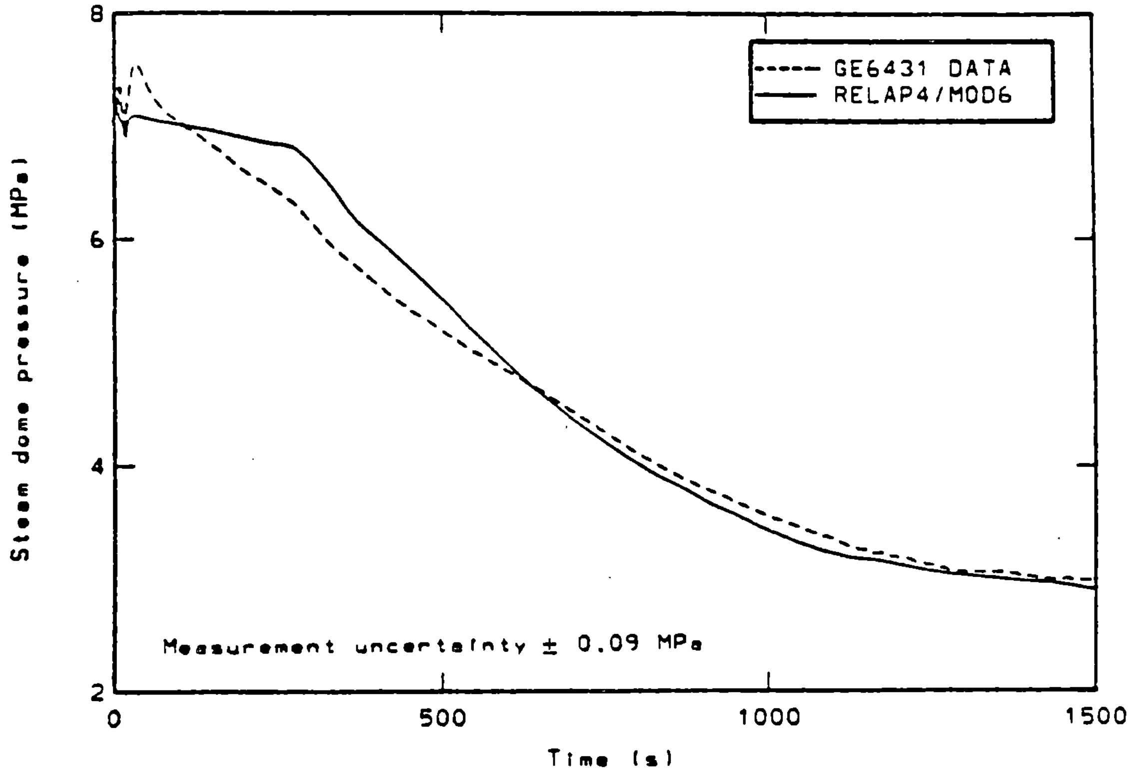

Figure 1 Test 6431 system pressure response.

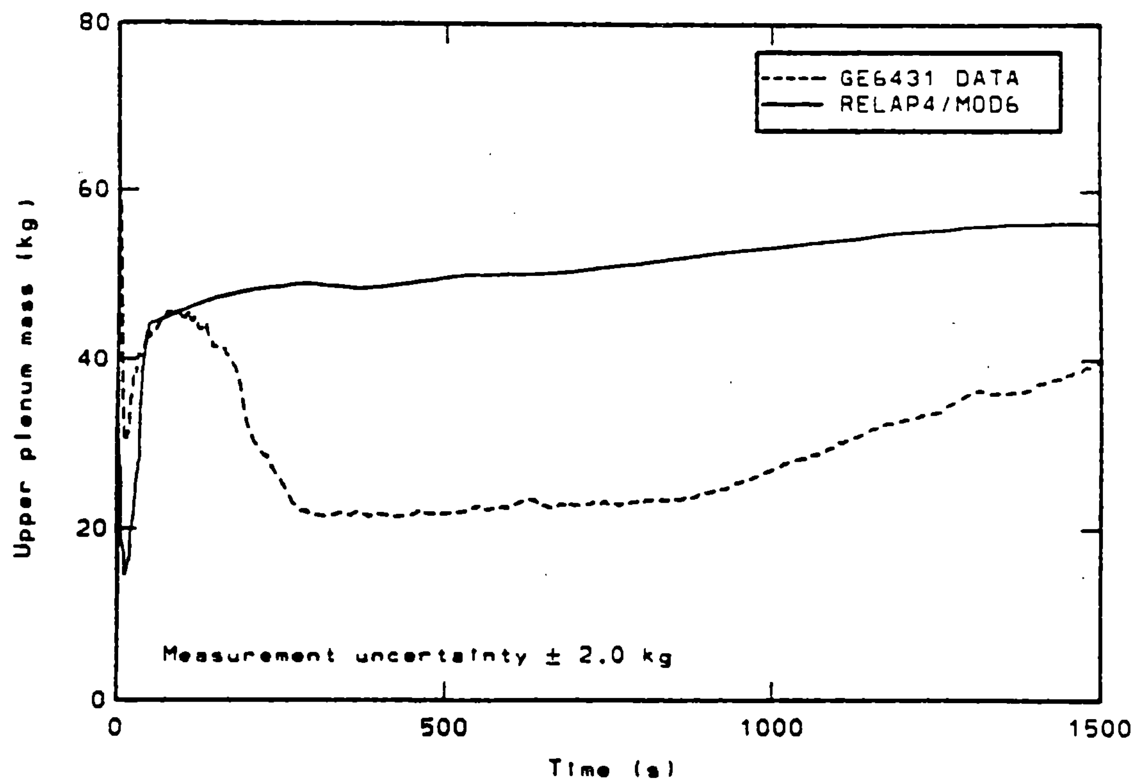

Figure 2 Test 6431 upper plenum mass.

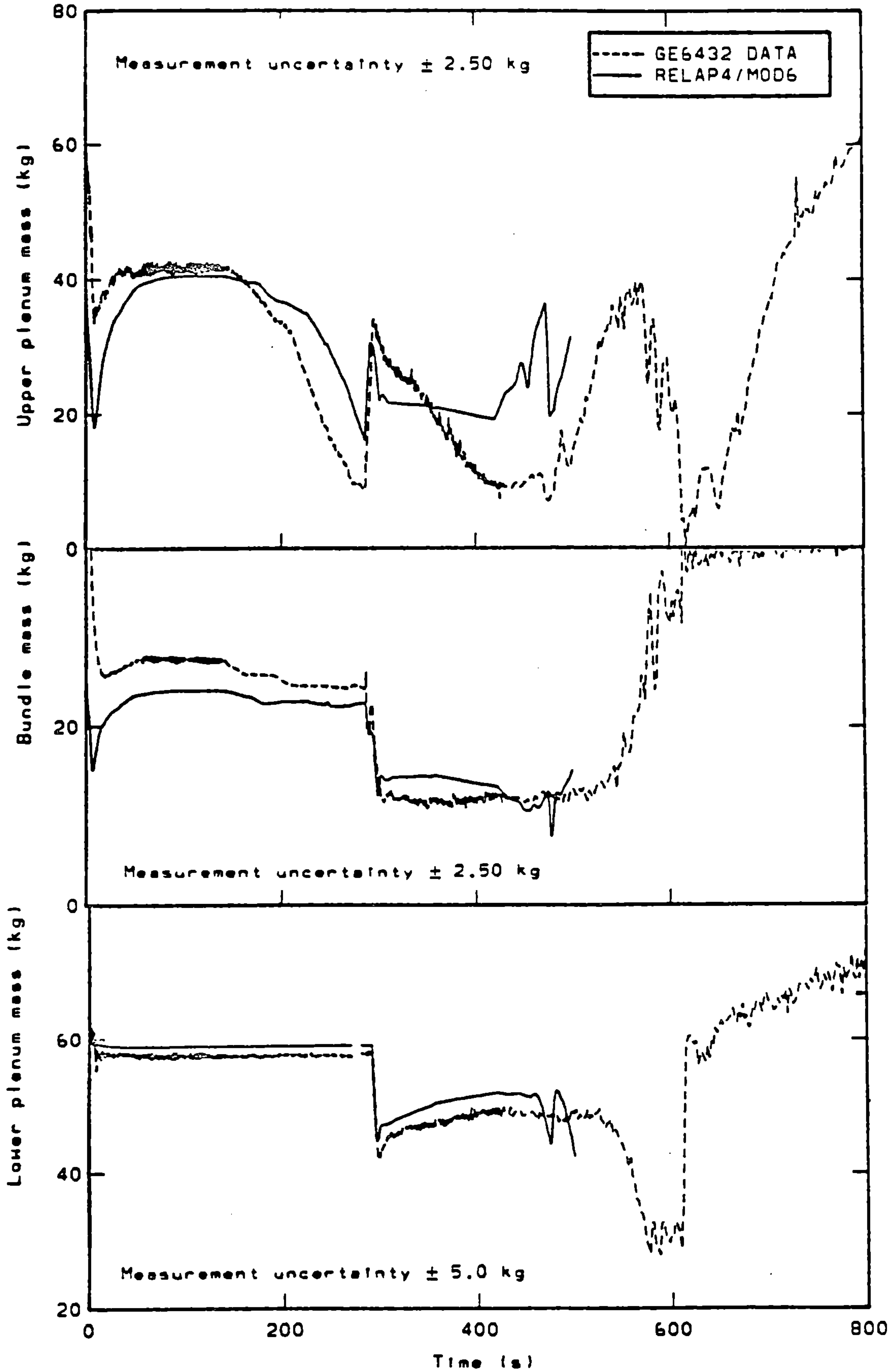

Figure 3 Test 6432

Enclosure 2

ANALYSIS OF TLTA SMALL BREAK TESTS AND COMPARISONS TO RELAP4/MOD6 CALCULATIONS

by

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ANALYSIS OF TLTA SMALL BREAK TESTS AND COMPARISONS TO RELAP4/MOD6 CALCULATIONS

Introduction

Following the Three Mile Island Unit 2 (TMI-2) accident, the TMI-2 Lessons Learned Task Force identified the need for improved operator response to potential accidents and transients.[1] The task force recommended that the analysis methods used to specify operator actions be verified by comparisons with test data. The General Electric (GE) Operating Plants Owner's Group elected to use data from the Two-Loop Test Apparatus (TLTA) to verify boiling water reactor (BWR) analysis methods. This facility is operated within the BWR Blowdown/Emergency Core Cooling (BD/ECC) Program[2] under joint sponsorship of the United States Nuclear Regulatory Commission (USNRC), Electric Power Research Institute (EPRI) and GE.

Two small break experiments were conducted in the TLTA; the first (Test 6431) with simulated high pressure core spray (HPCS), the second (Test 6432) with simulated low pressure core spray (LPCS) and low pressure coolant injection (LPCI). Blind calculations (using actual initial conditions) were performed at the Idaho National Engineering Laboratory (INEL) using the RELAP4/MOD6 computer code.[3] This paper summarizes the results from these two experiments and compares data to the code calculations. Special modeling requirements are identified, and conclusions are made concerning the capabilities of RELAP4/MOD6 to accurately predict BWR small break transient response.

Test Facility Description

The TLTA is operated by GE in San Jose, California, and it is described in detail in Reference 2. The facility is scaled to the 218-BWR/6 624-bundle reactor[a] and is shown schematically in Figure 1. Two recirculation loops with jet pumps are provided, one simulating the intact loop, and the other simulating the broken loop in a recirculation line break. The core simulator is a single, full length, 8 x 8 electrically heated bundle.

Because the TLTA was originally designed for large break loss-of-coolant experiments (LOCEs), several deficiencies existed for small break LOCEs. Feedwater and heat rejection were limited and did not allow steady state full power initial conditions. System leakage and ambient heat loss could be significant for small breaks. The annulus area was too large and resulted in excess system mass if the annulus level was correct.

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a. The 218 designation represents a pressure vessel nominal inside diameter of 5.54 m (218 in.).

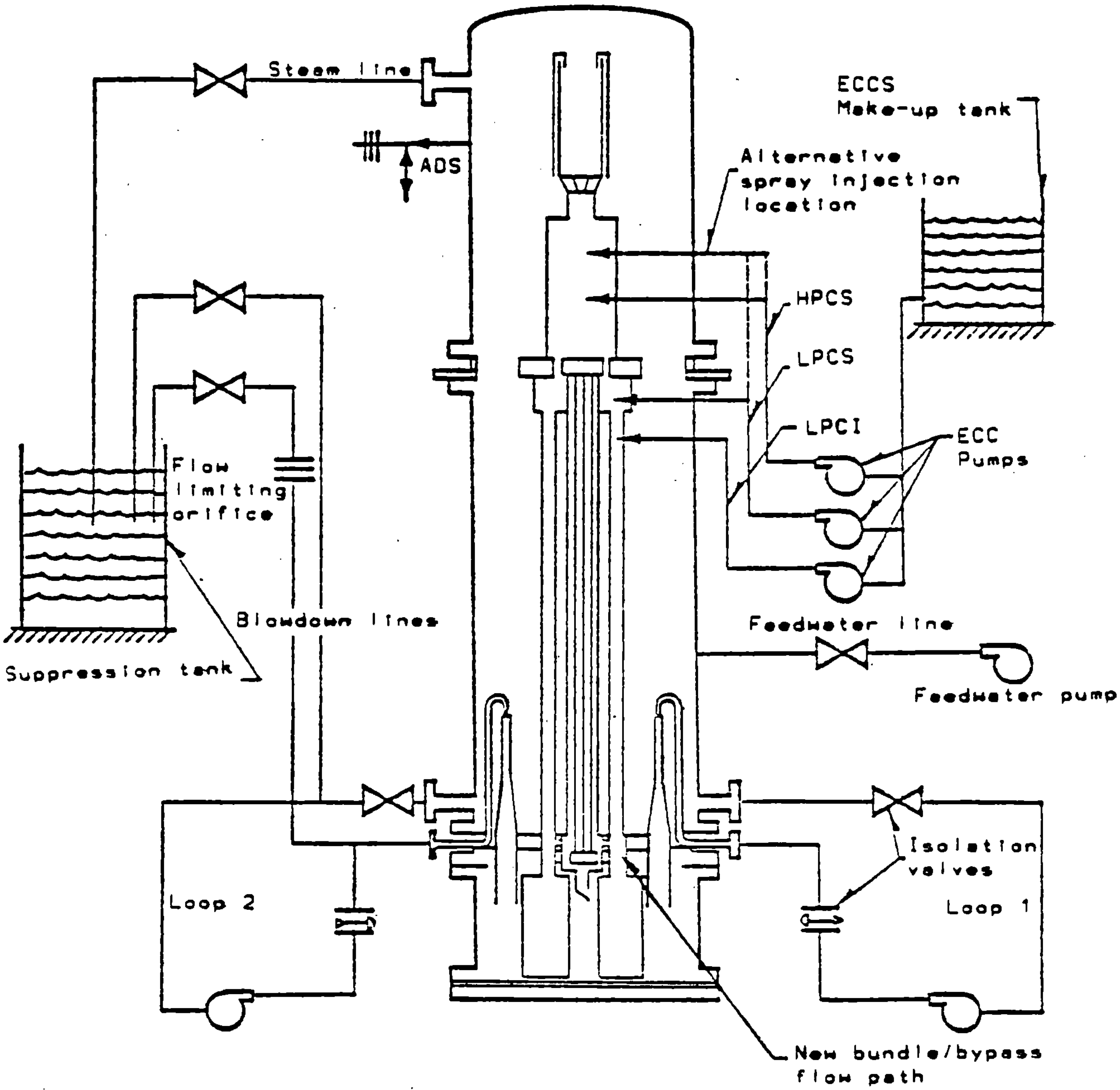

Figure 1. Two-Loop Test Apparatus schematic.

The lower plenum was too short and this would result in too little level swell through the bundle during rapid depressurizations. It was determined, however, that by adjusting boundary conditions, the TLTA could be induced to follow a scenario similar to that expected in a BWR.

Test 6431 Description and Results

TLTA Test 6431[4] simulated a small (scaled from 0.0046 m^2) break of one recirculation line suction with all emergency core cooling (ECC) systems functioning. The test was conducted at an initial power level of 2.07 MW to allow steady state initial conditions as shown in Table 1. The power was held constant until approximately 7 s. It was then tripped and followed a typical average power decay curve. Since this break was within the capabilities of the HPCS, the water level remained well above the bundle and recovered as the vessel slowly depressurized. LPCS and LPCI systems did not inject, and the automatic depressurization system (ADS) was not activated.

RELAP4/MOD6 has demonstrated the ability to adequately predict TLTA system behavior during large break LOCEs. Based on this success, a model similar to those used for large break calculations[5] was employed to predict Test 6431. A system nodalization diagram is shown in Figure 2. Heat loss from the system was modeled by exposing Heat Slabs 27 through 33 to constant ambient sink conditions on one side. These conditions were set to obtain an initial heat loss of approximately 50 KW, based on calibration tests performed by GE.

Early system pressure response is shown in Figure 3. The test data show an initial pressure increase due to the loss of cold feedwater, followed by a pressure decrease when the power decay started. At 17 s a pressure increase was initiated as the steamline was isolated and continued until HPCS injection at 27 s terminated the pressure rise. During the test, liquid in the upper part of the annulus was heated due to the loss of feedwater and steamline isolation, which resulted in the production of steam and pressure increases. Liquid in the lower part of the annulus remained subcooled. In the calculation, the steam dome and annulus above the feedwater inlet were modeled as one volume. Due to the equilibrium character of the code, this volume contained a two-phase mixture at uniform temperature. Thus, stored energy was used primarily to heat the liquid and produced less steam than in the test. Consequently, the early pressure rises were not as large in the calculation.

Subsequent system pressure response (Figure 4) is governed mainly by the relative magnitudes of break flow and HPCS injection. The calculation did not follow the rapid depressurization of the data until approximately 270 s. At this time, the calculated depressurization experienced a slope change and then approached the data. This is attributed to an increased rate of steam condensation in the upper plenum, which was modeled as a single, homogeneous volume. A homogeneous volume is calculated by the code to be full of a single fluid phase or a two-phase mixture at uniform pressure and temperature. Subcooled liquid and steam cannot exist at the

TABLE 1. TEST CONDITIONS FOR TLTA SMALL BREAK TESTS

	Test 6431	Test 6432
Break size		
Line No. 1	0.318 ± 0.003 cm dia.	0.318 ± 0.003 cm dia.
Line No. 2	N/A	0.389 ± 0.003 cm dia.
ADS orifice size	N/A	1.720 ± 0.003 cm dia.
ECCS		
Inlet fluid temperature	302 ± 2 K	305 ± 2 K
HPCS	Activated	Deactivated
LPCS	Deactivated	Activated
LPCI	Deactivated	Activated
Initial conditions		
Steam dome pressure	7.18 ± 0.03 MPa	7.23 ± 0.03 MPa
Annulus water level	7.19 ± 0.08 m	7.19 ± 0.08 m
Bundle flow	20 ± 2 Kg/s	15 ± 2 Kg/s
Bypass flow (total)	0.9 ± 0.2 Kg/s	1.0 ± 0.2 Kg/s
Steamline flow	1.1 ± 0.2 Kg/s	0.7 ± 0.2 Kg/s
Bundle inlet subcooling	9 ± 2 K	12 ± 2 K
Annulus temperature		
Above feedwater sparger	562 ± 2 K	563 ± 2 K
Below feedwater sparger	555 ± 2 K	551 ± 2 K
Timings		
Pump No. 1 trip	0.0 ± 0.1 s	0.0 ± 0.1 s
Pump No. 2 trip	4.0 ± 0.2 s	4.0 ± 0.2 s
Feedwater trip	0.0 ± 0.5 s	0.1 ± 0.5 s
Break open line No. 1	-0.9 ± 0.5 s	t ≥138 ± 1 s
Break open line No. 2	N/A	138 <t< 286 ± 1 s
ADS opening	N/A	286 ± 1 s
Steamline valve closure	16.6 ± 0.5 s	165 ± 1 s
ECCS activated	26.8 ± 0.5 s	37 ± 1 s
Recirculation line No. 1 (intact) isolation	19.6 ± 0.5 s	20 ± 0.5 s

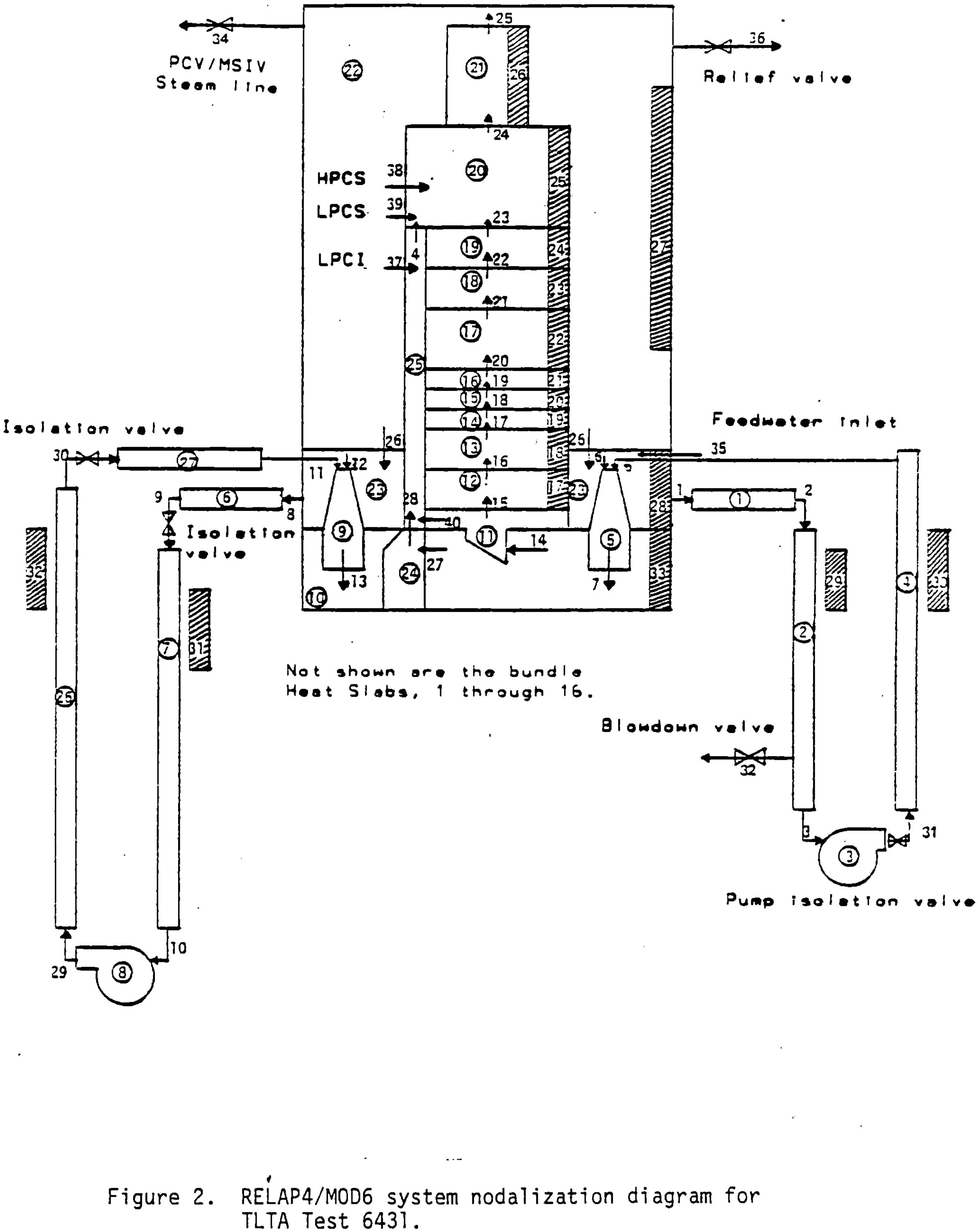

Figure 2. RELAP4/MOD6 system nodalization diagram for TLTA Test 6431.

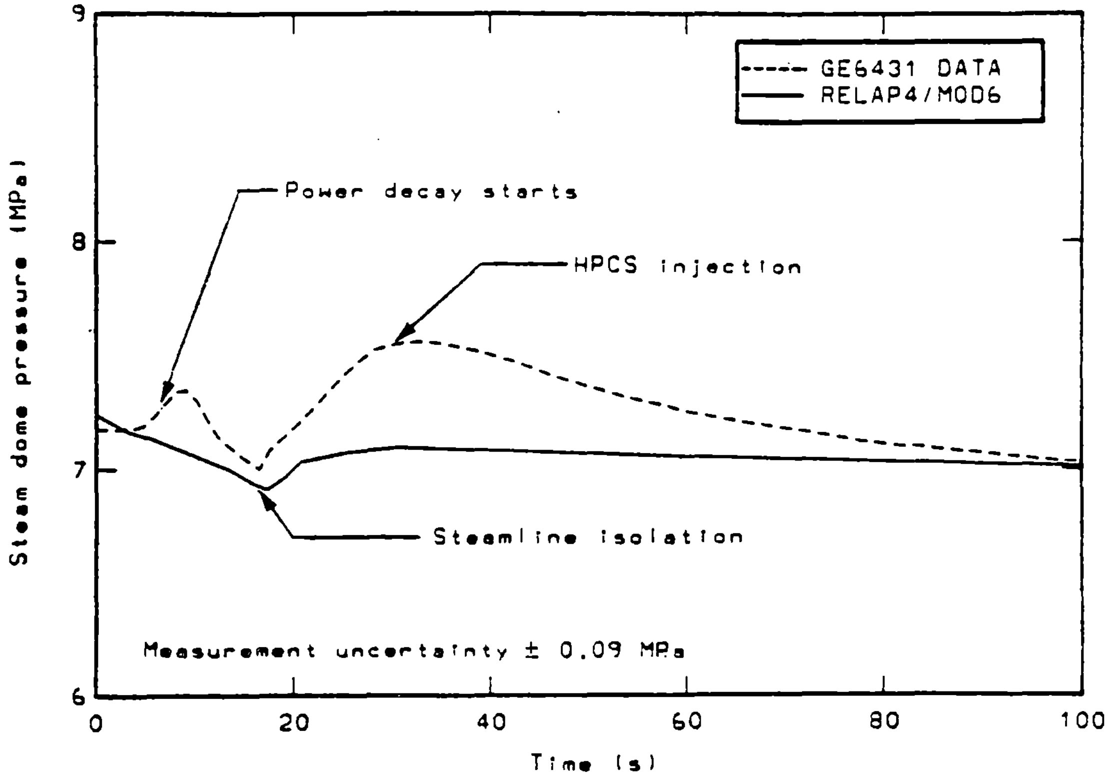

Figure 3. Test 6431 early system pressure response.

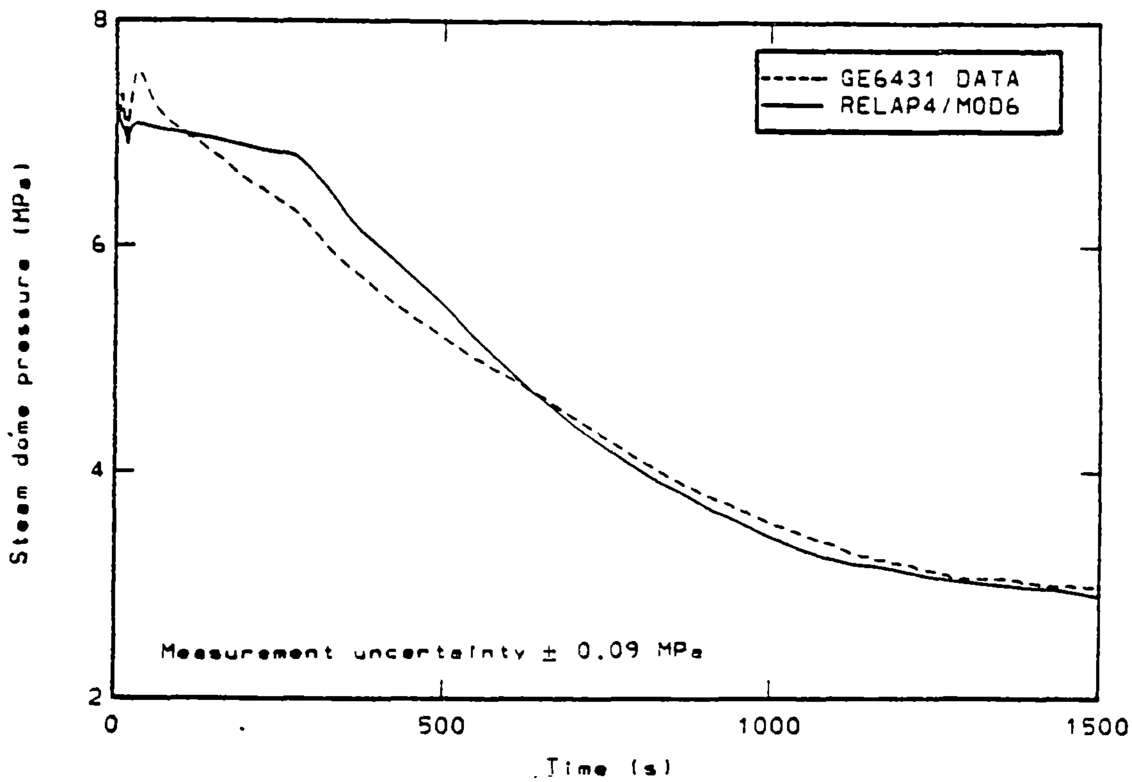

Figure 4. Test 6431 system pressure response.

same time. At 270 s the two-phase mixture in the steam separator dropped to the very top of the upper plenum, allowing steam to enter from the steam dome and be condensed. The upper plenum remained full of subcooled liquid for the remainder of the calculation.

Break flow in the test was strongly influenced by small amounts of vessel subcooling due to the geometry of the break. The break consisted of a long 1.27-cm break line between the recirculation line and an orifice at which critical flow occurred. Saturated vessel conditions would allow flashing to occur in the break line due to pressure loss. However, a small amount of subcooling in the vessel would allow single-phase liquid to reach the orifice. Figure 5 indicates that the break flow increased by 25% between 600 and 750 s. This corresponds to an increase in subcooling near the break line of 0 to 2 K. Further increases in subcooling showed little effect on break flow. The calculation did not model the break line upstream of the orifice and thus could not predict this sensitivity to small amounts of subcooling. Since the calculated break flow unchoked shortly after 1500 s, comparisons of all data and calculational results were terminated at that time.

Figure 6 shows that ECC injection was underpredicted early in the transient due to an overprediction of pressure (Figure 4). However, this underpredicted HPCS flow was offset by the low calculated break flow and, therefore, the total calculated system mass closely matched the test data.

While the calculated total mass was in good agreement with data, too much was calculated to remain in the upper plenum (Figure 7), resulting in too little calculated mass in the downcomer. As mentioned before, in the calculation the upper plenum remained full of subcooled water. This cold fluid in the upper plenum was calculated to flow down the bypass. In the lower bypass the flow split, with part of the liquid continuing downward through the guide tubes and into the lower plenum, and approximately two-thirds entering the lower bundle through the leakage holes. The liquid entering the bundle further split, with some going into the lower plenum and the rest proceeding upward through the bundle. The liquid flowing up the bundle was heated to produce a low quality mixture entering the upper plenum. A calculated natural circulation path was thus completed.

The internal flow path in the test was quite different from the calculated scenario described above. Initially, flow was upward in the bundle and downward in the bypass. At aproximately 175 s, countercurrent flow limiting (CCFL) at the top of the bundle broke down due to increased subcooling in the upper plenum. This CCFL breakdown rapidly subcooled the entire bundle as evidenced by heater rod thermocouples. At this time the bypass fluid was saturated, and this resulted in a driving head in the bundle that reversed flow in the bypass by communication through the leakage holes. Once the flow is upward in the bypass and downward in the bundle, the bypass will always be warmer than the bundle since all fluid entering the bypass must first pass through the bundle. Thus, this "reverse natural circulation" path was maintained.

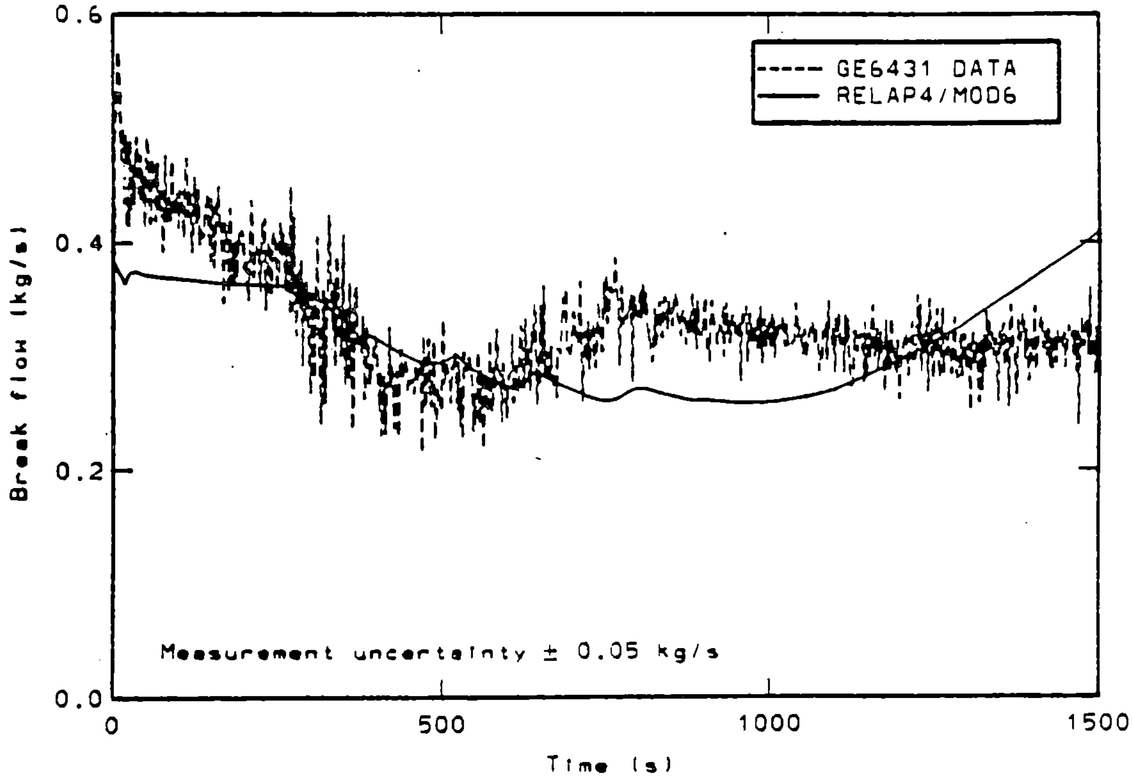

Figure 5. Test 6431 break flow.

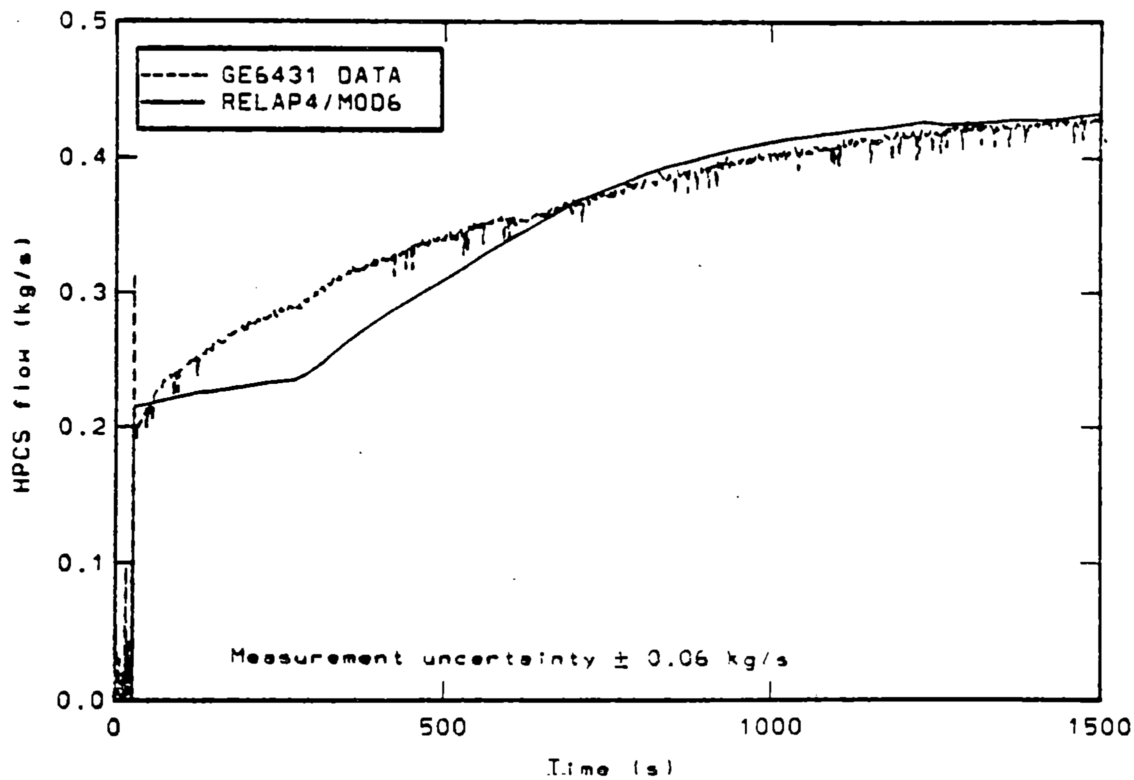

Figure 6. Test 6431 HPCS flow.

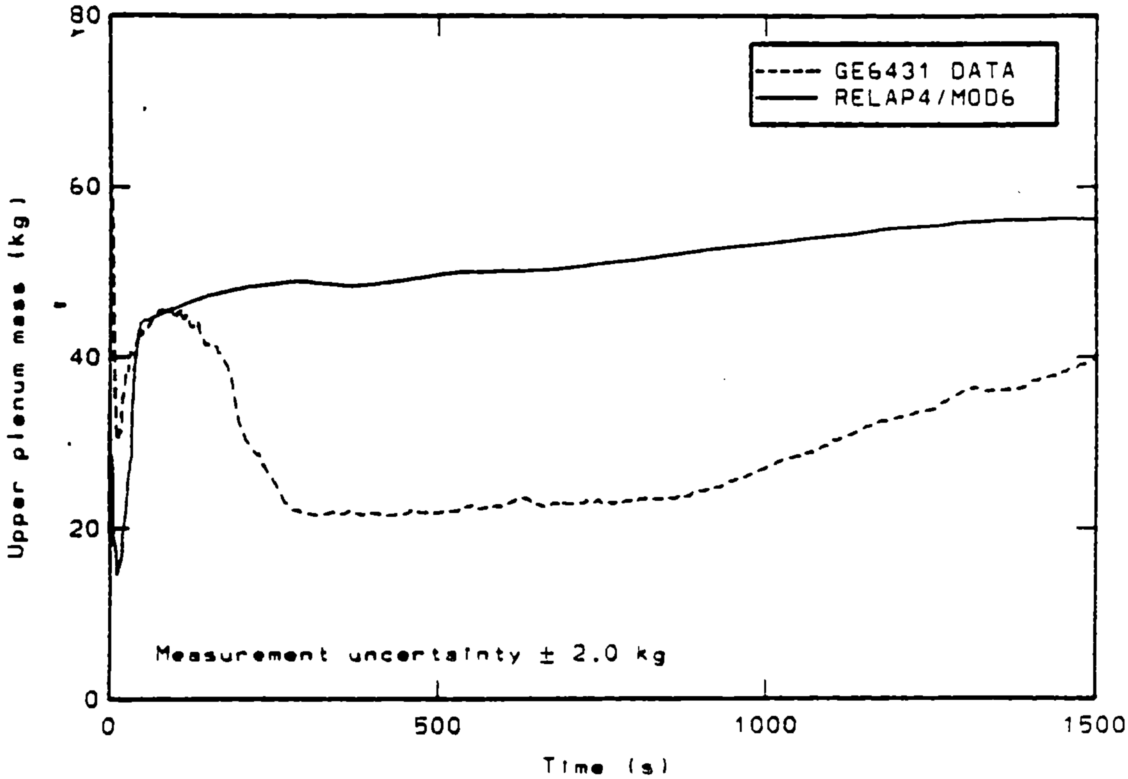

Figure 7. Test 6431 upper plenum mass.

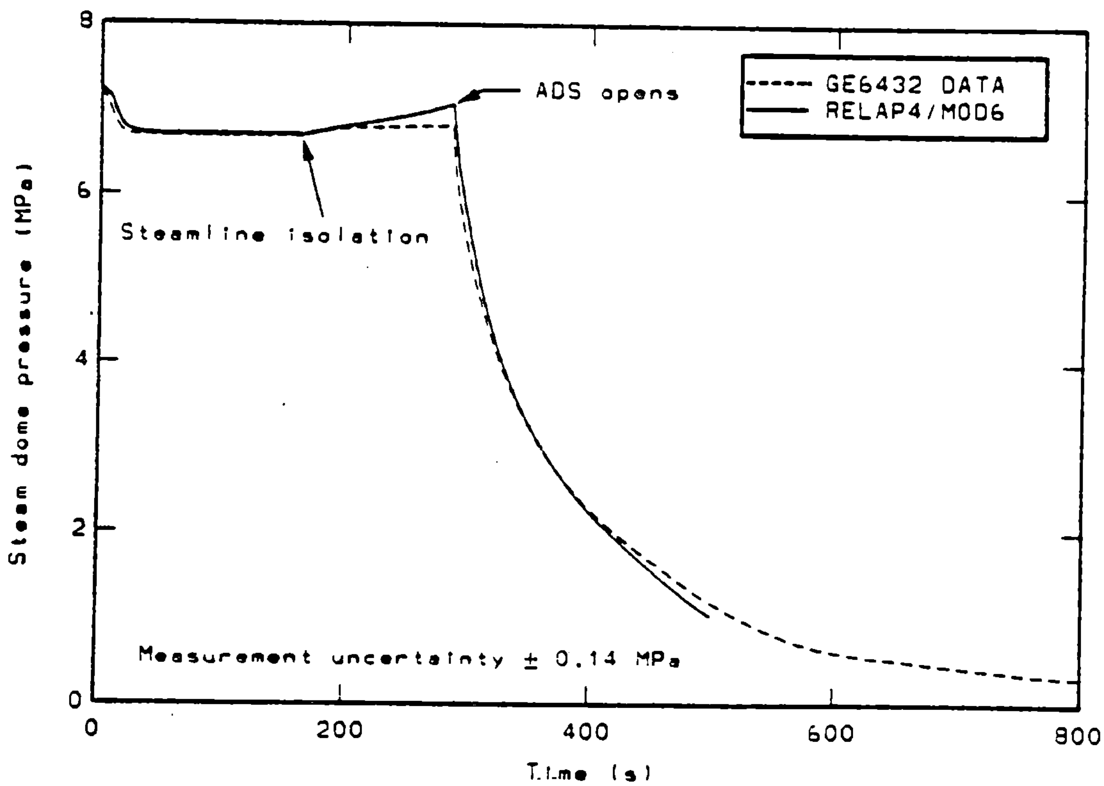

Figure 8. Test 6432 system pressure response.

In the calculation, the vertical slip model was used at the top of the bundle in an attempt to get liquid penetration from the upper plenum. Using default values this proved unsuccessful. Calculated slip velocities were too low to allow liquid downflow at the bundle exit. The heater rods, however, were well cooled throughout the calculation due to the positive core flow. No rod heatup occurred in the calculation or the test.

Test 6432 Description and Results

TLTA Test 6432[4] also simulated a small break of one recirculation line suction. It was conducted under the degraded condition of a failed HPCS system. The remaining ECC systems (LPCS, LPCI and ADS) were operable. Initial conditions for this test are shown in Table 1. In this test, a second break line, which was open for part of the transient, was used to remove excess mass from the downcomer. This second break would reduce inventory in the downcomer that could eventually lead to partial uncovery of the bundle. In this test, however, CCFL at the side entry orifice kept inventory in the bundle and no rod heatup occurred.

Based on results from the Test 6431 calculation, several changes were made to the RELAP4/MOD6 system model. The break lines between the recirculation line and the break orifices were modeled in an attempt to predict subcooling effects on break flow. To calculate more realistic steam condensation in the upper plenum, it was renodalized into two volumes as was the steam separator. Phase separation was used in the steam separator, upper plenum, and bundle to permit mixture level tracking. This also allowed a mixture level to fall into the upper plenum rather than stay at the steam separator interface as happened in Test 6431. Finally, a multiplier was applied to the vertical slip option at the bundle exit to allow more liquid penetration from the upper plenum. This was set such that the calculated slip velocity would be multiplied by a factor of two.

Due to the nature of the steamline flow control (programmed flow for the first 35 s, then pressure controlled until 165 s), three junctions were required to model steam flow. For the first 35 s steam flow was input as a time-dependent boundary condition. From 35 to 165 s a flow versus pressure boundary condition was input to maintain a constant pressure of approximately 6.7 MPa. The ADS, which opened at 286 s, was originally modeled with a critical flow calculation. This greatly underpredicted the ADS flow, and consequently, a flow versus pressure boundary condition was utilized from the actual data.

Changes made to the code model resulted in improvements of predicted system response, however, they also contributed to calculational difficulties. The lower volume in the upper plenum filled with subcooled liquid at about 500 s due to increased LPCS injection. When the mixture level passed through the top of this volume, pressure spikes and flow oscillations occurred. This was caused by the inability of the code to correctly calculate the interaction of subcooled water with saturated steam. Thus, the calculation was terminated at 500 s.

System pressure response is shown in Figure 8. The calculated pressure is higher than the data after 200 s, due to underpredicted break flow as shown in Figure 9. After 400 s the calculated pressure drops slightly below the data, resulting in early calculated ECC initiation (Figure 10). Figure 11 indicates good agreement with steamline flow as expected, since this was a flow versus pressure boundary condition.

A comparison of total vessel mass is shown in Figure 12. The calculation shows a slower decrease in mass from 140 to 286 s that is consistent in magnitude with the integrated break flow error and the experimental mass balance difference shown in Figure 13. The figure compares vessel mass calculated from differential pressure strings with that calculated from the net integrated boundary flows. The mass balance deviates significantly after ADS opening by an amount similar to the recirculation line mass. This is illustrated by Figure 14 that shows the calculated liquid mass in the unisolated portions of the recirculation lines. At ADS opening, the calculation indicates that flashing transfers mass from the recirculation lines into the vessel. It is thought that this same phenomenon occurred in the test, but over a longer period of time.

The distribution of mass is shown in Figures 15 through 19. Comparisons of mass over approximately the first 50 s should be ignored since significant flow effects distort the derived mass measurements in the test. Up to ADS opening, mass distribution calculations are good. The upper plenum (Figure 15) and annulus (Figure 16) show too slow a decrease in the calculated mass by an amount consistent with the underpredicted break flow. After ADS opening fluid is expelled from the lower plenum, bundle, bypass and recirculation lines into the upper plenum and annulus. The decrease in lower plenum mass (Figure 17) and bundle mass (Figure 18) is well predicted.

After ADS opening and ECC injection, the calculated system mass distribution is qualitatively similar to the data but differs in timing and magnitude. The data show a draining of the upper plenum after ADS opening until about 450 s when ECC fluid rapidly fills the bypass and starts to fill the upper plenum. Increasing vertical slip at the top of the bundle allowed some liquid drainage from the upper plenum. However, this was still less than that indicated by the data. The liquid that did drain into the bundle was adequate to keep the rods cooled, and no heatup occurred in the calculation.

At approximately 525 to 550 s, the data show that CCFL at the upper tieplate breaks down and starts to fill the bundle. This filling reduces steam flow into the bundle from the lower plenum. Increased hydrostatic head in the bundle and upper plenum caused fluid to leave the lower plenum through the jet pumps. At approximately 575 s the mixture level in the lower plenum reached the jet pump exits. At 610 s CCFL at the side entry orifice breaks down and fills the lower plenum. This breakdown was caused by the venting of lower plenum steam through the jet pumps and increasing liquid subcooling in the bundle just above the side entry orifice. It

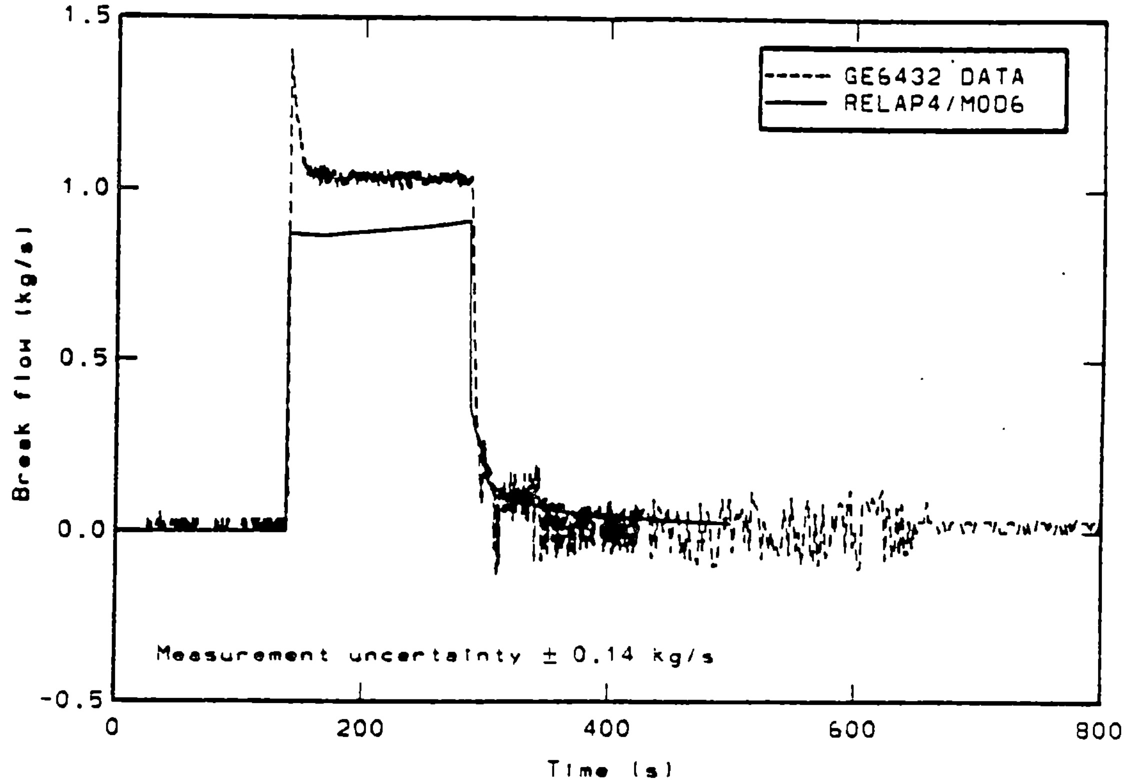

Figure 9. Test 6432 break flow.

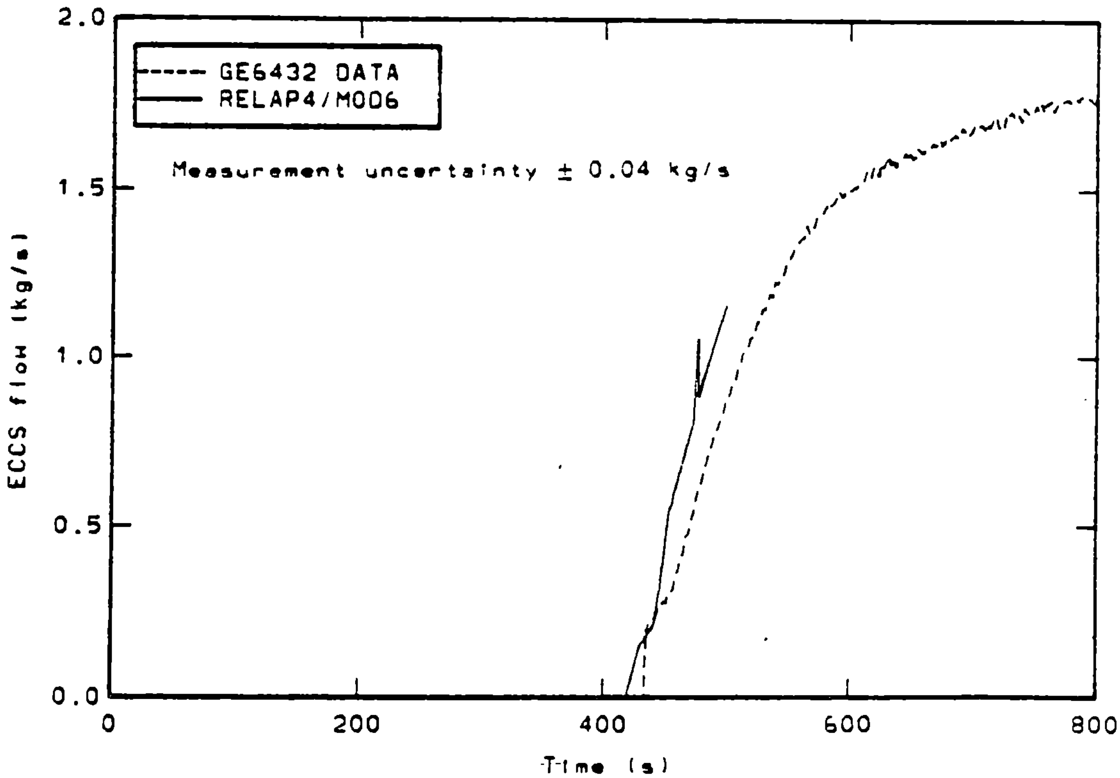

Figure 10. Test 6432 LPCS and LPCI flows.

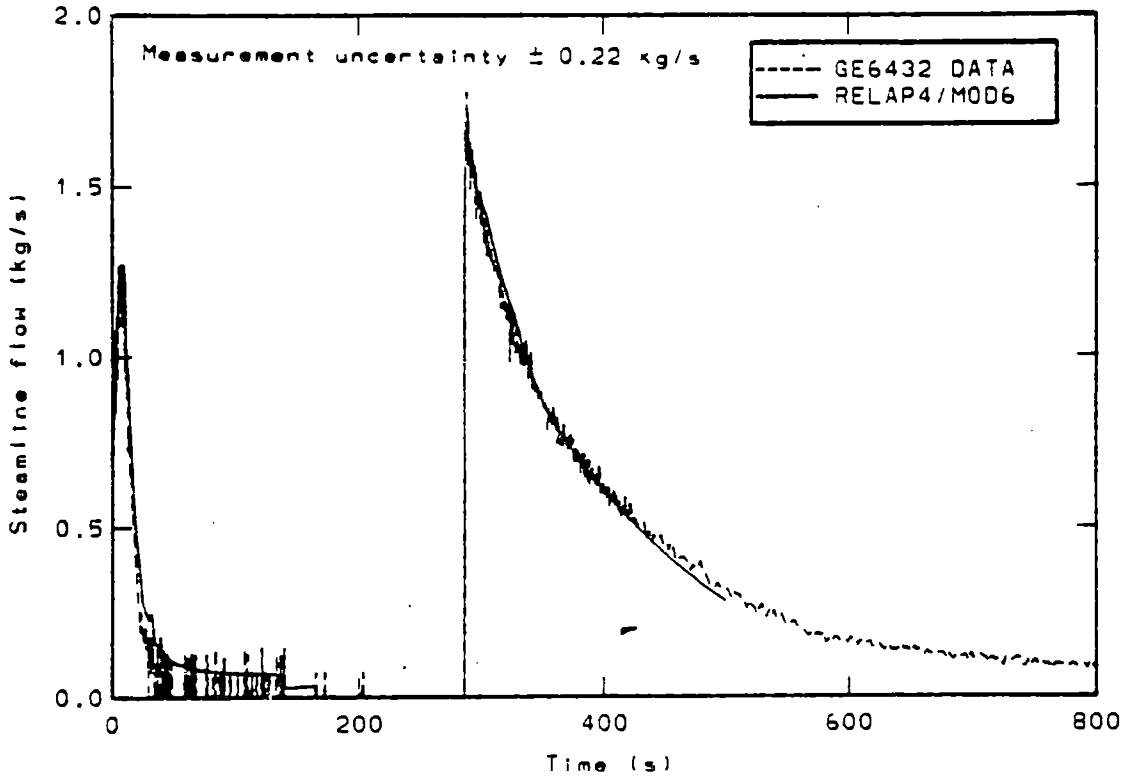

Figure 11. Test 6432 steamline flow.

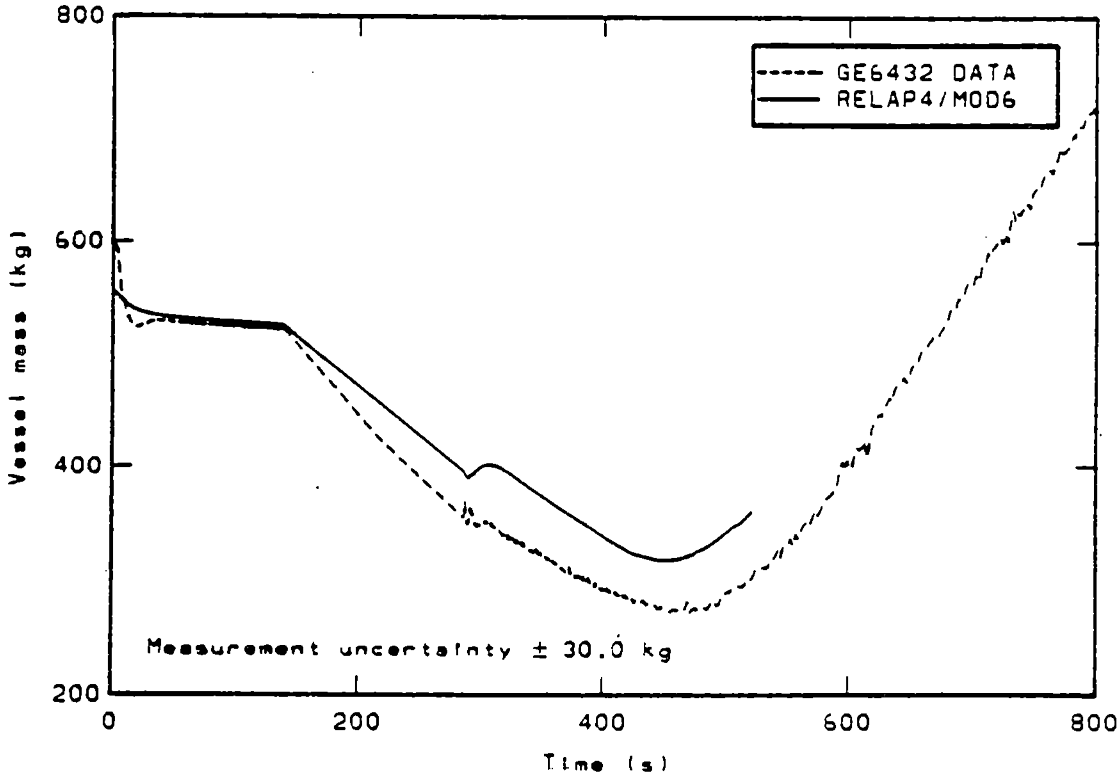

Figure 12. Test 6432 total vessel mass.

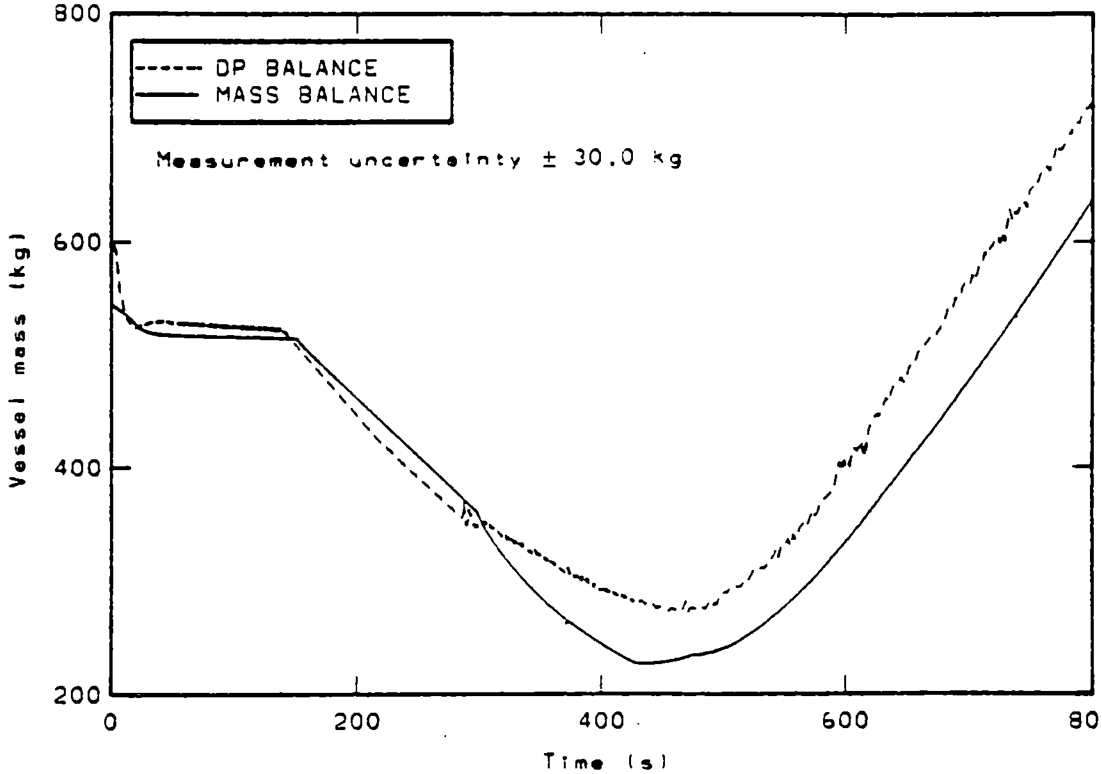

Figure 13. Test 6432 total vessel mass comparison from data.

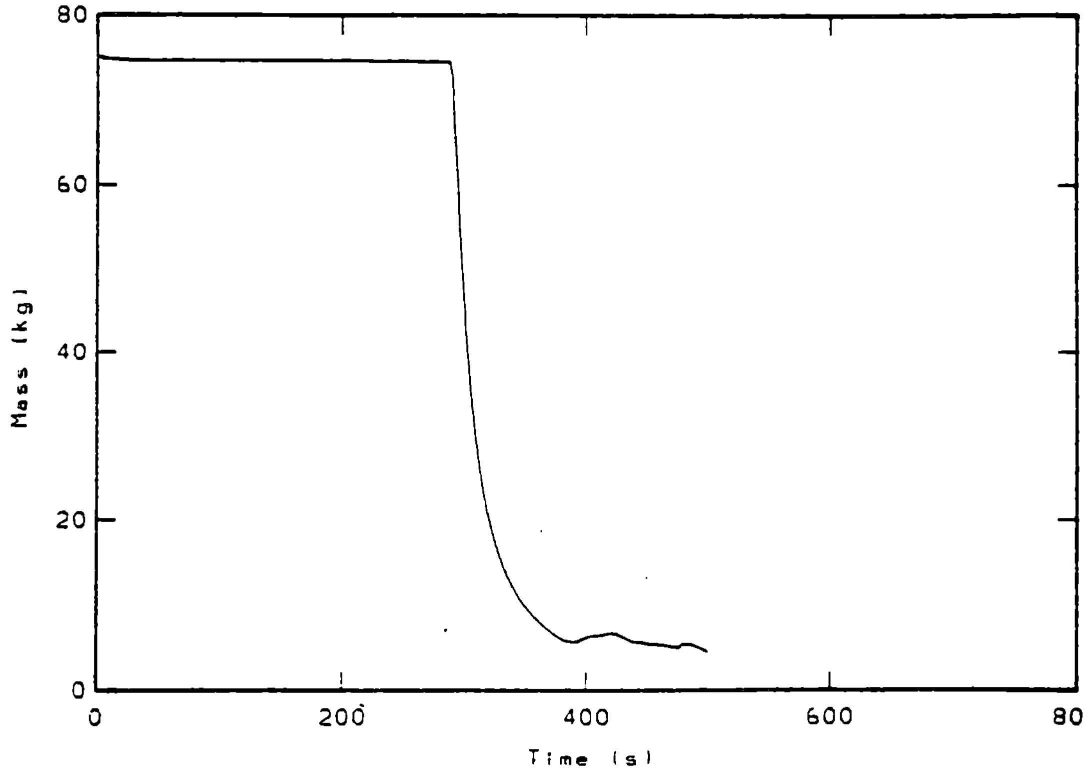

Figure 14. RELAP4/MOD6 calculated mass for Test 6432 of unisolated portions of recirculation lines.

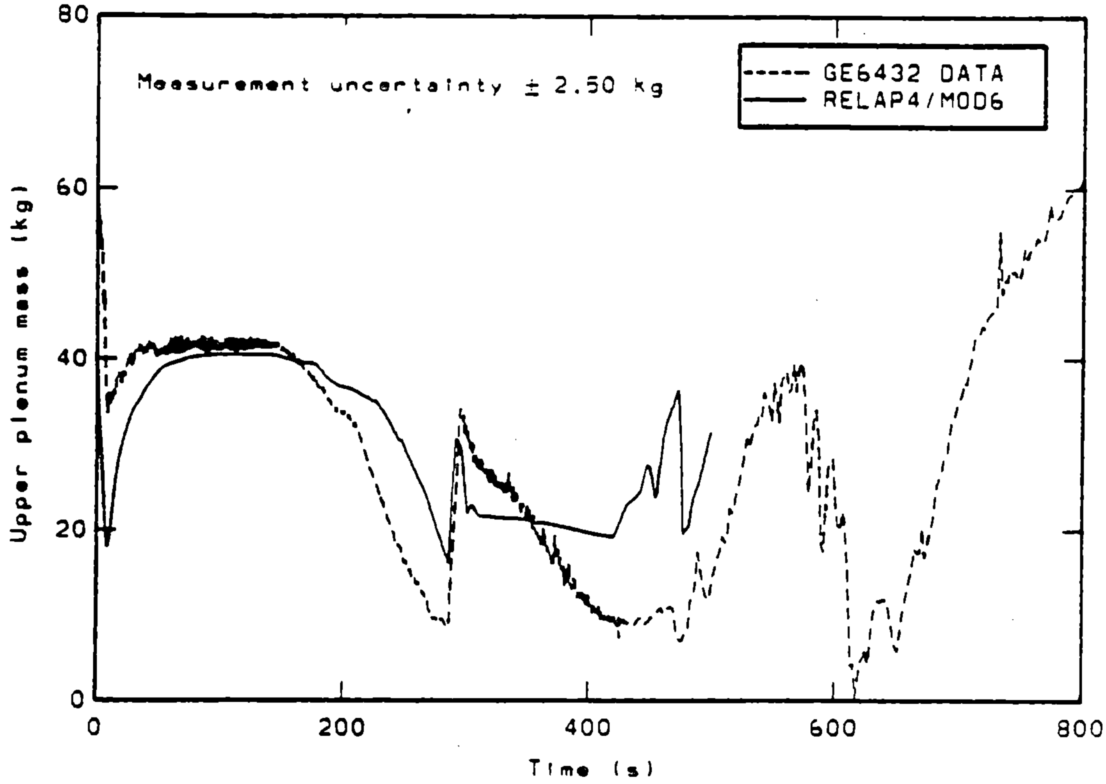

Figure 15. Test 6432 upper plenum mass.

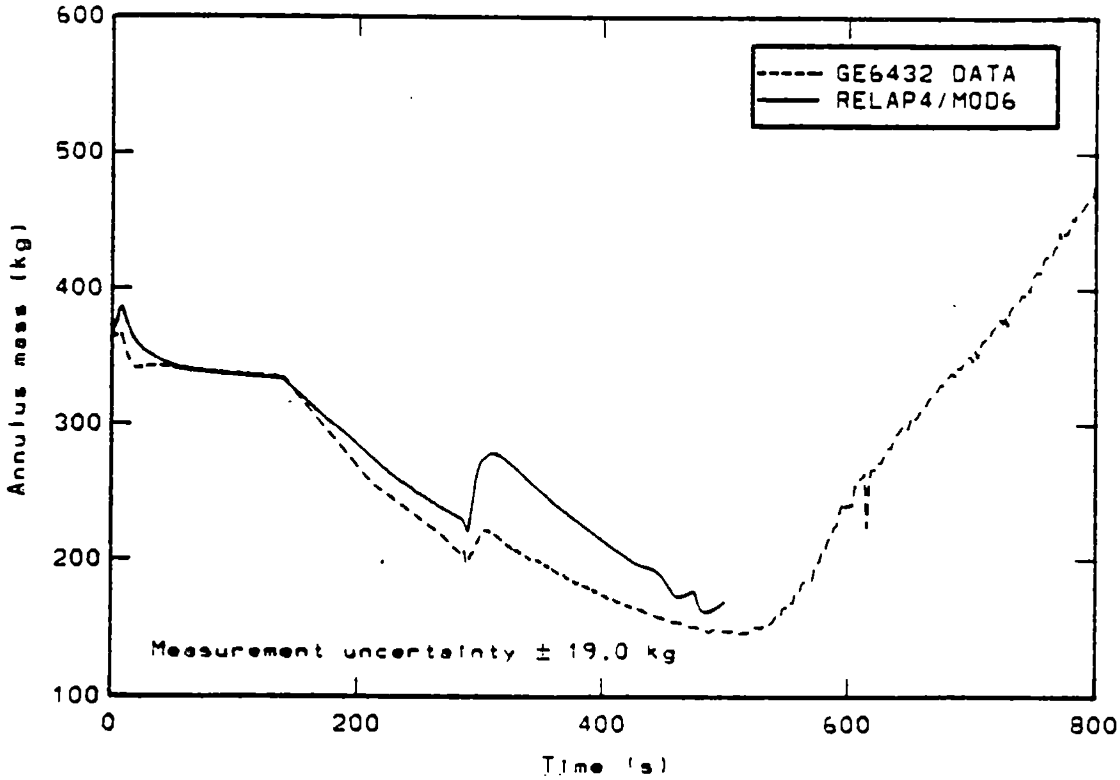

Figure 16. Test 6432 annulus mass.

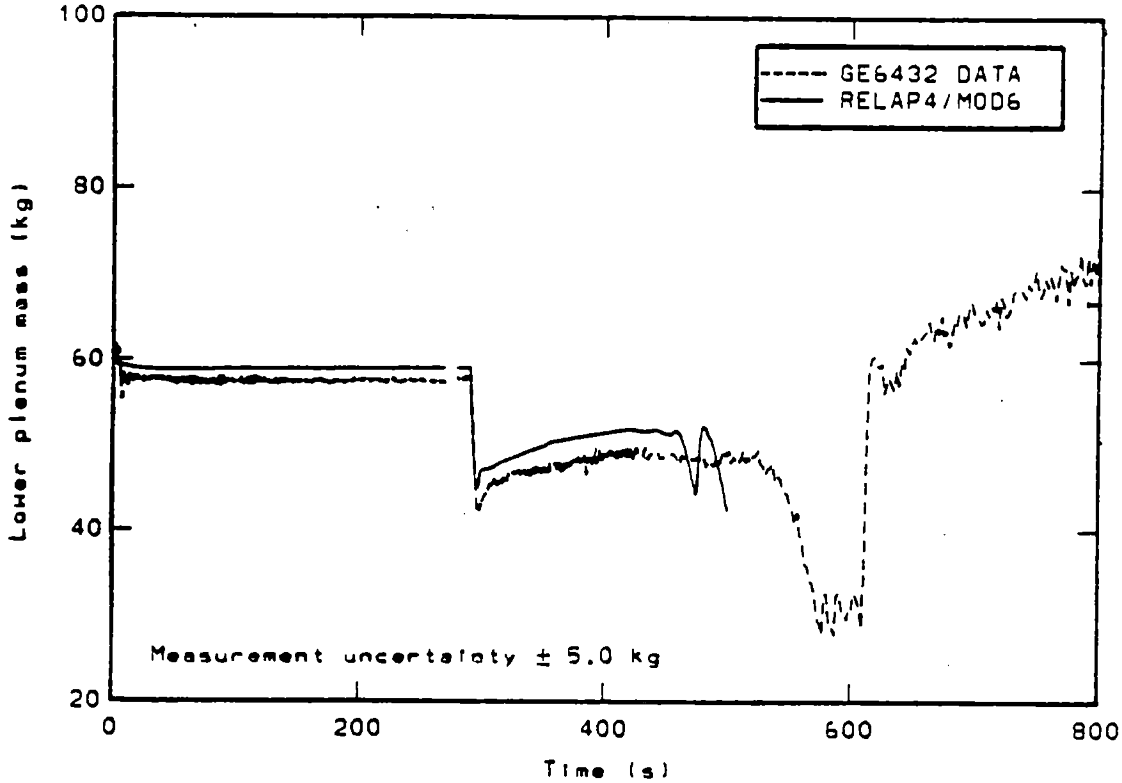

Figure 17. Test 6432 lower plenum mass.

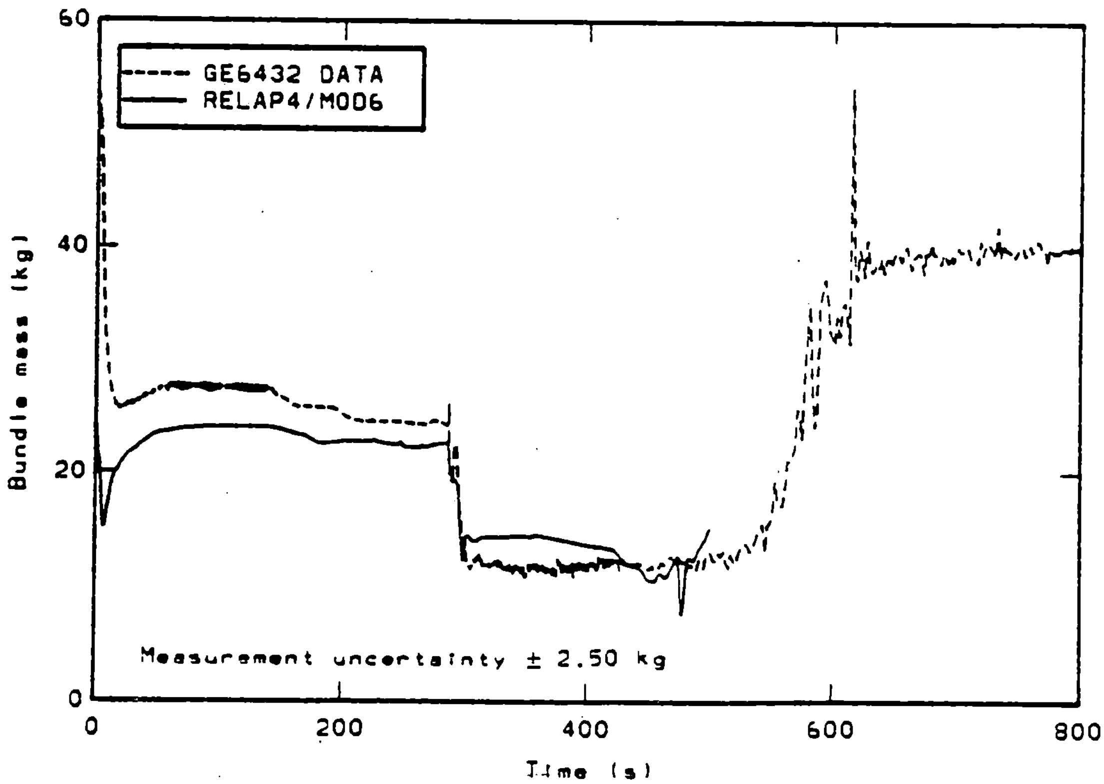

Figure 18. Test 6432 bundle mass.

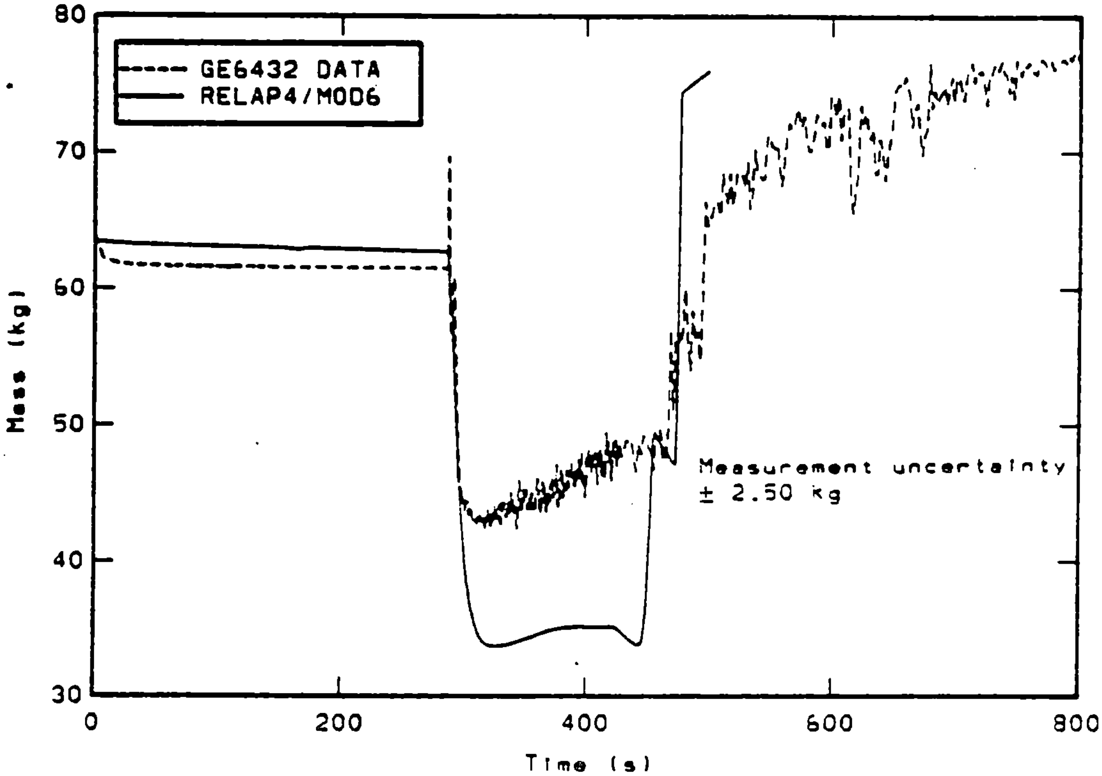

Figure 19. Test 6432 guide tube plus bypass mass.

should be noted that RELAP4/MOD6 cannot predict subcooled CCFL breakdowns. Due to the way that volume-averaged void fractions are used to calculate vertical slip velocities, a volume filled with subcooled liquid would actually cause reduced liquid penetration into the volume below.

Conclusions and Recommendations

Comparisons of RELAP4/MOD6 calculations with two TLTA small break tests resulted in the following conclusions and recommendations.

1. Break lines should be modeled in order to predict the effects of subcooling on break flow. Critical flow applications in general need further investigation.

2. Using homogeneous volumes with subcooled injection will cause atypical condensation rates and mass distributions. This is a generic problem of BWR-type applications.

3. Using phase separation in volumes with subcooled injecton will cause code stability problems. A nonequilibrium model is required to allow proper interaction of subcooled water with saturated steam.

4. The vertical slip model is not adequate in predicting countercurrent flow in BWR calculations. It should be replaced with a model that includes the effects of subcooling.

References

1. "TMI-2 Lessons Learned Task Force Status Report and Short Term Recommendations", NUREG-0578, July 1979.

2. W. J. Letzring, BWR Blowdown/Emergency Core Cooling Program Preliminary Facility Description Report for the BD/ECC 1A Test Phase, GEAP-23592, NRC-2, December 1977.

3. RELAP4/MOD6 A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems, User's Manual, CDAP-TR-003, January 1978.

4. W. S. Hwang, BWR Blowdown/Emergency Core Cooling Program 64 Rod Bundle Core Spray Interaction (BD/ECC 1A), Small Break Simulation Tests Final Report, (to be published).

5. E. E. Ross, RELAP4/MOD6 Data Comparison for TLTA Test 6406, Run 1, CAAP-TR-056, September 1979.

SUMMARY

RESEARCH INFORMATION LETTER NO. 126

"BWR SMALL BREAK TESTS"

FIN B3014

Tests simulating small break LOCA's in a boiling water reactor (BWR) were conducted in the Two-Loop Test Apparatus. These tests were used to assess calculational methods used to analyze BWR transients and provide input to operator guidelines for response to transients. Calculations of these tests were also performed using NRC developed computer codes. Areas for improvement in the calculational methods have been identified.

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DEC 4 1981

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 126, "BWR SMALL-BREAK TESTS"

References:
(1) Letter from Denton to Levine, "TLTA Small-Break Tests (RR-NRR-79-27)" November 28, 1979.
(2) W. S. Hwang, "BWR Small-Break Simulation Tests With and Without Degraded ECC Systems-BWR Blowdown/Emergency Core Cooling Program," NUREG/CR-2230, March 1981.
(3) W. S. Hwang, "Analysis of TLTA Small-Break Test Results," NEDO-24823, August 1980.
(4) R. J. Dallman and W. D. Beckner, "Analysis of TLTA Small-Break Tests and Comparison of RELAP4/MOD6 Calculations," ANS Specialists Conference on Small-Breaks in LWRs, Monterey, California, August 25-27, 1981.

This memorandum transmits the results of initial testing and analysis of boiling water reactor (BWR) small-break loss of coolant accident (LOCA) simulations in the Two-Loop Test Apparatus (TLTA). This research was conducted under the Blowdown/Emergency Core Cooling program jointly sponsored by the U.S. Nuclear Regulatory Commission (NRC), the Electric Power Research Institute and the General Electric Company (GE). This research and the conclusions contained herein were reviewed by the BWR Blowdown Heat Transfer (BDHT) Research Review Group on September 18, 1981 and the Review Group's comments are included in this summary.

Reference 1 requested that small-break loss of coolant tests be conducted in the TLTA to aid in assessing calculational techniques used to analyze BWR transients and thus serve as input to operator guidelines for transient response. Reference 1 also requested that NRC conduct blind calculations of the tests to evaluate our own calculational techniques. Separately, NRC also required BWR owners to conduct pretest predictions of the tests.

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Evaluation of the TLTA capability indicated that the TLTA, designed to test large-break LOCA's, could not adequately simulate small-break LOCA's. By forcing the boundary conditions, however, it was thought that the TLTA could be made to duplicate conditions similar to those expected in a BWR during a small-break accident. These tests should not be viewed as representative of what could happen in a BWR. However, they serve the intended purpose of assessing calculational techniques.

A summary of the tests and calculations is enclosed. The test data are reported in Reference 2 and the results of the calculations are reported in References 3 and 4.T

The TLTA small-break tests were successful in their goal of providing data requested by NRR for assessment of calculational techniques. Blind calculations of the tests both by GE and by NRC-developed codes have enabled us to identify areas for improvement in the modeling. Lack of modeling of a countercurrent flow limit (CCFL) at the SEO (restriction at the bottom of the bundle) has been identified as a major shortcoming of the GE calculation. While not modeling CCFL at the SEO is conservative, the calculation may be misleading since an incorrect scenario is predicted. The NRC calculation, which did model SEO CCFL, did a much better job of predicting the data trends, but illustrated generic problems with handling subcooling and problems with subcooled CCFL in particular.

Future work in this area will involve both experimental and modeling improvements. The TLTA is being upgraded to improve its ability to simulate both small-break LOCAs and other BWR transients. The BWR-TRAC code currently being developed is a nonequilibrium code and improvements in modeling CCFL have been included in the code. These improvements address the major modeling deficiencies observed. The BWR-TRAC code is currently being assessed using TLTA data and will be used for pretest predictions of the upgrade TLTA facility.

Any questions concerning this report should be directed to William Beckner (427-4260).

Original signed by:
ROBERT B. MINOGUE

Robert B. Minogue, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Summary of TLTA Small-Break LOCA Tests and Calculations
2. Reference 4

*See Previous Concurrence

OFFICE	AE:EPB:ISS*	AE:EPB:ISS*	AE:EPB*	AE	AE	RES	RES
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DATE	11/18/81	11/19/81	11/19/81	11/ /81	12/4/81	11/ /81	12/4/81