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Comparison of CONTEMPT-LT Containment Code Calculations with Marviken, LOFT, and Battelle-Frankfurt Blowdown Tests

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COMPARISON OF CONTEMPT-LT CONTAINMENT CODE CALCULATIONS WITH

MARVIKEN, LOFT, AND BATTELLE-FRANKFURT

BLOWDOWN TESTS

by

Gordon J. E. Willcutt, Jr. and Richard G. Gido

ABSTRACT

We compared the CONTEMPT-LT/026 containment analysis code calculations with large-scale test results. We reviewed 7 large-scale experimental test programs and selected 5 of the 16 Marviken tests for pressure-suppression containment analysis comparisons and 1 LOFT test as a secondary investigation. In addition, we used 1 Marviken test to investigate the effects of 18 code parameter variations. We used a single Battelle-Frankfurt test for a dry containment comparison.

CONTEMPT-LT consistently underpredicted peak drywell pressure for all five Marviken tests modeled. This is attributed to higher drywell pressures early in the transient causing higher vent mass and energy transfer to the wetwell. High drywell pressures may be caused by either the code drywell thermodynamic modeling assumptions or the lumping of all the drywell rooms into one volume.

CONTEMPT-LT does not model the LOFT pressure-suppression system very accurately. This is caused primarily by the LOFT header (drywell) geometry, which is a long pipe with blowdown flow entering near one end and vent flow exiting near the other end.

CONTEMPT-LT modeled the Battelle-Frankfurt dry containment pressure very well using conventional heat transfer models and calculated peak pressures that were about 7 psi above the test value of 68 psia. Calculated peak temperatures occurred much later in the blowdown period than test observations.

Five recommendations are advanced relating to further investigation of CONTEMPT-LT. All concern aspects of the code used to model the Marviken pressure-suppression tests and the Battelle-Frankfurt dry containment test, because the LOFT geometry does not fit the CONTEMPT-LT assumptions.

I. INTRODUCTION

We compared CONTEMPT-LT/026 code[1] calculations with experimental results for blowdowns into large-scale pressure-suppression and dry containments. We reviewed seven test programs including the Marviken,[2-18] Battelle-Frankfurt,[19] LOFT,[20-22] Tagami,[23] CDE,[24] CSE,[25] and CVTR[26] tests.

Unfortunately some of the tests are of limited usefulness for code comparisons. In the CDE experiments, the heating and cooling used for controlling containment temperature vs time was not specified. The CSE experiment did not emphasize measurement of data pertinent to containment transient pressure-temperature response. For example, blowdown mass and energy flow rates were inadequately described. It appears that the CSE is a facility that could be used for large-scale-containment thermodynamic tests.

Reference 26 reports on the modeling of the CVTR experiments with the CONTEMPT-LT code. Reference 27 describes our comparison of the Tagami experiments with CONTEMPT-LT. The present report compares experimental results for the Marviken and LOFT pressure-suppression and the Battelle-Frankfurt dry containment tests with CONTEMPT-LT calculations. We performed these calculations using the CONTEMPT-LT code at the NRC computer facility.

Note that in this report, we often use the word blowdown in place of test for the Marviken application as was done in the Marviken reports, e.g., Marviken Blowdown 14 is equivalent to Marviken Test 14.

II. MARVIKEN PRESSURE-SUPPRESSION CONTAINMENT

A. Description of Test Facility

A detailed Marviken containment test facility description is provided in Ref. 2. Figure 1 shows a containment schematic including the room numbers referred to below.

Reactor (pressure) vessel blowdown flows go either up into Room 124 or down into Room 122. Blowdowns into Room 122 can occur through a feedwater pipe, a main steam pipe, or both. Flow from the drywell rooms eventually goes to Room 104 where it travels down four blowdown channels to the header, Room

106. From the header, the flow goes down a maximum of 57 vent pipes to the wetwell, Room 105.

For the first 9 of the 16 blowdowns,[3-18] a drain pipe also linked the drywell to the wetwell by connecting Room 113 to the wetwell. This drain pipe was closed during the blowdown period for the remaining blowdowns.

In the discussion that follows, upper drywell refers to Room 124, breakroom refers to Room 122, lower drywell refers to Rooms 111 and 112, header refers to Room 106, and wetwell refers to Room 105.

B. Blowdown Tests Selected for Modeling

Blowdowns 10, 11, 14, 15, and 16 were selected for modeling with CONTEMPT-LT. We eliminated Blowdowns 1 through 9 because the drain pipe between Room 113 and the wetwell was left open during the blowdown and CONTEMPT-LT cannot model this phenomenon (i.e., a pipe draining water from the drywell sump to the wetwell in parallel with the vent system). We eliminated Blowdown 12 because of significant leakage in the steam pipe after it was supposed to be closed and Blowdown 13 because of leakage before the blowdown began.

Table I compares characteristics of the five blowdowns modeled. Blowdown 10 was unique in that 57 vent pipes were open. Blowdown 11 had an intermediate number of vent pipes open (38), while the remaining blowdowns had 26. Blowdown 14 was unique with its higher initial wetwell pool temperature. Blowdown 15 used only the feedwater pipe for blowdown flow from the pressure vessel, while all the other blowdowns used both the steam pipe and feedwater pipes. Blowdown 16 had a reduced initial vent pipe submergence depth.

Appendix A contains tables summarizing the five Marviken blowdowns modeled.

C. CONTEMPT-LT Model

Our CONTEMPT-LT model includes a single drywell volume, a single wetwell volume, and a vent connecting the drywell and wetwell. We modeled all the drywell rooms by combining their total volume into the one drywell volume with no accounting for flow resistances between drywell rooms or water holdup in individual rooms. We calculated the drywell initial temperature by volume-weighting the temperatures of the individual drywell rooms.

Appendix B gives a detailed description of the input data derived for Blowdown 14. We used the same procedures to derive input data for the other blowdowns. Figure 2 shows a comparison of input blowdown flow rates for the five blowdowns modeled.

D. Model and Data Comparisons for Basic Blowdown Studies

Tables II to VI compare CONTEMPT-LT results with Marviken data for each of the five blowdowns modeled. These tables give comparisons at the initial time, at the time just before vent clearing, at 10 s for the double-pipe blowdowns (at 20 s for the single-pipe Blowdown 15), at a time shortly before the steam pipe closed for the double-pipe blowdowns, at 100 s, and at the end of the blowdown. They give comparisons for drywell pressure, wetwell (atmospheric) pressure, vent flow rate, drywell atmospheric temperature, wetwell pool temperature, wetwell atmospheric temperature, and pressure difference between drywell and wetwell atmospheres. Appendix C presents plots comparing CONTEMPT-LT results with drywell pressure data for each of the five blowdowns modeled. In addition, plots are given for Blowdown 14 representing the double-pipe blowdowns and Blowdown 15 representing a single-pipe blowdown for the other quantities mentioned above.

1. Pressures.

Table VII gives peak drywell and wetwell atmospheric pressures along with the maximum pressure difference between the drywell and wetwell. For all five blowdowns, the calculated peak drywell absolute pressure is lower than the Marviken data for the upper drywell, breakroom, lower drywell, and header. Calculated results are between 89 and 94% of the measurements. Calculated results are also lower for peak wetwell atmospheric absolute pressure, varying from 88 to 95% of the data. Maximum pressure differences between the drywell and wetwell agree quite closely in magnitude for calculated and observed lower drywell results, except for Blowdown 10 where the calculated results are 23% higher. However, the CONTEMPT-LT maximums occurred about the time of vent clearing while the observed maximums occurred much later. For the double-pipe blowdowns, the Marviken peak pressure differences occurred shortly before the steam pipe was closed while for the single-pipe blowdown, they occurred at the end.

Calculated drywell pressures rose much more rapidly early in the transient than indicated in the data. Before vent clearing, the calculated drywell pressures are from 1.9 to 4 psi above the observed lower drywell values. Calculated values exceed observed lower drywell pressures for the first 15 to 30 s for the double-pipe blowdowns and for the first 150 s for Blowdown 15.

As with the drywell pressures, calcu ted wetwell pressures exceed observations for the early part of the transient following vent clearing. Calculated drywell-to-wetwell pressure differences also are greater during the early stages of the transient and are lower in the later stages than test data.

2. Vent Clearing Time and Vent Flow Rate.

We determined Marviken vent flow rates from calculated results given in the individual test reports by summing the calculated rate of mass added to the wetwell pool and the fitted air flow rate into the wetwell atmosphere. In the test reports, the air flow rate was calculated from pressure and temperature measurements in the wetwell atmosphere using the ideal gas law. Temperature and liquid level measurements in the wetwell pool were used to estimate how much mass was added to it. Uncertainty levels for each flow rate are probably quite large as evidenced by the great difference between the calculated and fitted air flow rates for early times given in the test reports (see Table B:17, Ref. 16, for example).

Table VIII compares initial calculated and test vent clearing times and peak vent flow rates. Vent clearing times agree very well for the double-pipe blowdowns with no more than 0.15 s difference between calculated results and test data. For the single-pipe Blowdown 15, the comparison is not as good. Because of the much lower blowdown flow rate, a series of vent clearings and reclosings was observed from 13 to 30 s in the experiment.[17]

Calculated peak vent flow rates are greater than Marviken data except for Blowdown 16 where the calculated peak is about 1% lower than observed. Calculated vent flow rates are much higher in the early stages of the transients than the Marviken observations. This corresponds to the similar comparison for drywell-to-wetwell pressure differences. Apparently, high vent flow rates calculated by CONTEMPT-LT early in the transient removed so much mass from the drywell that they caused the lower peak pressures calculated later in the transient.

CONTEMPT-LT results readily show the effects of number of vents. Blowdowns 10, 11, and 14 with 57, 38, and 26 vents had peak-calculated vent flow rates of 2269, 1517, and 1067 lbm/s. A puzzling result is seen in the corresponding Marviken observations of 1169, 1278, and 1022 lbm/s where the largest flow rate involved the intermediate number of vents.

Blowdowns 14 and 16 demonstrate the effect of initial vent submergence. Decreasing the initial vent submergence from 9.25 to 5.38 ft caused an increase in peak vent flow rate of 10% for CONTEMPT-LT and 16% for Marviken data.

An additional difference between calculated and observed vent flow rates occurs for the double-pipe blowdowns after the steam pipe is closed. Marviken data show fairly continuous vent flow rates of low magnitude after this time. CONTEMPT-LT results oscillate between zero and several times the Marviken value.

3. Temperatures.

Table IX compares CONTEMPT-LT results with Marviken data for peak temperatures in the drywell atmosphere, wetwell pool, and wetwell atmosphere. The calculated drywell atmospheric temperature is bounded by the Marviken breakroom and header temperatures until late in the transient when it decreases slightly below both of them. Calculated peaks are from 2.3°F to 24.3°F lower than the measured breakroom temperatures for the five blowdowns.

CONTEMPT-LT overpredicted the peak temperature in the wetwell pool and substantially underpredicted the peak temperature in the wetwell atmosphere. Calculated wetwell atmospheric temperatures remain almost constant while the Marviken data show a peak late in the transient. Two factors may cause this. In the calculation, too much vent flow energy was added to the wetwell pool rather than being carried through to the atmosphere. and too little heat was transferred from the pool surface to the wetwell atmosphere. Heat transfer coefficients calculated by the code for the pool surface-to-atmosphere interchange are between 0.005 and 0.036 Btu/h/ft^2/$^{\circ}$F.

E. Effect of Heat Transfer on CONTEMPT-LT Results

We added four heat conducting structures to the base-case data for CONTEMPT-LT simulations of the five basic blowdowns. These structures are based on extensive descriptions in Ref 2. They include concrete with liner plus gap conductance, concrete with no liner, steel plate, and aluminum sheet. Appendix D describes the structures in detail and gives plots of drywell pressures calculated with and without heat transfer compared with lower drywell pressures. Table X shows the calculated peak drywell pressures for the cases with and without heat transfer and for the breakroom and lower drywell measured values. Heat absorbing structures lowered the calculated peak drywell pressure by only 0.13 to 0.99 psi.

F. CONTEMPT-LT Parameter Studies for Blowdown 14

We selected Blowdown 14 for parameter studies because it was one of the double-pipe blowdowns, it had a single peak in the blowdown flow rate, and it had the shortest blowdown period.

An extensive study was conducted to determine the effects of various input parameter assumptions. Table XI describes the parameters varied. Tables XII to XVIII compare CONTEMPT-LT results with Marviken data for drywell pressures, wetwell atmospheric pressures, drywell-to-wetwell pressure differences, vent flow rates, drywell atmospheric temperatures, wetwell pool temperatures, and wetwell atmospheric temperatures. Table XIX gives the peak pressures in the drywell and wetwell atmospheres, the peak drywell-to-wetwell pressure difference, and the Marviken data. Table XX compares initial vent clearing time and peak vent flow rate for all the cases with Marviken data. Table XXI compares peak temperatures in the drywell atmosphere, wetwell pool, and wetwell atmosphere with Marviken data.

Discussion of the results of the different parameter studies is given below.

1. Time Step Size (Case 2).

Time steps were halved for the entire transient. This change reduced peak drywell pressure by only 0.35 psi, did not alter peak wetwell pressure, reduced the maximum peak temperature by only about 0.5°F, and reduced the peak vent flow rate by about 2.9%. After the steam pipe was closed, this case had reduced fluctuations in vent flow amplitude compared to the base case.

2. Vent Closing-and-Opening Parameters (Cases 3 and 4).

Vents are assumed closed if the product of the vent closing parameter and the vent submergence hydrostatic head is greater than the drywell-to-wetwell pressure difference. Vent clearing calculations are restarted if the drywell-to-wetwell pressure difference is greater than or equal to the product of the vent opening parameter and the vent submergence hydrostatic head. We used vent closing parameter values of 0.0 for the base case, 1.0 for Case 3, and 0.5 for Case 4, and values of the vent opening parameter of 0.0 for the base case and 1.0 for Cases 3 and 4.

These parametric changes had virtually no effect on peak quantities. The primary effect was the number of times that the vents closed (and opened) in the 180-s transient. For the base case, there were six occasions starting at 90 s when no vent flow was printed after the initial vent clearing, although no vent closing messages were printed. For Case 3, the first reclosing occurred at 85.5 s with 90 cycles of clearing and reclosing in the rest of the transient. For Case 4, only at 95 s was a zero vent flow observed after the initial vent clearing, and no vent closing message was printed. It is not clear why the vent clearing and reclosing messages were printed for Case 3 and not for the base case or Case 4.

3. Vent Roughness and Loss Coefficient (Cases 5 and 6).

For Case 5, we increased the effective roughness of the vent pipe's concrete surface by 50% with negligible changes in the peak pressures, temperatures, and vent flow rate. Doubling the entrance loss coefficient from the drywell to the vent opening in Case 6 caused a 1.2-psi increase in peak drywell pressure and a 0.8-psi increase in the peak drywell-to-wetwell pressure difference.

4. Number of Pipe Elements in Vents (Case 7).

For Case 7, we doubled the number of elements in the vents from 10 to 20. This had no effect on initial vent clearing time and negligible effect on any of the peak quantities. Vent flow oscillations remained comparable in magnitude to the base case near the end of the transient after the steam pipe was closed. Computer time requirements increased substantially from the base-case value of 5.38 min to 9.84 min.

5. Drywell Volume (Case 8).

Because the flow areas are relatively small between the upper drywell and the rest of the drywell, we ran a case without including the upper drywell in the drywell volume. This produced a surprising result; instead of increasing, the peak drywell pressure decreased about 11% from 40.71 to 36.34 psia, and the peak wetwell pressure dropped even more from 32.48 psia to 26.36

psia. The vents cleared about a tenth of a second earlier, and the peak vent flow rate increased about 13%. Drywell and wetwell peak atmospheric temperatures dropped 6.9°F and 3.5°F respectively, while the wetwell pool temperature increased 4.3°F.

A partial explanation of these observations is that the smaller volume caused a more rapid rise in drywell pressure, which caused a more rapid mass transfer to the wetwell. Peak drywell pressure occurred at a relatively long time after considerable mass and energy were transferred to the wetwell. At the time of peak pressure in the drywell, the mass of the drywell vapor was only 3895 lbm with an energy of 4.25×10^6 Btu for Case 8, while for the base case the conditions were 6586 lbm and 7.20×10^6 Btu at peak pressure. The peak wetwell pressure and temperature decreased because more energy was contained in the wetwell pool (indicated by the increased wetwell pool temperature), and also because less drywell air entered the wetwell atmosphere. The wetwell pool temperature increased because of more flow into it at a higher temperature.

6. Heat Sinks (Case 9).

Section E described effects of heat sinks on drywell pressures. In addition to lowering the peak drywell pressure 0.87 psi for Blowdown 14, heat sinks reduced the peak drywell atmospheric temperature about 1.2°F and the peak wetwell pool temperature by 10.7°F.

7. Number of Vents (Case 10).

Increasing the number of vents from 26 to 38 reduced the peak drywell pressure by 2.33 psi and the peak drywell-to-wetwell pressure difference by 0.55 psi. Even with this reduced driving force, the peak vent flow rate increased by 34% because of the larger vent area. The peak drywell atmospheric temperature decreased 3.5°F, while the peak wetwell pool temperature increased 0.6°F; these variations reflect the increased drywell-to-wetwell energy transfer.

8. Air Energy Transport Through Wetwell Pool (Case 11).

When we changed both air energy transport multipliers for the wetwell pool from 0.0 to 1.0 (see p. 183 of Ref. 1), the peak wetwell atmospheric temperature increased to 319.6°F, (which is higher than either the 282.8°F peak drywell atmospheric temperature or the 179.9°F peak wetwell pool temperature). This is a 4.6°F drop in peak wetwell pool temperature. Both drywell and wetwell peak pressures increased over 10 psi.

We do not fully understand how these parameters work, but the results do have some encouraging aspects. Each of the peak values changed in the direction from the base-case value toward the Marviken data value. Many changed too much and passed the data. It appears that choosing air energy transport multipliers nearer 0.0 in the 0.0 to 1.0 range will make the results agree much better with the data.

9. Vent Submergence Depth (Case 12).

For Case 12, the initial vent submergence depth was decreased from 9.25 to 5.28 ft, which required an increase in the initial wetwell atmospheric volume from 55 876 to 60 962 ft^3 and a corresponding decrease in the initial wetwell pool volume from 19 638 to 14 552 ft^3. Peak pressures in the drywell and wetwell dropped 2.6 and 1.5 psi, while the peak difference between them dropped 1.3 psi. The peak vent flow rate increased 2%. We found a 4°F decrease in peak drywell atmospheric temperature, a 0.15°F decrease in peak wetwell atmospheric temperature, and a 23.7°F increase in peak wetwell pool temperature because of the smaller pool volume.

10. No Pressure-Suppression System (Cases 13 and 14).

We ran CONTEMPT-LT with no pressure-suppression system as a limiting case. We first deleted heat transfer surfaces (Case 13) and then included heat transfer surfaces (Case 14). As expected, the peak pressure increased considerably from 40.7 psia with a pressure-suppression system to 383 psia for Case 13 and to 251 psia for Case 14.

11. Water Carry-Over Fraction (Cases 15 to 17).

For the base case, the fraction of liquid water entering the vents was assumed equal to the fraction of liquid water in the drywell atmospheric region. For these three cases, the ratio of these fractions was assumed to be 0.75 (Case 15), 0.50 (Case 16), and 0.25 (Case 17). These three ratios decreased peak drywell pressures by 0.18, 0.36, and 0.62 psi, respectively, and had no effect on peak wetwell pressure or maximum drywell-to-wetwell pressure difference. Vent clearing times remained unchanged while peak vent flow rates decreased 2.9% for all three cases. Drywell peak temperatures decreased 0.31°F, 0.49°F, and 0.92°F, while wetwell peak pool temperatures decreased 0.15°F, 0.30°F, and 0.41°F. Essentially no change occurred in wetwell peak atmospheric temperatures.

The primary observed change was in the vent flow rate in the period from about 10 s until the steam pipe closed. Vent flow rate decreased with decreasing water carry-over fraction. For example, at 70 s the vent flow rates dropped 4.5%, 7.4%, and 11.6% from the base case for water carry-over fractions of 0.75, 0.50, and 0.25.

12. Condensed Mass Removal (Case 18).

For this case, Word 13 on the 11001 General Control Card (p. 165 of Ref. 1) equaled 1.0 in addition to the heat transfer additions of Case 9. This option was added to CONTEMPT-LT since the original manual was written and therefore was not included in the manual's card description. Changes were negligible compared to Case 9 which had heat transfer with no condensed mass removal.

13. Wetwell Heat Transfer (Case 19).

When the wetwell heat transfer coefficient multiplier between the pool and vapor region was increased by a factor of 100 (because the code-calculated heat transfer coefficients were only 0.005 to 0.036 $Btu/h/ft^2/^{\circ}F$), the peak wetwell atmospheric temperature increased 6.14°F and the peak wetwell pool temperature dropped 0.08°F. After this increase, the peak wetwell atmospheric temperature remained about 30°F below the test data.

G. Comparisons with Other Analyses

CONTEMPT-LT was used by W. J. Mings and J. I. Mills at EG&G Idaho, Inc.[28] to model Blowdown 18 from the second series of Marviken tests. Even though we did not model this test, it is interesting to note that their results also indicated the breakroom peak pressure data from Marviken was higher than the calculated drywell pressure.[28]

An earlier version of the code, CONTEMPT-PS, was used by A. Sonnet and H. Tartu at the French Atomic Energy Commission to model Marviken Blowdown 11.[29] Some of their input data was described in their report, but most of the parametric assumptions were not given. One major difference in their model input is that they assumed a total wetwell volume of 55 621 ft^3 that is very close to the wetwell atmospheric volume given in the Marviken test report[13] but doesn't include the volume of the wetwell pool. We ran CONTEMPT-LT with the wetwell volume given in the Marviken test report[13] and also ran it with the wetwell volume decreased to the volume used in the French work.[29] Our results for drywell pressures are compared in Fig. 3 with the

Marviken data for the breakroom and lower drywell and with the French results. The Marviken peak pressures are higher than the CONTEMPT-LT base case. When the wetwell volume was reduced to that used in the French case, the CONTEMPT-LT peak pressures are higher than the Marviken data but not as high as the French CONTEMPT-PS results. Since many of the input assumptions were not specified for the CONTEMPT-PS calculation, it is not possible to determine the causes of the remaining differences. They could be due to differences in modeling or differences between CONTEMPT-LT and CONTEMPT-PS.

H. Comparison of Marviken and BWR Parameters

Table XXII shows ratios of typical General Electric Mark I, II, and III geometric quantities to corresponding Marviken quantities. Dr. T. Huang of the Containment Systems Branch of the US Nuclear Regulatory Commission provided the data used for the Mark I, II, and III containments. For the Mark I and II vertical vent system designs, the drywell and wetwell volumes are between 2.4 and 3.3 times as large as Marviken, while the initial wetwell pool volumes are between 5.2 and 6.0 times as large. Total vent areas for the vertical vent systems are 12.7 to 13.1 times as large as Marviken.

III. LOFT PRESSURE-SUPPRESSION CONTAINMENT

We briefly investigated how effectively CONTEMPT-LT could simulate LOFT Test L1-3A. Blowdown flows enter the header pipe through two pipes connected to the side of the header near one end. The flows then pass horizontally through the header pipe that makes two bends totaling 90 degrees until exiting near the other end through four pipes connected along the bottom. After going through these four downcomer pipes, the flows enter a cylindrical pressure-suppression tank.

Appendix E describes the system model that treats the header pipe as the drywell, the four downcomer pipes as the vent system, and the pressure-suppression tank as the wetwell. Rather than resembling a conventional drywell, the header pipe is a long pipe with length/diameter of about 19. Blowdown flow entering the header cannot be expected to be mixed instantaneously with the material in the entire length of pipe as is assumed in the CONTEMPT-LT drywell.

Another major problem in validating the code was a large discrepancy in measured blowdown flow rate (see Appendix E). Even after applying recommended correction factors to the four methods of determining cold leg break flow, large discrepancies remained.

We ran CONTEMPT-LT for the first 3 s of the blowdown, which is well beyond the calculated 0.18-s vent clearing time. Table XXIII compares calculated values of drywell pressure, wetwell pressure, wetwell atmospheric temperature, and wetwell pool temperature with data. Appendix E includes plots of these quantities. LOFT data were not available for comparison for drywell temperature, vent clearing time, or vent flow rate.

Observed peak drywell pressures greatly exceeded those calculated. This was due to the geometry and flow rate problems mentioned above plus air compression in the header as the blowdown flow began. The peak header pressure was found to be 13 psi higher at position 4 near the downcomer pipe closest to the header end than at position 1 near the downcomer pipe closest to the blowdown source. At the time of peak pressure, the observed pressures increased in the flow direction rather than decreasing.

IV. BATTELLE-FRANKFURT DRY CONTAINMENT

Battelle-Frankfurt Test C5 was simulated using CONTEMPT-LT for the 30-s blowdown period. Appendix F describes the code input. Nine of the test compartments were included in the drywell with 63% of the total volume in the main compartment. We modeled (1) no heat transfer structures, (2) Uchida heat transfer coefficient, (3) Tagami heat transfer coefficient until the end of blowdown, (4) Uchida heat transfer coefficient with condensation mass removal, and (5) combination of Tagami heat transfer coefficient for the first 21 s (approximate time of peak pressure) and then exponential decay to Uchida heat transfer coefficient. Appendix F includes derivations of the Tagami heat transfer coefficient and the combination case.

Table XXIV compares peak calculated pressures and temperatures with test data for the main compartment. With no heat transfer, the code results are about 41 psi above the test data. When the Uchida heat transfer coefficient with and without condensation mass removal was used, the peak pressure exceeds the data by only 12.7 psi. When the Tagami heat transfer coefficient was used for the entire blowdown, the peak pressure decreased to only 11.4 psi above the data peak. With the combination heat transfer coefficient, the data peak was exceeded by only 7 psi. Peak temperatures improved in the same order with best agreement for the combination case with the peak about 22°F higher than observed. Even though the peak temperatures agree quite well, the shapes of the curves are quite different. The test data rose rapidly to a peak in the first few seconds and then slowly decreased. CONTEMPT-LT predictions rose gradually to a peak late in the transient.

Pressures and temperatures are given at five different times in Table XXV. Figure 4 compares data and calculated pressures for no heat transfer, Uchida, Tagami and combination Tagami-Uchida cases, and Fig. 5 compares the data and calculated temperatures for the same heat transfer cases.

V. CONCLUSIONS

A. Marviken Pressure-Suppression Containment

CONTEMPT-LT underpredicted peak drywell pressures for all five Marviken blowdowns modeled. Before vent clearing, calculated drywell pressures rose much faster than Marviken data; this indicates either a problem in modeling drywell thermodynamics or in modeling the drywell rooms and flow paths as one large volume. Once vents cleared, calculated vent flow rates exceeded data in the early part of the transient. This more rapid transfer of mass and energy from drywell to wetwell early in the transient (due to high early drywell pressure) may cause the discrepancy between calculated and observed peak drywell pressure late in the transient.

Calculated and observed vent clearing times agreed to within 0.15 s for each of the four double-pipe blowdowns. For the single-pipe blowdown, comparison was not as good.

CONTEMPT-LT overpredicted peak wetwell pool temperature and underpredicted peak wetwell atmospheric temperature. Possible causes are too large a fraction of vent flow energy added to the pool and very small heat transfer between the pool surface and the atmosphere. Energy in the wetwell pool was also high because of no drywell heat transfer surfaces for the base case assumptions. At the end of the blowdowns, 67 to 76% of the total energy of the drywell and wetwell was in the wetwell pool.

Adding drywell heat-conducting structures decreased peak drywell pressures by less than 1 psi. Energy removed by these heat sinks is seen in reduced wetwell pool temperatures of 10.7°F for Blowdown 14, for example.

We conducted extensive parameter studies using Blowdown 14 as a test case. Many conclusions are given in the individual studies' discussions. A few highlights are given here.

1. Vent closing and opening parameters had virtually no effect on peak pressures, temperatures, or vent flow rates.

2. A 50% increase in vent surface roughness also had a negligible effect on peak quantities.

3. Doubling the vent entrance loss coefficient increased the peak drywell pressure 1.2 psi.

4. Doubling the number of pipe elements in the vents had no effect on initial vent clearing time and negligible effect on peak quantities, but it increased computer time by 83%.

5. Decreasing the drywell volume by the volume of the upper drywell decreased peak drywell pressure by 4.4 psi because more mass and energy was transferred to the wetwell early in the blowdown before the peak drywell pressure occurred.

6. Increasing the number of vents from 26 to 38 reduced the peak drywell pressure by 2.33 psi.

7. Changing air energy transport multipliers for the wetwell pool from 0.0 to 1.0 caused peak values of drywell pressure and temperature, wetwell atmospheric pressure and temperature, wetwell pool temperature and peak vent flow rate all to move from base-case results toward the Marviken data. Some of these quantities moved beyond the Marviken data, indicating an intermediate value of the multipliers would better match Marviken data than the base-case assumptions.

8. Reducing initial vent submergence from 9.25 to 5.38 ft reduced the peak drywell pressure 2.6 psi.

9. Reducing water carry-over fractions from 1.0 to 0.75, 0.50, and 0.25 reduced peak drywell pressures 0.18, 0.36, and 0.62 psi, respectively.

10. Condensed mass removal in the drywell produced negligible changes over the heat transfer case without condensed mass removal.

11. An increase by a factor of 100 in heat transfer coefficient between the wetwell pool and atmosphere increased the peak wetwell atmospheric temperature by 6.14°F.

B. LOFT Pressure-Suppression Containment

CONTEMPT-LT does not model the LOFT system very well. This is due primarily to the geometry of the header (drywell), where blowdown flows enter on the side of the header pipe, flow through the pipe around two bends totaling 90 degrees, and exit through four downcomer pipes near the other end. The header has a length/diameter ratio of about 19. During blowdown test L1-3A, the peak pressure increased in the flow direction near the downcomer pipes' end of the header pipe.

C. Battelle-Frankfurt Dry Containment

CONTEMPT-LT overpredicted the peak pressure and temperature for Battelle-Frankfurt Test C5. Peak pressures exceeded the 68.17 psia observed by 7 to 41 psi, depending on the heat transfer assumptions used. Peak calculated temperatures exceeded the 263.8°F measured by 22 to 55°F. The test temperature rose rapidly to an early peak while the CONTEMPT-LT results had a more gradual rise to a peak late in the blowdown period. By using a Tagami heat transfer coefficient out to peak pressure and then an exponential decay to a Uchida heat transfer coefficient, we obtained the best agreement with Battelle-Frankfurt data.

VI. RECOMMENDATIONS

Our recommendations for further work concern aspects of the code used to model the Marviken pressure-suppression tests and the Battelle-Frankfurt dry containment test, because the LOFT geometry does not fit the CONTEMPT-LT assumptions. We recommend the following.

(1) Determine why the drywell pressures calculated by the code increased so much faster before vent clearing than the Marviken data. This requires an investigation of how the code treats the thermodynamics of the blowdown mass and energy addition and also possibly the lumping of room volumes into the composite drywell volume.

(2) Investigate the vent calculations to increase code efficiency. In our Marviken Blowdown 14 parameter studies, computer time increased by 83% (from 5.38 to 9.84 min) when the number of elements in the vents was increased from 10 to 20.

(3) Investigate the calculation of heat transfer coefficients between wetwell pool surface and the wetwell atmosphere because the code calculated extremely low values, 0.005 to 0.036 Btu/h/ft^2/$^\circ$F.

(4) Investigate the code modeling of the air energy transport through the wetwell pool. Results were highly sensitive to the two code multipliers, and the upper limit values of the multipliers gave peak wetwell atmospheric temperatures exceeding all other temperatures in the system by 37°F for Marviken Blowdown 14.

(5) Investigate why the code did not predict the rapid rise to an early temperature peak in the Battelle-Frankfurt C5 test.

ACKNOWLEDGEMENTS

We would like to thank Messrs. P. Baranowsky, S. Brown, T. Huang, and N. Su of the Containment Systems Branch, Division of Systems Safety, US Nuclear Regulatory Commission for their help in this work. Messrs. Huang and Su helped us choose standard base-case values for many input parameters for CONTEMPT-LT. Mr. Baranowsky helped us decide on the parameter studies. Mr. Brown ran our CONTEMPT-LT cases on the NRC computer system. Mr. Huang also provided sample CONTEMPT-LT runs for the Mark I, II, and III containments and reviewed a draft version of this report.

We would also like to thank Mr. J. White of EG&G Idaho, Inc. for his assistance in interpreting LOFT test data and Mr. W. Gregory of the Los Alamos Scientific Laboratory for providing Battelle-Frankfurt data.

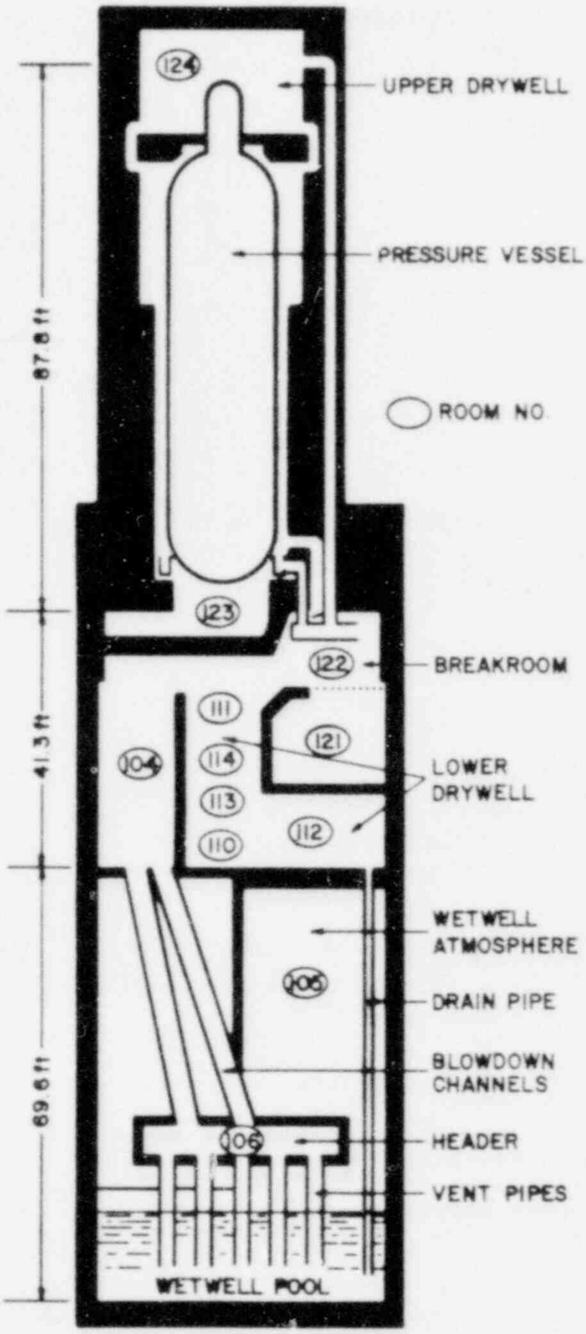

Fig. 1. Marviken containment schematic.

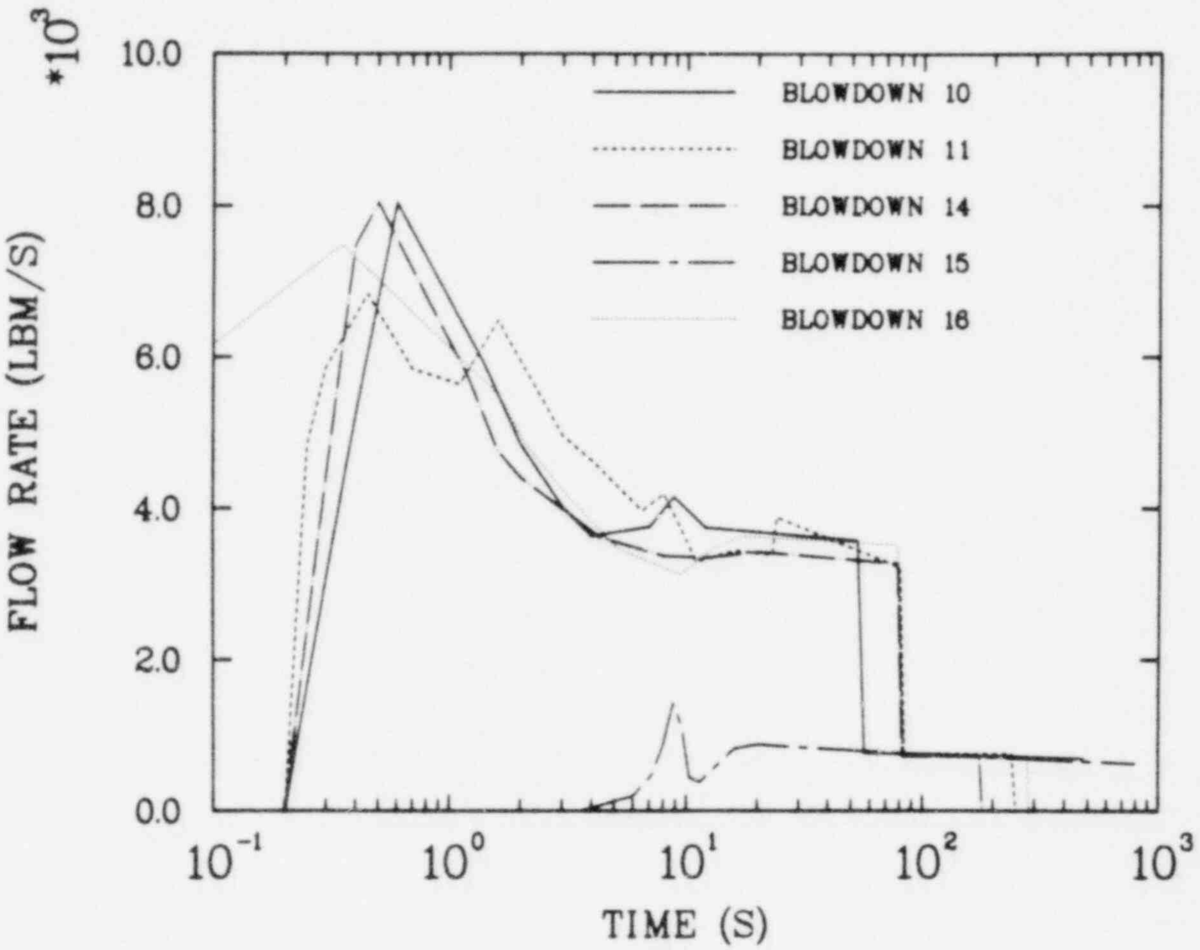

Fig. 2. CONTEMPT-LT input flow rates for Marviken blowdown tests.

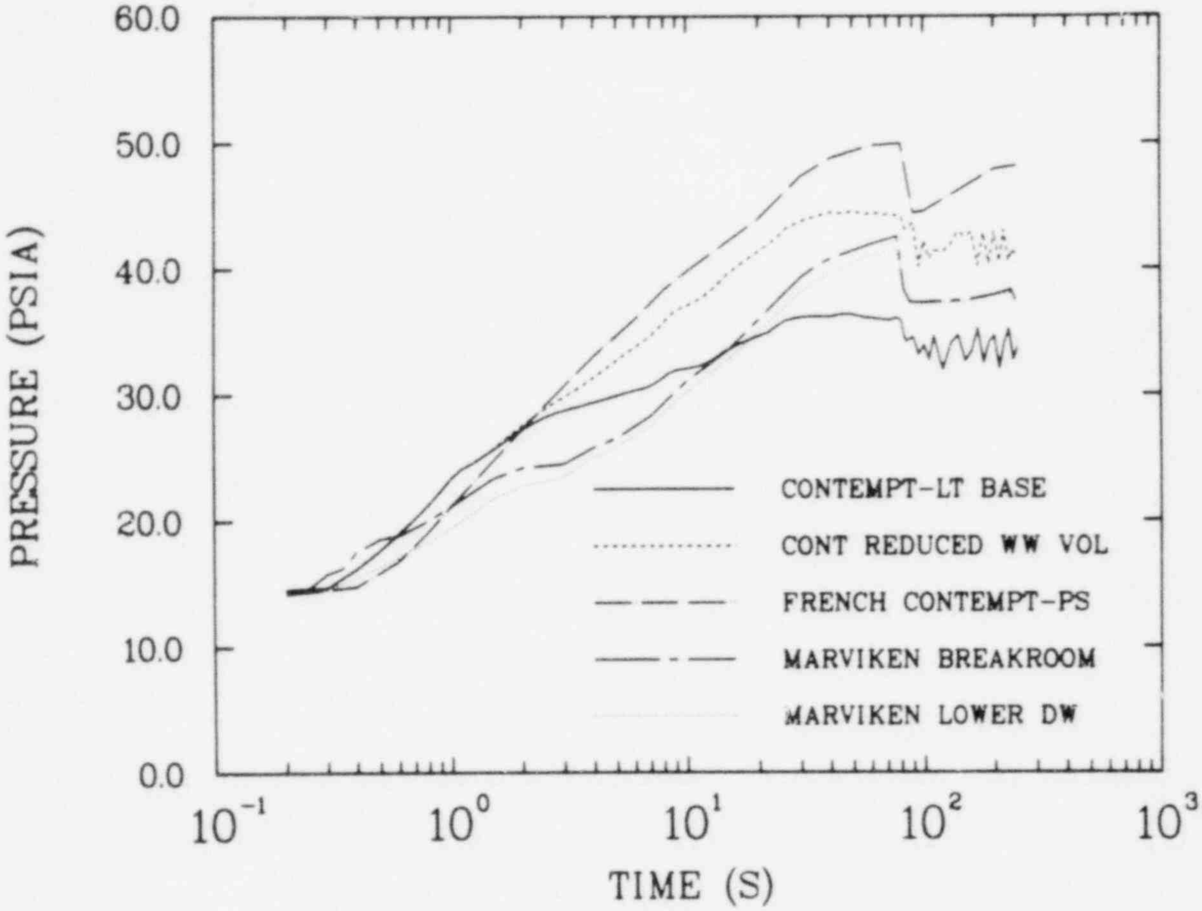

Fig. 3. Comparison of Marviken Blowdown 11 drywell pressures for

1. CONTEMPT-LT base case,
2. CONTEMPT-LT with wetwell volume reduced to same value used in French work,[29]
3. CONTEMPT-PS results from French work,
4. Marviken breakroom data, and
5. Marviken lower drywell data.

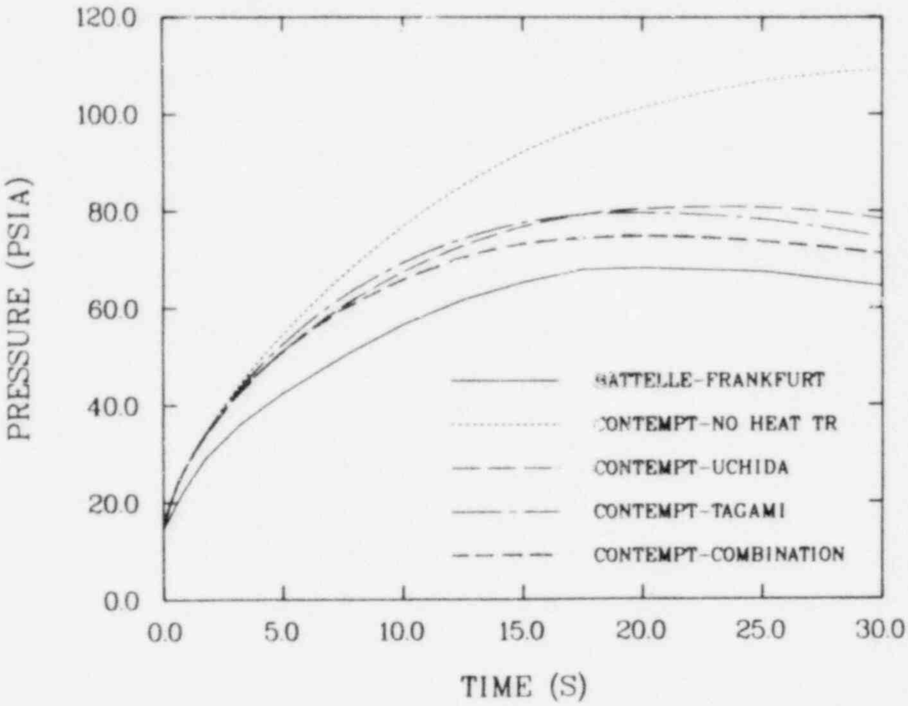

Fig. 4. Comparison of Battelle-Frankfurt Test C5 containment pressures with CONTEMPT-LT calculations for various heat transfer assumptions.

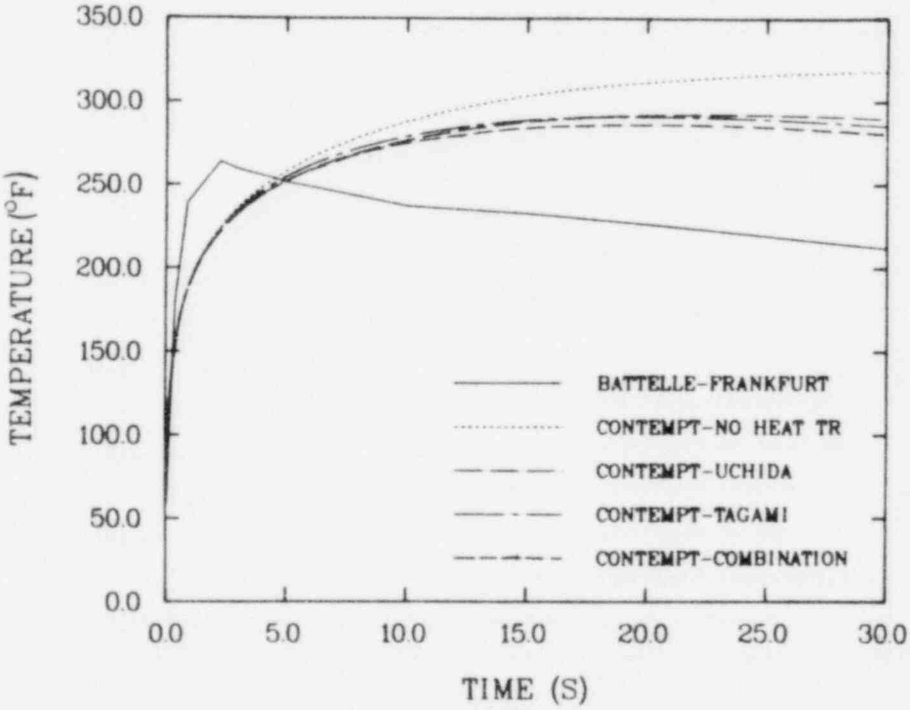

Fig. 5. Comparison of Battelle-Frankfurt Test C5 containment temperatures with CONTEMPT-LT calculations for various heat transfer assumptions.

TABLE I

MARVIKEN BLOWDOWNS MODELED WITH CONTEMPT-LT

Blowdown Number	Type of Break	Vent Submergence	Number of Open Vent Pipes	Initial Pool Temperature
10	Steam + Feedwater Pipes	9.19 ft	57	61.9°F
11	Steam + Feedwater Pipes	9.32 ft	38	63.9°F
14	Steam + Feedwater Pipes	9.25 ft	26	114.4°F
15	Feedwater Pipe	9.45 ft	26	63.7°F
16	Steam + Feedwater Pipes	5.38 ft	26	56.5°F

TABLE II

MARVIKEN BLOWDOWN 10 COMPARISON OF DATA AND CONTEMPT-LT OUTPUT

QUANTITY	0 s	1.0 s	10 s	50 s	100 s	480 s
DRYWELL PRESSURE (psia)						
1. Marviken Upper Drywell	14.94	19.44	31.47	40.32	36.99	40.32
2. Marviken Breakroom	14.94	22.77	32.78	41.19	37.57	40.61
3. Marviken Lower Drywell	14.94	20.74	31.33	40.03	37.13	40.32
4. Marviken Header	14.94	20.74	30.46	40.90	36.84	40.61
5. CONTEMPT-LT	14.94	24.01	33.66	36.19	33.41	35.00
WETWELL PRESSURE (psia)						
1. Marviken	14.94	15.08	24.66	32.05	32.63	35.24
2. CONTEMPT-LT	14.94	14.94	28.24	31.04	31.04	31.07
VENT FLOW RATE (lbm/s)						
1. Marviken	0	0	583	964	162	182
2. CONTEMPT-LT	0	0	1144	1156	878	0
DRYWELL ATMOSPHERIC TEMP. (^{O}F)						
1. Marviken Breakroom	128.30	232.70	253.40	266.90	260.60	266.00
2. Marviken Header	60.80	73.40	246.20	267.80	264.20	271.40
3. CONTEMPT-LT	118.60	181.94	251.48	261.25	256.56	259.28
WETWELL POOL TEMP. (^{O}F)						
1. Marviken	61.90	61.90	63.88	93.63	103.15	147.51
2. CONTEMPT-LT	61.90	61.90	67.87	104.45	117.00	174.20
WETWELL ATMOSPHERIC TEMP. (^{O}F)						
1. Marviken	60.30	61.16	81.14	128.12	162.32	107.42
2. CONTEMPT-LT	60.30	60.30	61.84	62.79	62.81	63.10
DRYWELL-WETWELL ΔP (psi)						
1. Using Marviken Breakroom Pressure	0.00	7.69	8.12	9.14	4.94	5.37
2. Using Marviken Lower Drywell Pressure	0.00	5.66	6.67	7.98	4.50	5.08
3. Using Marviken Header Pressure	0.00	5.66	5.80	8.85	4.21	5.37
4. CONTEMPT-LT	0.00	9.07	5.42	5.15	2.37	3.93

TABLE III

MARVIKEN BLOWDOWN 11 COMPARISON OF DATA AND CONTEMPT-LT OUTPUT

QUANTITY	0 s	1.0 s	10 s	77 s	100 s	250 s
DRYWELL PRESSURE (psia)						
1. Marviken Upper Drywell	14.50	18.42	30.02	41.77	37.13	36.84
2. Marviken Breakroom	14.50	21.18	31.04	42.50	37.28	36.99
3. Marviken Lower Drywell	14.50	19.44	30.17	41.48	37.13	36.99
4. Marviken Header	14.50	19.44	29.73	38.44	37.42	36.99
5. CONTEMPT-LT	14.50	23.46	34.14	36.15	34.50	32.96
WETWELL PRESSURE (psia)						
1. Marviken	14.36	14.36	23.21	31.91	32.49	32.63
2. CONTEMPT-LT	14.36	14.36	27.63	30.23	30.24	30.25
VENT FLOW RATE (lbm/s)						
1. Marviken	0	0	583	1275	306	217
2. CONTEMPT-LT	0	0	1053	906	0	0
DRYWELL ATMOSPHERIC TEMP. (^{o}F)						
1. Marviken Breakroom	131.90	229.10	252.50	268.16	261.50	262.40
2. Marviken Header	60.80	69.80	237.20	265.64	262.40	264.20
3. CONTEMPT-LT	115.70	180.94	252.79	261.20	258.44	255.77
WETWELL POOL TEMP. (^{o}F)						
1. Marviken	63.90	63.90	65.52	109.35	114.82	134.08
2. CONTEMPT-LT	63.90	63.90	70.55	126.95	134.02	157.63
WETWELL ATMOSPHERIC TEMP. (^{o}F)						
1. Marviken	60.30	60.30	78.62	124.18	122.72	109.22
2. CONTEMPT-LT	60.30	60.30	62.93	64.00	64.02	64.13
DRY' ELL-WETWELL ΔP (psi)						
1. Using Marviken Breakroom Pressure	0.14	6.82	7.83	10.59	4.79	4.36
2. Using Marviken Lower Drywell Pressure	0.14	5.08	6.96	9.57	4.64	4.36
3. Using Marviken Header Pressure	0.14	5.08	6.52	6.53	4.93	4.36
4. CONTEMPT-LT	0.14	9.10	6.51	5.92	4.26	2.71

TABLE IV

MARVIKEN BLOWDOWN 14 COMPARISON OF DATA AND CONTEMPT-LT OUTPUT

QUANTITY	0 s	1.0 s	10 s	78 s	100 s	180 s
DRYWELL PRESSURE (psia)						
1. Marviken Upper Drywell	14.79	18.71	30.60	43.80	39.02	39.02
2. Marviken Breakroom	14.79	20.60	31.47	44.09	39.02	38.87
3. Marviken Lower Drywell	14.79	19.58	30.60	43.22	38.73	38.73
4. Marviken Header	14.79	19.44	29.73	42.21	38.73	38.87
5. CONTEMPT-LT	14.79	23.47	35.23	40.25	36.39	36.06
WETWELL PRESSURE (psia)						
1. Marviken	14.65	14.65	23.79	34.08	34.23	34.23
2. CONTEMPT-LT	14.65	14.65	27.75	32.47	32.47	32.48
VENT FLOW RATE (lbm/s)						
1. Marviken	0	0	464	1022	397	127
2. CONTEMPT-LT	0	0	858	961	378	134
DRYWELL ATMOSPHERIC TEMP. (°F)						
1. Marviken Breakroom	116.60	222.80	251.60	268.79	262.40	263.30
2. Marviken Header	82.40	86.00	226.40	269.60	266.00	268.16
3. CONTEMPT-LT	112.30	178.71	251.31	257.56	261.59	261.05
WETWELL POOL TEMP. (°F)						
1. Marviken	114.40	114.40	115.97	153.21	160.70	170.20
2. CONTEMPT-LT	114.40	114.40	118.91	168.50	173.22	184.49
WETWELL ATMOSPHERIC TEMP. (°F)						
1. Marviken	89.20	89.20	109.22	137.30	140.72	137.84
2. CONTEMPT-LT	89.20	89.20	101.39	104.55	104.57	104.62
DRYWELL-WETWELL ΔP (psi)						
1. Using Marviken Breakroom Pressure	0.14	5.95	7.68	10.01	4.79	4.64
2. Using Marviken Lower Drywell Pressure	0.14	4.93	6.81	9.14	4.50	4.50
3. Using Marviken Header Pressure	0.14	4.79	5.94	8.13	4.50	4.64
4. CONTEMPT-LT	0.14	8.82	7.48	7.78	3.92	3.58

TABLE V

MARVIKEN BLOWDOWN 15 COMPARISON OF DATA AND CONTEMPT-LT OUTPUT

QUANTITY	0 s	2 s	20 s	100 s	400 s	800 s
DRYWELL PRESSURE (psia)						
1. Marviken Upper Drywell	17.98	19.44	25.38	35.53	39.02	41.70
2. Marviken Breakroom	17.98	19.51	25.53	35.68	39.09	41.70
3. Marviken Lower Drywell	17.98	19.44	25.38	35.24	38.87	41.55
4. Marviken Header	17.98	19.36	25.53	35.54	38.51	41.92
5. CONTEMPT-LT	17.98	21.93	27.60	36.86	37.40	38.79
WETWELL PRESSURE (psia)						
1. Marviken	17.55	17.55	20.89	31.04	34.16	36.40
2. CONTEMPT-LT	17.55	17.55	23.05	33.34	33.88	33.95
VENT FLOW RATE (lbm/s)						
1. Marviken	0	4	106	132	192	184
2. CONTEMPT-LT	0	0	260	403	350	0
DRYWELL ATMOSPHERIC TEMP. (°F)						
1. Marviken Breakroom	167.00	201.65	239.00	257.90	264.20	268.25
2. Marviken Header	68.00	69.80	152.60	253.40	267.80	272.30
3. CONTEMPT-LT	139.10	170.27	217.25	261.42	263.21	265.40
WETWELL POOL TEMP. (°F)						
1. Marviken	63.70	63.70	63.70	68.67	105.12	152.71
2. CONTEMPT-LT	63.70	63.70	64.52	78.67	128.41	180.13
WETWELL ATMOSPHERIC TEMP. (°F)						
1. Marviken	69.00	69.00	73.58	118.40	106.64	112.82
2. CONTEMPT-LT	69.00	69.00	68.57	68.63	68.93	69.77
DRYWELL-WETWELL ΔP (psi)						
1. Using Marviken Breakroom Pressure	0.43	1.96	4.64	4.64	4.93	5.30
2. Using Marviken Lower Drywell Pressure	0.43	1.89	4.49	4.20	4.71	5.15
3. Using Marviken Header Pressure	0.43	1.81	4.64	4.50	4.35	5.52
4. CONTEMPT-LT	0.43	4.38	4.55	3.52	4.63	4.84

TABLE VI

MARVIKEN BLOWDOWN 16 COMPARISON OF DATA AND CONTEMPT-LT OUTPUT

QUANTITY	0 s	0.5 s	10 s	78.1 s	100.1 s	284.1 s
DRYWELL PRESSURE (psia)						
1. Marviken Upper Drywell	15.95	18.20	30.28	41.77	35.39	36.45
2. Marviken Breakroom	15.95	21.25	31.31	42.35	35.53	36.59
3. Marviken Lower Drywell	15.95	19.51	30.42	41.48	35.43	36.59
4. Marviken Header	15.95	18.93	38.75	38.58	37.74	35.38
5. CONTEMPT-LT	15.95	21.44	33.55	37.77	32.42	31.84
WETWELL PRESSURE (psia)						
1. Marviken	15.81	15.81	24.65	32.05	32.38	33.40
2. CONTEMPT-LT	15.81	15.81	27.06	30.07	30.07	30.11
VENT FLOW RATE (lbm/s)						
1. Marviken	0	0	550	969	389	227
2. CONTEMPT-LT	0	0	897	1103	281	317
DRYWELL ATMOSPHERIC TEMP. ($^{\circ}$F)						
1. Marviken Breakroom	123.80	221.90	251.42	265.82	257.32	258.81
2. Marviken Header	68.00	68.00	238.37	266.36	260.60	262.42
3. CONTEMPT-LT	121.80	170.68	250.23	263.80	254.81	253.76
WETWELL POOL TEMP. ($^{\circ}$F)						
1. Marviken	56.50	56.50	59.57	115.41	127.51	158.83
2. CONTEMPT-LT	56.50	56.50	64.20	140.13	148.02	183.95
WETWELL ATMOSPHERIC TEMP. ($^{\circ}$F)						
1. Marviken	67.10	67.10	91.09	129.02	127.42	113.90
2. CONTEMPT-LT	67.10	67.10	65.68	66.21	66.23	66.67
DRYWELL-WETWELL ΔP (psi)						
1. Using Marviken Breakroom Pressure	0.14	5.44	6.66	10.30	3.15	3.19
2. Using Marviken Lower Drywell Pressure	0.14	3.70	5.77	9.43	3.05	3.19
3. Using Marviken Header Pressure	0.14	3.12	4.10	6.53	5.36	1.98
4. CONTEMPT-LT	0.14	5.63	6.49	7.70	2.35	1.73

TABLE VII

MARVIKEN BASIC BLOWDOWN STUDIES

PEAK PRESSURES (psia) AND MAXIMUM PRESSURE DIFFERENCES

LOCATION	Blowdown 10	Blowdown 11	Blowdown 14	Blowdown 15	Blowdown 16
DRYWELL ATMOSPHERE					
1. Marviken Upper Drywell	40.32	41.77	43.80	41.70	41.77
2. Marviken Breakroom	41.19	42.50	44.09	41.70	42.35
3. Marviken Lower Drywell	40.32	41.48	43.22	41.55	41.48
4. Marviken Header	40.90	38.73	42.21	41.92	38.58
5. CONTEMPT-LT	36.36	37.02	40.71	38.79	38.28
WETWELL ATMOSPHERE					
1. Marviken	35.24	32.92	34.23	36.40	33.40
2. CONTEMPT-LT	31.07	30.25	32.48	33.95	30.11
DRYWELL MINUS WETWELL					
1. Based on MarViken Breakroom	9.57	11.17	11.17	5.30	11.31
2. Based on Marviken Lower Drywell	8.27	10.01	10.15	5.15	10.15
3. Based on Marviken Header	8.85	9.57	8.41	5.52	7.25
4. CONTEMPT-LT	10.21	10.04	10.15	4.84	10.26

TABLE VIII

MARVIKEN BASIC BLOWDOWN STUDIES

INITIAL VENT CLEARING TIMES (s)

AND PEAK VENT FLOW RATES (lbm/s)

QUANTITY	Blowdown 10	Blowdown 11	Blowdown 14	Blowdown 15	Blowdown 16
INITIAL VENT CLEARING TIME					
1. Marviken	0.98	1.05	1.20	13.20	0.70
2. CONTEMPT-LT	1.13	1.05	1.08	9.03	0.60
PEAK VENT FLOW RATE					
1. Marviken	1169.	1278.	1022.	325.	1189.
2. CONTEMPT-LT	2269.	1517.	1067.	558.	1175.

TABLE IX

MARVIKEN BASIC BLOWDOWN STUDIES

PEAK TEMPERATURES (°F)

LOCATION	Blowdown 10	Blowdown 11	Blowdown 14	Blowdown 15	Blowdown 16
DRYWELL ATMOSPHERE					
1. Marviken Breakroom	285.80	269.60	270.50	268.25	268.70
2. Marviken Header	271.40	266.00	269.60	272.30	267.80
3. CONTEMPT-LT	261.53	262.46	268.23	265.40	264.51
WETWELL POOL					
1. Marviken	147.51	134.08	170.20	152.71	156.83
2. CONTEMPT-LT	174.20	157.63	184.49	180.13	183.95
WETWELL ATMOSPHERE					
1. Marviken	128.12	124.88	140.90	119.30	130.64
2. CONTEMPT-LT	63.10	64.13	104.62	69.77	67.10

TABLE X

EFFECT OF HEAT TRANSFER ON

PEAK DRYWELL PRESSURES (psia)

FOR FIVE MARVIKEN BLOWDOWNS

LOCATION	Blowdown 10	Blowdown 11	Blowdown 14	Blowdown 15	Blowdown 16
Marviken Breakroom	41.19	42.50	44.09	41.70	42.35
Marviken Lower Drywell	40.32	41.48	43.22	41.55	41.48
CONTEMPT-LT without Heat Transfer	36.36	37.02	40.71	38.79	38.28
CONTEMPT-LT with Heat Transfer	36.23	36.35	39.84	37.88	37.29

TABLE XI

CONTEMPT-LT PARAMETER STUDIES FOR MARVIKEN BLOWDOWN 14

Case	Description
1	Base case
2	Base case with time steps cut in half
3	Vent closing and opening parameters changed from 0.0 to 1.0
4	Vent closing parameter changed to 0.5; vent opening parameter changed to 1.0
5	Roughness factor increased 50% in vent pipe to 0.0075 ft
6	Entrance loss coefficient from drywell to vent doubled to 1.00
7	Number of pipe elements in vent doubled from 10 to 20 (also cuts vent element lengths in half)
8	Decrease drywell compartment volume by volume of upper drywell from 67 913 to 44 684 ft^3
9	Heat sinks
10	Number of vents increased arbitrarily from 26 to 38
11	Change multiplier on $(C_p - C_v)$ difference term for air energy transport through the wetwell pool to atmosphere region from 0.0 to 1.0 and multiplier on $(T_{v_3} - T_{\ell_2})$ difference term from 0.0 to 1.0
12	Change vent submergence depth arbitrarily from 9.25 to 5.38 ft. This requires initial wetwell pool volume to be changed from 19 638 to 14 552 ft^3
13	No pressure-suppression system and no heat transfer
14	No pressure-suppression system with heat transfer
15	Water carry-over fraction of 0.75
16	Water carry-over fraction of 0.50
17	Water carry-over fraction of 0.25
18	With condensed mass removal
19	Wetwell heat transfer coefficient multiplier between wetwell pool and vapor region increased from 1.0 to 100.0

TABLE XII

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

DRYWELL PRESSURES (psia)

Time	0	1 s	10 s	78 s	100 s	180 s
Marviken Upper Drywell	14.79	18.71	30.60	43.80	39.02	39.02
Marviken Breakroom	14.79	20.60	31.47	44.09	39.02	38.87
Marviken Lower Drywell	14.79	19.58	30.60	43.22	38.73	38.73
Marviken Header	14.79	19.44	29.73	42.21	38.73	38.87
CONTEMPT-LT Case 1	14.79	23.47	35.23	40.25	36.39	36.06
2	14.79	23.48	35.20	40.02	36.57	36.16
3	14.79	23.47	35.23	40.13	36.22	36.06
4	14.79	23.47	35.23	40.22	36.33	35.91
5	14.79	23.47	35.23	40.23	36.46	35.99
6	14.79	23.47	36.17	41.23	36.72	36.35
7	14.79	23.47	35.23	40.27	37.00	36.00
8	14.79	27.07	33.33	35.51	31.14	29.86
9	14.79	23.41	32.51	39.82	36.88	35.96
10	14.79	23.45	33.84	38.04	35.92	35.35
11	14.79	23.47	40.61	51.19	48.33	48.61
12	14.79	22.84	33.43	37.62	33.56	33.57
13	14.79	23.52	80.27	335.60	349.70	383.00
14	14.79	23.45	69.06	237.55	235.09	250.71
15	14.79	23.47	35.20	39.96	36.22	36.06
16	14.79	23.47	35.20	39.81	36.90	36.11
17	14.79	23.47	35.18	39.73	36.22	35.93
18	14.79	23.41	32.50	39.63	36.19	36.06
19	14.79	23.47	35.24	40.32	37.12	36.50

TABLE XIII

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

WETWELL ATMOSPHERIC PRESSURES

(psia)

Time	0	1 s	10 s	78 s	100 s	180 s
Marviken	14.65	14.65	23.79	34.08	34.23	34.23
CONTEMPT-LT Case 1	14.65	14.65	27.75	32.47	32.47	32.48
2	14.65	14.65	27.75	32.47	32.47	32.48
3	14.65	14.65	27.75	32.47	32.47	32.48
4	14.65	14.65	27.75	32.47	32.47	32.48
5	14.65	14.65	27.75	32.47	32.47	32.48
6	14.65	14.65	27.40	32.47	32.47	32.48
7	14.65	14.65	27.75	32.47	32.47	32.48
8	14.65	14.72	25.13	26.35	26.35	26.36
9	14.65	14.65	26.90	32.46	32.46	32.47
10	14.65	14.65	28.30	32.46	32.46	32.47
11	14.65	14.65	34.37	44.83	44.84	44.84
12	14.65	15.05	27.16	31.01	31.01	31.02
13	-----	-----	-----	-----	-----	-----
14	-----	-----	-----	-----	-----	-----
15	14.65	14.65	27.75	32.47	32.47	32.48
16	14.65	14.65	27.76	32.47	32.47	32.48
17	14.65	14.65	27.76	32.47	32.47	32.48
18	14.65	14.65	26.90	32.46	32.46	32.47
19	14.65	14.65	27.75	32.57	32.62	32.83

TABLE XIV

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

PRESSURE DIFFERENCES (psi) BETWEEN DRYWELL AND WETWELL

Time	0	1 s	10 s	78 s	100 s	180 s
Marviken Breakroom	0.14	5.95	7.69	10.01	4.79	4.64
Marviken Lower Drywell	0.14	4.93	6.82	9.14	4.50	4.50
CONTEMPT-LT Case 1	0.14	8.82	7.48	7.78	3.92	3.58
2	0.14	8.83	7.45	7.55	4.10	3.68
3	0.14	8.82	7.48	7.66	3.75	3.58
4	0.14	8.82	7.48	7.75	3.86	3.43
5	0.14	8.82	7.48	7.76	3.99	3.51
6	0.14	8.82	8.77	8.76	4.25	3.87
7	0.14	8.82	7.48	7.80	4.53	3.52
8	0.14	12.35	8.20	9.16	4.79	3.50
9	0.14	8.76	5.61	7.36	4.42	3.49
10	0.14	8.80	5.54	5.58	3.46	2.88
11	0.14	8.82	6.24	6.36	3.49	3.77
12	0.14	7.79	6.27	6.61	2.55	2.55
13	----	----	----	----	----	----
14	----	----	----	----	----	----
15	0.14	8.82	7.45	7.49	3.75	3.58
16	0.14	8.82	7.44	7.34	4.43	3.63
17	0.14	8.82	7.4[illegible]	7.26	3.75	3.45
18	0.14	8.76	5.60	7.17	3.73	3.59
19	0.14	8.82	7.49	7.75	4.50	3.67

TABLE XV

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

VENT FLOW RATES (lbm/s)

Time	0	1 s	10 s	78 s	100 s	180 s
Marviken	0	0	464	1022	397	127
CONTEMPT-LT Case 1	0	0	858	961	378	134
2	0	0	847	903	198	0
3	0	0	858	983	386	0
4	0	0	858	958	383	173
5	0	0	858	978	193	0
6	0	0	858	917	176	0
7	0	0	858	972	0	0
8	0	1175	889	1089	0	0
9	0	0	608	908	0	0
10	0	0	856	978	389	0
11	0	0	758	908	372	0
12	0	942	878	983	156	0
13	—	—	—	—	—	—
14	---	---	---	---	---	---
15	0	0	858	936	381	135
16	0	0	847	897	0	0
17	0	0	847	856	394	168
18	0	0	600	908	322	0
19	0	0	858	964	0	0

TABLE XVI

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

DRYWELL ATMOSPHERIC TEMPERATURES (^{O}F)

Time	0	1 s	10 s	78 s	100 s	180 s
Marviken Breakroom	116.60	222.80	251.60	268.79	262.40	263.30
Marviken Header	82.40	86.00	226.40	269.60	266.00	267.73
CONTEMPT-LT Case 1	112.30	178.71	251.31	267.56	261.59	261.05
2	112.30	178.74	251.24	267.28	261.89	261.21
3	112.30	178.71	251.31	267.44	261.30	261.04
4	112.30	178.71	251.31	267.58	261.49	260.80
5	112.30	178.71	251.30	267.60	261.70	260.94
6	112.30	178.71	252.39	269.09	262.13	261.53
7	112.30	178.71	251.31	267.66	262.58	260.94
8	112.30	196.02	253.10	260.13	252.48	250.07
9	112.30	178.39	244.34	266.97	262.38	260.88
10	112.30	178.68	249.75	264.23	260.82	259.88
11	112.30	178.71	258.56	282.50	278.67	279.24
12	112.30	177.46	248.93	263.57	256.82	256.84
13	112.30	178.82	293.94	421.32	425.39	434.49
14	112.30	178.44	281.33	388.32	387.35	393.34
15	112.30	178.71	251.27	267.18	261.30	261.05
16	112.30	178.71	251.27	266.97	262.41	261.13
17	112.30	178.71	251.25	266.84	261.30	260.84
18	112.30	178.38	244.33	266.69	261.26	261.04
19	112.30	178.71	251.32	267.74	262.78	261.76

TABLE XVII

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

WETWELL POOL TEMPERATURES ($^{\circ}F$)

Time	0	1 s	10 s	78 s	100 s	180 s
Marviken	114.40	114.40	115.97	153.21	160.70	170.20
CONTEMPT-LT Case 1	114.40	114.40	118.91	168.50	173.22	184.49
2	114.40	114.40	118.91	168.23	172.91	184.22
3	114.40	114.40	118.91	168.52	173.24	184.48
4	114.40	114.40	118.91	168.50	173.22	184.50
5	114.40	114.40	118.91	168.50	173.21	184.49
6	114.40	114.40	118.80	168.10	172.88	184.16
7	114.40	114.40	118.91	168.48	173.13	184.48
8	114.40	114.41	120.00	171.57	177.01	188.82
9	114.40	114.40	117.98	159.42	163.54	173.83
10	114.40	114.40	119.06	169.29	173.82	185.11
11	114.40	114.40	118.13	164.82	169.22	179.88
12	114.40	114.44	120.75	187.13	193.34	208.15
13	----	----	----	----	----	----
14	----	----	----	----	----	----
15	114.40	114.40	118.91	168.36	173.07	184.34
16	114.40	114.40	118.90	168.22	172.84	184.19
17	114.40	114.40	118.90	168.07	172.77	184.08
18	114.40	114.40	117.98	159.42	163.60	173.80
19	114.40	114.40	118.91	168.49	173.13	184.41

TABLE XVIII

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

WETWELL ATMOSPHERIC TEMPERATURES (^{o}F)

Time	0	1 s	10 s	78 s	100 s	180 s
Marviken	89.20	89.20	109.22	137.30	140.72	137.84
CONTEMPT-LT Case 1	89.20	89.20	101.39	104.55	104.57	104.62
2	89.20	89.20	101.40	104.57	104.58	104.64
3	89.20	89.20	101.39	104.55	104.57	104.62
4	89.20	89.20	101.39	104.55	104.57	104.62
5	89.20	89.20	101.39	104.55	104.57	104.62
6	89.20	89.20	101.22	104.64	104.65	104.71
7	89.20	89.20	101.39	104.55	104.57	104.62
8	89.20	89.32	99.97	101.01	101.03	101.10
9	89.20	89.20	100.85	104.47	104.48	104.53
10	89.20	89.20	101.66	104.40	104.42	104.47
11	89.20	89.20	267.04	319.55	319.56	319.52
12	89.20	89.84	101.31	104.38	104.40	104.47
13	----	----	----	----	----	----
14	----	----	----	----	----	----
15	89.20	89.20	101.40	104.54	104.56	104.61
16	89.20	89.20	101.40	104.54	104.55	104.60
17	89.20	89.20	101.40	104.53	104.54	104.60
18	89.20	89.20	100.85	104.47	104.48	104.52
19	89.20	89.22	101.49	106.28	107.21	110.76

TABLE XIX

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

PEAK PRESSURES (psia) AND MAXIMUM PRESSURE DIFFERENCES

	Drywell	Drywell-Wetwell	Wetwell
Drywell P Based on Marviken Upper Drywell	43.80	10.59	34.23
Drywell P Based on Marviken Breakroom	44.09	11.17	
Drywell P Based on Marviken Lower Drywell	43.22	10.15	
Drywell P Based on Marviken Header	42.21	8.41	
CONTEMPT-LT CASE 1	40.71	10.15	32.48
2	40.36	10.15	32.48
3	40.63	10.15	32.48
4	40.65	10.15	32.48
5	40.70	10.16	32.48
6	41.94	10.94	32.48
7	40.61	10.15	32.48
8	36.34	12.70	26.36
9	39.84	9.94	32.47
10	38.38	9.60	32.47
11	51.45	9.65	44.84
12	38.09	8.82	31.02
13	383.00	----	----
14	250.79	----	----
15	40.53	10.15	32.48
16	40.35	10.15	32.48
17	40.09	10.15	32.48
18	39.86	9.94	32.47
19	40.68	10.15	32.83

TABLE XX

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

INITIAL VENT CLEARING TIMES (s)

AND PEAK VENT FLOW RATES (lbm/s)

	INITIAL VENT CLEARING TIME	PEAK VENT FLOW RATE
Marviken	1.20	1022
CONTEMPT-LT CASE 1	1.0836	1067
2	1.0834	1036
3	1.0836	1067
4	1.0836	1067
5	1.0847	1067
6	1.0836	1050
7	1.0836	1067
8	0.9765	1206
9	1.0845	1017
10	1.0865	1433
11	1.0836	1000
12	0.8419	1089
13	---	--
14	---	--
15	1.0836	1036
16	1.0836	1036
17	1.0836	1036
18	1.0845	1017
19	1.0836	1067

TABLE XXI

MARVIKEN BLOWDOWN 14 PARAMETER STUDIES

PEAK TEMPERATURES (°F)

	DRYWELL ATMOSPHERE	WETWELL POOL	WETWELL ATMOSPHERE
Marviken	270.50	170.20	140.90
CONTEMPT-LT CASE 1	268.23	184.49	104.62
2	267.70	184.22	104.64
3	268.15	184.48	104.62
4	268.15	184.50	104.62
5	268.22	184.49	104.62
6	269.95	184.16	104.71
7	268.12	184.48	104.62
8	261.37	188.82	101.10
9	266.99	173.83	104.53
10	264.72	185.11	104.47
11	282.82	179.86	319.56
12	264.19	208.15	104.47
13	434.49	---	---
14	393.37	---	---
15	267.92	184.34	104.61
16	267.74	184.19	104.60
17	267.31	184.08	104.60
18	267.04	173.80	104.52
19	268.19	184.41	110.76

TABLE XXII

RATIO OF MARK I, II, AND III

GEOMETRIC QUANTITIES TO CORRESPONDING MARVIKEN QUANTITIES

Quantity	Mark I	Mark II	Mark III
Total wetwell volume	3.29	2.58	15.47
Initial volume of wetwell pool	5.98	5.19	6.63
Wetwell horizontal area	8.52	4.01	5.51
Total drywell volume	2.41	2.65	4.04
Drywell horizontal area	1.71	3.75	0.38
Initial vent submergence	0.43	1.08	----
Total vent area	12.70	13.13	----

TABLE XXIII

LOFT TEST L1-3A COMPARISON OF EXPERIMENTAL DATA WITH CONTEMPT-LT RESULTS

QUANTITY	VALUE
PEAK DRYWELL PRESSURE (psia)	
1. LOFT Drywell Position 1	5[illegible].00
2. LOFT Drywell Position 4	67.00
3. CONTEMPT-LT	32.94
PEAK WETWELL PRESSURE (psia)	
1. LOFT Wetwell Position 1	41.90
2. LOFT Wetwell Position 4	[illegible]2.40
3. CONTEMPT-LT	31.14
PEAK WETWELL ATMOSPHERIC TEMP. (°F)	
1. LOFT	183.00
2. CONTEMPT-LT	180.00
PEAK WETWELL POOL TEMP. (°F)	
1. LOFT	156.50
2. CONTEMPT-LT	164.94

TABLE XXIV

BATTELLE-FRANKFURT TEST C5 PEAK PRESSURES AND TEMPERATURES

SOURCE	PEAK PRESSURE (psia)	PEAK TEMPERATURE (°F)
1. BATTELLE-FRANKFURT DATA	68.17	263.80
2. CONTEMPT-LT		
a. No heat transfer	109.16	318.28
b. Uchida heat transfer	80.83	292.33
c. Tagami heat transfer until end of blowdown	79.59	291.00
d. Uchida heat transfer with condensation mass removal	80.77	292.33
e. Tagami heat transfer until peak pressure then exponential decay to Uchida heat transfer	75.12	286.03

TABLE XXV

BATTELLE-FRANKFURT TEST C5

PRESSURES AND TEMPERATURES

QUANTITY	0	2.25 s	10 s	20 s	30 s
PRESSURE (psia)					
1. Battelle-Frankfurt	14.86	31.43	56.57	68.17	64.54
2. CONTEMPT-LT					
a. No heat transfer	14.86	37.66	76.88	101.39	109.16
b. Uchida heat transfer	14.86	36.84	67.42	80.37	78.37
c. Tagami heat transfer until end of blowdown	14.86	37.32	69.32	79.59	74.61
d. Uchida heat transfer with condensation mass removal	14.86	36.84	67.42	80.38	78.43
e. Tagami heat transfer until peak pressure then exponential decay to Uchida heat transfer	14.86	37.09	66.21	75.08	71.70
TEMPERATURE (°F)					
1. Battelle-Frankfurt	59.00	263.80	237.20	226.40	212.00
2. CONTEMPT-LT					
a. No heat transfer	59.00	223.41	288.02	311.75	318.25
b. Uchida heat transfer	59.00	221.25	276.70	291.83	289.67
c. Tagami heat transfer until end of blowdown	59.00	222.52	279.11	291.00	285.46
d. Uchida heat transfer with condensation mass removal	59.00	221.25	276.70	291.85	289.83
e. Tagami heat transfer until peak pressure then exponential decay to Uchida heat transfer	59.00	221.91	275.14	285.98	282.03

APPENDIX A

SUMMARY OF MARVIKEN BLOWDOWNS

Marviken Blowdowns 10, 11, 14, 15, and 16 are briefly summarized in the tables that follow. These summaries are based on the Marviken blowdown reports, Refs. 12, 13, 16, 17, and 18.

For the initial pressure vessel conditions, the water mass includes the water mass in the pressure vessel and in the steam and water pipes down to the valves. The steam mass is contained in the space above the water level in the pressure vessel.

TABLE A-I

SUMMARY OF MARVIKEN BLOWDOWN CHARACTERISTICS - BREAK

Blowdown Number	10	11	14	15	16
Initial Pressure Vessel Conditions					
P(psia)	739.7	739.7	694.7	723.7	722.3
T_{steam} (^{o}F)	509	510	496	502	500
T_{water} (^{o}F)	493-511	495-509	487-498	493-504	491-502
Steam mass (10^3 lbm)	3.53	3.53	3.09	3.09	1.32
Water mass (10^3 lbm)	642	642	650	631	705
Room 124, Upper Drywell					
Orifice diam (ft)	0.656	0.656	0.295	0.295	0.295
Time open (s)	None	None	None	Open and closed	Leakage only
Room 122, Lower Drywell (Steam Pipe)					
Orifice diam (ft)	1.083	1.083	1.083	1.083	1.083
Time open(s)	0-57	0-80	0-82	None	0-83

TABLE A-I (cont)

Blowdown Number	10	11	14	15	16
Room 122, Lower Drywell (Feedwater Pipe)					
Orifice diam (ft)	0.492	0.492	0.492	0.492	0.492
Time open(s)	4-486	4-240	4-180	12-2000	10-283
Max. Total Flow (10^3 lbm/s)	8.04	6.83	8.04	1.43	7.49
Water Mass Discharged (10^3 lbm)	529	408	344	617	441

TABLE A-II

SUMMARY OF MARVIKEN BLOWDOWN

CHARACTERISTICS - DRYWELL, VENTS, AND WETWELL

Blowdown Number	10	11	14	15	16
Drywell					
Max. Press. (psia)	40.6	42.1	43.5	45.0	42.1
Max. Press. Diff. Between Drywell Rooms (psi)	3.9	2.9	3.6	0.7	2.9
Max. Temp. (^oF)	262-273	248	271	279	271
% of Energy Released from Vessel Stored in Drywell	53	50	52	53 for first 800s	48
Vents					
Initial Vent Submergence Depth (ft)	9.19	9.32	9.25	9.45	5.38
Total Open Vent Flow Area (ft^2)	43.4	28.9	19.8	19.8	19.[illegible]
Wetwell					
Steam & Water Mass Transferred to Wetwell (10^3 lbm)	126	121	88	137	119
Max. Press. (psia)	34.8	33.4	34.1	39.2	33.4
Initial Pool Temp. (^oF)	62	64	114	64	57
Max. Pool Temp. (^oF)	147	104	171	189	158
Max. Air Space Temp. (^oF)	158	122	176	138	154

TABLE A-III

SUMMARY OF MARVIKEN BLOWDOWN

CHARACTERISTICS - ADDITIONAL INFORMATION

Blowdown	Time when sprays turned on (s)	Time When Drain Pipe[a] open (s)	Comments[b]
10	None	900	Leakage of 33-44 lbm/s after blowdown. Wetwell water temp. varied up to 18° F with position.
11	1200	1000	None
14	650	286	Leakage of 33-44 lbm/s after blowdown. Wetwell water temp. varied by 27°F with position.
15	1100	800	There was leakage before and after blowdown.
16	610	540	Leakage before blowdown. Leakage after blowdown 33 lbm/s. Near end of blowdown, wetwell water temp. varied up to 50°F with position.

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[a]Drain pipe goes from lower drywell to wetwell.

[b]Leakage is from pressure vessel.

APPENDIX B

CONTEMPT-LT INPUT DATA FOR MARVIKEN BLOWDOWN 14 BASE CASE

This appendix describes the input data derived to simulate Marviken Blowdown 14 using CONTEMPT-LT. The card numbers and input word numbers refer to those described on pages 164 to 187 of the CONTEMPT-LT users Manual.[1]

11001 - General Control Card.

W1 - Problem end time. The blowdown ended at 180 s so a time of 0.050 h was used.

W2 - 0 heat conducting structures.

W3 - 1 indicates standard vertical vent system model.

W4 - 70°F was assumed as the outside air temperature (not used in calculation).

W5 - 14.7 psia was assumed as the outside air pressure (not used).

W6 - 0.5 was assumed as the outside air relative humidity (not used).

W7 - 70°F was assumed as the heat structure bulk temperature control (not used).

W8 - 0.0 was assumed as the amount of water added to the drywell as a step input at the start of the run.

W9 - 0.0 was assumed as the total internal energy of the water in W8.

W10 - 0.0 was assumed as the amount of water left in the primary system at the end of blowdown (not used).

W11 - 0.0 was assumed as the total internal energy associated with the water in W10 (not used).

W12 - 0.0 selects use of evaporation-condensation model in the drywell prior to end of blowdown and end of vent flow.

W13 - 0.0 indicates no mass removal associated with condensation heat transfer.

10021 - Wetwell Compartment Description Card.

W1 - Total compartment volume.

Water volume = 19 638 ft^3 (p. 17, Ref. 16).

Air volume = 55 876 ft^3 (p. 17, Ref. 16).

Total volume = 75 514 ft^3.

W2 - Liquid pool volume was 19 638 ft^3 (p. 17, Ref. 16).

W3 - Vapor region initial temperature was 89.2°F (p. 17, Ref. 16).

W4 - Wetwell pool average initial temperature was 114.4°F (p. 17, Ref. 16).

W5 - Initial pressure was 14.65 psia (p. 16, Ref. 16).

W6 - Initial vapor region relative humidity was assumed to be 1.00 (p. 17, Ref. 16).

W7 - Horizontal cross-sectional area of wetwell was 1 157 ft^2 (p. 46, Ref. 2).

W8 - The recommended value of 1.0 was used for the film heat transfer coefficient multiplier (p. 165, Ref. 1).

W9 - The recommended value of 1.0 was used for the mass transfer multiplier for evaporation model (p. 165, Ref. 1).

10031 - Drywell Compartment Description Card.

W1 - Total compartment volume includes everything down to header.

Total volume including half of vent pipes = 68 302 ft^3 (p. 96, Ref. 2).

Volume of half of vent pipes = 389 ft^3 (p. 93, Ref. 2).

Total drywell volume = 67 913 ft^3.

W2 - Initial pool volume was assumed to be 0.0.

W3 - A volume-weighted average initial vapor region temperature of 112.3°F was calculated based on the room volumes given on p. 96 of Ref. 2 and the initial room temperatures given on pages 16 and 17 of Ref. 16.

W4 - Because the pool volume was assumed initially to be 0.0, the initial pool temperature was input as the same as the drywell vapor region temperature of 112.3°F.

W5 - The initial pressure was 14.79 psia (p. 16, Ref. 16).

W6 - The initial vapor region relative humidity was estimated to be 0.20 based on p. 17 of Ref. 16.

W7 - The horizontal cross-sectional area was 1 267 ft^3. This included the floor areas of Rooms 110, 111, 112, 113, and 114 from pages 33, 35, 37, 38, and 40 of Ref. 2. The floor area of Room 104 was not included because pipes drain out the bottom of it to the header.

W8 - The recommended value of 1.0 was used for the film heat transfer coefficient multiplier (p. 165, Ref. 1).

W9 - The recommended value of 1.0 was used for the mass transfer multiplier for evaporation model (p. 165, Ref. 1).

10 - Plot Control Card.

W1 - 1 entered for Calcomp plot.

W2 - 2 entered for semilog scale.

W3 - SEC entered for units of time.

W4 - 0.0 s entered for minimum time.

W5 - 180.0 s entered for maximum time.

W6-W9 - 0.0 to allow minimum and maximum for pressure and temperature to be used as plot limits.

9000 to 9007 - Time Step Control Cards.

Interval End Time (s)	Time Step (s)	Heat-conducting Structures Print Frequency	Thermodynamics Print Frequency
0.2	0.2	1	1
2.0	0.001	200	100
10.0	0.05	200	10
78.0	0.5	200	4
83.0	0.05	200	5
85.0	0.5	200	4
180.0	0.5	200	10

300 to 315 Blowdown Mass Flow Rate and Enthalpy Cards.

The blowdown flows occurred in a steam pipe and a feedwater pipe. The flow rates in each pipe were obtained from plotted data on Diagrams 19 and 20 of Ref. 16. The specific enthalpies in each pipe were obtained from plotted data on Diagram 21 of Ref. 16. The total flow rate in the two pipes and the average enthalpy were derived from this data and the results are given below.

TIME (s)	FLOW RATE (lbm/s)	ENTHALPY (Btu/lbm)
0.0	0	284
0.2	0	284
0.4	7490	350
0.5	8041	361
1.2	5728	374
1.6	4758	398
2.0	4406	406
4.3	3625	452
8.0	3371	456
12.0	3349	471
20.0	3426	482
78.0	3271	472
82.0	727	469
175.0	727	467
180.0	33	467

1801 Vertical Vent System Control Card.

W1 - 10 pipe elements were used in normal vent pipes.

W2 - 8 quantities were entered in tables of time and mass fractions of air, steam, and water for use with normal vents.

W3 - -1 indicates minimum output.

W4 - 0.0 for no detailed printout of vent flow.

W5 - 26. downcomers in normal vent system. (p. 17, Ref. 16).

W6 - 1.0 was assumed as the ratio of the liquid water entering the normal vent system to the fraction of liquid water in the drywell atmosphere.

W7 - The recommended value of 0.005 was used as the convergence criterion for vent flow (p. 181, Ref. 1).

W8-W11 - All of these inputs apply to failed vents and were set equal to 0 for no failed vents.

1802 Miscellaneous Vent Data Card.

W1 - The initial vent submergence was 9.25 ft (p. 17, Ref. 16).

W2 - The vent pipe roughness used was 0.005 ft for concrete (p. 58, Ref. 30).

W3 - The vent entrance loss coefficient used was 0.50 (p. 249, Ref. 31).

W4 - The vent opening inside diameter was 0.984 ft (p. 3, Ref. 16).

W5 - Failed vent loss coefficient is 0.0 (no failed vents).

W6 - Failed vent pipe diameter is 0.0 (no failed vents).

W7 - 0 selects standard friction factor calculation.

W8 - 0.0 was selected as multiplying factor for vent closing.

W9 - 0.0 was selected as multiplying factor for vent reclearing.

W10 - 0.0 was selected as the multiplier on $(C_p - C_v)$ term for air energy transport through the wetwell pool to atmosphere region.

W11 - 0.0 was selected as the multiplier on $(T_{v_3} - T_{\ell_2})$ term for air energy transport through the wetwell pool to atmosphere region.

1803 Vacuum Relief System Card.

W1 - Vacuum breakers between wetwell and drywell open at 3.63 psi pressure difference (p. 87, Ref. 2).

W2 - A loss coefficient of 1.5 was chosen to represent a 0.5-inlet loss coefficient plus a 1.0-exit loss coefficient (p. 249, Ref. 31).

W3	-	The total effective flow area of all of the breakers was 0.65 ft^2 (p. 87, Ref. 2).
W4	-	1.0 effective break was assumed to go with the total flow area of 0.65 ft^2. There were actually four with a total area of 0.65 ft^2.

1101 Pipe Element Type Card.

W1-W10	-	All 10 pipe elements were constant diameter so they are all Type 1.

1201 Pipe Element Roughness Data Card.

W1-W10	-	0.005 ft was used for the concrete inner pipe surface (see card 1802).

1301 Pipe Element Vertical Height Data Card.

W1-W10	-	The total vent pipe height was 17.4 ft (p. 91, Ref. 2). The elevation change from inlet to exit of each of the ten elements was then -1.74 ft.

1401 Pipe Element Diameter Data Card.

W1-W10	-	All pipe elements were 0.984 ft in diameter (p. 3, Ref. 16).

1501 Pipe Element Length Data Card.

W1-W10	-	All pipe elements were 1.74 ft long (see card 1301 note).

1601 Pipe Element Subdivision Data Card.

W1-W10	-	There were 0 subdivisions in all pipe elements.

1701 Pipe Element Branch Fraction Data Card.

W1-W10	-	All Type 1 elements had 1.0 branch fractions.

1901 Vent Mass Fraction Table Card.

All mass fraction multipliers were entered as 1.0.

APPENDIX C

MARVIKEN BASIC BLOWDOWN STUDIES OUTPUT PLOTS

Graphical comparisons are made between CONTEMPT-LT output and test data for Marviken Blowdowns 10, 11, 14, 15, and 16.

Figures C-1 to C-5 show the drywell pressure calculated by CONTEMPT-LT compared with Marviken pressures in the breakroom, lower drywell, and header. In all cases, the drywell peak pressures calculated by CONTEMPT-LT were less than the peak pressures observed in the Marviken blowdowns. In the first few seconds, the pressures calculated by CONTEMPT-LT rose much more rapidly than those observed in the Marviken blowdowns, but then the CONTEMPT-LT pressures peaked while the Marviken pressures continued to rise until they reached a higher peak.

Wetwell atmospheric pressures calculated by CONTEMPT-LT are compared with the Marviken data in Fig. C-6 for Blowdown 14 representing the double-pipe blowdowns and in Fig. C-7 for the single-pipe Blowdown 15. As in the drywell, the CONTEMPT-LT wetwell atmospheric pressures were higher in the early stages of the transients than the Marviken data, but the Marviken data had a higher peak pressure in the later stages after the CONTEMPT-LT result leveled off.

Pressure differences between the drywell atmosphere and the wetwell atmosphere are shown in Figs. C-8 and C-9 for Blowdowns 14 and 15. CONTEMPT-LT results are compared with Marviken data for pressure differences based on the Marviken breakroom, lower drywell, and header locations. The CONTEMPT-LT results for the double-pipe Blowdown 14 peaked at about 10-psi pressure difference while the single-pipe Blowdown 15 peaked at about 5 psi. All of the CONTEMPT-LT results peaked in the first few seconds of the blowdown. The Marviken data peaks occurred much later in the blowdowns. For the double-pipe blowdowns, the peaks occurred shortly before the steam pipe was closed, while for the single-pipe blowdown the peak occurred at the end of the blowdown.

Vent flow rates were much higher in the early stages of the transients for CONTEMPT-LT than in the Marviken blowdowns (Fig. C-10 and C-11).

Figures C-12 and C-13 show the CONTEMPT-LT drywell atmospheric temperature compared with the Marviken data for the breakroom and header. The CONTEMPT-LT result was bounded by the Marviken breakroom and header temperatures until late in the transient when it was slightly lower than both of them.

Wetwell pool temperatures, shown in Fig. C-14 and C-15, were consistently higher for the CONTEMPT-LT calculations than for the Marviken data. Wetwell atmospheric temperatures, shown in Fig. C-16 and C-17, remained almost constant for the CONTEMPT-LT calculations, while the Marviken data showed a considerable rise to a peak late in the transient.

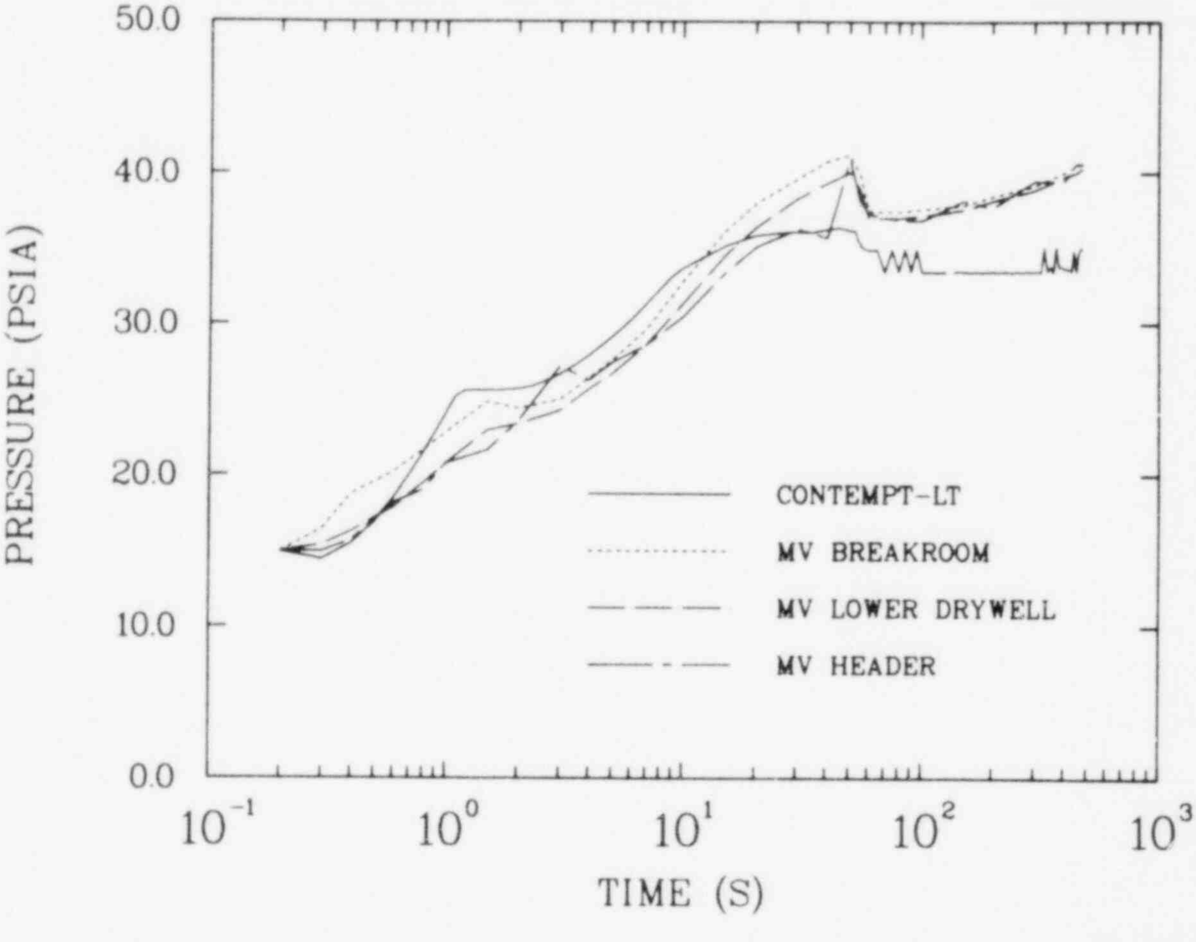

Fig. C-1. Marviken Blowdown 10 drywell pressures.

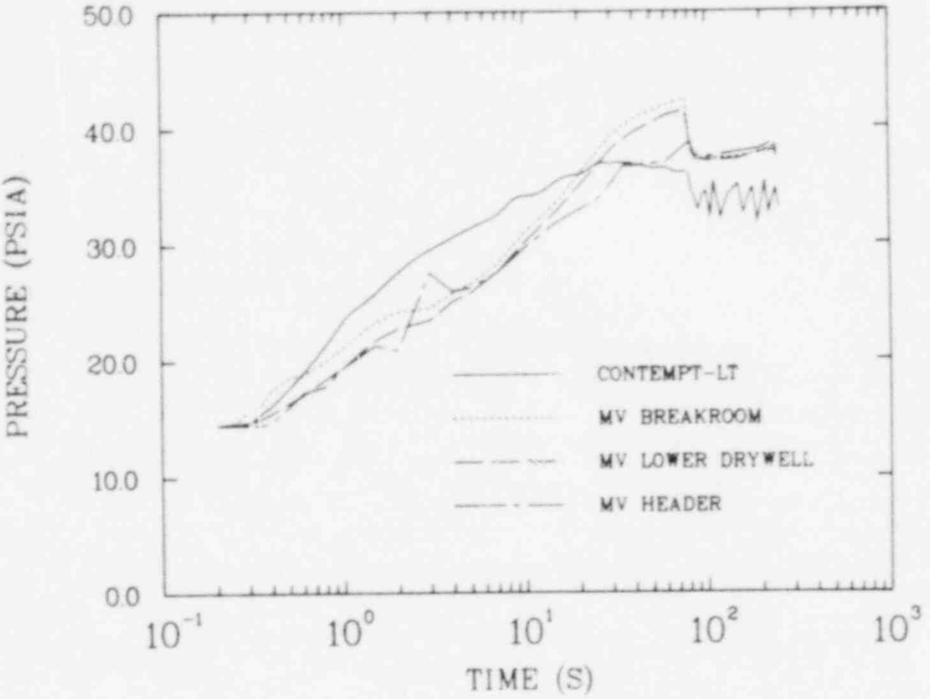

Fig. C-2. Marviken Blowdown 11 drywell pressures.

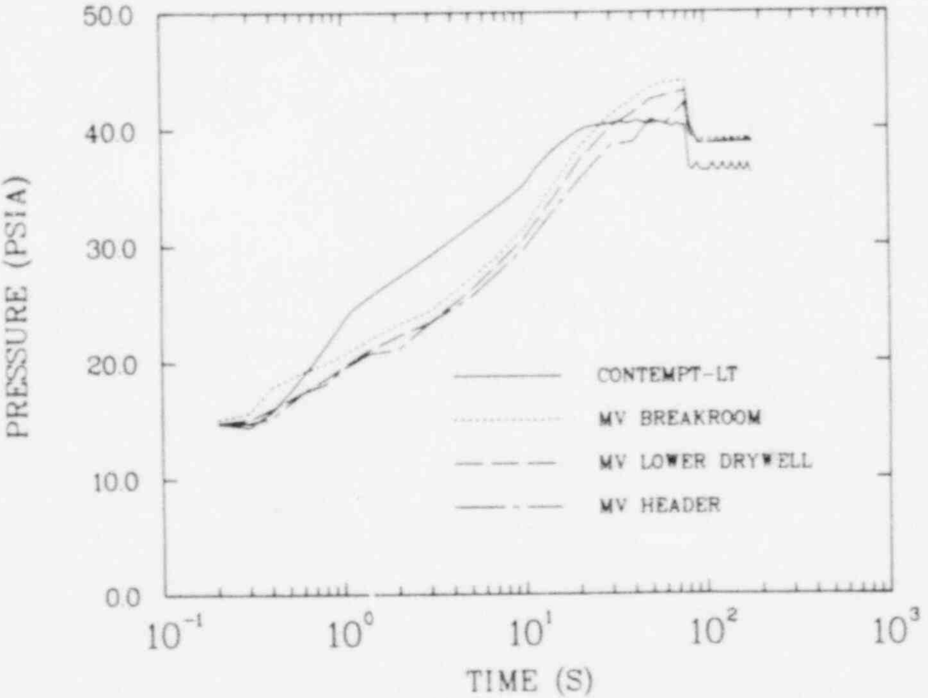

Fig. C-3. Marviken Blowdown 14 drywell pressures.

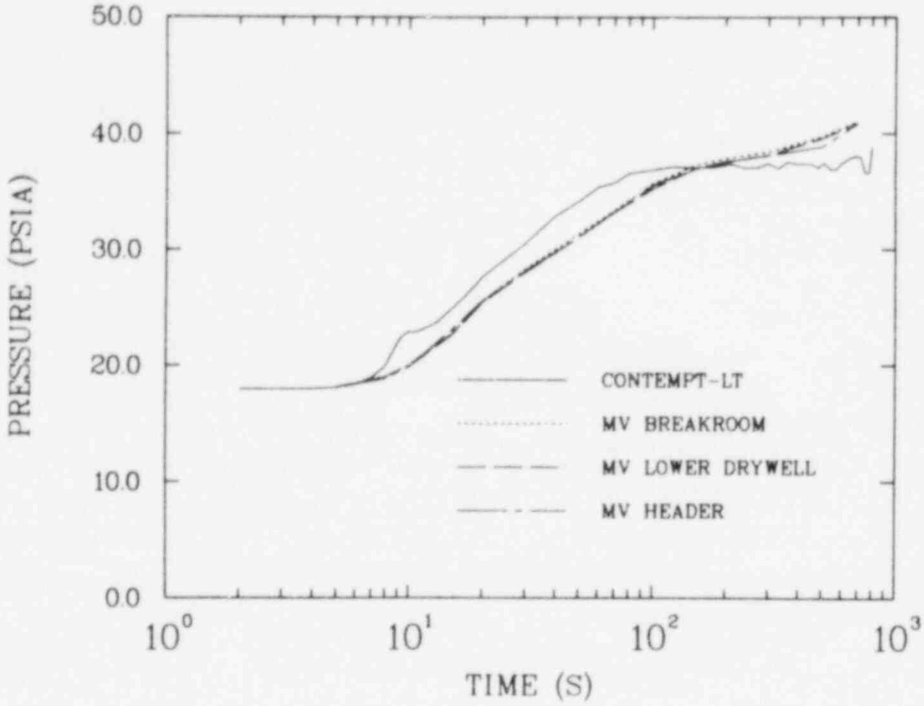

Fig. C-4. Marviken Blowdown 15 drywell pressures.

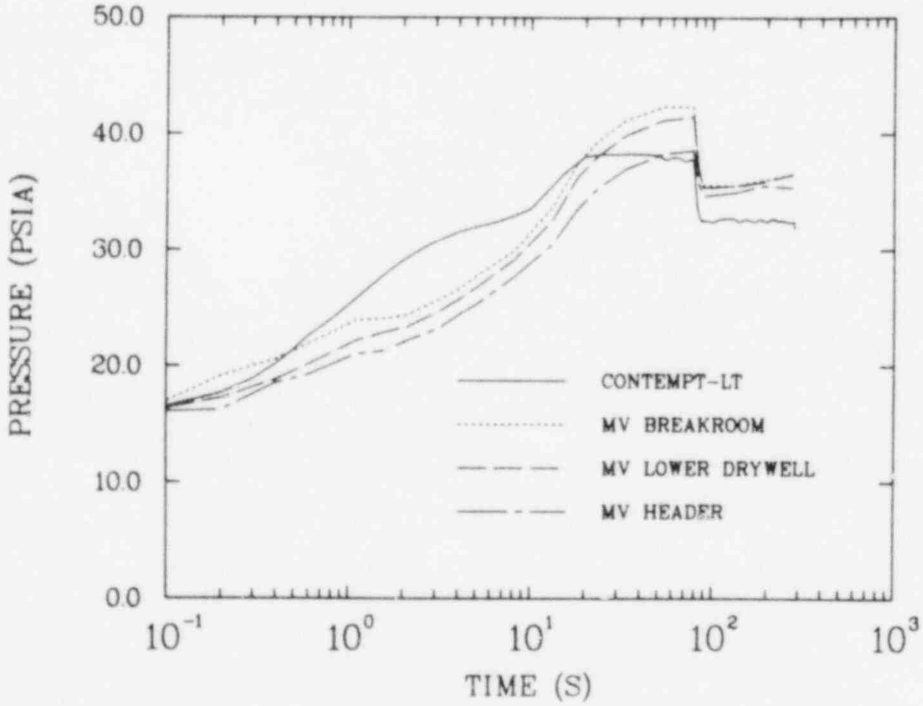

Fig. C-5. Marviken Blowdown 16 drywell pressures.

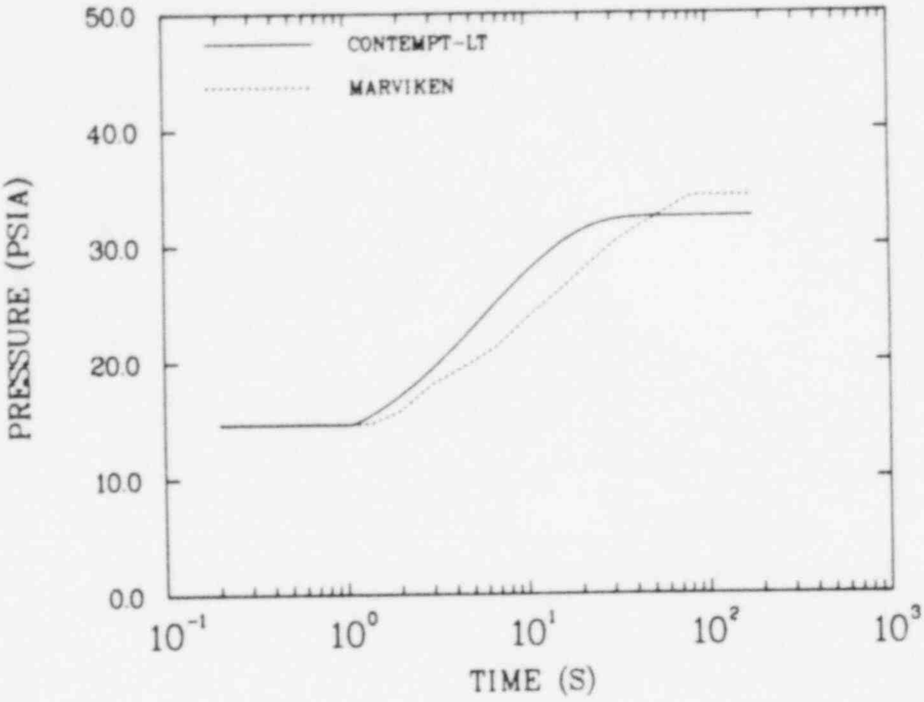

Fig. C-6. Marviken Blowdown 14 wetwell atmospheric pressures.

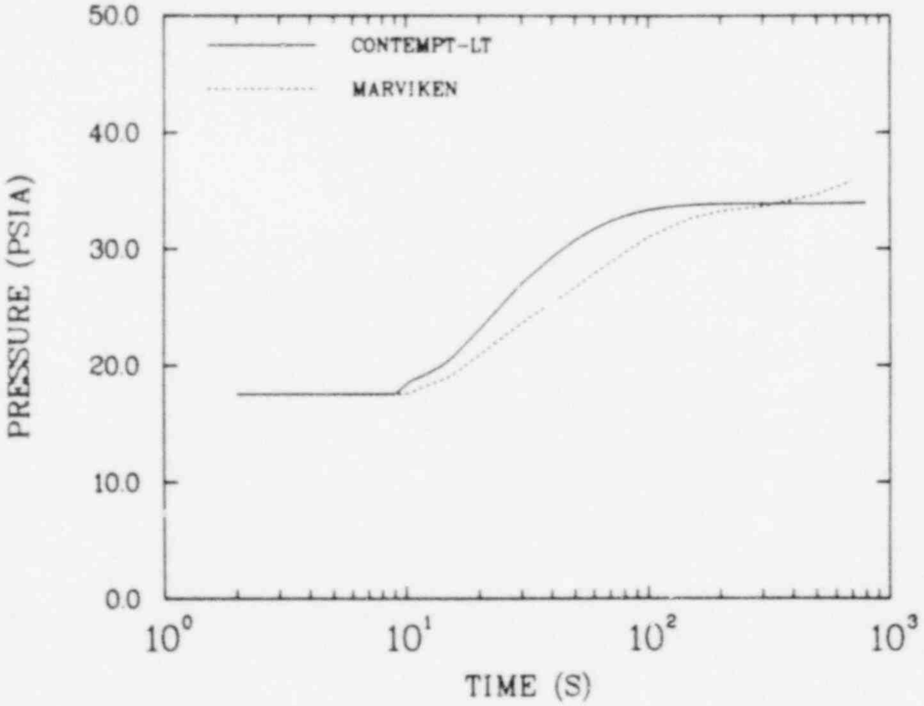

Fig. C-7. Marviken Blowdown 15 wetwell atmospheric pressures.

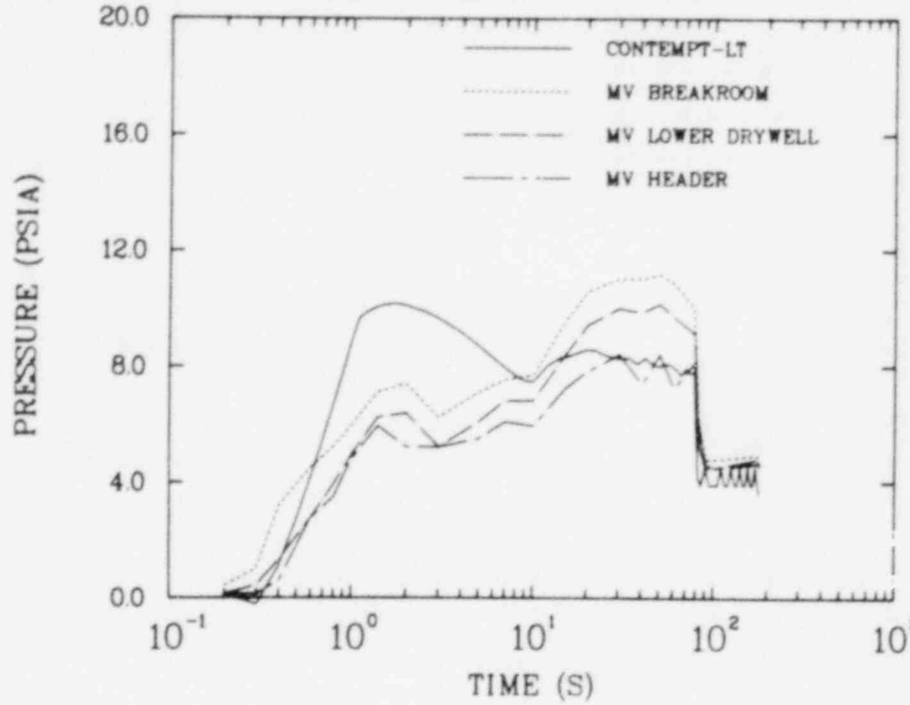

Fig. C-8. Marviken Blowdown 14 pressure differences between drywell and wetwell.

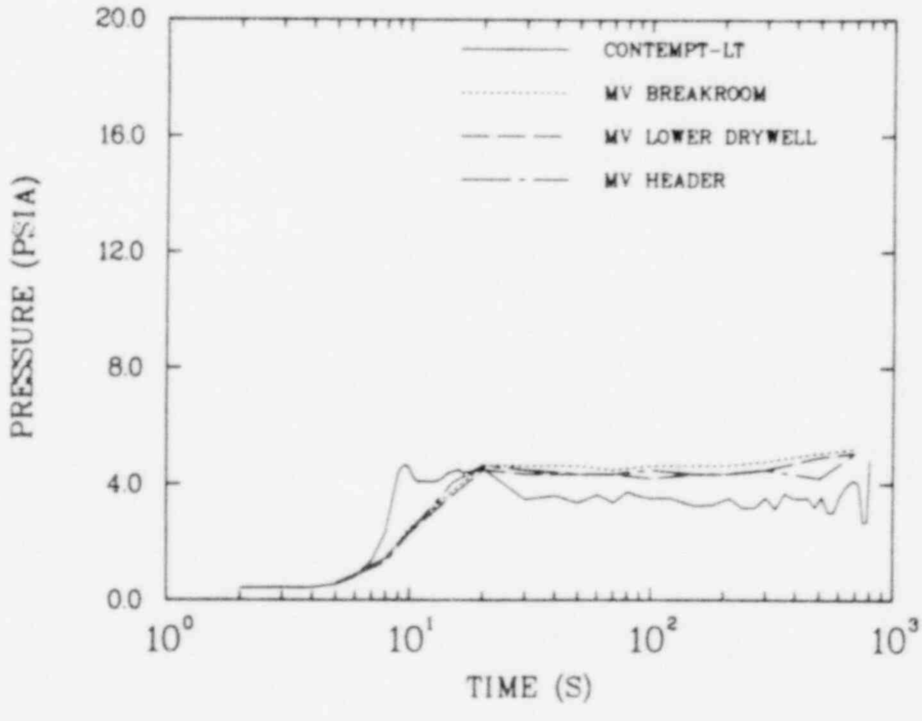

Fig. C-9. Marviken Blowdown 15 pressure differences between drywell and wetwell.

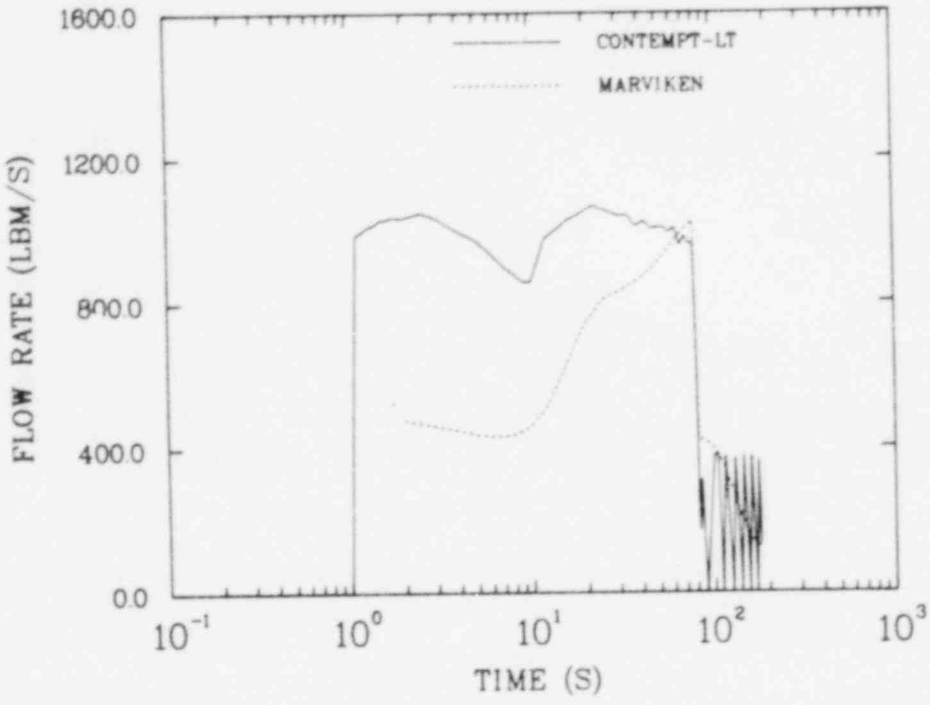

Fig. C-10. Marviken Blowdown 14 vent flow rates.

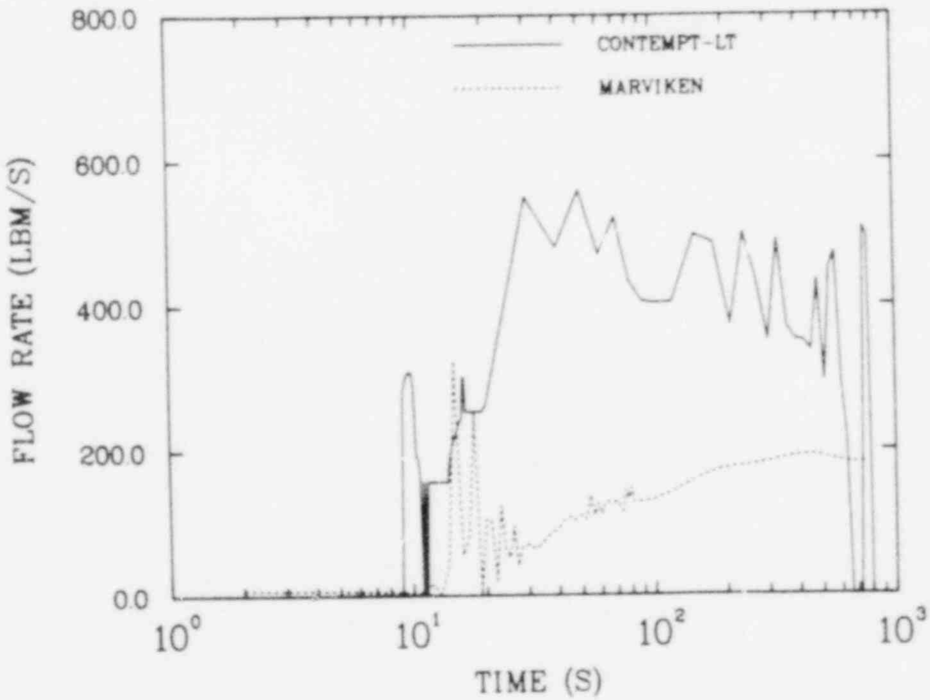

Fig. C-11. Marviken Blowdown 15 vent flow rates.

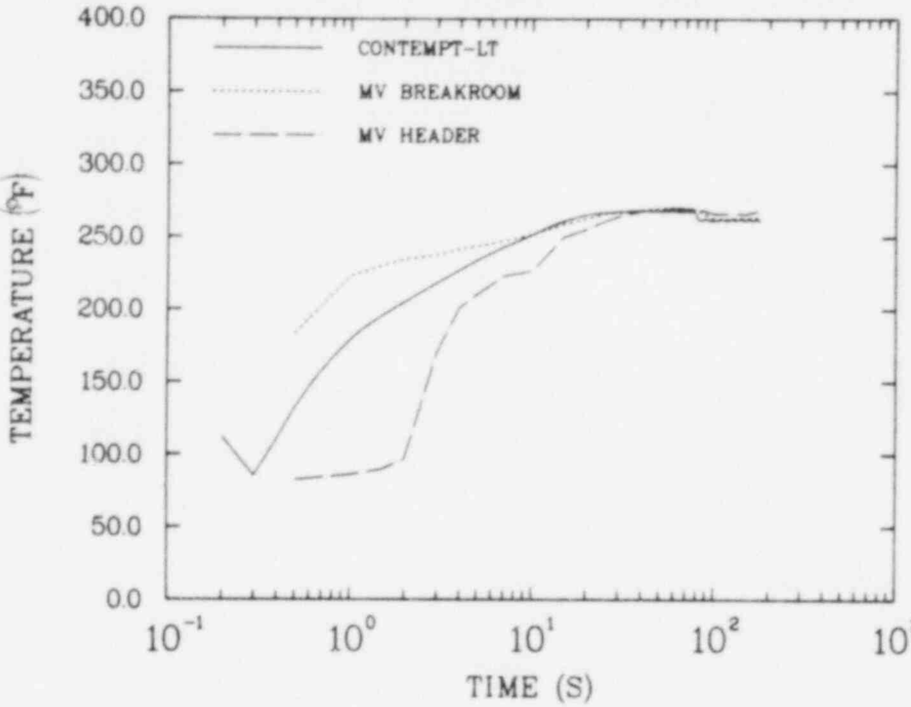

Fig. C-12. Marviken Blowdown 14 drywell atmospheric temperatures.

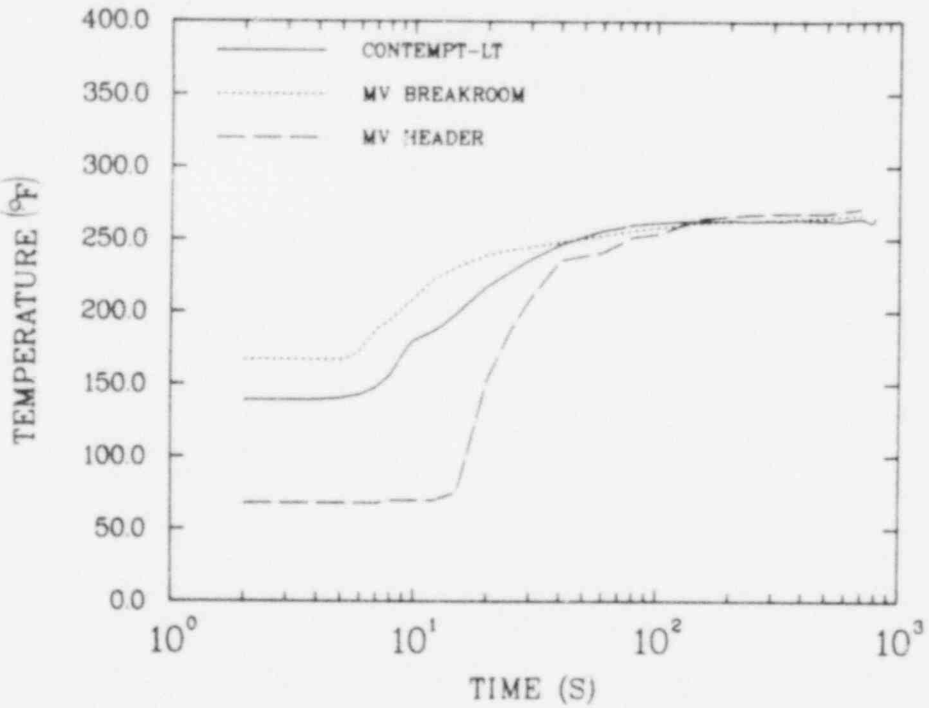

Fig. C-13. Marviken Blowdown 15 drywell atmospheric temperatures.

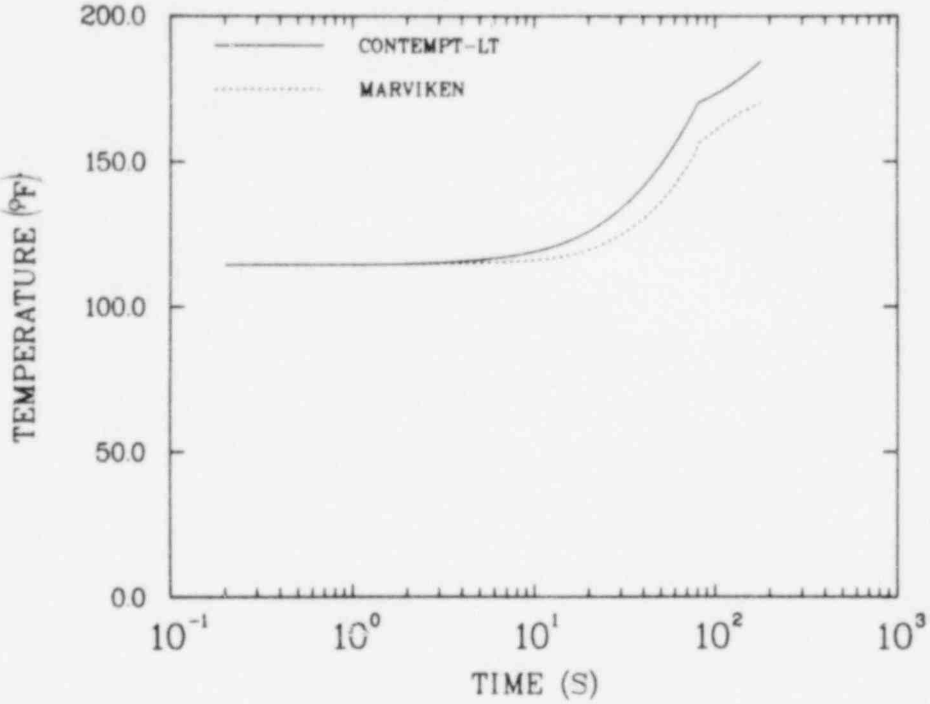

Fig. C-14. Marviken Blowdown 14 wetwell pool temperatures.

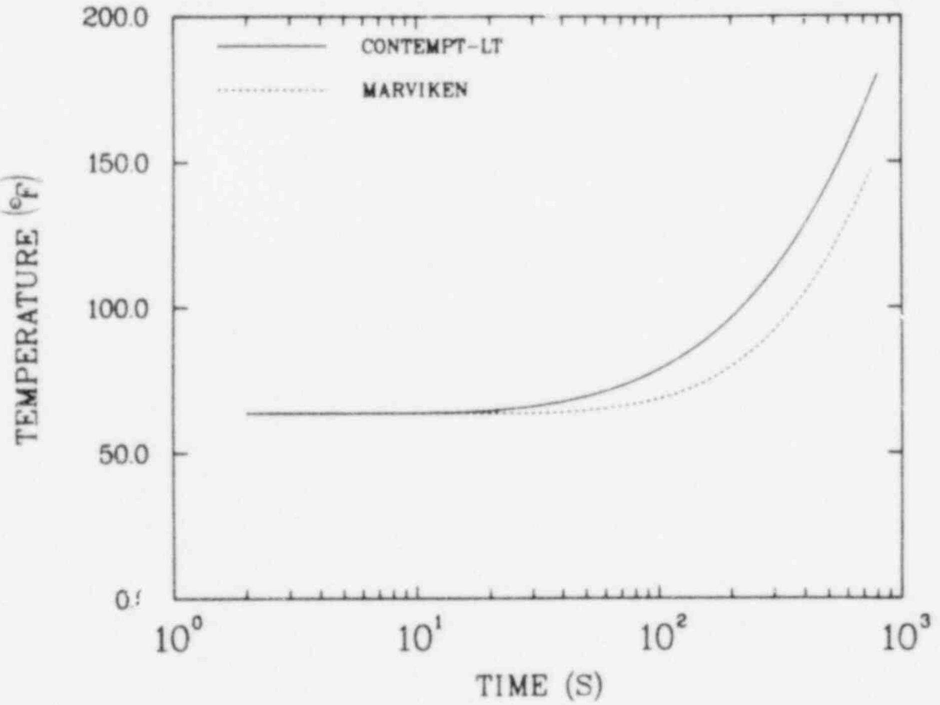

Fig. C-15. Marviken Blowdown 15 wetwell pool temperatures.

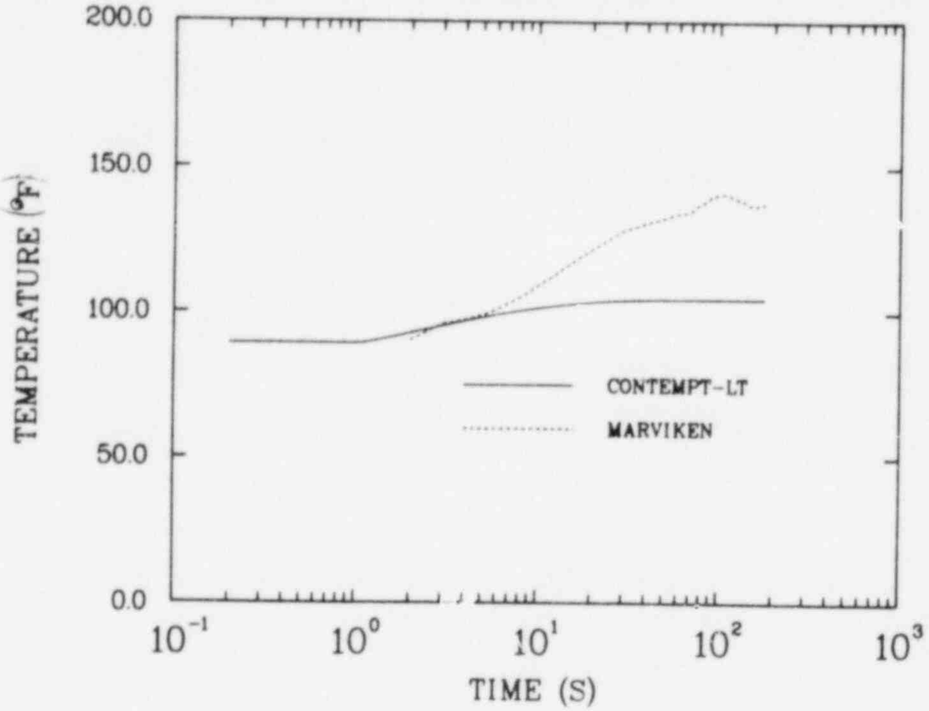

Fig. C-16. Marviken Blowdown 14 wetwell atmospheric temperatures.

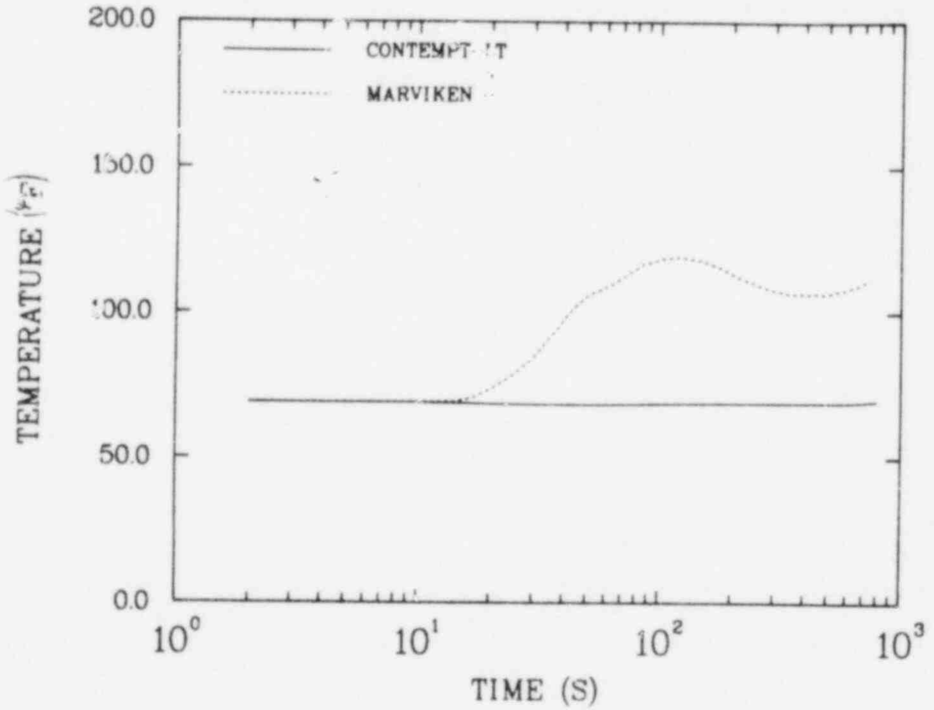

Fig. C-17. Marviken Blowdown 15 wetwell atmospheric temperatures.

APPENDIX D

EFFECTS OF HEAT TRANSFER FOR MARVIKEN BLOWDOWNS

We added four heat conducting structures to the base-case model for CONTEMPT-LT simulations of Blowdowns 10, 11, 14, 15, and 16 based on extensive room surface area descriptions in Ref. 2. These structures included (1) concrete with liner plus gap conductance, (2) concrete with no liner, (3) steel plate, and (4) aluminum sheet. Structure 1 was modeled as a 0.013-ft-thick steel plate, a 0.01-ft gap with conductivity to give a gap conductance of 10 Btu/h/ft^2/^{o}F, and 5/12-ft-thick concrete. Structure 2 was mod led as 5/12 ft of concrete. Structures 3 and 4 were modeled as 1/24 ft of steel and 0.00225 ft of aluminum. All structures had Uchida heat transfer coefficients on the drywell surface and an adiabatic other surface. Table D-I summarizes the heat-conducting structures.

CONTEMPT-LT calculations of drywell pressures with and without heat transfer are compared with Marviken data for the lower drywell for the five blowdowns in Figs. D-1 to D-5. Peak pressures without heat transfer were a maximum of 2.7% higher than peak pressures with heat transfer. The maximum difference in pressures between the model with heat transfer and without heat transfer did not occur at the time of peak pressure. At the time of peak difference in pressures, the pressure for the model without heat transfer was between 5.3% and [illegible].2% higher.

TABLE D-I

HEAT-CONDUCTING STRUCTURES SUMMARY

A.

Structures Used

1. Concrete with liner plus gap conductance
2. Concrete with no liner
3. Steel plate
4. Aluminum

TABLE D-I (cont)

B.

Material Description

Material Number	Material	Thermal Conductivity Btu/h/ft/°F	Volumetric Heat Capacity Btu/ft^3/°F
1	Steel Liner	29.0	51.0
2	Gap	0.1	1.0
3	Concrete	1.01	30.0
4	Aluminum	119.0	36.0

C.

Structure Description (CONTEMPT-LT input parameters)

Item	St. 1	St. 2	St. 3	St.4
Number of mesh points	22	19	5	3
Number of regions	4	2	1	1
Type of geometry	slab	slab	slab	slab
Coordinate of left boundary	0.0	0.0	0.0	0.0
Power factor	0.0	0.0	0.0	0.0
Delay time until source is started	0.0	0.0	0.0	0.0
Heat-transfer surface multiplier	17 297.0	15 321.0	24 504.0	13 142.0
Left compartment number	3.0	3.0	3.0	3.0
Right compartment number	0	0	0	0
Number of intervals in the first region	2	10	4	2
Right boundary of the first region	0.013 ft	0.08333 ft	0.04167 ft	0.00225 ft
Number of intervals in the second region	1	8	-	-
Right boundary of the second region	0.023 ft	0.41666 ft	-	-
Number of intervals in the third region	10	-	-	-
Right boundary of the third region	0.10633 ft	-	-	-
Number of intervals in the fourth region	8	-	-	-
Right boundary of the fourth region	0.43966 ft	-	-	-

TABLE D-I (cont)

Item	St. 1	St. 2	St. 3	St.4
Material number for Region 1	1	3	1	4
Material number for Region 2	2	3	-	-
Material number for Region 3	3	-	-	-
Material number for Region 4	3	-	-	-
Source type control	0	0	0	0
Source value	0.0	0.0	0.0	0.0
Heat transfer coefficient control for left boundary	2	2	2	2
Bulk temperature control for left boundary	2	2	2	2
Heat transfer coefficient control for right boundary	0	0	0	0
Bulk temperature control for right boundary	0	0	0	0

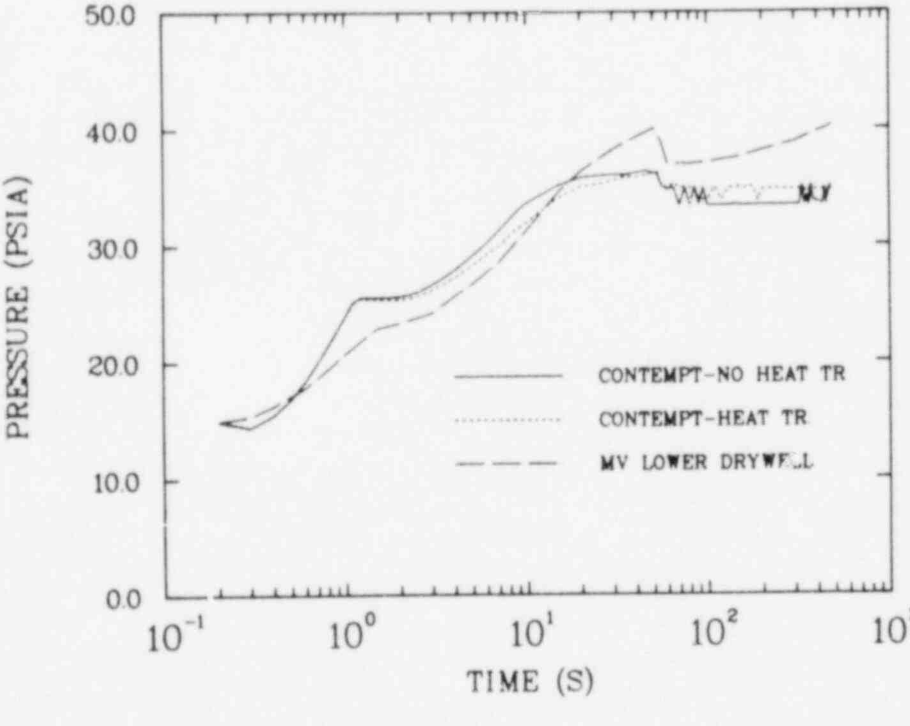

Fig. D-1. Marviken Blowdown 10 comparison of Marviken data with CONTEMPT-LT calculated drywell pressures with and without heat transfer.

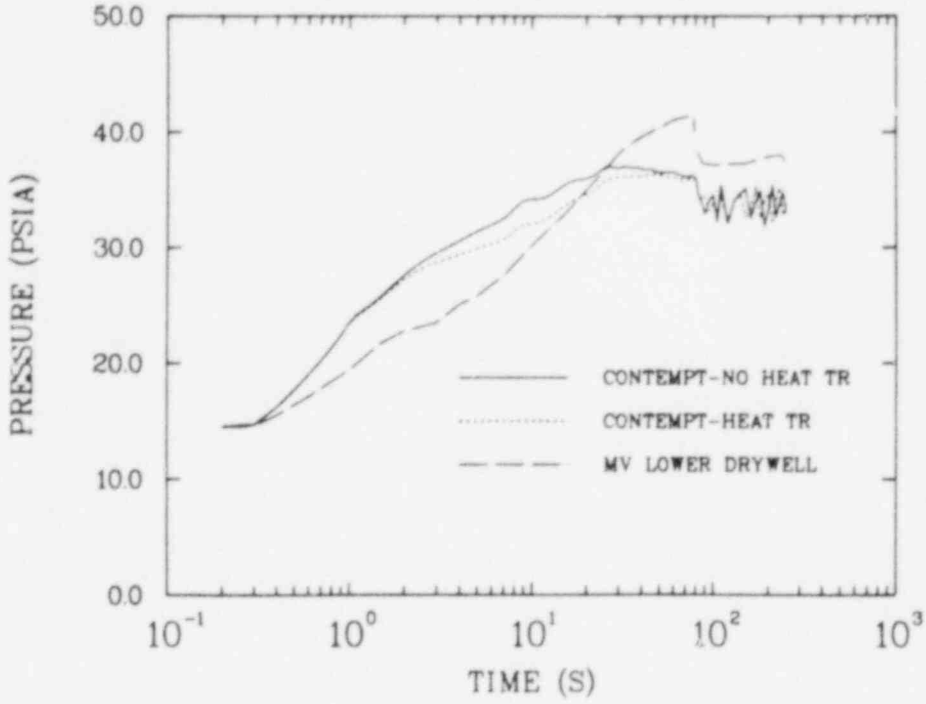

Fig. D-2. Marviken Blowdown 11 comparison of Marviken data with CONTEMPT-LT calculated drywell pressures with and without heat transfer.

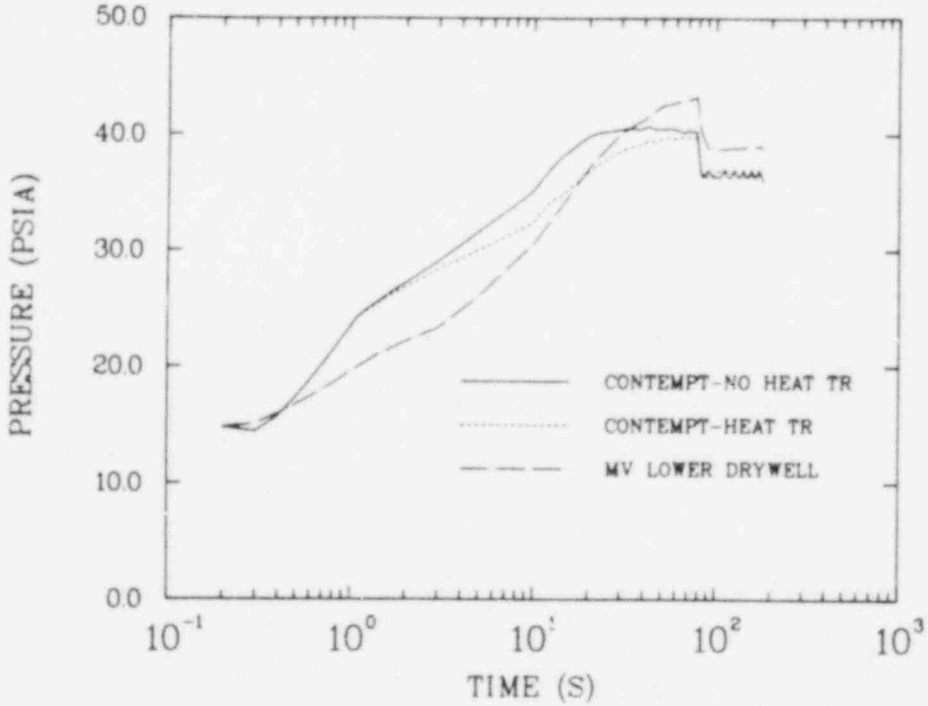

Fig. D-3. Marviken Blowdown 14 comparison of Marviken data with CONTEMPT-LT calculated drywell pressures with and without heat transfer.

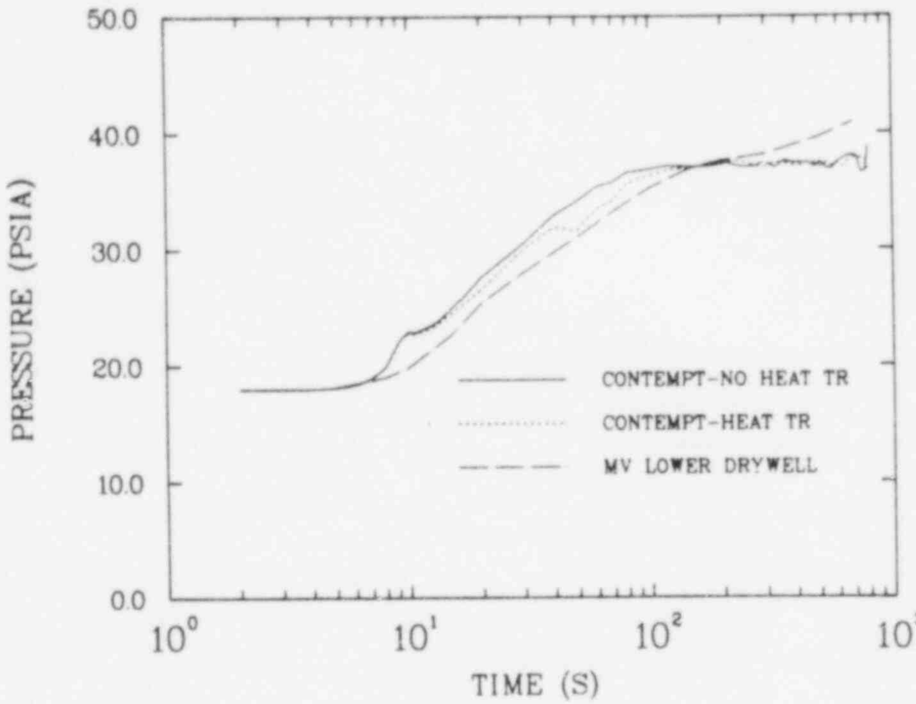

Fig. D-4. Marviken Blowdown 15 comparison of Marviken data with CONTEMPT-LT calculated drywell pressures with and without heat transfer.

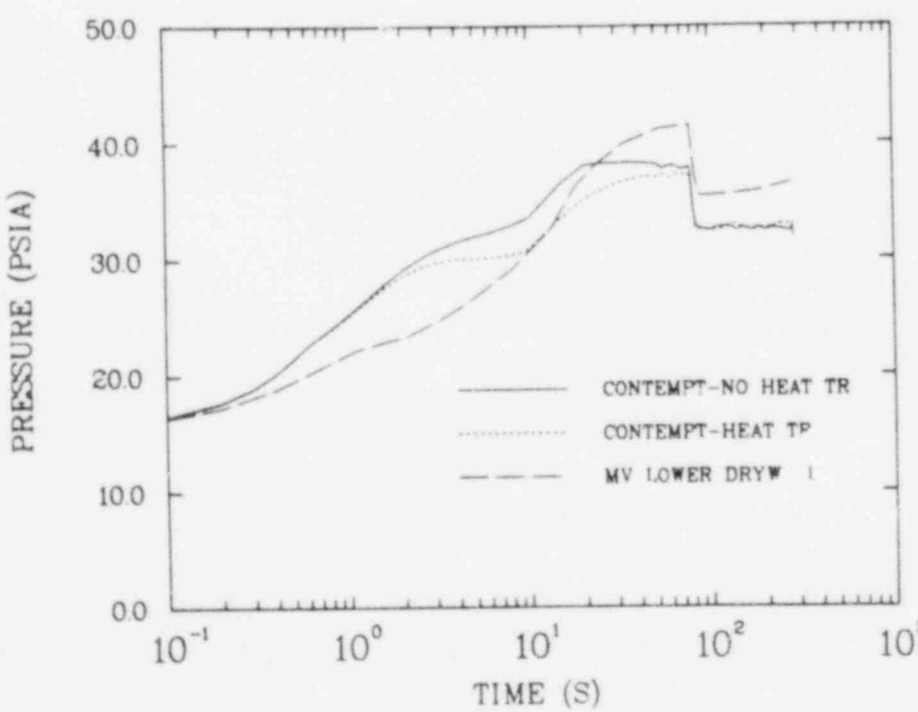

Fig. D-5. Marviken Blowdown 16 comparison of Marviken data with CONTEMPT-LT calculated drywell pressures with and without heat transfer.

APPENDIX E

LOFT TEST L1-3A

In this appendix we first describe the input data derived to simulate the LOFT Test L1-3A using CONTEMPT-LT. We then compare the output obtained from the code with the LOFT data.

1. Derivation of LOFT Test L1-3A Input Data for CONTEMPT-LT.

The card numbers and input word numbers refer to those described on pages 164 to 187 of the CONTEMPT-LT users manual.[1]

11001 - General Control Card.

W1 - Problem end time. The blowdown flow rate is nearly zero after 40 s (p. 202-204, Ref. 20). Use 40 s = 0.0111111 h.

W2 - 0 heat-conducting structures.

W3 - 1 indicates standard vertical vent system model.

W4 - 70°F was assumed as the outside air temperature (not used in calculation).

W5 - 14.7 psia was assumed as the outside air pressure (not used).

W6 - 0.5 was assumed as the outside air relative humidity (not used).

W7 - 70°F was assumed as the heat structure bulk temperature control (not used).

W8 - 0.0 was assumed as the amount of water added to the drywell as a step input at the start of the run.

W9 - 0.0 was assumed as the total internal energy of the water in W8.

W10 - 0.0 was assumed as the amount of water left in the primary system at the end of blowdown (not used).

W11 - 0.0 was assumed as the total internal energy associated with the water in W10 (not used).

W12 - 0.0 selects use of evaporation-condensation model in the drywell before the end of blowdown and end of vent flow.

W13 - 0.0 indicates no mass removal associated with condensation heat transfer.

10021 Wetwell Compartment Description Card.

W1 - Total compartment volume was 3 010 ft^3 (p.32, Ref. 20).

W2 - Liquid pool volume was 1 048 ft^3 (p. 32, Ref. 20).

W3 - Vapor region initial temperature was 180°F (p. 148, Ref. 20).

W4 - Pool average initial temperature was 156°F (p. 156, Ref. 20).

W5 - Initial pressure was 23.6 psia based on 10.6 psig from p. 32 of Ref. 20 and an assumed 13 psia atmospheric pressure.

W6 - Initial vapor region relative humidity was assumed to be 1.00.

W7 - Effective cross-sectional area of wetwell was 328 ft^2 based on the initial water level given on p. 32 of Ref. 20 and the suppression tank geometry given on pages 9 and 98 of Ref. 21.

W8 - The recommended value of 1.0 was used for the film heat transfer coefficient multiplier (p. 165, Ref. 1).

W9 - The recommended value of 1.0 was used for the mass transfer multiplier for the evaporation model (p. 165, Ref. 1).

10031 Drywell Compartment Description Card.

The drywell was taken to be the header plus the four downcomer tubes' sloping section.

W1 - Total compartment volume was 719.8 ft^3 based on pages 10, 96, 103, and 108 of Ref. 21.

W2 - Initial pool volume was assumed to be 0.0.

W3 - There were no temperature measurements in the header so the initial vapor region temperature was assumed to be the same as the initial wetwell water temperature, 156°F.

W4 - The initial pool temperature was also assumed to be 156°F.

W5 - The initial pressure was 24.25 psia (p. 95, 97, Ref. 21).

W6 - The initial vapor region relative humidity was assumed to be 1.00.

W7 - The horizontal cross-sectional area was estimated to be 114.8 ft^2. This area for pool surface heat transfer was estimated to be the product of one-half the header diameter times its length.

W8 - The recommended value of 1.0 was used for the film heat transfer multiplier (p. 165, Ref. 1).

W9 - The recommended value of 1.0 was used for the mass transfer multiplier for the evaporation model (p. 165, Ref. 1).

300-311 Blowdown Mass Flow Rate and Enthalpy Cards.

Derivation of the blowdown mass flow rate and enthalpies involved combining results for the broken loop cold leg and broken loop hot leg. The enthalpies were obtained from smoothed curves for the very noisy data shown in Fig. 224 and 225 in Ref. 20.

TABLE E-I

ENTHALPY IN COLD LEG AND HOT LEG

Time (s)	Enthalpy Cold Leg (Btu/lbm)	Enthalpy Hot Leg (Btu/lbm)
0	525	525
1	525	525
2	525	525
5	525	525
10	550	525
15	600	580
20	800	680
25	1050	850
30	1200	1180
35	1190	1180
40	1180	1180

Flow rates in the broken loop cold leg were measured by four different methods. The raw data results for these four methods are given in Fig. 229 - 232 of Ref. 20. Page 40 of Ref. 20 gives different correction factors for each of these four curves. A smooth curve was drawn through each of the noisy flow rate curves and used to derive the corrected flow rate per system volume data shown below.

TABLE E-II

CORRECTED COLD LEG FLOW RATE PER SYSTEM VOLUME[a] BASED ON FIGURE INDICATED

Time (s)	Fig. 229	Fig. 230	Fig. 231	Fig. 232
0	0.00	0.00	0.00	0.00
1	2.22	2.88	3.83	2.57
2	1.24	1.71	2.27	2.02
5	1.11	1.52	1.98	1.93
10	1.02	1.24	1.56	1.83
15	0.97	0.93	1.13	1.47
20	0.93	0.70	0.85	1.10
25	0.31	0.39	0.50	0.64
30	0.13	0.16	0.28	0.23
35	0.09	0.08	0.14	0.18
40	0.04	0.04	0.00	0.09

[a]System volume = 273 ft^3 (pp. 1-5 of Ref. 22).

TABLE E-III

CORRECTED COLD LEG FLOW RATE

Time (s)	Average Flow Rate Per System Volume	Cold Leg Flow Rate (lbm/s)
0	0.00	0
1	2.88	786
2	1.81	494
5	1.64	448
10	1.41	385
15	1.12	306
20	0.90	246
25	0.46	126
30	0.20	[illegible]5
35	0.12	33
40	0.04	11

The hot leg flow rate was derived from Fig. 233 of Ref. 20, again using a correction factor given on p. 40 of Ref. 20. Table E-IV shows the total flow rate in the hot and cold legs combined and the average enthalpy used as code inputs.

TABLE E-IV

LOFT L1-3A BLOWDOWN FLOW RATE AND ENTHALPY

Time(s)	Flow Rate (lbm/s)	Enthalpy (Btu/lbm)
0	0	525
1	936	525
2	614	525
5	563	525
10	489	545
15	388	596
20	309	776
25	164	1004
30	71	1195
35	41	1188
40	19	1180

1801 Vertical Vent System Control Card.

W1 - 10 pipe elements were used in normal vent pipes.

W2 - 8 quantities were entered in tables of time and mass fractions of air, steam, and water for use with normal vents.

W3 - -1 indicates minimum output.

W4 - 0.0 for no detailed printout of vent flow.

W5 - 4.0 downcomers in normal vent system (p. 103, Ref. 21).

W6 - 1.0 was assumed as the ratio of the liquid water entering the normal vent system to the fraction of liquid water in the drywell atmosphere.

W7 - The recommended value of 0.005 was used as the convergence criterion for vent flow (p. 181, Ref. 1).

W8-W11 - All of these inputs apply to failed vents and were set equal to 0 for no failed vents.

1802 Miscellaneous Vent Data Card.

W1 - The initial vent submergence was 1.33 ft (p. 32, Ref. 20).

W2 - The vent pipe roughness used was 0.00015 ft for steel (p. 58, Ref. 30).

W3 - The irreversible energy loss coefficient used was 0.8 to represent 0.50 for entrance and 0.30 for the 33° bend in the vent (p. 249, Ref. 31).

W4 - Vent-opening inside diameter was 1.9375 ft (p. 108, Ref. 21).

W5 - Failed vent loss coefficient was 0.0 (no failed vents).

W6 - Failed vent pipe diameter was 0.0 (no failed vents).

W7 - 0 selects standard friction factor calculation.

W8 - 0.0 was selected as the multiplying factor for vent closing.

W9 - 0.0 was selected as the multiplying factor for vent reclearing.

W10 - 0.0 was selected as the multiplier on $(C_p - C_v)$ term for air energy transport through the wetwell pool to atmosphere region.

W11 - 0.0 was selected as the multiplier on $(T_{v_3} - T_{\ell_2})$ term for air energy transport through the wetwell pool to atmosphere region.

1101 Pipe Element Type Card.

W1-W10 - All 10 pipe elements were constant diameter so they are all Type 1.

1201 Pipe Element Roughness Data Card.

W1-W10 - 0.00015 ft was used (see card 1802).

1301 Pipe Element Vertical Height Data Card.

W1-W8 - The elevation change for each of the slanted sections was -0.92 ft (p. 10, 108 of Ref. 21).

W9-W10 - The elevation change for each of the vertical sections was -1.25 ft (p. 108, Ref. 21).

1401 Pipe Element Diameter Data Card.

W1-W10 - All pipe elements were 1.9375 ft diameter (p. 108, Ref. 21).

1501 Pipe Element Length Data Card.

W1-W8 - Length of slanted elements was 1.10 ft (p. 10, 108, Ref. 21).

W9-W10 - Length of vertical elements was 1.25 ft (p. 108, Ref. 21).

1601 Pipe Element Subdivision Data Card

W1-W10 - There were 0 subdivisions in all pipe elements.

1701 Pipe Element Branch Fraction Data Card.

W1-W10 - All Type 1 elements had 1.0 branch fractions.

1901 Vent Mass Fraction Table Card.

All mass fraction multipliers were entered as 1.0.

2. Discussion of CONTEMPT-LT Results for LOFT Test L1-3A

CONTEMPT-LT simulation results are compared with the LOFT test results in Fig. E-1 to E-4 for the first 3 s of the blowdown. We ran only 3 s of the transient because this took over 10 min of computer time. Computer time (CPU) per time step for LOFT was about 80% more than the average for Marviken. This may be due to the much more rapid vent clearing time of only 0.18 s for LOFT.

In Fig. E-1, the measured drywell (header) pressures are much higher than those calculated by CONTEMPT-LT. Several factors contribute to this. The header, rather than being a large drywell, is a long pipe with two bends. Blowdown flow entered at two places near one end and flowed down the pipe and out four pipes attached to the bottom. The peak pressure observed in the header was higher at Position 4 than at Position 1 even though Position 4 is farther from the break location than Position 1. Apparently the air was rapidly pressurized ahead of the flow, thus leading to a higher pressure at the end of the header. Pressure oscillations also are observed in the header data, thereby indicating compression and expansion waves. Another possible factor in the difference between observed and CONTEMPT-LT calculated pressures is the blowdown flow rate, which varied considerably among the four methods used to measure it.

Wetwell atmospheric pressures shown in Fig. E-2 also were considerably higher than CONTEMPT-LT calculations. Wetwell pool and atmospheric temperatures (Fig. E-3 and E-4) showed the same types of results as for the Marviken blowdowns. CONTEMPT-LT calculated a more rapid rise in pool temperature and a less rapid rise in atmospheric temperature than was observed. In fact, because the initial pool temperature is 24°F less than the atmospheric temperature, the CONTEMPT-LT atmospheric temperature actually decreased slightly for the first 3 s.

No LOFT data were available for drywell temperature or vent flow rate, so these quantities could not be compared.

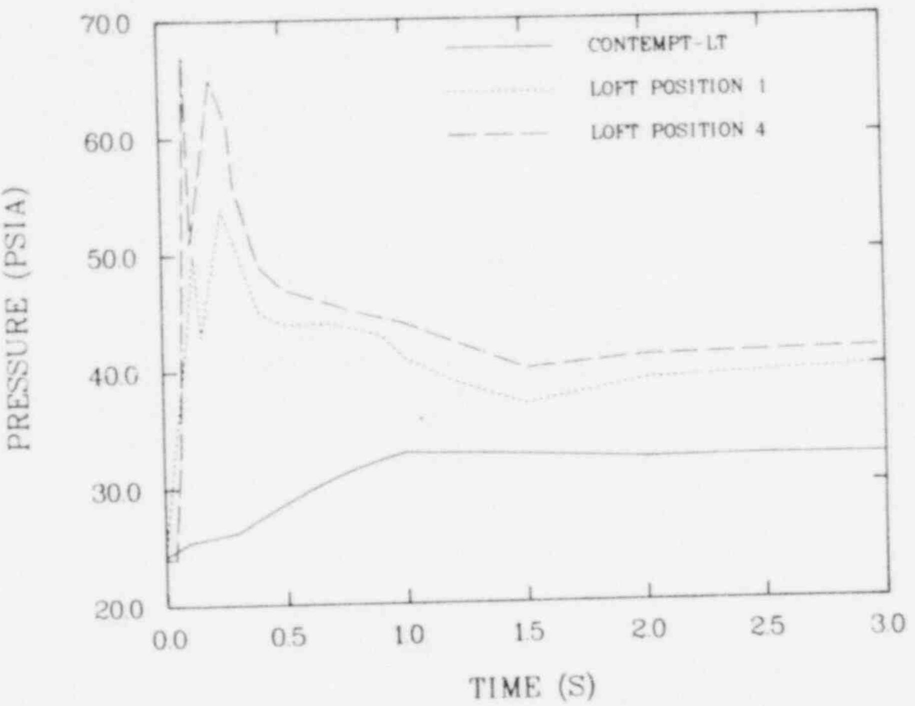

Fig. E-1. Comparison of LOFT Test L1-3A data with CONTEMPT-LT calculated drywell pressures.

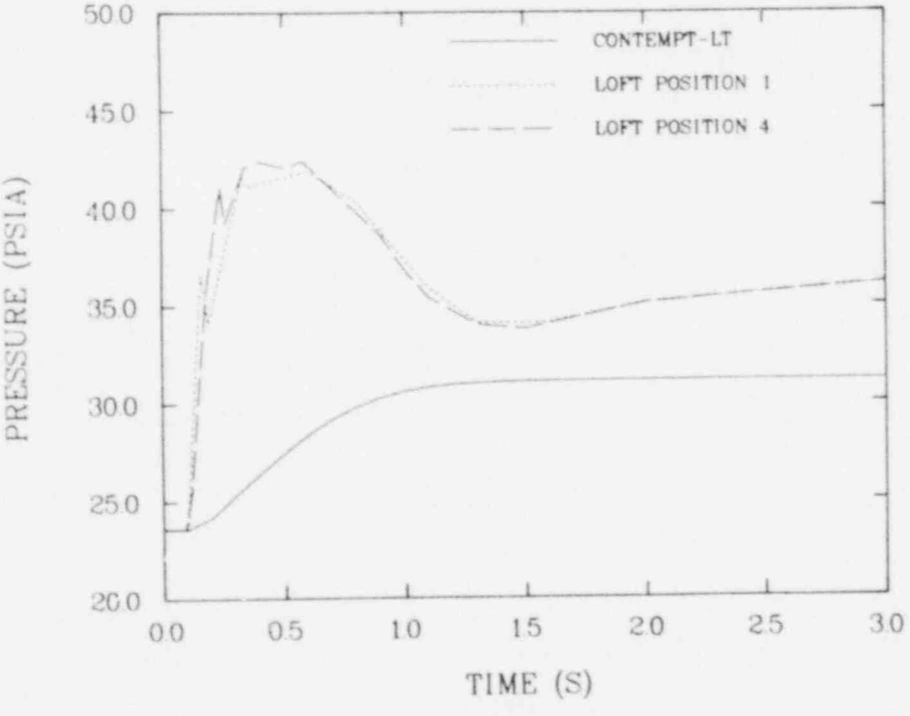

Fig. E-2. Comparison of LOFT Test L1-3A data with CONTEMPT-LT calculated wetwell atmospheric pressures.

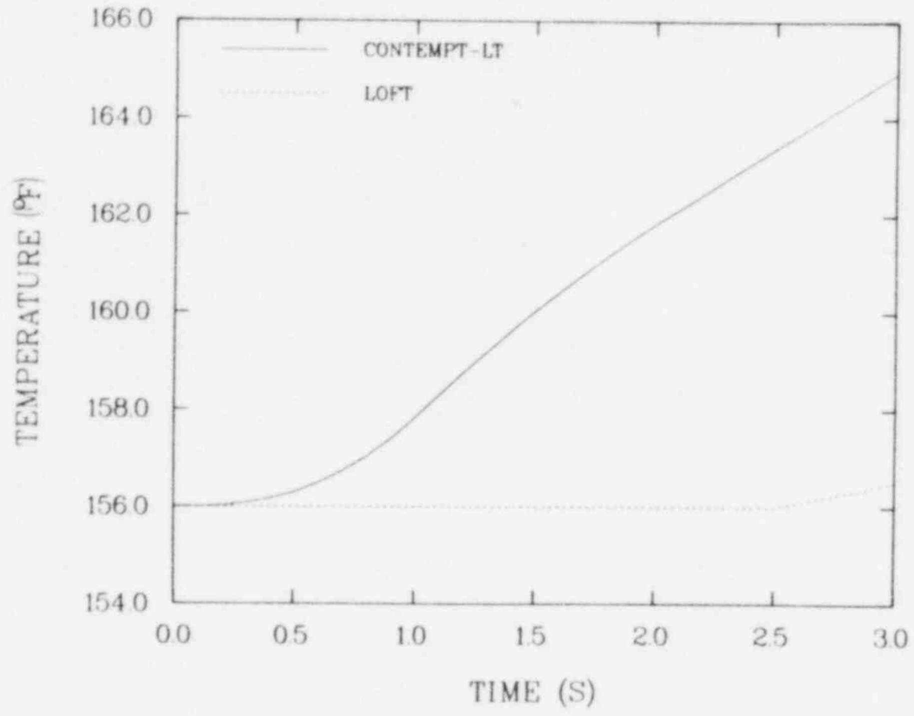

Fig. E-3. Comparison of LOFT Test L1-3A data with CONTEMPT-LT calculated wetwell pool temperatures.

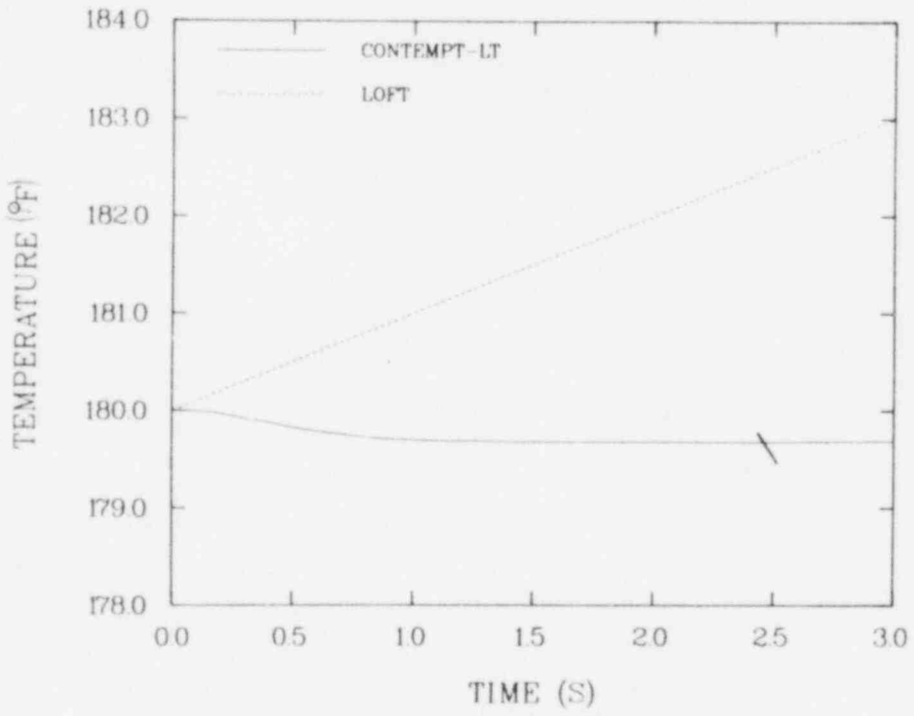

Fig. E-4. Comparison of LOFT Test L1-3A data with CONTEMPT-LT calculated wetwell atmospheric temperatures.

APPENDIX F

BATTELLE-FRANKFURT TEST C5 INPUT DESCRIPTION

In this appendix we describe the input data derived to simulate the Battelle-Frankfurt Test C5. First, we present the data required for a simulation without heat conducting structures. Later, the changes required to run with different heat transfer assumptions are presented. The card numbers and input word numbers refer to those described on pages 164 to 187 in the CONTEMPT-LT users manual.[1]

11001 General Control Card.

W1 - Problem end time. The blowdown ends after 30 s, so a time of 0.0083333 h is used. (Table X, Ref. 19).

W2 - 0 heat-conducting structures.

W3 - 0 indicates no pressure-suppression system.

W4 - 70°F was assumed as the outside air temperature (not used in calculation).

W5 - 14.7 psia was assumed as the outside air pressure (not used).

W6 - 0.5 was assumed as the outside air relative humidity (not used).

W7 - 70°F was assumed as the heat structure bulk temperature control (not used).

W8 - 0.0 was assumed as the amount of water added to the drywell as a step input at the start of the run.

W9 - 0.0 was assumed as the total internal energy of the water in W8.

W10 - 0.0 was assumed as the amount of water left in the primary system at the end of blowdown (not used).

W11 - 0.0 was assumed as the total internal energy associated with the water in W10 (not used).

W12 - 0.0 - doesn't apply if no vents.

W13 - 0.0 indicates no mass removal associated with condensation heat transfer.

10031 Drywell Compartment Description Card.

W1 - Total compartment volume was 20 592 ft^3 (p. 35, Ref. 19).

W2 - Initial pool volume was assumed to be 0.0.

W3 - Initial vapor region temperature was 59°F (p. 38, Ref. 19).

W4 - Initial temperature of liquid pool region was assumed to be same as vapor, 59°F.

W5 - The initial pressure was 14.86 psia (p. 38, Ref. 19).

W6 - The initial vapor region relative humidity was assumed to be 1.00 (Ref. 32).

W7 - The horizontal cross-sectional area was 543 ft^2 based on compartments 3, 4, 6, 8, and 9 (Ref. 32).

W8 - The recommended value of 1.0 was used for the film heat transfer coefficient multiplier (p. 165, Ref. 1).

W9 - The recommended value of 1.0 was used for the mass transfer multiplier for the evaporation model (p. 165, Ref. 1).

300 to 344 Blowdown Mass Flow Rate and Enthalpy Cards.

The blowdown occurred through two pipes. Mass flow rate and enthalpy data for the two pipes are given in Tables X and XI of Ref. 19. We used these flow rates to derive the total flow rate and average enthalpy plotted in Figs. F-1 and F-2.

TABLE F-I

HEAT-CONDUCTING STRUCTURES[a]

Compartment	Concrete Surface (ft^2)	Aluminum Surface (ft^2)	Steel Surface (ft^2)
1	894.16	19.37	116.21
2	918.90	6.46	115.24
3	1235.25	6.46	52.83
4	447.62	6.46	36.15
5	999.60	12.91	240.92
6	1082.46	38.74	150.32
7	983.46	12.91	130.52
8	1065.24	12.91	91.03
9	5881.52	45.19	45.19
Total:	13508.21	161.41	978.41

[a]Compartment heat transfer surfaces were obtained from Table IV, Ref. 19.

The average steel thickness was estimated to be 0.75 in. Heat transfer to the aluminum was neglected. The model was constructed with 13 508 ft^2 of concrete that was 6 in. thick to an adiabatic boundary and had 978 ft^2 of steel 0.375 in. thick to an adiabatic boundary.

1. Tagami Heat Transfer Until End of Blowdown.

We ran one case with CONTEMPT-LT using the Tagami heat transfer coefficient for the entire 30-s blowdown:*

$$h = 72.5\left(\frac{t}{t_p}\right)\left(\frac{Q}{Vt_p}\right)^{0.62}$$

where

Q = total energy input = 6.152×10^6 Btu (obtained by integrating blowdown input),

V = volume of drywell compartment = 20 592 ft^3 (p. 35, Ref. 19), and

t_p = time of peak pressure or end of blowdown = 30 s.

At the end of the blowdown, the heat transfer coefficient determined was 301.46 Btu/h/ft^2/^oF. For early times when the Tagami correlation predicts heat transfer coefficients less than 2 Btu/h/ft^2/^oF, we used a natural convection value of 2 Btu/h/ft^2/^oF.

2. Tagami Heat Transfer for 21 s Followed by Exponential Decay to Uchida Heat Transfer.

We observed from Battelle-Frankfurt data that the peak pressure occurred at about 21 s.[19] We used the Tagami correlation to determine heat transfer coefficients out to this time based on the blowdown energy input up to 21 s. This gave a peak heat transfer coefficient of 362.6 Btu/h/ft^2/^oF at 21 s. Again, we assumed a natural convection heat transfer coefficient of 2 Btu/h/ft^2/^oF for early times when the Tagami correlation predicts a lower value. For times greater than 21 s, we determined the heat transfer coefficient from

---

*Ref. 33, p. III-14.

$$h = h_{stag} + (h_{max} - h_{stag})e^{-0.05(t-t_p)},^*$$

where

h_{stag} = 100 Btu/h/ft^2/$^{\circ}$F,

h_{max} = 362.6 Btu/h/ft^2/$^{\circ}$F,

t = time, and

t_p = time of peak pressure = 21 s.

The h_{stag} is the Uchida correlation given by

$$h_{stag} = 2 + 50x \quad ,$$

where x is the steam/air mass ratio.

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*Ref. 34, p. 10.

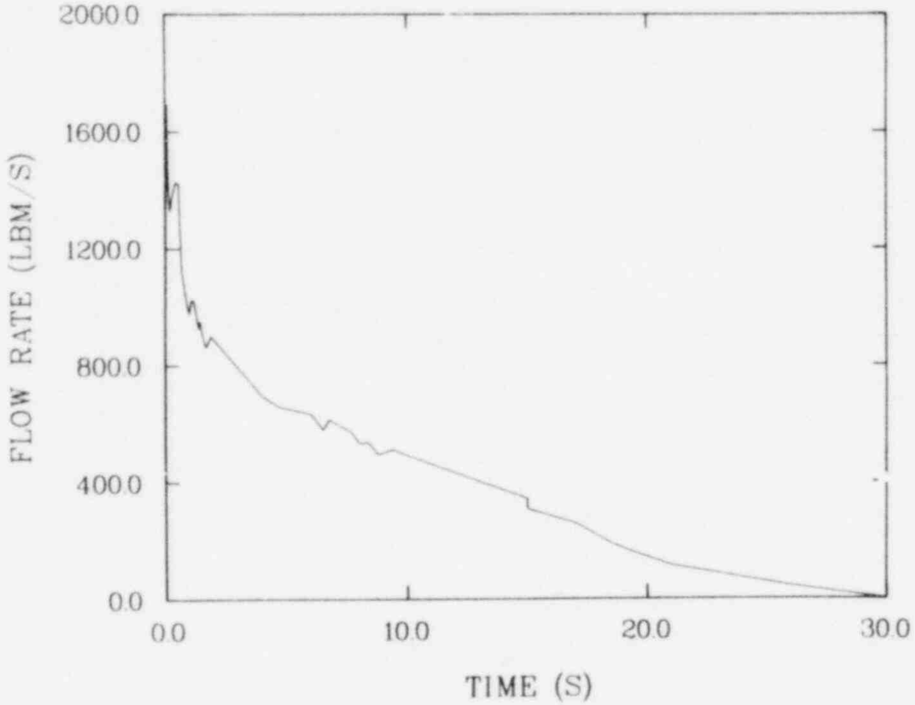

Fig. F-1. Battelle-Frankfurt Test C5 input flow rate.

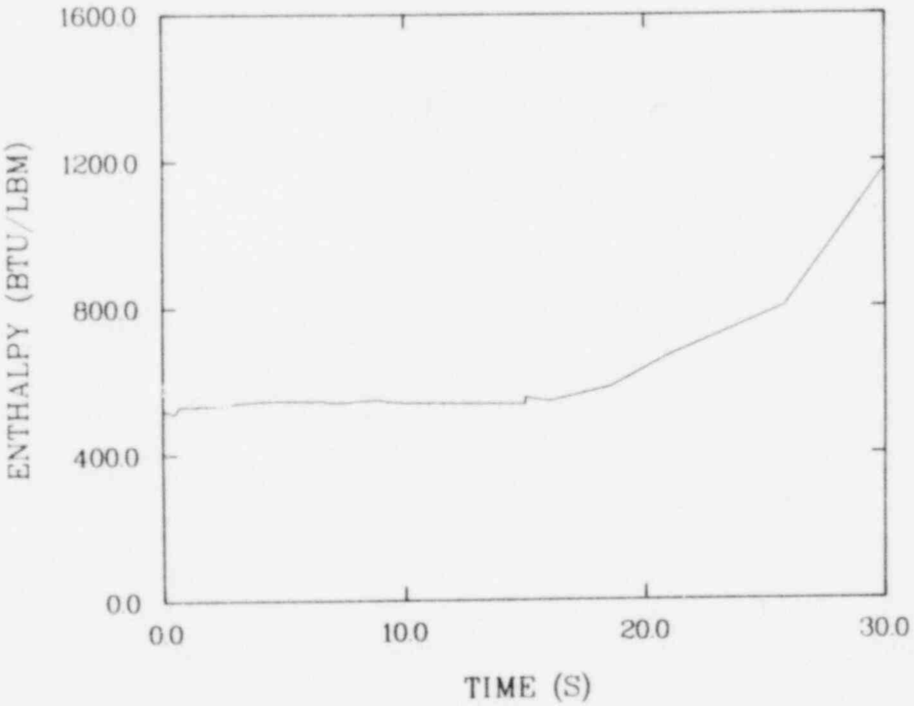

Fig. F-2. Battelle-Frankfurt Test C5 input enthalpy.

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his study compared the CONTEMPT-LT/026 containment analysis code calculations with large-le test results. LASL reviewed 7 large-scale experimental test programs and selected 5 the 16 Marviken tests for pressure-suppression containment analysis comparisons and 1 T test as a secondary investigation. In addition, 1 Marviken test was used to investigate effects of 18 code parameter variations. A single Battelle-Frankfurt test was used for a containment comparison.

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