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CONTAIN 2.0 CODE RELEASE AND THE TRANSITION TO LICENSING*

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ABSTRACT

CONTAIN is a reactor accident simulation code developed by Sandia National Laboratories under US Nuclear Regulatory Commission (USNRC) sponsorship to provide integrated analysis of containment phenomena, including those related to nuclear reactor containment loads and radiological source terms. The recently released CONTAIN 2.0 code version represents a significant advance in CONTAIN modeling capabilities over the last major code release (CONTAIN 1.12V). The new modeling capabilities are discussed here. The principal motivation for many of the recent model improvements has been to allow CONTAIN to model the special features in advanced light water reactor (ALWR) designs. The work done in this area is also summarized. In addition to the ALWR work, the USNRC is currently engaged in an effort to qualify CONTAIN for more general use in licensing, with the intent of supplementing or possibly replacing traditional licensing codes. To qualify the CONTAIN code for licensing applications, studies utilizing CONTAIN 2.0 are in progress. A number of results from this effort are presented in this paper to illustrate the code capabilities. In particular, CONTAIN calculations of the NUPEC M-8-1 and ISP-23 experiments and CVTR test #3 are presented to illustrate (1) the ability of CONTAIN to model non-uniform gas density and/or temperature distributions, and (2) the relationship between such gas distributions and containment loads. CONTAIN and CONTEMPT predictions for a large-break loss-of-coolant accident scenario in the San Onofre plant are also compared.

1. INTRODUCTION

CONTAIN is a reactor accident simulation code developed by Sandia National Laboratories (SNL) under US Nuclear Regulatory Commission (USNRC) sponsorship to provide integrated analysis of containment phenomena. CONTAIN provides the analyst with the capability to predict nuclear reactor containment loads, radiological source terms, and associated phenomena

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under accident conditions. The principal purpose of CONTAIN is to provide the USNRC with predictive containment analysis capabilities and to serve as a tool to provide technical information in support of regulatory decisions. The recently released CONTAIN 2.0 code version[1] represents a significant advance in CONTAIN modeling capabilities over the last major code release (CONTAIN 1.12V) in 1993. The principal motivation for many of the recent model improvements has been to allow CONTAIN to model the special features in advanced light water reactor (ALWR) designs. As a result, CONTAIN has been used successfully to model the Westinghouse AP600 containment, for several different types of loss-of-coolant accidents (LOCAs),[2] and to model many of the Westinghouse Large Scale Test (LST) 1/8-scale experiments.[3] CONTAIN has also been successfully used to model the passive safety features of the simplified boiling water reactor (SBWR) design from General Electric.[4]

In addition to the ALWR work, the USNRC is currently engaged in an effort to qualify CONTAIN for more general use in licensing, with the intent of supplementing or possibly replacing traditional licensing codes such as CONTEMPT[5] and COMPARE.[6] CONTAIN represents enhanced modeling capability and reflects the current status in our understanding of containment phenomena.

To qualify the CONTAIN code for licensing applications, a number of studies utilizing CONTAIN 2.0 are in progress. These studies are intended to (1) provide comparisons to previous design-basis-accident (DBA) licensing calculations performed with CONTEMPT and COMPARE, and (2) establish a methodology for use of CONTAIN in a manner consistent with the philosophy of conservatism taken in the USNRC's Standard Review Plan for containment analysis. At this point in time, a series of validation calculations involving DBA experiments has been completed; these include the early General Electric boiling water reactor (BWR) tests,[7] tests utilizing the Carolinas Virginia Tube Reactor (CVTR),[8] and two tests, International Standard Problem (ISP)-16 and ISP-23, in the German HDR facility.[9,10] Other validation calculations involving the NUPEC M-8-1 test[11] and the HDR E11.2 experiment[12] were also done to support the DBA analyses. Calculations of separate effects tests and comparisons to other codes have been performed to validate the CONTAIN approach to heat and mass transfer modeling under both natural and forced convective conditions. CONTAIN 2.0 has also been used to provide comparisons to CONTEMPT calculations for the San Onofre plant, a large dry pressurized water reactor (PWR), and the Grand Gulf plant, a Mark III BWR.

This paper provides a status report on the CONTAIN code qualification activities. In the next section, we provide background information on the code and discuss some of the differences between CONTAIN and traditional licensing codes. In Section 3, we summarize CONTAIN 2.0 calculations of NUPEC M-8-1, CVTR Test #3, and ISP-23 to illustrate (1) the ability of CONTAIN to model non-uniform gas density and/or temperature distributions under stratified conditions, and (2) the relationship between such gas distributions and containment loads. In Section 4, the differences between CONTAIN and CONTEMPT predictions for the San Onofre large break LOCA scenario are also discussed. Finally, Section 5 presents overall conclusions.

DISCLAIMER

2. BACKGROUND INFORMATION

The CONTAIN code, up to and including the CONTAIN 2.0 release,[1] is a best-estimate, control volume code that is capable of handling a variety of fields in each cell, or control volume. These fields can include:

- gaseous atmosphere and any suspended water
- the water pool
- aerosols (including aerosolized water)
- gaseous and aerosolized fission products, and
- dispersed core debris fields from high pressure melt ejection.

Three methods are available for treating liquid coolant carried by the gas. The first or default method is to treat it as homogeneously dispersed, in which case the liquid is carried indefinitely with the gas unless it happens to evaporate. The second is to use the dropout option, in which case any liquid that forms is removed instantaneously to the pool or sump in the same control volume. The third method is intermediate between the other two: suspended water is represented as an aerosol component, in which case water aerosols are assumed to form by condensation and to have behavior governed by the CONTAIN aerosol dynamics models. The most important removal mechanism in the last case is typically gravitational settling.

Sweeping changes have recently been made in the ability of CONTAIN to handle the dynamics of water pools. In versions prior to CONTAIN 1.2, the pool was treated as an explicit field that was not coupled logically to the atmosphere dynamics. For example, the effects of submergence of gas flow paths and of atmosphere heat sinks were not considered, regardless of the degree of filling of the control volume by the pool. Beginning with CONTAIN 1.2 and including CONTAIN 2.0, the gas and water pool fields are treated on the same footing, and the submergence effects discussed above are taken into account. For flow paths, a simple pool-gas flow hierarchy has been implemented to allow sequential processes such as BWR vent clearing to be taken into account, and multiple vents such as those present in the Mark III may now be constructed of standard flow paths. Fully water-solid cells and pool stratification may also be treated in principle.

In addition to the above fields, any number of heat sinks may be modeled within a given control volume, and, if appropriate, the concrete basemat for the water pool may be modeled as well. The heat transfer from the atmosphere to these heat sinks is assumed to be governed by standard Nusselt correlations, and steam condensation on such sinks is assumed to be governed by Sherwood correlations of the same functional form as the Nusselt correlations, subject to appropriate substitutions for the dimensionless groups appearing in the Nusselt number. Such a correspondence can be established through boundary layer similarity arguments, customarily referred to as the heat and mass transfer analogy (HMTA).[13] While the basic HMTA treatment of heat transfer has not changed in CONTAIN 2.0, a number of heat transfer improvements have been made, including (1) incorporation of gas boundary layer composition effects in the Grashof number, (2) more accurate representation of gas boundary layer transport properties, (3) enhanced output for heat transfer processes, and (4) a number of user options for specifying the

Nusselt and Sherwood correlations used by the code and for combining the effects of forced and natural convection.

In contrast to the HMTA method used in CONTAIN, licensing codes typically use Uchida or Tagami/Uchida correlations for the total heat transfer coefficient under condensing conditions.[14,15] Unfortunately, such correlations are known not to scale properly away from the experimental conditions for which they were derived. For example, the Uchida correlation is assumed to depend only on the air/steam ratio. However, even under the saturated conditions of the experiments, this correlation should also depend strongly on other parameters such as the total pressure and the gas-wall temperature difference. Such limitations restrict the usefulness of such correlations to the narrow range of conditions under which they were derived or qualified. Because the HMTA method scales more correctly, it can be extrapolated over a broader range of conditions and is potentially more useful for licensing purposes. Recently, Peterson[16] has shown that the HMTA method gives good agreement with the Uchida data under the conditions of the experiments, and therefore the HMTA method is also consistent with the data.

Figure 1 gives a comparison of the total heat transfer coefficient between the HMTA method as calculated by CONTAIN and the Uchida correlation as implemented in CONTEMPT.[5] Good agreement is obtained for the conditions shown (i.e., a total pressure of 2 bars saturated and the gas-wall temperature differences shown). For lower total pressures or larger gas-wall temperature differences, the functional dependencies of the HMTA heat transfer rate on these quantities cause it to decrease or become more conservative relative to the Uchida correlation (which is independent of these quantities, as discussed above). For higher pressures or smaller gas-wall temperature differences, the converse is true: HMTA becomes less conservative relative to Uchida. Note that the heat transfer during a blowdown typically occurs over a range of pressures and gas-wall temperature differences. The heat transfer from the HMTA method on the average may be either conservative or nonconservative relative to the Uchida correlation, depending on the conditions.

Additional modeling capabilities in CONTAIN 2.0 include a new dynamic condensate film flow model for heat transfer structures, a new mass and energy conservation tracking scheme, and an improved equation of state for steam. Substantial improvements in the ability of the code to treat stable stratification have also been made through implementation of a hybrid formulation of gravitational heads.[17] This formulation, which has been subjected to extensive evaluation and assessment, allows substantially better predictions of stratified conditions than previous CONTAIN formulations, for stable stratification resulting from injection of buoyant steam or gas at an elevated location within a containment. The ability to predict such stratification could be important for DBA analysis, since conservative peak temperatures under highly stratified conditions cannot be predicted by a code that overmixes gas under such conditions, unless extremely conservative assumptions are made.

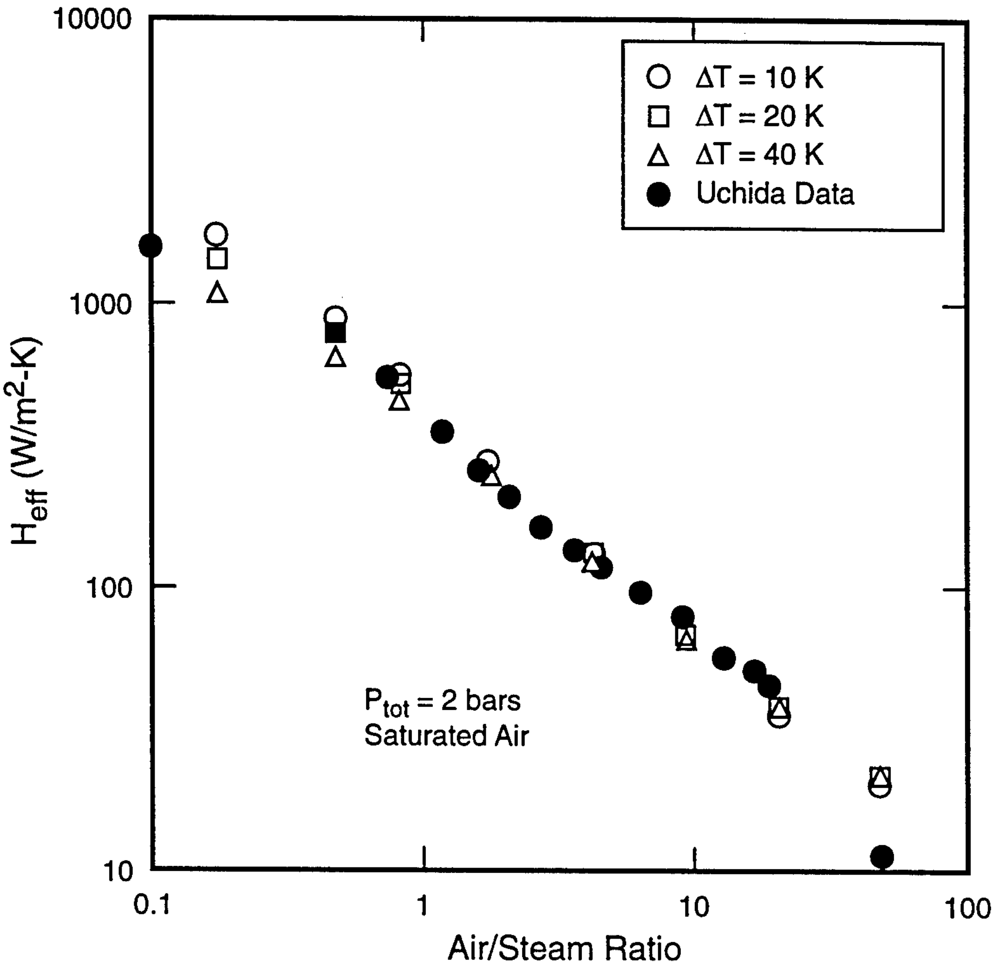

Figure 1. Comparison of the Total Heat Transfer Coefficient Calculated by CONTAIN and the Uchida Correlation, as Implemented in CONTEMPT, for a Total Pressure of P_{tot}=2 bars and Saturated Conditions

3. EXPERIMENT COMPARISONS

3.1 NUPEC Helium Mixing Test M-8-1

The NUPEC model containment was built to represent a 4-loop Pressurized Water Reactor (PWR) at 1/4 linear scale.[11] The NUPEC facility was constructed as a domed cylinder, approximately 10.8 m in diameter, 17.4 m high, and 1310 m^3 in volume. The facility contained 28 separate compartments of which only 25 were interconnected. Of the 25 compartments that were interconnected, however, the dome compartment constituted approximately 71% of the total containment volume.

A series of tests was performed in the NUPEC 1/4-scale model containment to investigate the thermal hydraulics of injecting helium and steam into a containment with and without the operation of water sprays. The tests simulated severe accident conditions in a nuclear power plant under simplified conditions in which helium (as a nonflammable substitute for hydrogen) and steam were released into a containment. The purpose of conducting the test series was to determine the thermal-hydraulic response and the mixing behavior of helium injected into the containment and to provide data for code verification.

Figure 2 shows the 35-cell nodalization used in the analysis, superimposed on a schematic of the facility. In this figure, the cells are denoted by the circled numbers, and the flow paths are denoted by the boxed numbers. The water storage tank, reactor vessel, and primary shield rooms (cells 26-28, respectively) were closed rooms and are not represented. The 35-cell nodalization basically uses one cell for each physical room except for the dome and the pressurizer room. To model gas circulation, the dome is subdivided into central and annular cells, and the pressurizer room is divided into three cells (cells 16, 22, and 35).

In test M-8-1, steam and helium were injected into the pressurizer room, and sprays were not involved. Because the pressurizer room was closed except for openings at the top, these openings determined the injection conditions into the remainder of the containment. The Froude number of this injection, based on jet diameter and velocity, was quite low. Based on the major flow path from the pressurizer room into the remainder of the containment the Froude number is estimated to have been 0.08. Thus, one would expect a stable stratification to form in the facility external to the pressurizer room, with the stratification interface located approximately at the openings at the top of the pressurizer room.

The gas pressure in the facility at the beginning of the experiment was approximately 101 kPa, and the structure and gas temperatures were at room temperature (approximately 280 K to 283 K). The helium and steam mass injection rates were constant at 0.027 kg/s and 0.33 kg/s, respectively, during the 30 minute injection period. It was assumed that helium and saturated steam were injected into the containment at 283 K and 381 K, respectively.

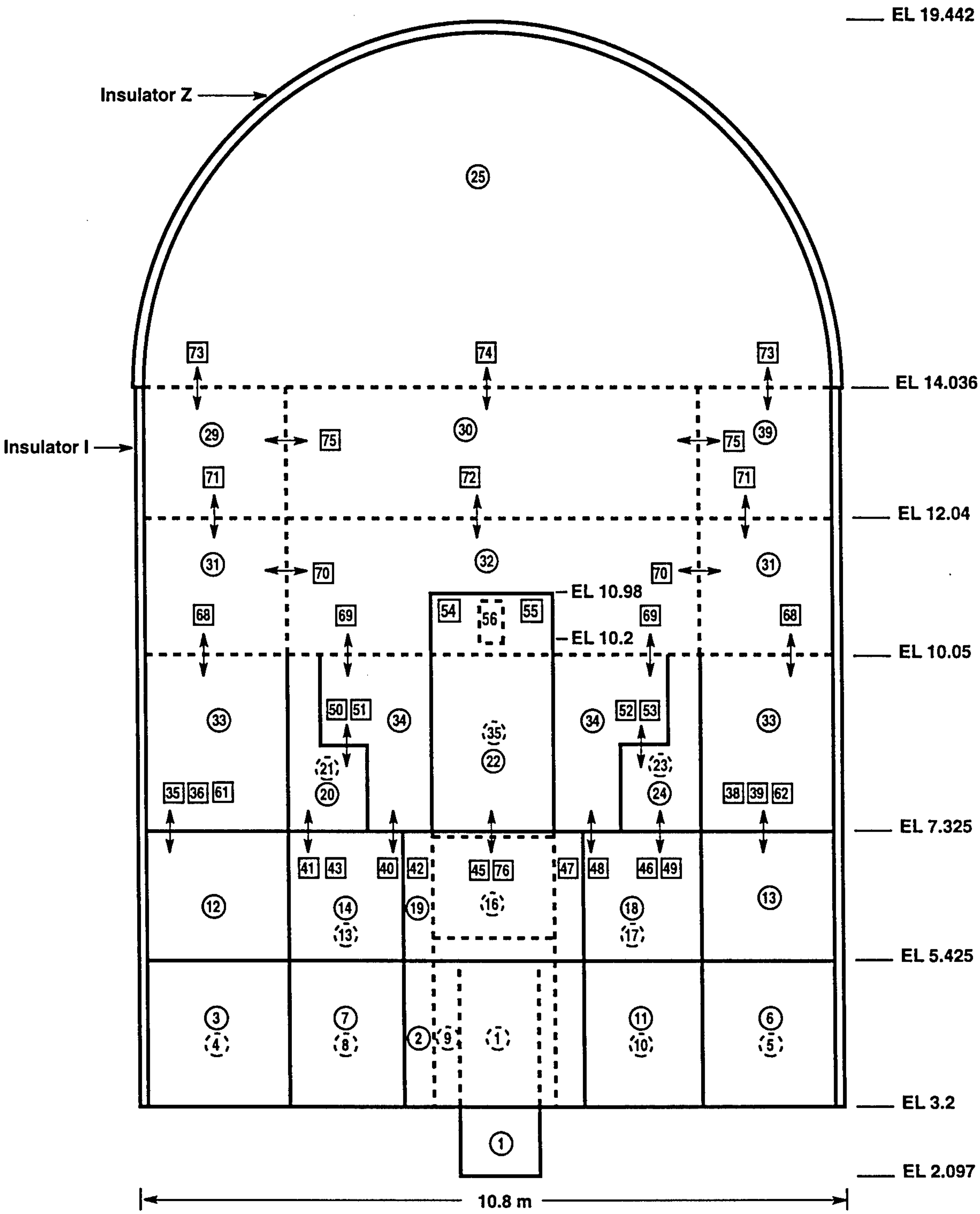

Figure 2. The CONTAIN 35-Cell Nodalization of the NUPEC 1/4-Scale Containment Model

Calculations with the hybrid gravitational head formulation have already been performed and reported in Reference 18 for a number of the NUPEC tests. More recently, the M-8-1 results were recalculated with CONTAIN 2.0. The predicted pressures from the hybrid and old gravitational head formulations are compared with the measured pressures in Figure 3. In Figure 4, the predicted gas temperatures from the hybrid formulation are compared to the measured gas temperatures at locations along a vertical axis through one of the steam generator towers. (The middle column of rooms referred to in this figure corresponds to the cells along this axis.) Good agreement is found between the predicted and measured pressures and temperatures; in addition the predicted peak pressure and temperature are shown to be conservative.

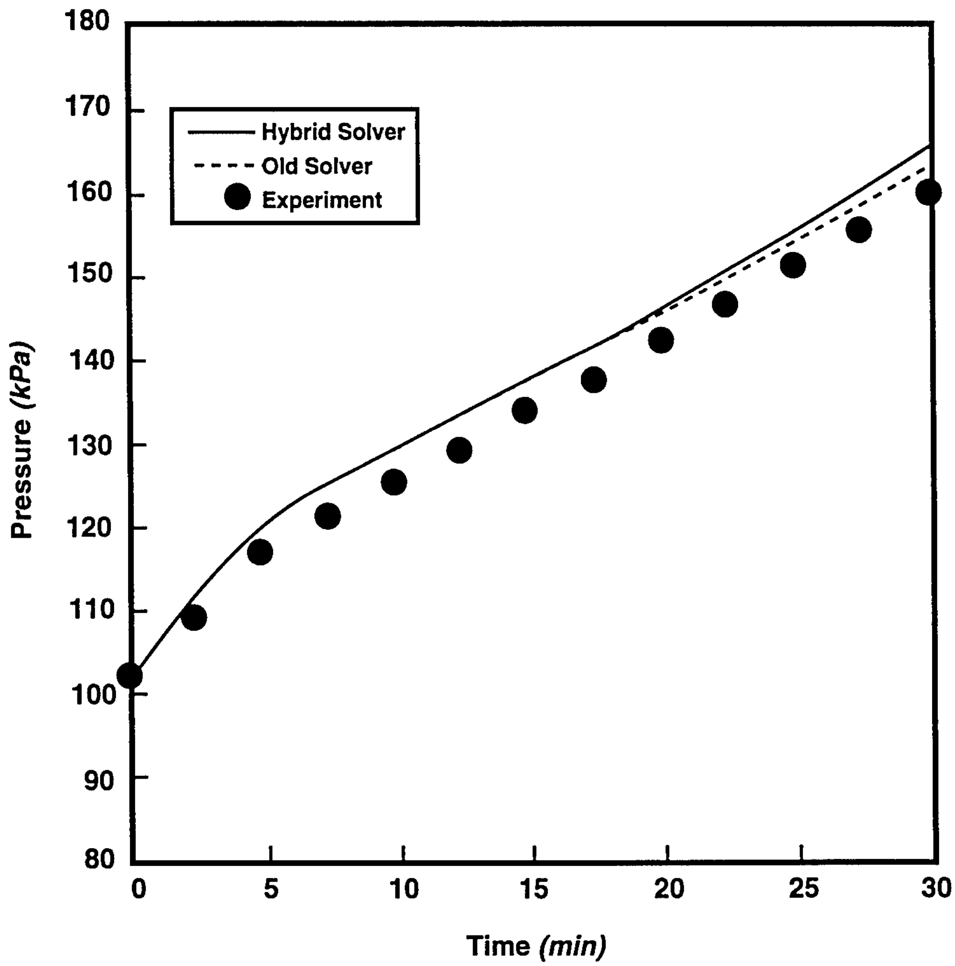

Figure 3. Predicted Pressures Compared to the Measured Pressures for the NUPEC M-8-1 Test

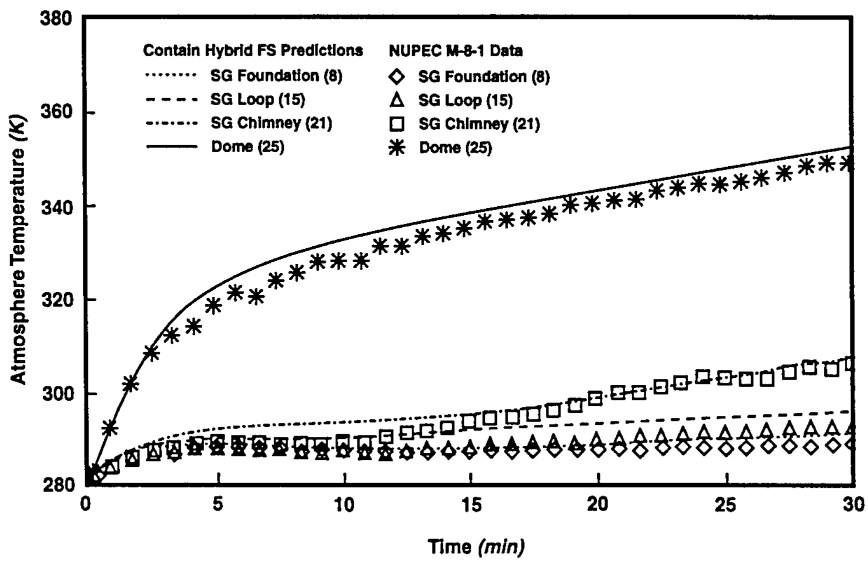

Figure 4. Predicted Gas Temperatures Using the Hybrid Formulation Compared to the Measured Temperatures for the NUPEC M-8-1 Test

With regard to the predicted stratification behavior, the differences between the hybrid and old formulations may be summarized through the predicted gas temperature profiles at the end of the 30-minute gas injection period. As shown in Figure 5, good agreement between the predicted and measured profiles is obtained with the hybrid formulation, but not the old formulation. The results from the latter clearly exhibit overmixing. It should also be noted that, in contrast to the hybrid formulation, the peak temperature is not conservatively predicted with the old formulation. With the hybrid formulation, good agreement is also found with the measured temperatures at other locations and with the measured helium concentrations.[17,18]

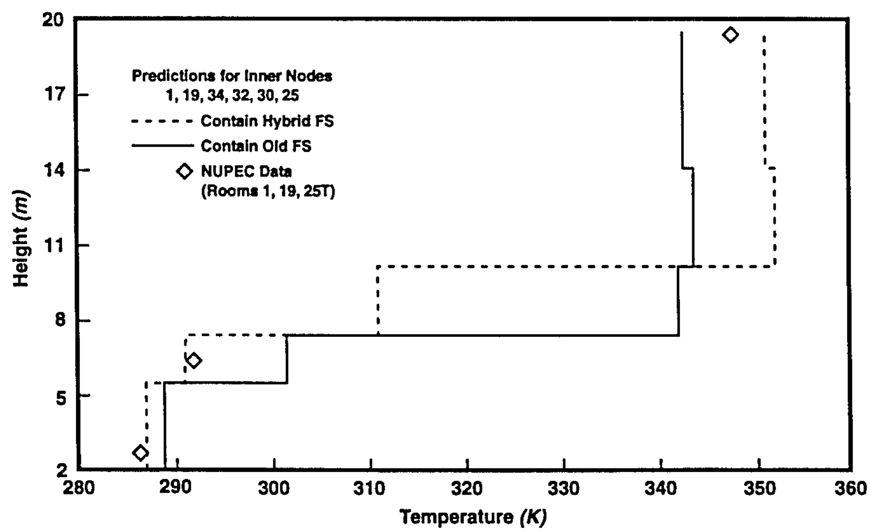

Figure 5. Predicted Temperature Profiles at the End of the Gas Injection Period Compared to the Measured Profile for the NUPEC M-8-1 Test

3.2 ISP-23

International Standard Problem (ISP)-23 (also known as test T31.5) was conducted in the German HDR facility.[10] This test was designed to represent a large-break LOCA, with the break occurring at mid-elevation in the containment, as shown in Figure 6. SNL was an original participant in this ISP, and a blind CONTAIN calculation was submitted in August 1988.[10] That submittal used a detailed nodalization of the HDR facility, as shown in Figure 7, with 33 cells to describe the containment within the steel shell representing its pressure boundary. Calculations using this 33-cell representation were recently redone with CONTAIN 2.0, and the results are shown in Figure 8. In the case labeled "No Forced Convection," the effects of forced convection on heat and mass transfer were ignored; in the case labeled "With Forced Convection," the degree of forced convection was estimated, and the forced convection velocities were specified through input. These two calculations utilized the aerosol method for treating suspended liquid water. In the case labeled "No Dropout," this water was treated in the default manner, as homogeneously dispersed liquid not subject to gravitational settling. Figure 9 shows local temperature comparisons at four elevations, ranging from -5 to 40 meters, in the "No Forced Convection" case. As indicated in this figure, the predicted temperature distribution within the containment and its time dependence agree reasonably well with the measured local temperatures, but the temperatures below the injection point at one elevation, namely at 5 m, are considerably overpredicted.

When steam is injected into the upper containment, one would expect the temperature rise in the lower containment to be partly the result of heating by compression, as the buoyant steam/air mixture in the upper containment expands and pressurizes the containment. Since this steam tends to be excluded from the lower containment because of its buoyancy, this compression would tend to produce superheated conditions in the lower containment. Overprediction of the lower containment temperatures may indicate that the superheating in the lower containment is suppressed by rainout of liquid into the lower containment and its concurrent evaporation, an effect that was not explored with respect to ISP-23, but was explored with respect to CVTR test #3 (see Section 3.3). The rainout conjectured here could arise either from liquid introduced during the blowdown or from entrainment of condensate films that have formed on heat sinks.

Another interesting feature of the ISP-23 calculation is the sub-compartment pressure differential between the break room and dome shown in Figure 10, for the "No Forced Convection" case. As shown in this figure, the peak pressure differential is slightly overpredicted by the code; however, the calculated pressure differential with the aerosol method of treating suspended liquid decreases rapidly enough that the prediction slightly underestimates the pressure differential at late times. As indicated by the no dropout case, this rapid drop-off may be an artifact. The difficulty is that the flow model neglects the inertial mass of the aerosolized water in calculating the flow rate, resulting in a flow rate out of the blowdown cell that is too high. A more realistic treatment of aerosol inertia would result in a pressure differential that lies somewhere between those of the two cases shown.

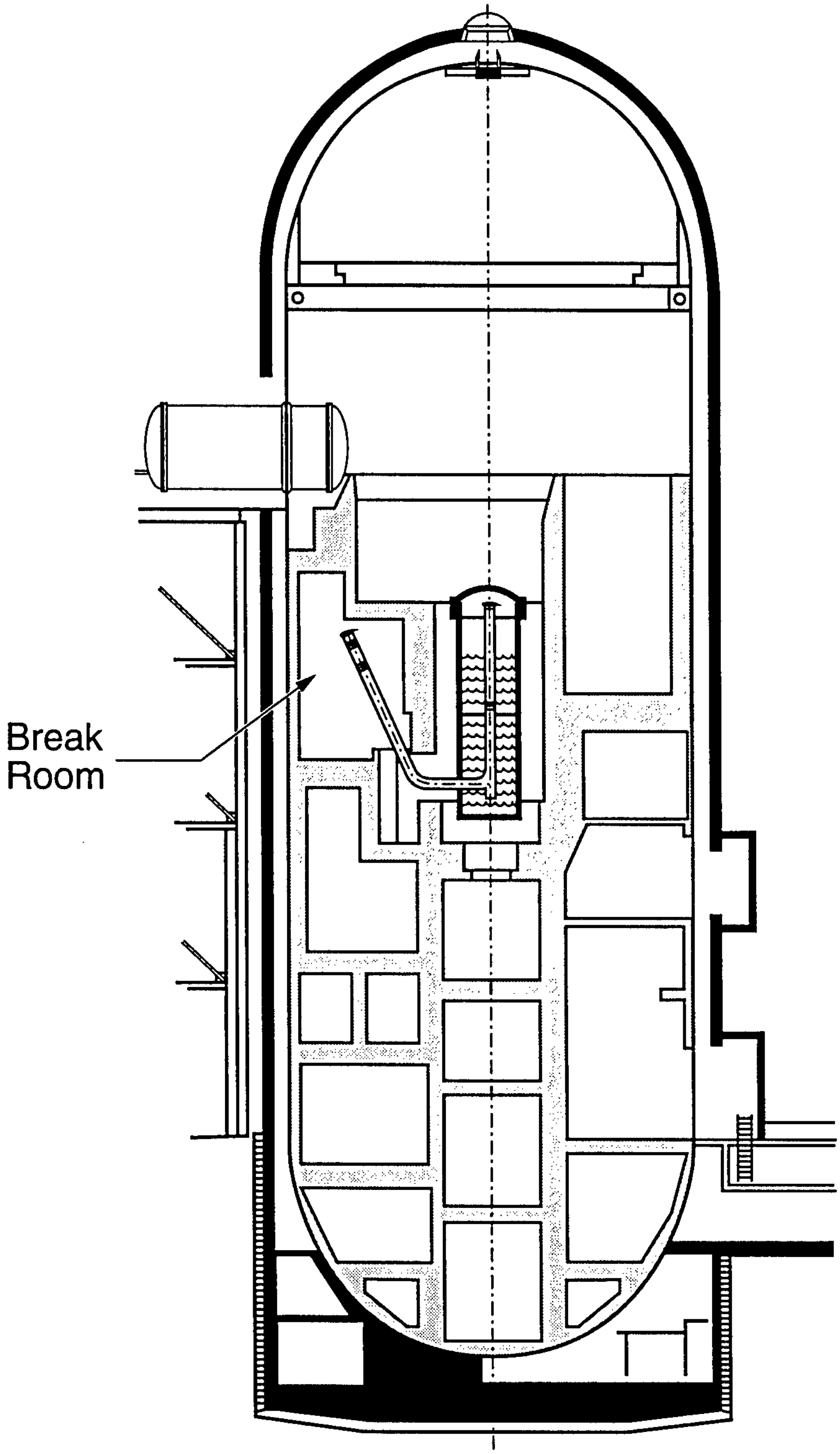

Figure 6. Layout of the HDR Facility, Showing the Blowdown Location Used for ISP-23

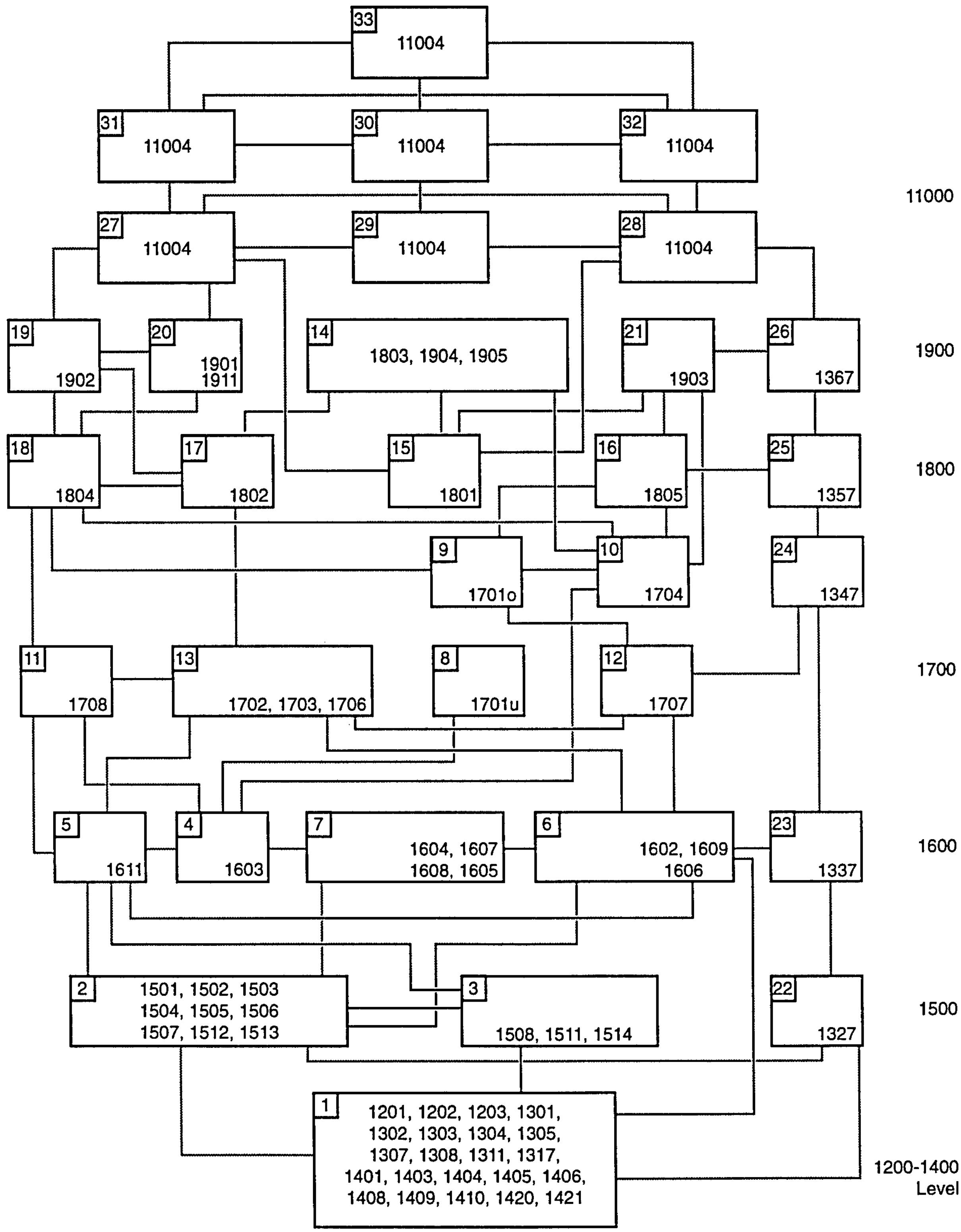

Figure 7. The 33-Cell Nodalization Used for ISP-23

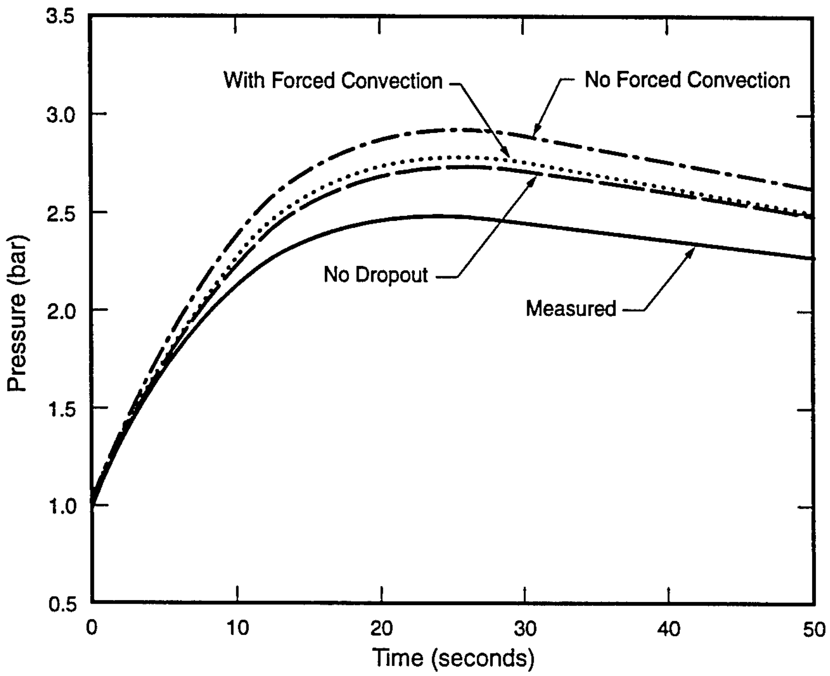

Figure 8. Various Pressure Predictions for ISP-23, Compared to Experiment

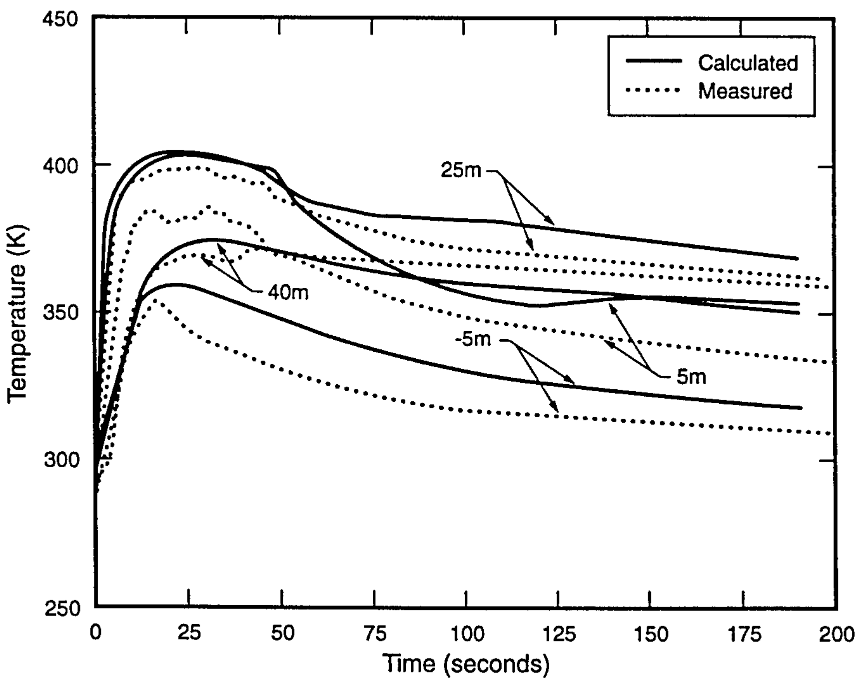

Figure 9. Predicted Gas Temperatures for ISP-23, Compared to Experiment

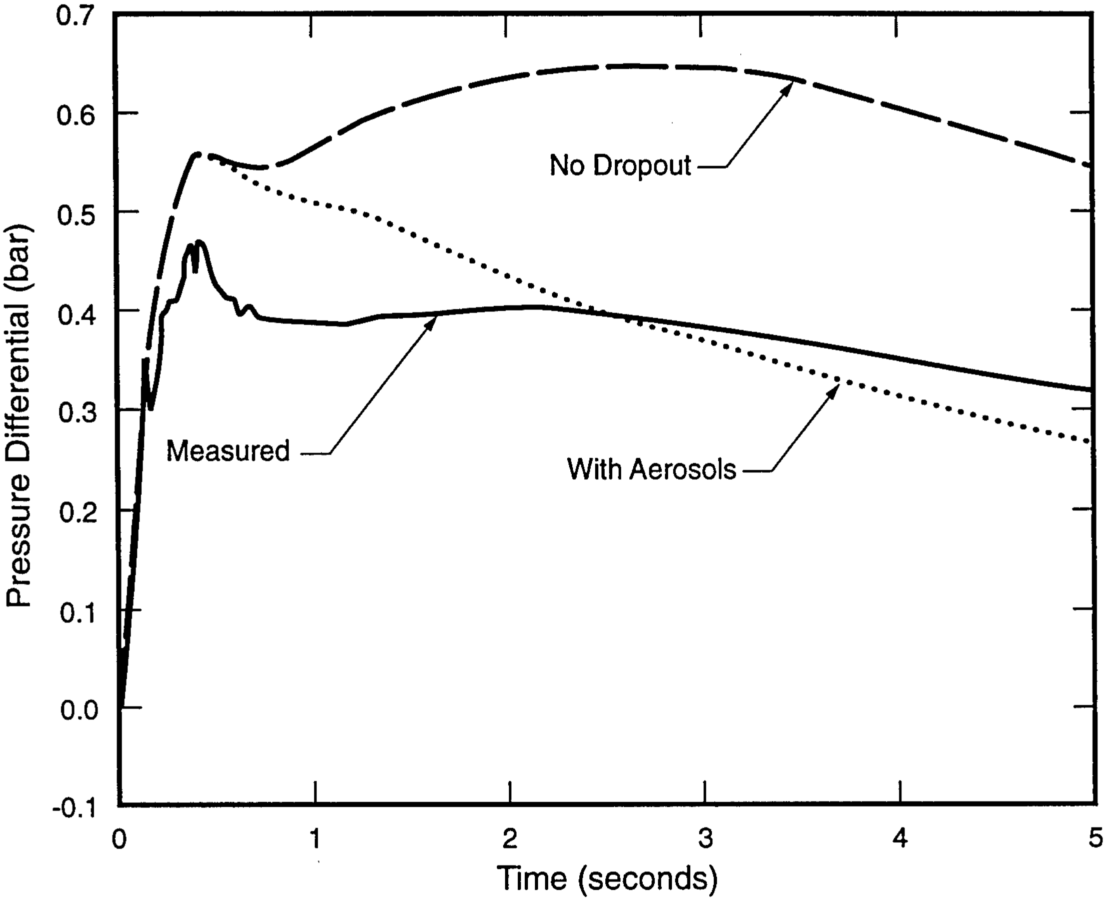

Figure 10. Predicted Sub-Compartment Pressure Differentials for ISP-23, Compared to Experiment

The pressure differential depends on other parameters such as loss coefficients that are difficult to determine accurately. However, with sufficient user guidance it should be possible to set flow parameters to assure conservative differentials. It should be noted that in the ISP-23 blind submittal, the CONTAIN predictions for sub-compartment pressures represented one of the best predictions from either control volume or fluid dynamics codes. The comparable agreement shown in Figure 10 is therefore as good as can be expected based on state-of-the-art code comparisons.

3.3 CVTR Test #3

CVTR test #3 is of particular interest because it has been used in the past for validating models in DBA codes.[19,20,21] In this test, steam was injected at a location just above the operating deck, and significant steam stratification was observed. Nevertheless, most containment analyses reported in the literature for this test have been performed using a single-cell representation of the containment. The CONTEMPT code was utilized for many of these analyses; therefore, the reported results also reflect specific limitations of CONTEMPT. Some of the more important modeling limitations common to past CVTR analyses include: (1) the use of the Uchida correlation for determining condensation heat transfer, (2) the neglect of the air gap resistance for the containment shell, (3) the neglect of condensate film resistance and film flow, and (4) the neglect of paint resistance for structures. In addition to these heat and mass transfer modeling limitations, there are uncertainties involving the specification of heat sink areas, such as the miscellaneous steel and internal concrete wall areas.

The multi-cell CONTAIN model for CVTR uses the 19-cell nodalization shown in Figure 11. This model uses relatively fine nodes in the lower containment to help capture the motion of the steam stratification interface that formed between the upper and lower containment during the experiment. Note that this stratification interface, which formed initially at operating deck level (shown at 325 ft. in the figure), moved downward into the lower containment as a result of pressurization effects during the blowdown. Capturing the motion of this interface was found to be the most challenging numerical aspect of the calculations. The multi-cell CVTR model uses the CONTAIN 2.0 default forced convection option for the heat and mass transfer, with parameters set so that its effects are minimal. The heat sink input is based on "best-estimate" concrete areas as tabulated in the final report on the CVTR DBA tests[8] and on the upper bound estimate for exposed miscellaneous steel (this corresponds to 50% of the tabulated major-component steel area at 3/8 in. thickness).

Predicted pressures from two single-cell calculations and the multi-cell calculation are compared in Figure 12. The single-cell calculation labeled "No Misc. Steel" used the same input as the multi-cell calculation except for reduction to one cell, elimination of the miscellaneous steel heat sinks, and use of lower-bound concrete heat sink areas. This apparently results in a containment response similar to that from the CONTEMPT model used by other authors.[19,20] In particular, the peak pressure and peak temperature of 416 K predicted for this case are nearly identical to the results reported by Carbajo[19] for his case 5, which used a Uchida correlation with an assumed condensation efficiency of 0.92. The other single-cell calculation shown in Figure 12 used the same heat sinks as the multi-cell calculation. The predicted pressures from this single-cell calculation are considerably lower than the first and tend to follow closely the multi-cell predicted pressures during the blowdown period. However, during the relaxation period after the blowdown, when heat transfer to structures dominates the pressure response, the multi-cell calculation gives good agreement with the measured pressure relaxation rate, whereas the single-cell calculations tend to overpredict the pressure relaxation rate.

The gas temperature predictions from the single-cell models are shown in Figure 13. These should be compared to the predictions, shown in Figure 14, from the multi-cell calculation. During the blowdown, the predicted temperatures from the single-cell calculations are conservative with respect to the measured maximum temperatures, although obtaining this conservatism clearly requires the use of extremely conservative assumptions when highly stratified conditions are present. The predictions from the multi-cell calculation in Figure 14 indicate more clearly the degree of conservatism present with respect to the local temperatures. After the blowdown, the single-cell calculation is no longer conservative and underpredicts the maximum temperatures in the containment. In contrast, the predictions from the multi-cell calculation predict the relative temperature variation in the containment quite well at all times and give good agreement with the temperature distributions at late times.

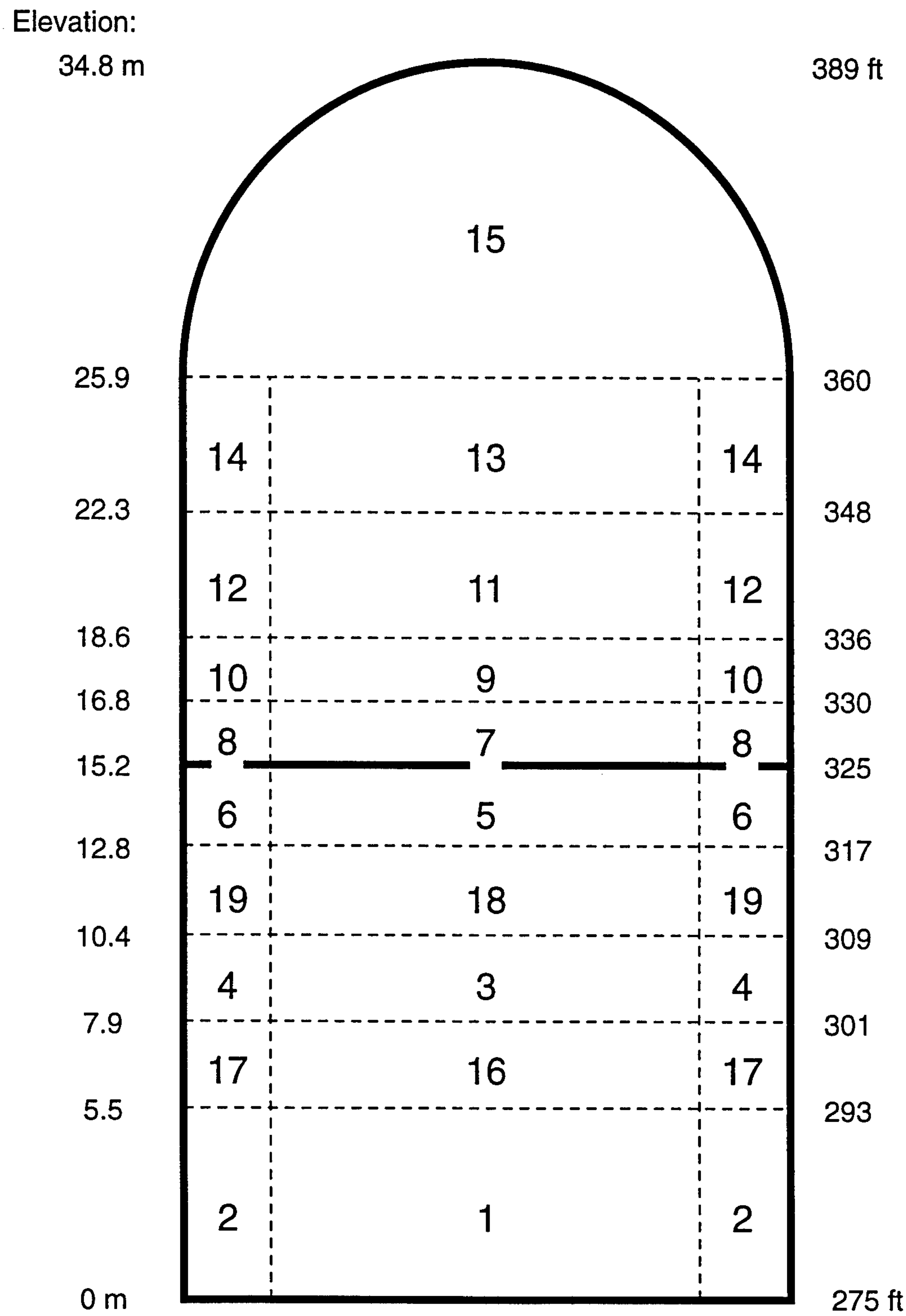

Figure 11. CVTR 19-Cell Nodalization

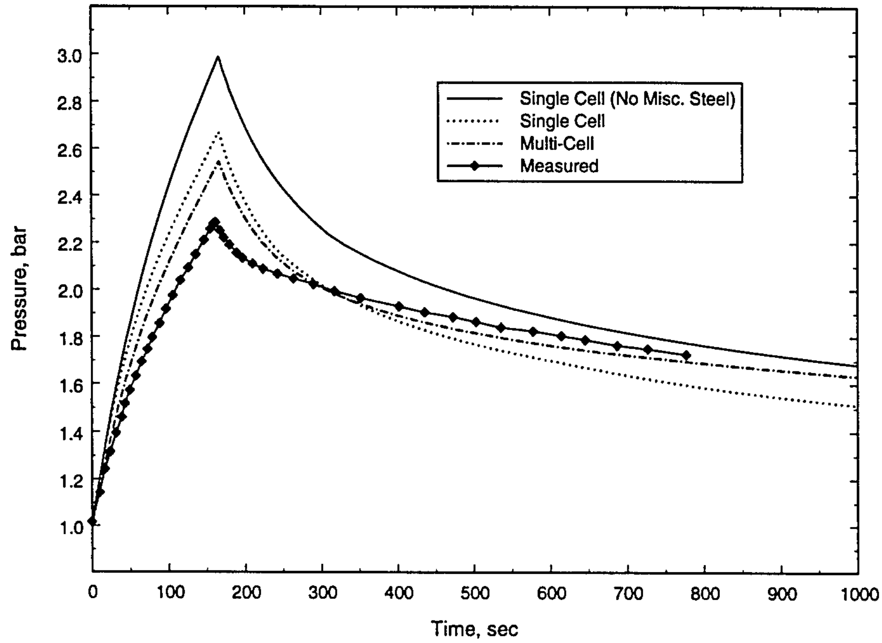

Figure 12. Predicted Pressures for CVTR Test #3 for Various Cases, Compared to Experiment

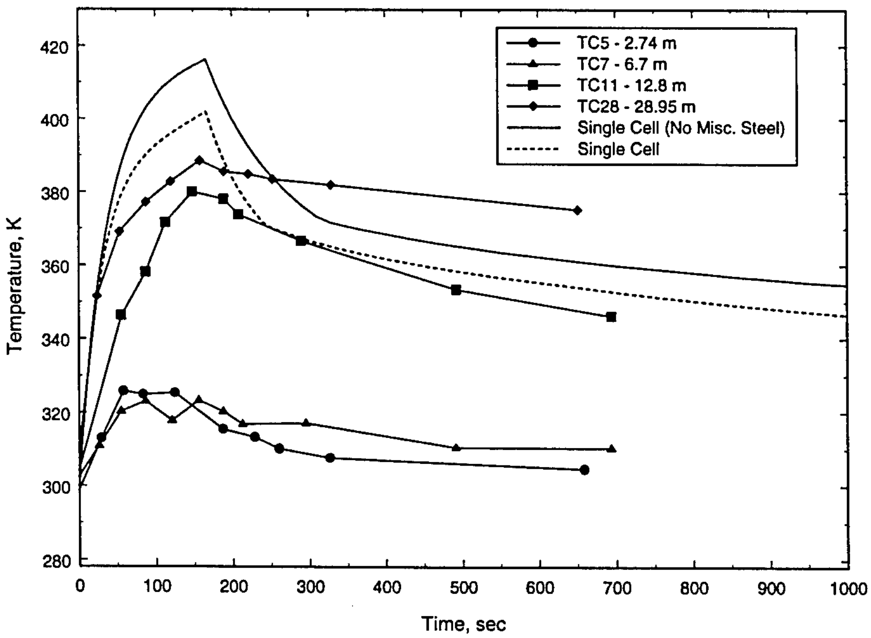

Figure 13. Single-Cell Temperature Predictions for CVTR Test #3, Compared to Experiment

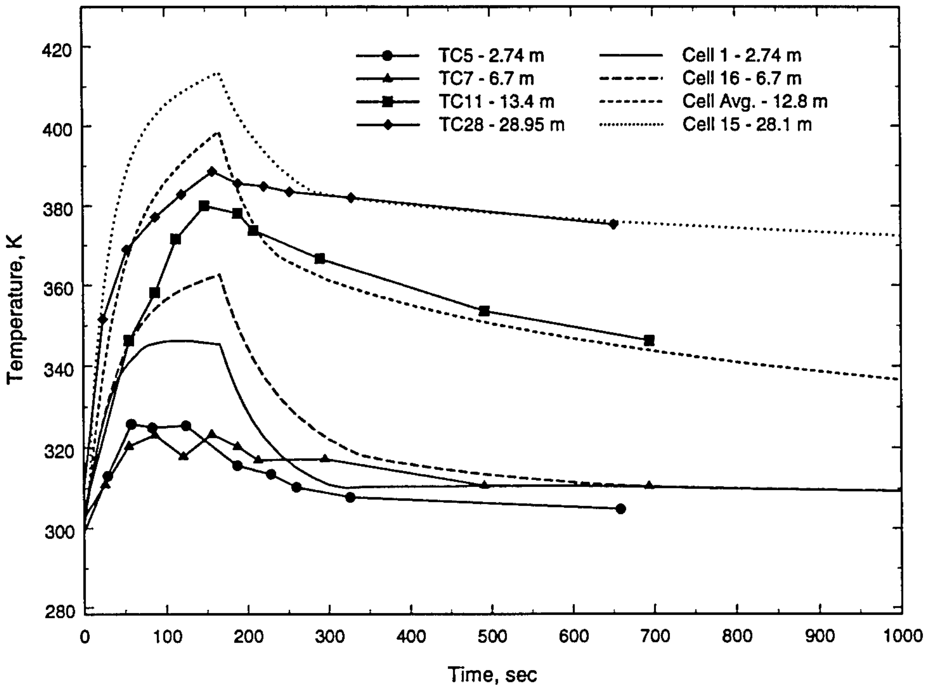

Figure 14. Multi-Cell Gas Temperature Predictions for CVTR Test #3, Compared to Experiment

In the results shown in Figure 14, the maximum calculated temperature corresponds to about 25 K of superheat, with the saturation temperature being approximately equal to the maximum measured temperature of 389 K. Likewise, in the lower regions of the containment the calculated maximum local temperatures correspond to approximately 20 K of superheat. The existence of such superheated conditions is clearly not supported by the data. To explore the uncertainties related to this superheat, sensitivity calculations were done with respect to forced convection effects, injected steam enthalpy, and rainout effects. Forced convection effects were introduced through flow boundary conditions that were imposed at the junctions between the annular cells 8, 10, and 12 of Figure 11 and the adjacent central cells, so as to match the observed forced convection velocities of 4.5 to 9 m/s along the containment wall during the blowdown.[8] Such flow boundary conditions result in long-range flow patterns that determine the forced convection conditions in the rest of the containment. This forced convection was found to affect primarily the pressure and upper containment temperatures: the discrepancy shown in Figure 12 between the predicted multi-cell and measured peak pressures was reduced by 1/2 and the discrepancy shown in Figure 14 between the predicted upper containment and measured peak temperatures was reduced by 1/3 by the effects of forced convection. A second sensitivity calculation indicated that, in the absence of forced convection, the discrepancy between the predicted and measured upper containment temperatures could be removed through a 2.8% reduction in the experimentally determined injected steam enthalpy of 2779.6 kJ/kg[8] used to obtain the results in Figures 12-14. This is comparable to the experimental uncertainty in the enthalpy, which was stated to be 2%.[8] It is, therefore, likely that a combination of forced convection effects and enthalpy measurement errors can explain the discrepancies between the multi-cell calculation and the experiment with respect to the peak pressure and peak temperature. The lower containment temperatures, however, were not significantly altered in these sensitivity calculations. A third sensitivity calculation was therefore done to explore the rainout hypothesis advanced above with respect to ISP-23, and this calculation showed that small amounts of rainout could be quite effective in suppressing the lower containment superheat.

Finally, Figure 15 shows another quantity of interest with respect to DBAs, the fraction of the total heat transfer attributable to sensible heat transfer, as opposed to condensation or latent heat transfer. (This is sometimes referred to as the "revaporization" fraction. The "condensation efficiency" mentioned above corresponds to one minus this quantity.) Because of the difference in conditions between the upper and lower containment, this fraction was calculated separately for the two regions. The 8% revaporization fraction sometimes used in DBA calculations is in reasonable agreement with the upper containment prediction during the blowdown period.

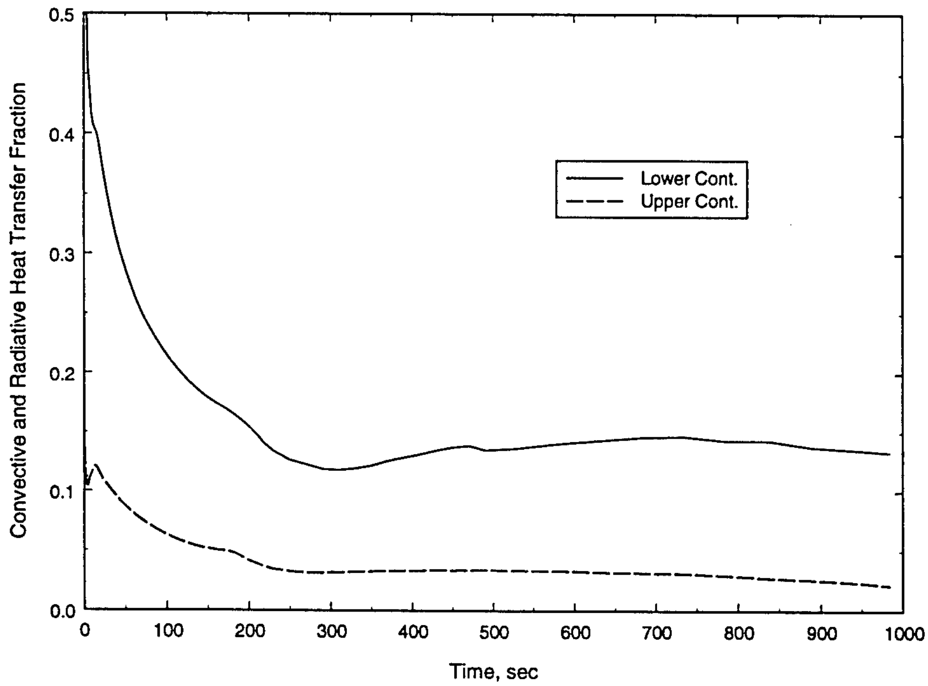

Figure 15. Sensible Heat Transfer Fraction Calculated for CVTR Test # 3

4. SAN ONOFRE PLANT CALCULATIONS

To illustrate how CONTAIN might perform in a conventional single-volume DBA analysis, comparisons between CONTAIN and CONTEMPT are presented in this section for a postulated large-break LOCA at the San Onofre plant. In this LOCA, fan coolers and sprays are assumed to be available. The CONTAIN and CONTEMPT modeling of this scenario were made to agree through CONTAIN input specifications, where possible. Such specifications eliminated uncertainties with regard to (1) concrete and steel properties, (2) paint thermal resistances, and (3) the treatment of suspended liquid water in the following comparisons. However, it should be noted that considerable differences still remain in the modeling. For example, in the CONTEMPT calculation, Tagami/Uchida heat transfer correlations for forced/natural convection were used; in the CONTAIN calculations, the HMTA model based on natural convection was used; in addition, the relatively small effect of forced convection was not taken into account in the results presented here.

As shown in Figure 16, CONTAIN predicts somewhat higher pressures than CONTEMPT for this scenario. The legend in this figure refers to the two options discussed in Section 2 for removing suspended liquid in CONTAIN, the dropout option similar to that used in CONTEMPT and the aerosol option. Figure 16 indicates that the effects on pressure from use of the aerosol option are approximately the same as those from the dropout option. The similarities during the initial pressure ramp are to be expected because the specific heat of liquid water is neglected once its mass is transferred to the aerosol field. Under condensing conditions, the water aerosols thus do not contribute thermally to the atmosphere, even if they remain suspended for some time.

Figure 17 shows various predictions for the gas temperature. As shown in this figure, and in contrast to the CONTEMPT prediction, the dropout option introduces a significant degree of superheat for this scenario, beginning at approximately 25 seconds. Note that fan coolers are assumed to actuate at 33 seconds and sprays at 55 seconds. Thus, the onset of superheat cannot be explained by the response to the latter. As shown in Figure 17, the tendency to superheat is reduced with the aerosol option, which retains more liquid in the atmosphere than the dropout option. Also, as shown in this figure, this tendency is further reduced by invoking the radiative heat transfer option, which allows additional heat to be transferred to heat sinks. The CONTAIN results with the aerosol option and radiative heat transfer are quite similar to the CONTEMPT results. However, since CONTEMPT treats suspended water in "drop-out" fashion similar to the CONTAIN option, and a comparison of heat transfer models[5] suggests that CONTEMPT should predict conditions that are more superheated than CONTAIN's prior to spray onset, the fact that the CONTEMPT calculations do not predict superheat is not understood.[†] Nevertheless, CONTAIN's pressures and temperatures are conservative relative to CONTEMPT's.

[†] After spray onset, the presence of superheat in the CONTAIN calculation indicates that the monodisperse spray droplets used in the CONTAIN spray model do not equilibrate with the atmosphere.

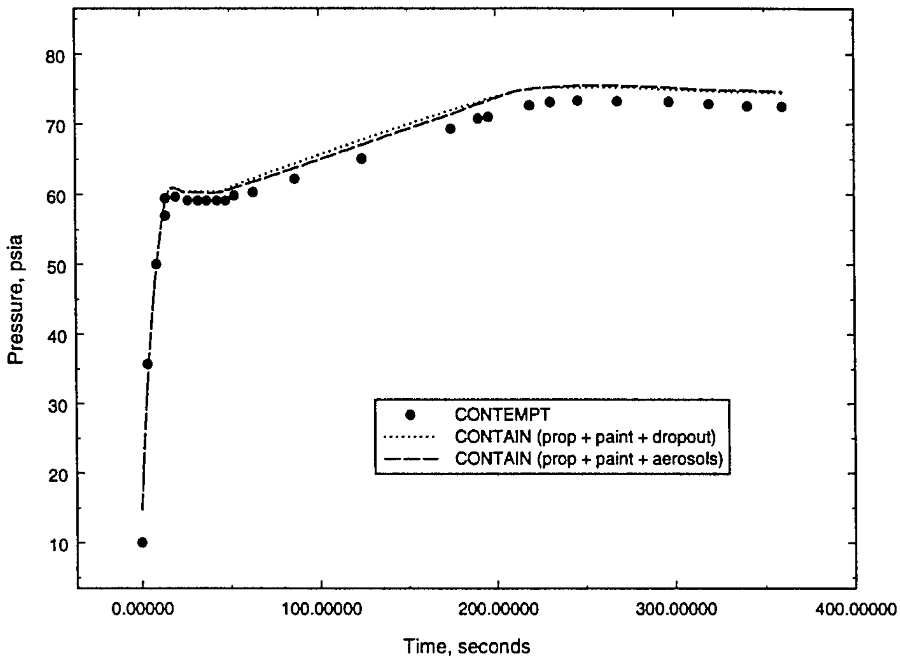

Figure 16. Comparison of CONTAIN and CONTEMPT Predicted Pressures for the San Onofre Large-Break LOCA

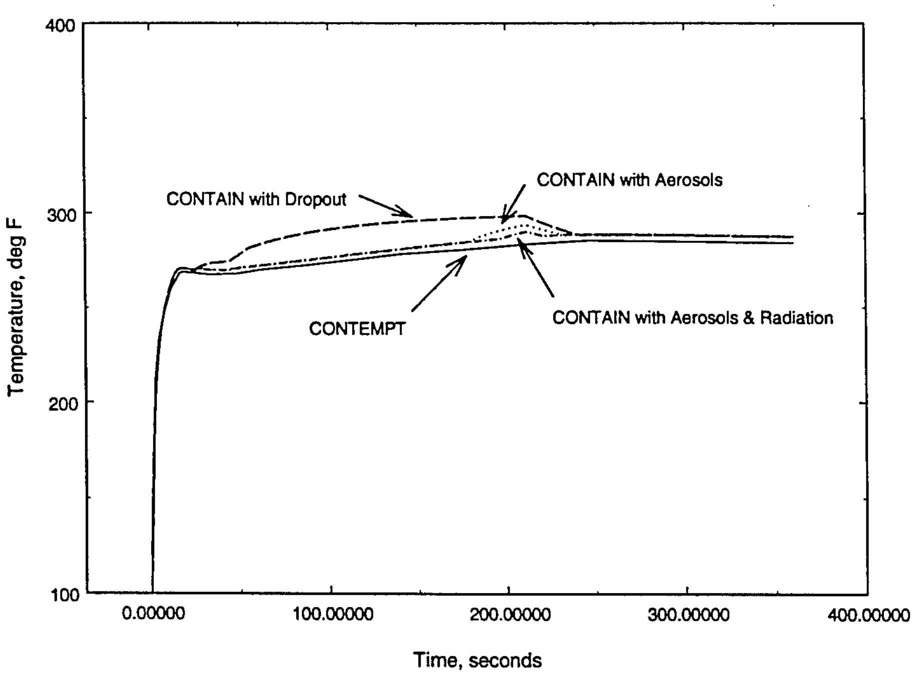

Figure 17. Comparison of CONTAIN and CONTEMPT Predicted Gas Temperatures for the San Onofre Large-Break LOCA

5. CONCLUSIONS

The new features of the CONTAIN 2.0 code release have been reviewed. In addition, work in progress to help qualify CONTAIN for more general use in licensing applications has been summarized. The work discussed here on PWR scenarios indicates that CONTAIN can predict conservative peak pressures and conservative peak temperatures, under well-mixed and highly stratified DBA conditions. These results also indicate that CONTAIN has potential for conservative prediction of subcompartment pressure differences, although further user guidance and perhaps model improvements in this area need to be developed.

REFERENCES

1. K. K. Murata et al., "Code Manual for CONTAIN 2.0: A Computer Code for Nuclear Reactor Containment Analysis," NUREG/CR-6533, SAND97-1735, Sandia National Laboratories, Albuquerque, NM, December 1997.

2. J. Tills, R. O. Griffith, K. K. Murata, and D. W. Stamps, "User Guidance on the CONTAIN Code for Advanced Light Water Reactors," SAND96-0947 (Proprietary), Sandia National Laboratories, Albuquerque, NM, 1996.

3. J. Tills, "Calculations and Analyses for the Large-Scale Passive Containment Cooling System (PCS) Tests," SAND96-1089 (Proprietary), Sandia National Laboratories, Albuquerque, NM, 1996.

4. J. Tills, K. K. Murata, and K. E. Washington, "PCCS Model Development for the SBWR Using the CONTAIN Code," presented at ARS '94 - International Topical Meeting on Advanced Reactor Safety, American Nuclear Society, Pittsburgh, PA, April 17-21, 1994.

5. D. W. Hargroves and L. J. Metcalf, "CONTEMPT-LT/028 — A Computer Program for Predicting Containment Pressure-Temperature Response to a Loss-of-Coolant Accident," NUREG/CR-0255, TREE-1279, Idaho National Engineering Laboratory, Idaho Falls, ID, 1979.

6. R. G. Gido, J. S. Gilbert, R. G. Lawton, and W.L. Jensen, "COMPARE MOD-1: A Code for the Transient Analysis of Volumes with Heat Sinks, Flowing Vents, and Doors," LA-7199-MS, Los Alamos National Laboratory, Los Alamos, NM, March 1978.

7. T. R. McIntyre, M. A. Ross, and L. L. Meyers, "Mark II Pressure Suppression Test Program Phase I Tests," NEDE-13442P-01 (Proprietary), General Electric Co., San Jose, CA, May 1976; L. L. Meyers, T. R. McIntyre, and R. J. Ernst, "Mark III Confirmatory Test Program Phase I - Large Scale Demonstration Tests: Test Series 5701-5703," NEDM-13377 (Proprietary), General Electric Co., San Jose, CA, October 1974.

8. R. C. Schmitt, G. E. Bingham, and J. A. Norberg, "Simulated Design Basis Accident Tests of the Carolinas Virginia Reactor Containment - Final Report," IN-1403, UC-80, Idaho Nuclear Corporation, National Reactor Testing Station, Idaho Falls, Idaho, December 1970.

9. M. Firnhaber, "ISP16: Rupture of a Steam Line Within the HDR-Containment Leading to an Early Two-Phase Flow — Results of the Post-Test Analysis," CSNI Report No. 112, Committee on the Safety of Nuclear Installations, OECD Nuclear Energy Agency, Paris, France, June 1985.

10. H. Karwat, "ISP23: Rupture of a Large Diameter Pipe Within the HDR Containment," CSNI Report No. 160, Vols. 1 and 2, Committee on the Safety of Nuclear Installations, OECD Nuclear Energy Agency, Paris, France, 1989.

11. "Final Comparison Report on ISP-35 NUPEC's Hydrogen Mixing and Distribution Test (Test M-7-1)," NEA/CSNI/R(94)29, Committee on the Safety of Nuclear Installations, OECD Nuclear Energy Agency, Paris, France, December 1994.

12. H. Karwat, "OECD-CSNI-ISP29, Distribution of Hydrogen Within the HDR-Containment Under Severe Accident Conditions – Final Comparison Report," OECD Committee on the Safety of Nuclear Installations, Paris, France, August 1992.

13. R. B. Bird, W. E. Stewart, and E. N. Lightfoot, *Transport Phenomena*, John Wiley and Sons, Inc., New York, 1960.

14. D. C. Slaughterbeck, "Review of Heat Transfer Coefficients for Condensing Steam in a Containment Building Following a Loss-of-Coolant Accident," IN-1338, Idaho Nuclear Corporation, National Reactor Testing Station, Idaho Falls, ID, September 1970.

15. H. Uchida et al., "Evaluation of Post Incident Cooling Systems of Light-Water Power Reactors," in *Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy, Held in Geneva, 31 August - 9 September, 1964*, 13, United Nations, New York, 1965.

16. P. F. Peterson, "Theoretical Basis for the Uchida Correlation for Condensation in Reactor Containments," *Nucl. Eng. and Design*, 162, pp. 301-306, 1996.

17. K. K. Murata, and D. W. Stamps, "Development and Assessment of the CONTAIN Hybrid Flow Solver," SAND96-2792, Sandia National Laboratories, Albuquerque, NM, November 1996.

18. D. W. Stamps, "CONTAIN Assessment of the NUPEC Mixing Experiments," SAND94-2880, Sandia National Laboratories, Albuquerque, NM, August 1995.

19. J. J. Carbajo, "Heat Transfer Coefficients Under LOCA Conditions in Containment Buildings," *Nucl. Engr. Design*, 65, pp. 369-386, 1981.

20. W. J. Krotiuk, and M. B. Rubin, "Condensing Heat Transfer Following a Loss-of-Coolant Accident," *Nucl. Tech.*, 37, pp. 118-128, February 1978.

21. E. Economos et al., "Condensation Heat Transfer Modelling for Containment Environmental Response Calculations - A Reappraisal for the Standard Review Plan - Main Report," Technical Report A-3719, Vol. 1, Department of Nuclear Energy, Brookhaven National Laboratory, Upton, NY, June 1987.

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