SMSAB-03-02

CONTAIN Code Qualification Report/User Guide for Auditing Design Basis BWR Calculations

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March 2003

Office of
Nuclear Regulatory Research

SAFETY MARGINS AND SYSTEMS ANALYSIS BRANCH

[1] Sandia National Laboratories, Modeling and Analysis Department, Org. 6421

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1.0 INTRODUCTION

1.1 Background and Purpose

Current U.S. Nuclear Regulatory Commission (NRC) policy provides guidance to nuclear reactor licensees about what types of calculations need to be performed, and what calculational methods can be used to demonstrate the adequacy of their containment system designs. A number of computer codes were developed in the time period 1960-1980 that embodied the NRC guidelines for Design Basis Accidents (DBAs). These codes, such as CONTEMPT-LT/028 (NUREG/CR-0255) and COMPARE (LA-NUREG-6488-MS) have been the principal calculational tools used by the NRC in reviewing license applications related to containment systems. Because licensing of new plants came to a standstill after that period, these codes, as well as NRC guidelines, have not been modified or updated significantly since then.

In the meantime, however, the NRC's research program following the TMI-2 accident has produced an abundance of technical information and scientific understanding about reactor accidents, applicable both to severe accidents and DBAs. Computer simulation codes are an important product of this research program, and in the containment area, the CONTAIN code [1] has been developed by Sandia National Laboratories for the NRC for studying conditions inside the containment building during and after postulated reactor accidents. It incorporates the best current understanding of all relevant phenomena, and has the most extensive validation basis of any code in its class.

CONTAIN can be used to model all types of domestic containments:

- the standard boiling water reactor (BWR) pressure suppression systems, including Mark I, II, and III configurations;
- the various pressurized water reactor (PWR) containments, including large dry, ice condenser and sub-atmospheric designs;
- the annular region of dual containment systems;
- advanced reactor designs (CONTAIN was used in NRC's review of the AP600).

The purpose of this document is to provide guidance on the use of CONTAIN to model the various BWR configurations for performing DBA audit calculations. Specifically, CONTAIN can be used for pressure and temperature analysis of short-term transients to predict peak drywell and wetwell temperatures and pressures. Long-term transients can be analyzed to calculate peak suppression pool temperatures.

Included in this report are targeted comparisons with sample plant analysis cases and other analysis procedures to demonstrate the adequacy of the CONTAIN code to achieve its intended objectives. This qualification component is to demonstrate and establish a degree of "equivalency" with the existing licensing framework, e.g., as specified in the NRC Standard

Review Plan. Thus, the calculated results tend to be bounding in nature or biased in a conservative manner.

It should be noted that, to the extent practicable, CONTAIN is a comprehensive containment analysis code which has been developed using a physics-based modeling approach consistent within a lumped parameter framework. Accordingly, user-defined parameters play a lesser role than with the older codes. However, the code does permit the user to perform sensitivity studies of containment response predictions using appropriate input parameters.

The CONTAIN code has been extensively assessed against a broad range of experimental programs. Therefore, CONTAIN can be used to pursue "best-estimate" containment response predictions. However, that aspect is beyond the scope of this report. A report entitled "User Guidance on the CONTAIN Code for Advanced Light Water Reactors," SAND96-0947, is a good illustration of a "best-estimate plus uncertainty" containment analysis applied to the AP600 design.

Besides the underlying regulatory related guidelines which dictate the licensing based assumptions, the CONTAIN 2.0 Code Manual (NUREG/CR-6533) is the key reference document that is used and extensively cited in this effort. Another document that provides additional insight to form the basis of selected recommended parameters is entitled, "An Assessment of CONTAIN 2.0: A Focus on Containment Thermal-Hydraulics (Including Hydrogen Distributions).

Chapters 2, 3, and 4 of this report will cover, respectively, the Mark I, Mark II, and Mark III configurations of BWRs. Each chapter will review the relevant phenomenology for DBA analysis and provide guidance on using CONTAIN. This guidance is intended to show how to prepare input decks that will produce CONTAIN calculations with an equivalent degree of conservatism to traditional approaches to DBA audit calculations. However, the experienced analyst will notice some differences between the CONTAIN treatments and traditional approaches. These differences derive primarily from the more consistent and more complete treatment of the applicable physics in CONTAIN.

The appendices of this report provide a basic supporting foundation for Chapters 2, 3, and 4. The specific support provided by the appendices is as follows:

(a) Detailed comparisons of the CONTAIN and traditional BWR analytical approaches are provided in Appendices A and B.

(b) Detailed input-deck examples of the application of CONTAIN for Mark I BWR short-term and long-term analysis are provided in Appendices C and D, respectively. In addition, Appendix E provides the input deck for a restart of the long-term analysis.

(c) A detailed input-deck example of the application of CONTAIN for Mark II BWR short-term analysis is provided in Appendix F.

(d) Detailed description of the calculation of CONTAIN Mark III inertial lengths is provided in Appendix G.

(e) A detailed input-deck example of the application of CONTAIN for Mark III BWR short-term analysis is provided in Appendix H.

CONTAIN can be used for all containment types and for several different scenarios (e.g., both short-term and long-term events), without the need to perform supplemental calculations that were found to be required in previous approaches. The result is a more consistent and defensible calculational method, with increased confidence in the results because of the thoroughness of the validation base of CONTAIN. On the other hand, this dependence on CONTAIN means that it is important that the analyst understand how the various elements of the input deck control the calculational assumptions. Thus one important purpose of the discussions in Chapters 2-4 is to provide clear and understandable instructions on how to use CONTAIN for conservative DBA analysis. It should be noted that broader studies involving "best-estimate plus uncertainty" approaches would require the analyst to depend much more heavily on the CONTAIN 2.0 Code Manual.

1.2 Key Phenomena and Accident Phases

Generally, a containment functional design evaluation includes calculations of the key containment loads, i.e., pressure and temperature effects, associated with a postulated large ruptures of the primary or secondary coolant system piping. The focus of this report is to provide adequate guidance in performing drywell and wetwell pressure and temperature transient response calculations in order to obtain peak conditions for auditing the licensing basis of the various BWR pressure suppression systems. Other key values obtained from these types of analysis are peak pressure differentials, such as between the drywell and wetwell volumes.

The qualitative nature of event sequence progression in BWR DBAs is similar for each of the containment types. During the blowdown of the reactor vessel, the mass and energy released from the primary system pressurizes the drywell. As the drywell pressure increases, the water in the vents is accelerated and flows into the suppression pool. Within seconds, the vents clear of liquid and a two-phase mixture of gas, steam, and suspended water flows into the suppression pool. This two-phase flow initially creates a gas bubble at the downstream end of the vent, which causes level swell and eventually breaks through the pool surface. The relevant bubble dynamics include initial acceleration of the liquid surrounding the bubble, level swell in the suppression pool, steam condensation in the bubbles, and release of the gas and steam to the wetwell atmosphere after bubble break through of the suppression pool surface occurs. This sequence of events is referred to as the vent-clearing transient. The peak drywell pressure is usually calculated in this short-term period.

It is clear that the short-term peak drywell pressure (and drywell-wetwell pressure difference) is to a large extent controlled by the vent clearing time, the working definition of which is the time required for the gas to penetrate to the far end of the vents on the wetwell side. Therefore, this time should be calculated in a conservative manner. Since the drywell pressure is also controlled to some extent by the pressure rise in the wetwell, a number of complications arise: (1) the two-phase and the single-phase liquid flows related to vent clearing should be modeled conservatively to yield conservative pressure values, and (2) the pool inertia constraining the expansion of the gas bubble that forms on the downstream side of the cleared vents initially impedes two-phase flow. The pool swell associated with this bubble is expected to significantly affect two-phase flow in the vents between the time of clearing and the time of bubble breakthrough of the suppression pool surface. While two-phase flows can be treated with CONTAIN, level swell and bubble inertia effects cannot be modeled with the three-cell model recommended in this report, and, only possibly, with additional cells and code modification. However, these effects are expected to be of minor importance.

In the long-term transient response, the peak suppression pool temperature response is calculated, thereby determining the effectiveness of the pool heat exchanger to mitigate the continuing mass and energy input directed to the pool.

In the next three chapters of this report, specific guidance is provided on using CONTAIN 2.0 for short-term transient response for each of the three containment types. For the long-term transient, the differences among the three containment types are not particularly important. Therefore, guidance on using CONTAIN for the long-term transient is provided for the Mark I design only. This guidance can be easily extended to the Mark II and Mark III designs.

2.0 MARK I CONTAINMENT ANALYSIS

In this section we discuss methods that can be used to model the DBA response of BWR Mark I containments with CONTAIN [1]. Figure 2-1 depicts the Mark I containment and shows the reactor pressure vessel, the drywell, the vent system from the drywell to the wetwell, and the wetwell (suppression chamber). Note that the wetwell is a torus that contains the suppression pool.

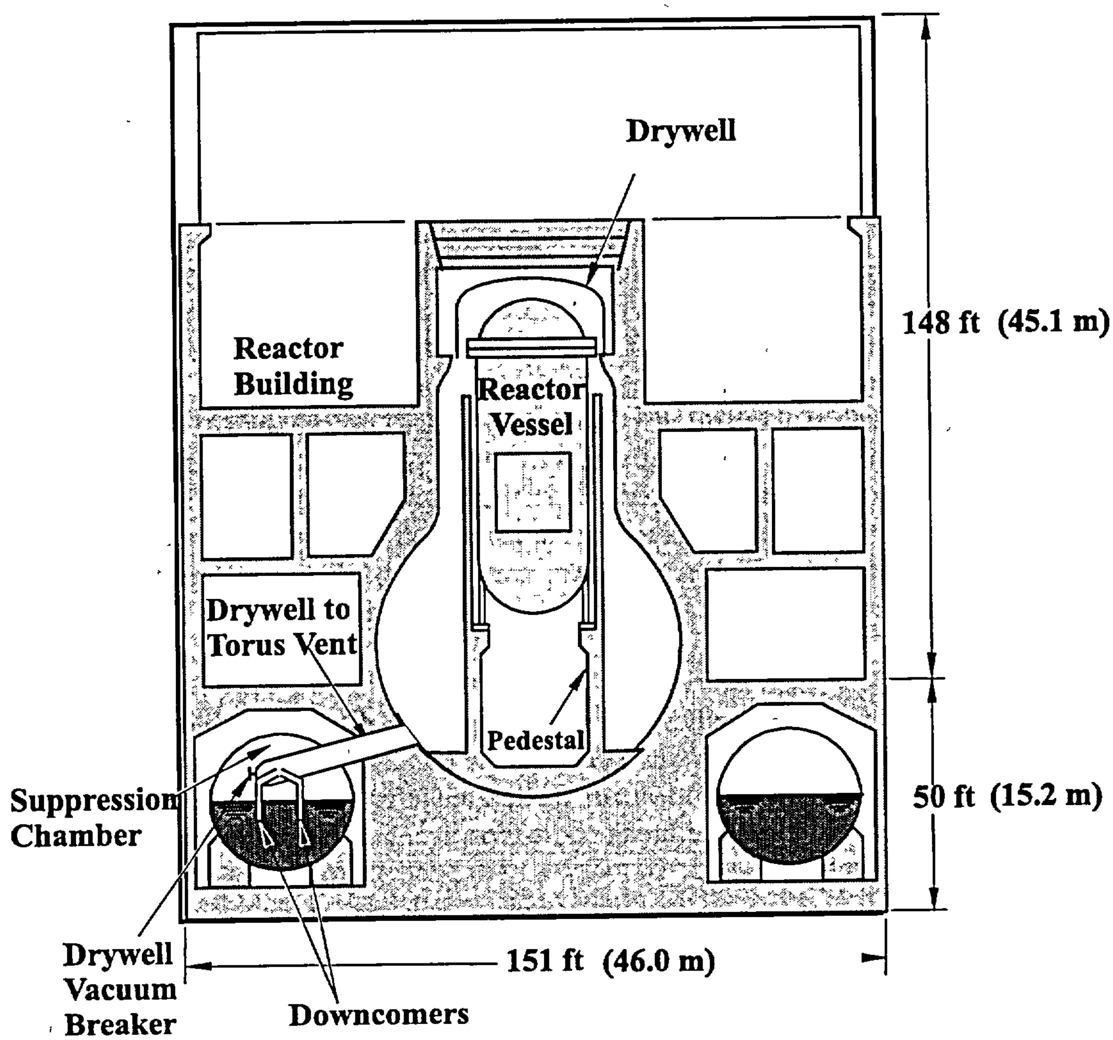

Figure 2-1 Mark I BWR containment showing the drywell, vent-system (vent and downcomers), and the wetwell.

For the Mark I containment, two types of DBA-response calculations lie within the domain of CONTAIN: (1) The Mark I short-term scenario for evaluation of the maximum drywell pressure, drywell temperature and drywell to wetwell pressure differential, which typically occurs during the blowdown, and (2) The Mark I long-term scenario evaluation of the maximum wetwell pressure and pool temperature that occur some hours after the initial blowdown. These two types of calculations are discussed in Sections 2.1 and Section 2.2, respectively. The procedures for the long-term scenario could be used for evaluating the long-term response in Mark II and Mark III containments.

2.1 Mark I Short-Term Accident Analysis

In Section 2.1.1, we describe the Mark I short-term scenario. Then, in Section 2.1.2 the recommended approach for Mark I short-term scenario modeling with CONTAIN is described. The objective of the recommended approach is to ensure that CONTAIN will predict conservative results, and that its predictions will be confirmed by traditional Mark I results. (A detailed comparison of the recommended CONTAIN approach and the traditional approach is given in Appendix A). In Section 2.1.3, the preparation of the CONTAIN input for a Mark I short-term scenario is discussed. Section 2.1.3 also discusses the calculation of a short-term scenario involving a recirculation line break for the Hope Creek plant (arbitrarily selected as the Mark I demonstration plant), based on data from the plant's Safety Analysis Report (SAR) [2].

2.1.1 Mark I Short-Term Scenario

The containment functional design evaluation, as described in Reference 2 for the Hope Creek plant, includes consideration of several postulated accidents, each of which results in the release of reactor coolant in the containment. These postulated accidents include (1) an instantaneous guillotine rupture of a recirculation line, (2) an instantaneous guillotine rupture of a main steam line, (3) an intermediate size reactor coolant system (RCS) break, and (4) a small size RCS break. Analysis of this spectrum of accidents indicates that the maximum temperatures and pressures experienced inside the containment do not all result from the same accident. Maximum drywell and wetwell pressures occur as a result of the recirculation line break. However, the most severe drywell temperature condition (peak temperature and duration) results from the small-size, steam-line break. Consequently, there is no single DBA for the containment.

The maximum drywell and wetwell pressure occurs near the end of the blowdown phase of a LOCA. Approximately the same peak occurs for the break of either a recirculation line or a main steam line. Therefore, both accidents are evaluated in Reference 2. However, for demonstration purposes, only the recirculation line break short-term scenario is analyzed for the Hope Creek plant in Section 2.1.3 below.

Figures 2-2 through 2-5, which were obtained from our Hope Creek short-term analysis, will be used to illustrate the containment response calculated by CONTAIN for the recirculation line break short-term scenario. Results from the Hope Creek SAR are also shown. These results show that, if the recommendations for Mark I short-term modeling in CONTAIN are followed, results will be very consistent with traditional analysis methods, and generally slightly conservative.

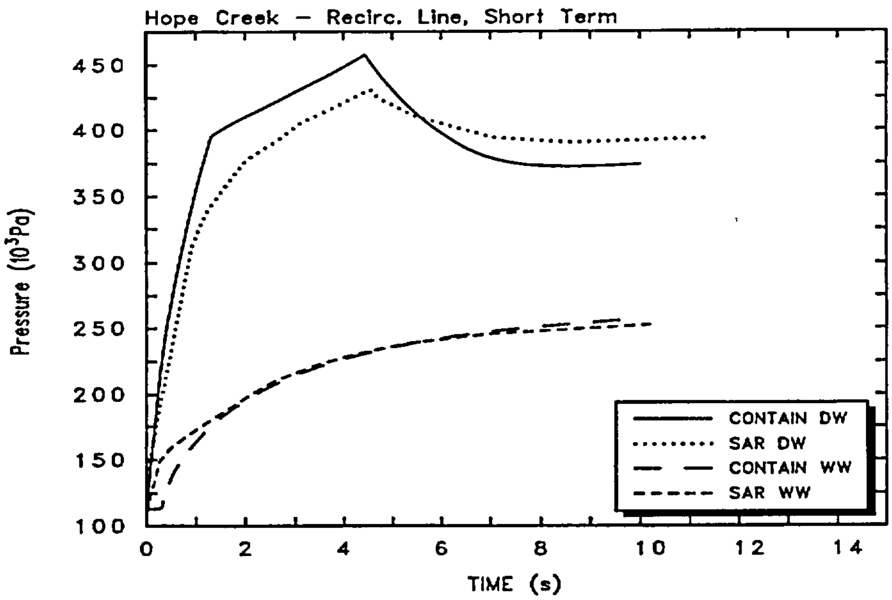

Figure 2-2. CONTAIN and SAR drywell and wetwell pressures for the Hope Creek recirculation line break short-term scenario.

All of the results shown in Figures 2-2 through 2-5 came from a single CONTAIN calculation. The input deck for this calculation is provided in Appendix C. Specific guidance on how to utilize the various CONTAIN models and options to generate this kind of a calculation are provided in Section 2.1.2. Details about the calculation are provided in Section 2.1.3.

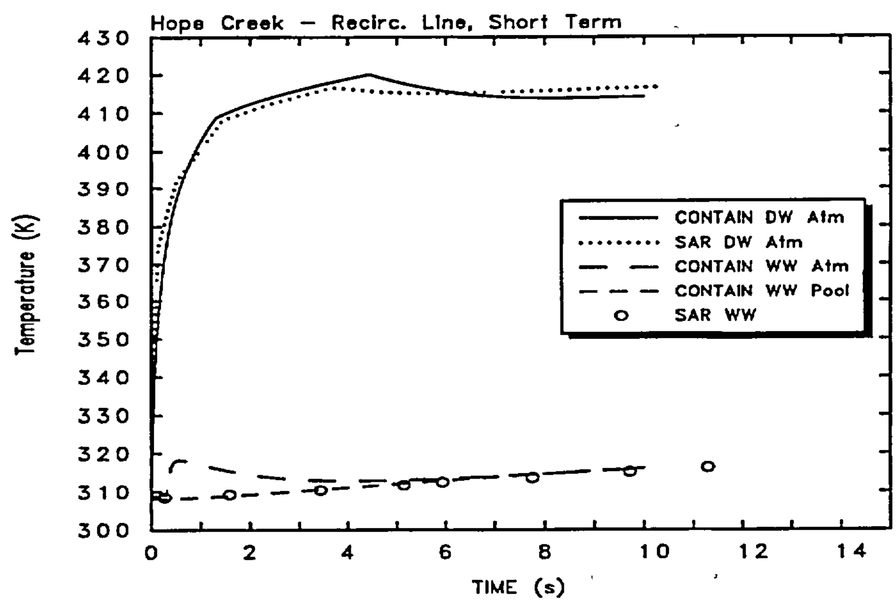

Figure 2-3. CONTAIN and SAR drywell and wetwell temperatures for the Hope Creek recirculation line break short-term scenario.

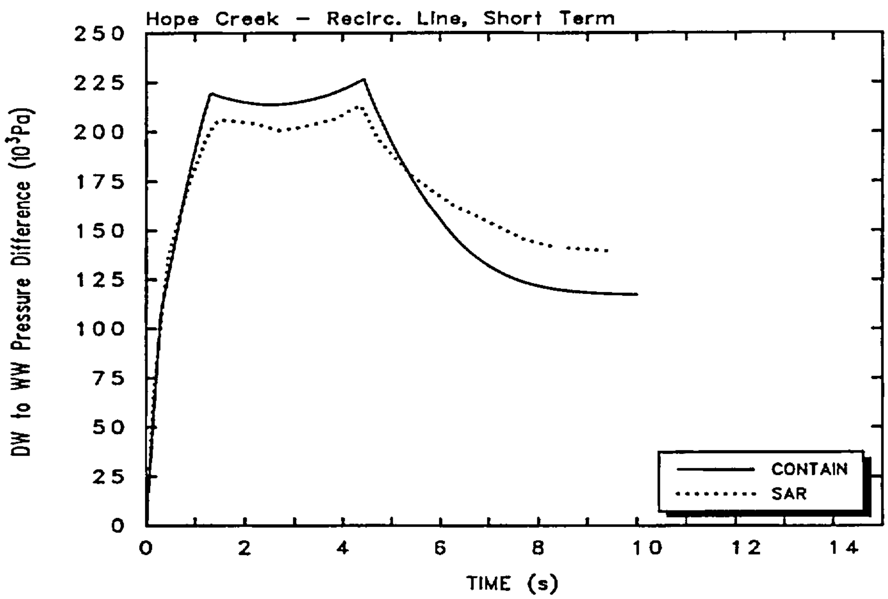

Figure 2-4. CONTAIN and SAR Drywell to Wetwell Pressure Difference for the Hope Creek Recirculation Line Break Short-Term Scenario.

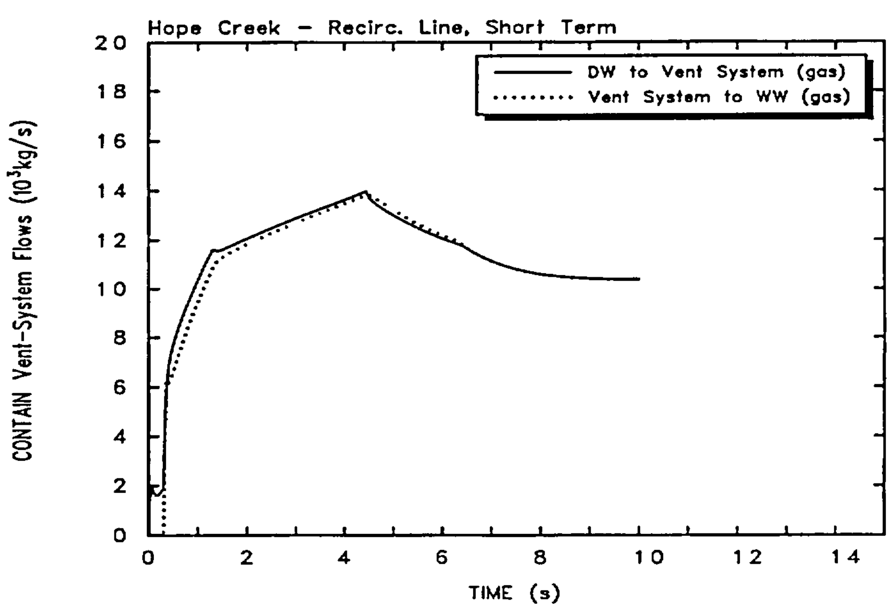

Figure 2-5. CONTAIN mass flow rates from the drywell to the vent system and from the vent system to the wetwell for the Hope Creek recirculation line break short-term scenario.

2.1.2 Modeling Recommendations for the Mark I Short-Term Scenario

As discussed in the CONTAIN code manual [1], the suppression pool vent models in CONTAIN are of two types. The first and newer type is a multi-node model comprised of standard CONTAIN gas and pool flow paths. This type of model can be used to model the vent clearing and vent gas flow of a BWR in terms of a serial or parallel arrangement of flow paths. As a result, the suppression vent system of a Mark I BWR can be represented as a separate (vent-system) cell, as shown in Figure 2-6. Then, flow communication between the drywell and the vent system is modeled by two parallel flow paths; one a pool flow path and the other a gas flow path, as shown in Figure 2-7. In a similar manner, flow communication between the vent system and the wetwell is modeled by two parallel flow paths, as shown in Figure 2-7. Note that the Mark I demonstration plant is based on the Hope Creek design. Therefore, vent characteristics, number of vents, etc., could be different for other Mark I plants.

The second type of suppression pool vent model, now considered obsolete for suppression vent thermal hydraulic modeling, is the dedicated suppression pool vent flow path model, which models vent clearing and gas flow as occurring within a single special flow path. However, the basic assumption of this second model is that the vent clearing process is controlled by quasi-steady (non-inertial) flow, but the input parameters for this model are difficult to determine from the parameters used in traditional DBA codes and analyses. In addition, the three rows of vents in a Mark III cannot be resolved within this model. Therefore, this option is not recommended for DBA calculations of any type.

The modeling recommendations for a Mark I short-term scenario analysis are presented in Table 2-1. Also see the annotated sample input deck in Appendix C.

It is noted that Table 2-1 also is used to provide the input guidelines for modeling the Mark II short-term scenario, see Section 3.1.2. As a result, Table 2-1 includes a note addressing the effect of the value of VCONTRA for the Mark II.

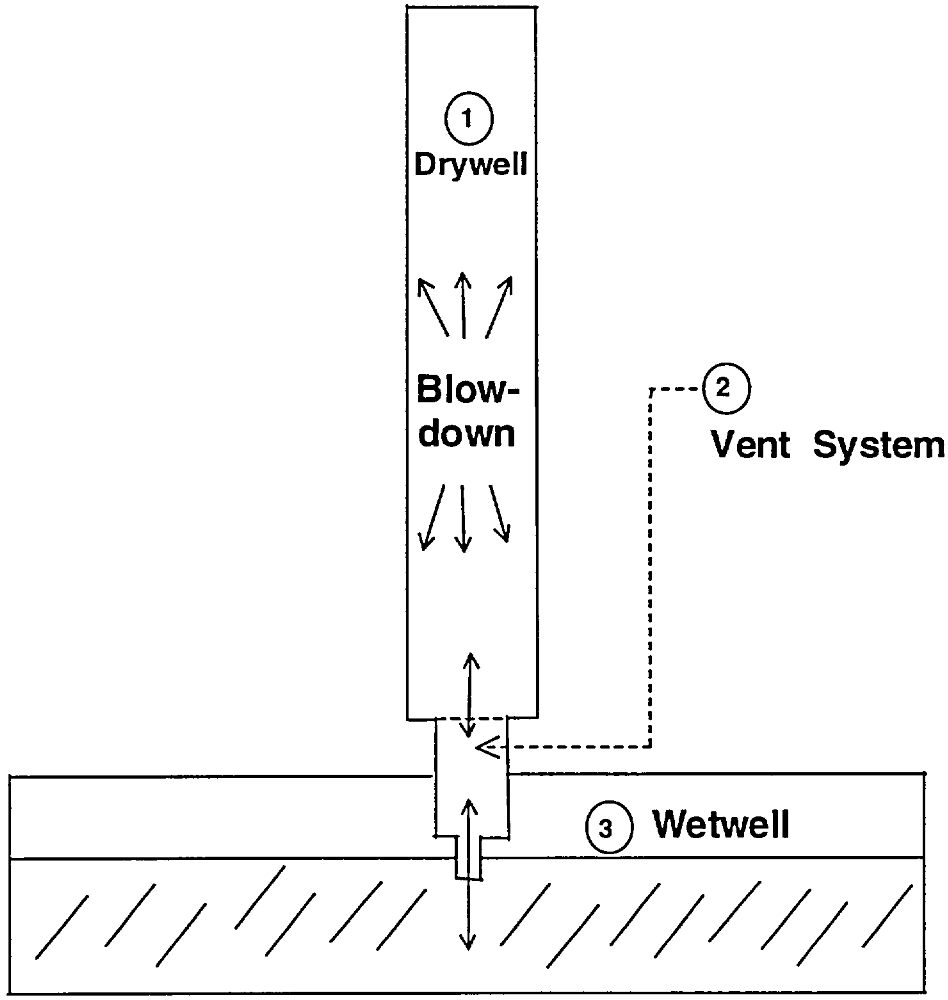

Figure 2-6. Basic CONTAIN three-cell model of a Mark I BWR for the Hope Creek recirculation line break short-term scenario. For additional details, see Figure 2-7.

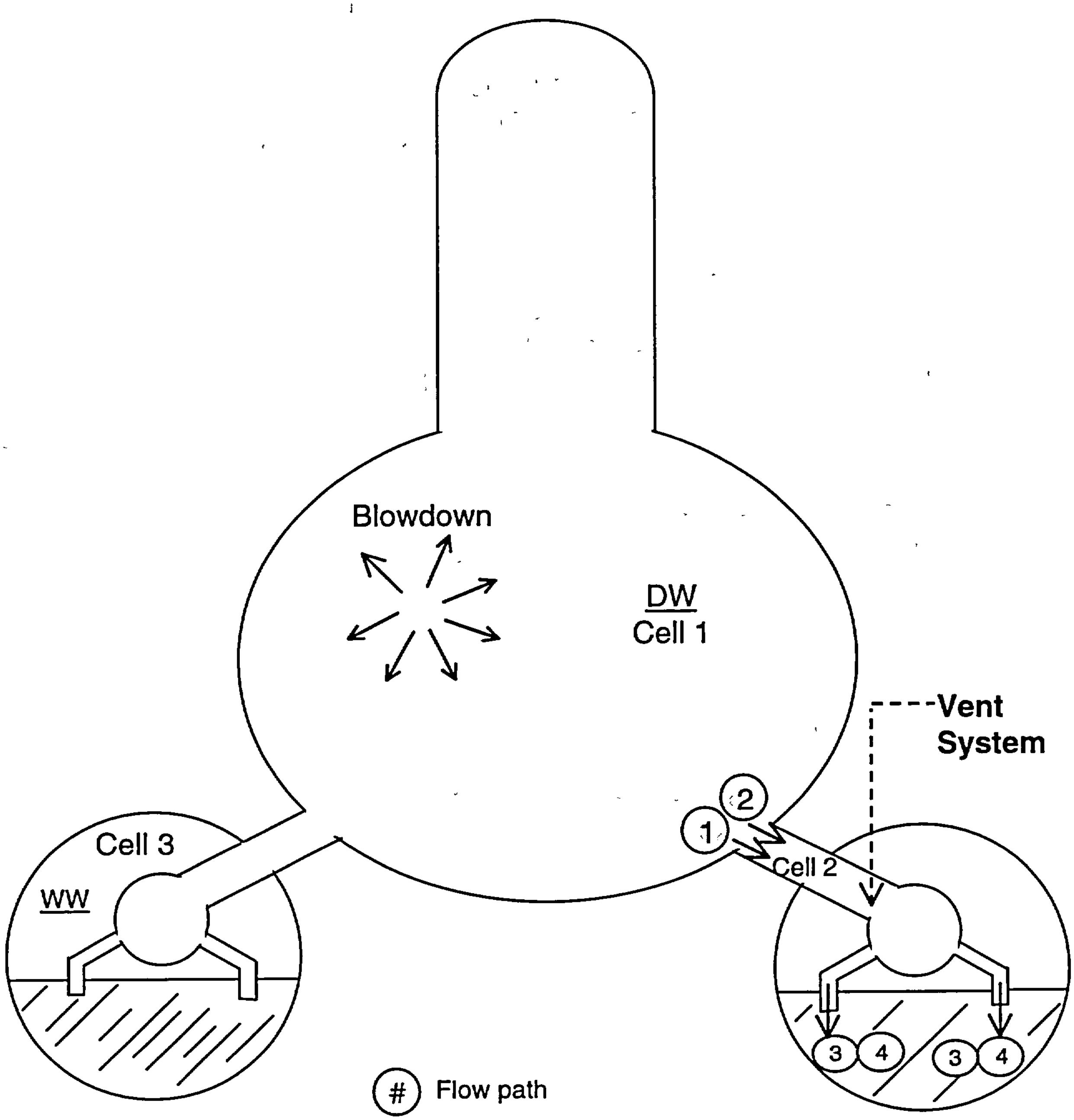

Figure 2-7. CONTAIN Mark I BWR model showing the drywell cell, the vent system cell, the wetwell cell and the flow paths for the Hope Creek recirculation line break short-term scenario.

2.1.3 Input Preparation and Calculated Results for the Mark I Short-Term Scenario

This section discusses the preparation of CONTAIN input for a Mark I short-term scenario and presents sample input and calculation for the Hope Creek plant based on data given in Reference 2. Input preparation for the short-term scenario should follow the recommended approach discussed above. This recommended approach is summarized and linked to specific input parameters in Table 2-1.

The Hope Creek sample problem in Appendix C may be consulted for examples of implementation of the recommended modeling approach. The initial conditions and characteristics of the cells and flow paths used in this sample problem are shown in Tables 2-2 and 2-3, respectively. In addition, the Appendix C input is annotated to further explain the basis for the input parameters.

Figures 2-2 through 2-5 present the CONTAIN-calculated values for various containment parameters for the first 10 seconds of the blowdown.[1] The parameters include drywell and wetwell pressures and temperatures, the drywell to wetwell pressure difference and the drywell to wetwell flows. Comparisons with values from the Hope Creek SAR are made.

In addition, Table 2-4 compares the CONTAIN and SAR values for the vent clearing times, peak pressures, peak temperatures, peak drywell to wetwell pressure difference and the times at which the values occurred. In the CONTAIN calculations, vent clearing is assumed to occur when the initial liquid in the downcomer has reached the bottom of the downcomer. These results show that CONTAIN is slightly conservative compared with the SAR values.

If the margin between the design values and the peak calculated values are small, sensitivity studies of significant parameters may be needed to understand the impact of inherent uncertainties. Key parameters for possible sensitivity study include those that affect the determination of the short-term peak drywell pressure. The peak pressure in turn is primarily determined by the dynamic response of the vent system, i.e., the vent clearing time. As a result, key parameters that should be considered for sensitivity analysis are the vent-system water (pool) mass and the vent system flow path characteristics (loss coefficients, inertial length, *vena contracta* value, and flow area).

1 The CPU time on a DEC Alpha workstation for the calculation discussed was 25s

Table 2-1. Input Guidelines for Modeling the Mark I Short-Term Scenario (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
Drywell, vent system, and wetwell free volumes based on a three-cell nodalization of the drywell, vent system, and the wetwell, as shown in Figures 2-6 and 2-7. Figure 2-7 shows the vent system in more detail.	Set to HWL (High Water Level). The drywell free volume is split between the drywell and vent system cells. Treat the drywell atmosphere as homogeneously mixed and in thermodynamic equilibrium. Maximize the flow density and minimize the two-phase flow rate by avoiding use of DROPOUT or water aerosol options, which tend to remove liquid from the atmosphere.	For each cell, setting the free volume requires coordination of the inputting of CELLHIST values for the variation of horizontal area vs. elevation, GASVOL volumes, and (wetwell) pool mass. The vent-system cell represents the eight vent pipes from the drywell to the vent header that distributes the vent flow to the numerous downcomers submerged in the wetwell pool. Note that the LWL is used for the long-term analysis, which evaluates the heat exchanger performance.
Drywell and wetwell pool volumes	Set wetwell pool to HWL specification. The drywell pool does not participate in the analysis. Also, the wetwell pool volume should not include the water in the submerged downcomers that is accounted for in the vent-system pool.	Set through the pool mass input. For the short-term response, the suppression pool should be assumed to be at HWL volume because a later vent clearing time is calculated. A later vent-clearing time is conservative because relief of the drywell pressure buildup is delayed, thus resulting in a (conservatively) higher drywell pressure. A drywell pool was not used because the blowdown coolant liquid was modeled to remain in suspension to maximize the calculated drywell pressure.

Table 2-1. Input Guidelines for Modeling the Mark I Short-Term Scenario
(See the input deck annotations for specific examples of application of the recommended approach.)

Modeling Area	Recommended Approach	Comment
Vent system free and pool volumes	The free volume should be based on the vent-system dimensions The pool volume should be based on the downcomer HWL submergence to the bottom of the downcomer. The vent system atmosphere conditions should be the same as those in the drywell. The vent system pool temperature should be the same as that for the wetwell pool.	The vent system in a Mark I has eight vent pipes through which flow can exit the drywell The vent pipes make up the major portion of the vent system by volume. The vent pipes are connected to the vent header that distributes flow to the numerous downcomers. The geometry of the vent system is such that the flow area is approximately constant for all of the vent system. A simple two-elevation CELLHIST-parameter volume distribution was chosen for the sample problem. Specifically, the downcomer volume was assigned to the lowest part of the vent system volume with the remainder of the volume assigned to the upper region (see Figure 2-6). A more elaborate area variation with elevation could be developed for the complicated Mark I vent system, but we believe this would not significantly enhance the calculated results.
Blowdown mass and energy rate	Introduce blowdown mass and energy as a drywell atmosphere source. A homogeneous mixture of air, steam, and decompressed and/or condensed liquid water in thermodynamic equilibrium should be modeled in the drywell atmosphere. In addition, this liquid water should be allowed to remain suspended in the atmosphere, so that the liquid contributes to the flow density in the suppression vent system.	Sensitivity calculations have shown that retention of the liquid in the atmosphere is conservative overall in the short-term scenario when a well-mixed and equilibrated drywell is assumed. The resulting dominant effect is the reduction of the two-phase volumetric flow rate through the vent system because of the higher upstream flow density. Therefore, liquid dropout or aerosol modeling options for this liquid should not be used. The resulting atmosphere source is treated in a manner similar to the "temperature-flash" approximation because all of the mass and energy goes into the atmosphere.

Table 2-1. Input Guidelines for Modeling the Mark I Short-Term Scenario (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
Four CONTAIN ENGVNT flow paths should be used:	There should be two (a gas and a pool) flow paths from the drywell to the vent system and two (a gas and a pool) flow paths from the vent system to the wetwell (see Figure 2-7).	The dynamics of these paths should be based on constant effective inertial lengths. This is conservative during the vent clearing process because the effective length actually decreases with time as the vent system water level decreases. In addition, for conservatism, these lengths for the pool flow paths should be based on an effective liquid slug length for the vent system equal to 1.25 times the actual length of the original liquid in the flow path, i.e., the submergence. The derivation of the inertial lengths appropriate for the vent system and vent geometry is discussed in more detail in the sample-problem input-deck annotation.
Gas flow path between the drywell and the vent system	Use (a) the vent pipe total flow area, (b) a path inertial length term equal to the inverse of the sum of the length/area for the flow path, (c) an appropriate turbulent loss coefficient VCFC, and (d) a VCONTRA = 0.7 to account for the combined adiabatic expansion and friction loss effects.	The inertial lengths are used to define the VAVL (area /length) input parameters. Note that the CONTAIN VCFC is ½ the value of the conventional loss coefficient. See the sample-problem input for examples of how the VCFC values are obtained (e.g., based on SAR flow loss coefficients). The VCONTRA 0.7 value was found to be needed to account for choking of the flow (see Appendix B). (To investigate the effect of VCONTRA values, sensitivity calculations were performed with values of 1.0 and with the recommended value of 0.7. For the Appendix C Mark I sample problem, the value 1.0 resulted in ~10% ***lower*** peak pressure. For the Mark II sample problem there was a similar difference for the early (2.8 s) peak pressure but there was ***no difference*** for the later (13.6 s) maximum pressure.)
Pool flow path between the drywell and the vent system	Use the same values as described above for the drywell to vent system gas flow path. Note that the VCONTRA is not used for liquid flow.	This path is defined for completeness although it does not participate because there will be no liquid flow from the drywell to the vent system.
Gas flow path between the vent system and the wetwell.	See the above gas flow path discussion.	See the above gas flow path discussion.

Table 2-1. Input Guidelines for Modeling the Mark I Short-Term Scenario
(See the input deck annotations for specific examples of application of the recommended approach.)

Modeling Area	Recommended Approach	Comment
Pool flow path between the vent system and the wetwell	The above gas flow path values should be used here except for the inertial length, which should be 1.25 times the length of the liquid initially in the flow path, i e , the submergence.	This flow path is of major importance because it determines the time needed to clear the vent system and allow pressure relief of the drywell.
Wetwell spray to equilibrate pool and atmosphere temperatures	An engineered safety system should be added to the wetwell. The specific features of the spray should include an engineered system composed of four components with the coolant source being the wetwell and the coolant sink also being the wetwell. The components of this engineered system are, (1) the spray set to start when the wetwell pressure reaches a value slightly above the wetwell initial pressure, (2) a tank with zero mass because we want the spray flow to come from the system source, i.e., the wetwell pool, (3) a pump that has a sufficiently high flow so that there is good energy exchange between the spray and wetwell atmosphere, e.g., we have used 5000 kg/s, and (4) a heat exchanger that does not change the coolant temperature so that the spray temperature is the wetwell pool temperature.	A significant difference between CONTAIN and traditional treatments of the wetwell involves the work done by compression as noncondensible gas is admitted to the wetwell atmosphere after bubbling through and equilibrating with the suppression pool. Traditional treatments (e g., Reference 4) either ignore this compression work or assume atmosphere-pool equilibration to reduce the superheating of the wetwell atmosphere that results from this compression work. The basis for the assumed equilibrium is that the gas-bubble breakthrough at the pool surface creates droplets that interact with the atmosphere resulting in the equilibrium. To remove this superheating in CONTAIN calculations of the short-term response for Mark Is (and Mark IIs), a wetwell spray should be included.

Table 2-2. Hope Creek Short-Term Scenario Initial Conditions and Geometry

Cell	Volume (m^3)	Area (m^2)	Height (m)	Cell+ Elevation (m)	Initial Conditions†
Drywell Atmosphere	4371.	158.6	27.56	Top, 35.20 Bottom, 7.64	T=330.4K P=1.1169e5 Pa Moles N2=96% Moles O2=4% RH=0.2
Vent System Atmosphere	414.2	72.52 (21.92)*	5.994	Top, 9.464 Bottom, 2.455	T=330.4K P=1.1169e5 Pa Moles N2=96% Moles O2=4% RH=0.2
Vent System Pool	22.52	21.92	1.015	Included in the above	T=308.2 K
Wetwell Atmosphere	3758.	995.0	3.798	Top, 7.27 Bottom, 0.0	T=308.2K P=1.1169e5 Pa Moles N2=96% Moles O2=4% RH=1.0
Wetwell Pool	3455.	995.0	3.472 (HWL)	Included in the above	T=308.2 K

†T=temperature, P=pressure, RH=relative humidity.
*Note that the area reduces to 21.92 m^2 below an elevation of 3.877 m.
+The elevation values are for the combined cell atmosphere and pool.

Table 2-3 Hope Creek Short-Term Scenario CONTAIN Flow Path Parameters

Flow Path	Area (m^2)	Area/Inertial Length[#] (m)	Elevation[†] (m)	Loss Coef.	Vena Contracta[‡]
Drywell to Vent System, POOL	21.92	1.9	From 9.464 To 9.464	2.3	0.7[*]
Drywell to Vent System, GAS	21.92	1.9	From 9.464 To 9.464	2.3	0.7
Vent System to Wetwell, POOL	21.92	19.2	From 2.455 To 2.455	0.5	0.7[*]
Vent System to Wetwell, GAS	21.92	100.	From 2.455 To 2.455	0.5	0.7

[†]Relative to suppression pool bottom.
[*]The *vena contracta* parameter has no effect on a pool flow path.
[#]Flow path area/inertial length.
[‡]See Appendix B.

Table 2-4 Hope Creek Short-Term Scenario SAR and CONTAIN Results

Result	Units	SAR	CONTAIN
Time of vent clearing	s	0.20	0.31
Peak drywell pressure	MPa	0.433	0.457
Time of peak drywell pressure	s	4.42	4.42
Peak drywell to suppression-chamber differential pressure	MPa	0.211	0.226
Time of peak differential pressure	s	4.42	4.42
Peak suppression-chamber pressure during blowdown	MPa	0.291	0.292[*]
Peak suppression-pool temperature during blowdown	K	329	329[*]

[*]These values were obtained by extending the CONTAIN calculation to 50 s.

2.2 Mark I Long-Term Accident Analysis

As discussed earlier, the general approach recommended for long-term analysis will be the same for Mark I, Mark II and Mark III containments. Therefore, the approach will be described only in the context of the Hope Creek Mark I plant. In Section 2.2.1, we describe the Mark I long-term analysis in general. Then, in Section 2.2.2 the recommended approach for Mark I long-term analysis modeling with CONTAIN is described. The objective of the recommended approach is to ensure that CONTAIN will predict conservative results and that its predictions will be confirmed by traditional Mark I results, for example, as given in the plant's Safety Analysis Reports (SARs). In Section 2.2.3, the preparation of the CONTAIN input for a Mark I long-term analysis is discussed. Finally, Section 2.2.3 discusses calculated results for a Hope Creek plant recirculation line break, long-term analysis based on data in the plant's SAR, (Reference 2).

2.2.1 Mark I Long-Term Scenario

The long-term analysis primarily addresses the effectiveness of the RHR heat exchanger over the hours of accident time following the blowdown period. The blowdown period is described in Section 2.1.1 where we describe the use of CONTAIN for the performance of the Mark I short-term analysis. However, it is important to note that the long-term analysis includes a short-term analysis with the addition of long-term considerations. In particular, the initial conditions, cell dimensions and blowdown sources used for the short-term analysis also are used for the long-term analysis. Minor differences result from the long-term analysis being based on the Low Water Level (LWL) and the short-term analysis being based on the High Water Level (HWL). Also, thermal equilibrium between the suppression pool and the wetwell atmosphere is not assumed (the equilibrating wetwell spray option is not used).

- For the long-term analysis following the blowdown period, the ECCS continues to provide suppression pool water for core flooding, containment sprays, and long-term (mostly decay) heat removal.
- Flow from one RHR pump can be manually diverted from the RPV to the containment sprays in cooling mode. Before activation of the containment cooling mode (assumed to occur at a controlled time), all of the RHR pump flow is used to flood the core.
- The effects of decay heat, sensible energy, energy added by ECCS pumps, etc. are accounted for.
- The suppression pool is the only heat sink available in the containment system prior to initiation of the RHR heat exchanger and its use of cooling water.

Specific considerations important to a long-term analysis are presented in Section 2.2.2. Details of input preparation and the calculated results are discussed in Section 2.2.3. The actual deck used to produce the long-term CONTAIN calculation is provided in Appendix D.

The performance of the Mark I ECCS equipment and subsequent containment response traditionally has been evaluated for each of three cases of interest. For example, in Reference 2 the three cases are identified as: Case A: All ECCS equipment operating – with containment spray; Case B: LOP[2] – With containment spray; Case C: LOP – No containment spray. See Reference 2 for a more complete description of the cases.

Note that the Hope Creek SAR Case C, beginning with a recirculation line break, is used as the long-term sample problem and is discussed more completely in Section 2.2.3 below. As a result, many of the typical values used in this report are for the Hope Creek Case C scenario. The long-term sample problem results are given in Figures 2-8 through 2-10. The terminology "no restart" refers to one of two methods to accommodate the transition to the long-term phase of the calculation and is discussed further in Section 2.2.2. Figures 2-8 through 2-10 show that a secondary peak in wetwell pressure and the peak wetwell pool temperature occur late in the transient. Also, the drywell, wetwell and RPV thermodynamic conditions equilibrate to the same temperature.

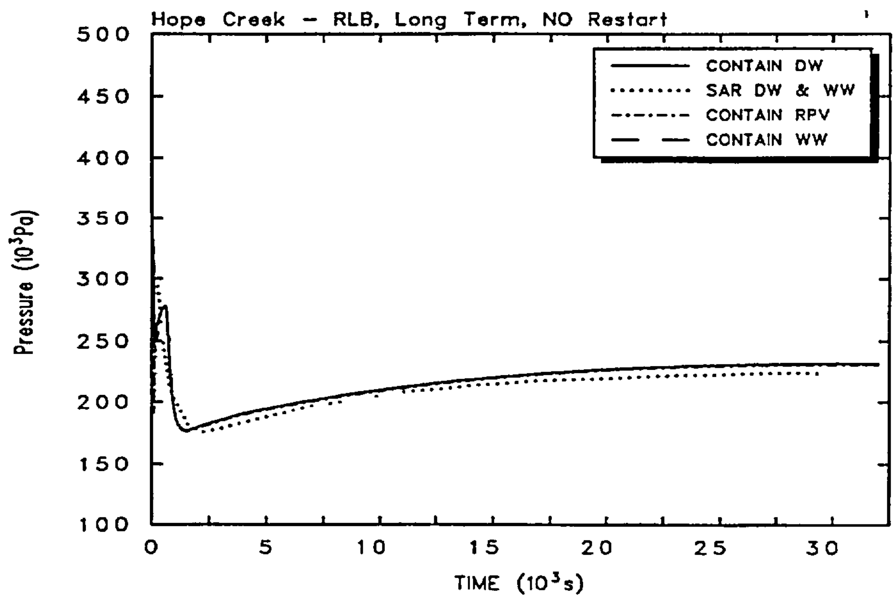

Figure 2-8. CONTAIN (no restart) and SAR drywell and wetwell pressures for the Hope Creek recirculation line break Case C long-term analysis. The CONTAIN RPV-cell pressure also is presented.

2 Loss of offsite power.

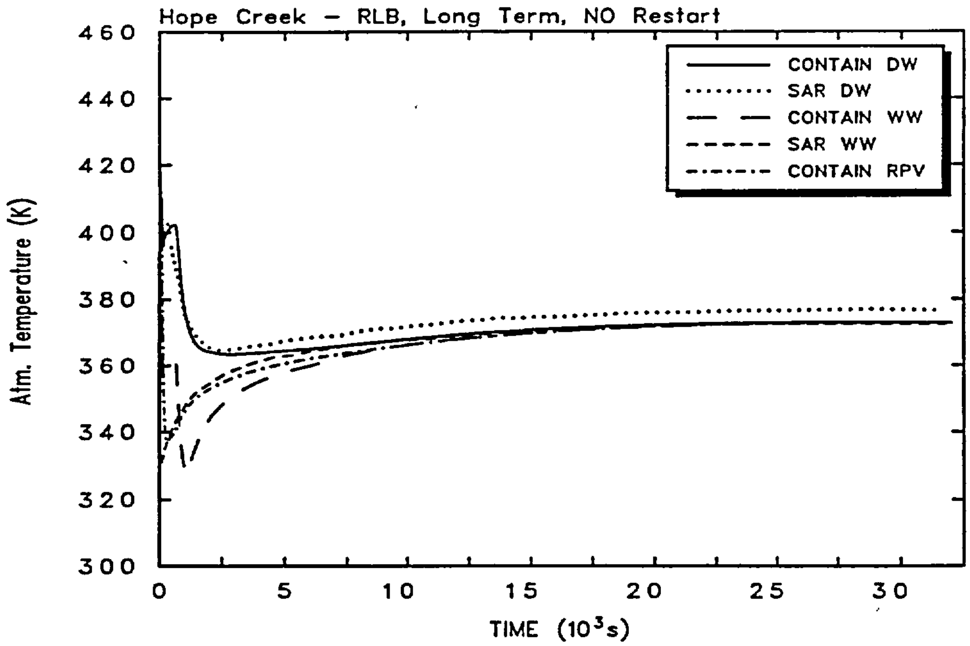

Figure 2-9. CONTAIN (no restart) and SAR drywell and wetwell atmosphere temperatures for the Hope Creek recirculation line break Case C long-term analysis. The CONTAIN RPV-cell atmosphere temperature also is presented.

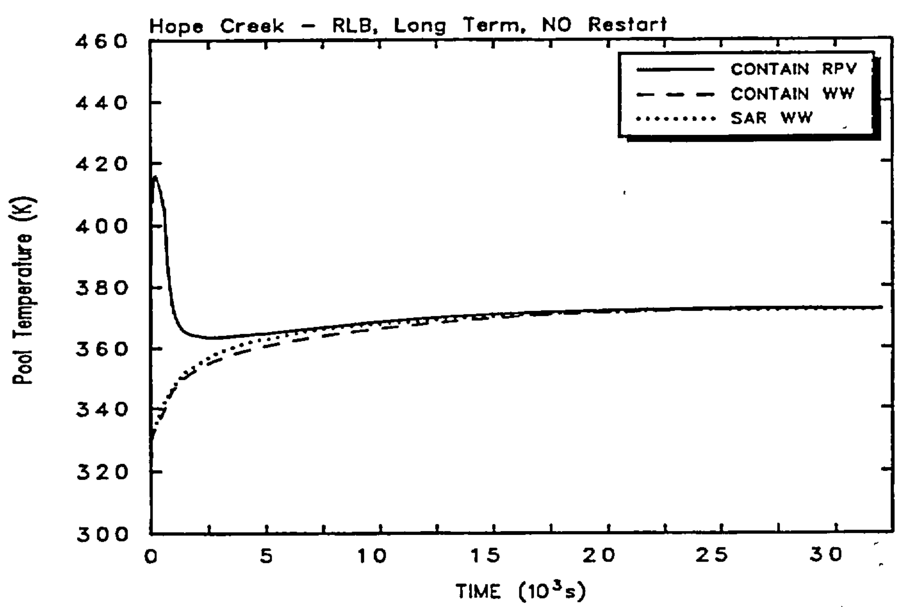

Figure 2-10. CONTAIN (no restart) and SAR wetwell pool temperatures for the Hope Creek recirculation line break Case C long-term analysis. The CONTAIN RPV-cell pool temperature also is presented.

2.2.2 *Modeling Recommendations for the Mark I Long-Term Analysis*

For the CONTAIN Mark I, long-term analysis, two approaches can be taken. The two approaches are referred to as the with-restart and the no-restart approaches. However, the no-restart approach is preferred because it is more direct and does not require use of the restart option. Note that both approaches produced the same values for the calculated results of interest.

The with-restart approach first performs a short-term analysis (like that discussed in Section 2.1) until thermal equilibrium for the system is reached. That is, the thermodynamic conditions are constant. For example, for the Hope Creek short-term analysis discussed above in Section 2.1, this would correspond to 50 s because the blowdown ends at 48.4 s. Then, the with-restart approach uses the CONTAIN restart feature to deactivate the wetwell spray used to enforce thermal equilibrium between the suppression pool and the wetwell atmosphere. The deactivation is appropriate because liquid entrainment into the wetwell atmosphere, the mechanism responsible for producing conditions close to equilibrium initially, is no longer present after blowdown. To complete the with-restart approach, the CONTAIN restart feature is used to extend the calculation to the problem end time (which is 3.2×10^4 s for the sample problem described in Section 2.2.3).

The no-restart approach performs the analysis as one calculation that goes from 0.0 s to the problem end time. The no-restart approach does not include the wetwell spray because this modeling only is used to account for the early-time entrainment. As a result, relative to the with-restart calculation and only at early times, the no-restart wetwell atmosphere temperature is higher than the wetwell pool temperature and the wetwell pressure is slightly higher. However, we found that the no-restart and with-restart approaches gave identical long-term analysis results at later times, which is when peak values for the long-term parameters of interest occurred.

The discussion that follows pertains directly to the no-restart, long-term analysis. However, the following discussion also is pertinent to the with-restart analysis because most of the modeling is the same for both the no-restart and with-restart analyses. The additional modeling details needed for the with-restart analysis are the equilibrating wetwell spray model used in the short-term analysis (see Section 2.1 and Appendix C) and the restart input given in Appendix E.

The modeling recommendations for a Mark I long-term scenario analysis, based on the model shown in Figure 2-11, are presented in Table 2-5. Note that many of these recommendations simply refer to those given for the Mark I short-term analysis in Table 2-1. This is appropnate because the long-term analysis requires an early-time analysis that is followed by the long-term analysis. Modeling features that are similar for the short- and long-term analyses include the basic geometry of the cells, the vent-system flow paths, blowdown, etc. Of course, there are some differences and these are addressed in Table 2-5. The additional long-term considerations include the representation of the RPV, the RPV heat sources, the circulation of the wetwell pool water to the RPV, the RHR cooling of some of the circulating wetwell water, the cooling of the drywell by the spillage of the RPV water falling through the drywell, the flow path between the RPV and the drywell, etc.

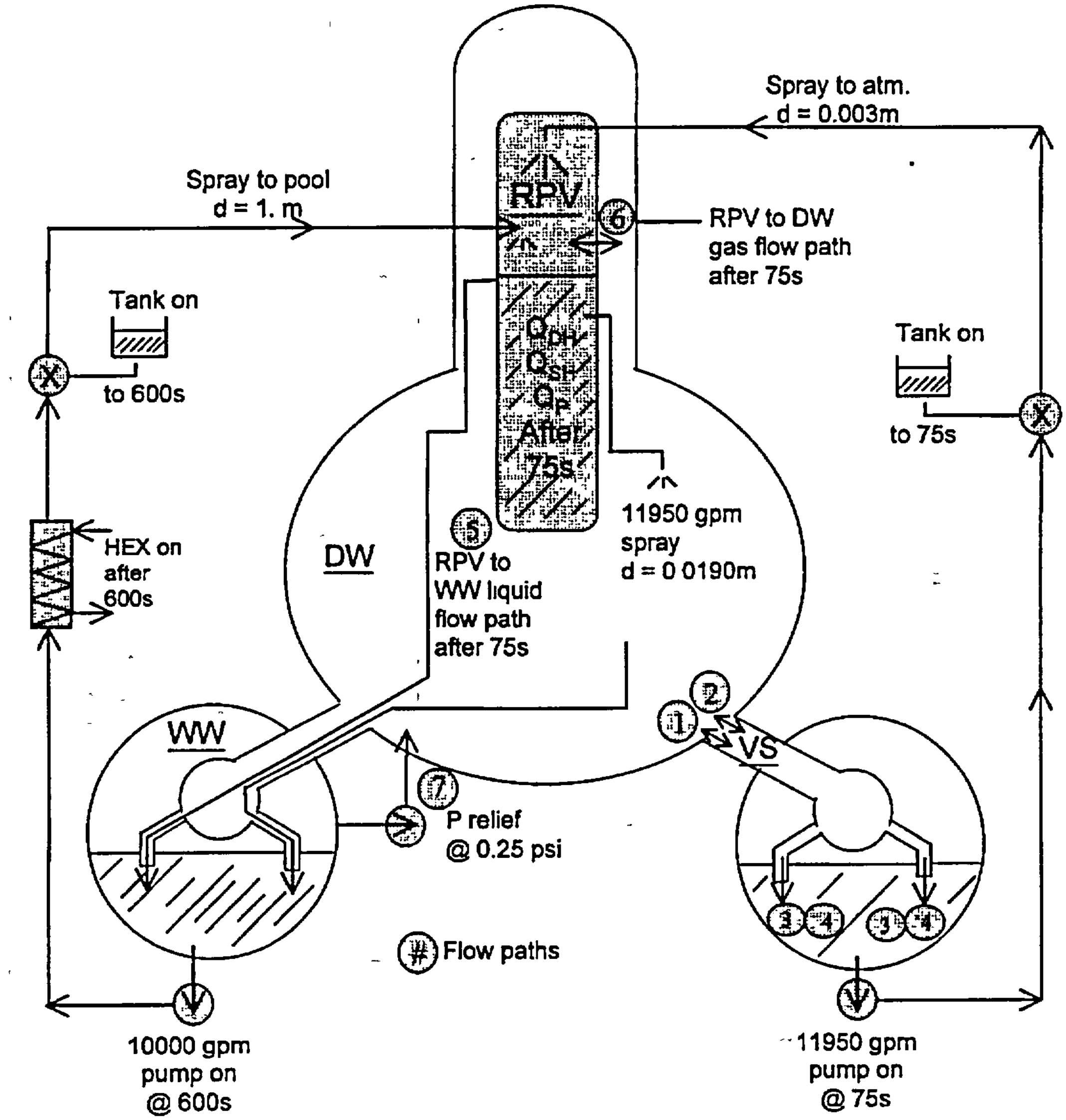

Figure 2-11 CONTAIN model of a Mark I BWR for the Hope Creek recirculation line break Case C long-term analysis.

Table 2-5. Input Guidelines for Modeling the Mark I Long-Term Analysis (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
Drywell (DW), vent system (VS), wetwell (WW), and RPV volumes should be based on a four-cell nodalization as shown in Figure 2-11.	Set to LWL values. See Table 2-1 for supplemental information regarding this modeling area. A sensitivity calculation is recommended using the DROPOUT option.	Note that the LWL is used and the RPV is modeled. See Table 2-1 for supplemental information regarding this modeling area.
Drywell and wetwell pool masses (and volumes)	Assume that there is no drywell pool mass. Set the wetwell pool mass based on the LWL specification with the wetwell heat transfer between the pool and atmosphere turned "on". In addition, the initial wetwell pool water inventory should be reduced to approximately account for the ECCS water removed from the wetwell for the RPV flooding.	Note that the use of a smaller amount of initial water is conservative because a higher water temperature will result for the same amount of energy addition. The heat transfer between the pool and the atmosphere is used so the pool and atmosphere temperatures will come to equilibrium, albeit slowly compared to the short-term case.
Blowdown mass and energy addition to the drywell	See Table 2-1 for supplemental information regarding this modeling area.	Note that there is additional (mostly decay) energy added to the RPV pool; see discussion below.
Spray through the drywell atmosphere, which ends up in the wetwell, to simulate the spillage of water out of the RPV and the resulting effect on the drywell.	This drywell spray engineered safety system should have four components with the coolant source being the RPV and the coolant sink being the wetwell. The components should provide (1) a tank with negligible water mass and a flow rate so the tank is depleted when the spillage begins, i.e., when the exchange of water between the RPV and the wetwell begins, (2) a spray with a large drop size (to simulate the spillage), (3) a pump that provides a flow that is representative of the spillage, and (4) no cooling of the circulating water.	The spray is taken from the RPV pool water and directed to the wetwell pool for simplicity. Alternatively, this flow could have been directed to the drywell pool with its overflow directed to the wetwell pool. This was not done because of the additional unnecessary modeling required.
Vent system free and pool volumes	See Table 2-1 for supplemental information regarding this modeling area.	See Table 2-1 for supplemental information regarding this modeling area.

Table 2-5. Input Guidelines for Modeling the Mark I Long-Term Analysis (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
RPV free volume and pool mass	Set these values to the initial-condition values as an approximation (e.g., from a SAR). The RPV atmosphere initial conditions for the should be set to the drywell conditions at the end of the short-term scenario analysis.	Note that the RPV pool elevation is used in engineered vent and engineered safety system models.
Spray in the RPV to simulate the RHR system that (after a specified time) pumps water from the wetwell pool, cools the water and then adds the water to the RPV pool.	This drywell spray engineered safety system should have four components with the coolant source being the wetwell and the coolant sink being the RPV. The components should provide (1) a tank with negligible water mass and a flow rate so the tank is depleted (and the spray will start) when the RHR is specified to begin, (2) a spray with a large drop size (so the water will essentially go directly to the RPV pool), (3) a pump having the RHR pump flow rate, and (4) a heat exchanger with the RHR specifications.	Note that the RHR flow is returned to the wetwell with an engineered vent (pool) flow path that simulates RPV overflow. As a result, a recirculation/exchange of the wetwell and RPV water is modeled.
Spray in the RPV to simulate the core-spray and HPCI flows that (after a specified time) take water from the wetwell pool for a spray in the RPV.	This drywell spray engineered safety system should have four components with the coolant source being the wetwell and the coolant sink being the RPV. The components should provide (1) a tank with negligible water mass and a flow rate so the tank is depleted (and the spray will start) when the flows are specified to begin, (2) a spray with a drop size appropriate for a spray, (3) a pump having the appropriate (core-spray and HPCI) pump flow rate, and (4) no cooling.	Note that this water is returned to the wetwell with an engineered vent (pool) flow path (discussed above) that simulates RPV overflow. As a result, a recirculation and exchange of the wetwell and RPV water is modeled. The water that is circulated is not cooled and, for our sample problem, we found that a spray drop size of 0.003 m was desirable because this size provided a more-stable calculation than the CONTAIN-code default drop size of 0.001 m.
The RPV lower cell "boil" option should NOT be used	This item is presented to clearly state that the "boil" parameter should NOT be used in the RPV.	It was found that setting of the "boil" option resulted in RPV pool/atmosphere mass and energy exchanges that required the unnecessary use of small time steps.

Table 2-5. Input Guidelines for Modeling the Mark I Long-Term Analysis (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
The RPV pool should have heat sources that account for the decay heat (including fuel relaxation energy), RPV structure sensible energy and the pump heat.	The values for these energies usually are specified (e.g., from the SAR). These heat sources should commence at the activation time of the water circulation systems that exchange water between the wetwell and RPV pools	For the sample problem discussed in Section 2 2.3, which is based on Reference 2, the decay heat (including fuel relaxation energy) and RPV-structure sensible energy-addition-rate variations with time were obtained by differentiation of integral-value-variation with time. This was necessary because, in Reference 1, the decay heat is a table of variation with time of normalized values and the RPV-structure sensible energy is a curve of its integrated-value with time. The resulting energy rates vs. time were introduced as source with mass flow rates of insignificant magnitude. See the Appendix D input deck.
Four ENGVNT flow paths should be used to model the vent system as described in Table 2-1	See Table 2-1 for supplemental information regarding the vent system flow path modeling.	See Table 2-1 for supplemental information regarding this modeling area.
Pool ENGVNT flow path between the RPV and the wetwell (flow path #5 in Figure 2-11) to simulate the overflow of RPV liquid out of the broken pipe.	Use the area of the broken pipe and arbitrary, but reasonable, values for the path inertial and turbulent loss coefficient parameters. No vena contracta factor is needed for liquid flow. This flow path should open when the exchange of water between the wetwell and the RPV begins. The elevations for the ends of this flow path should be from the RPV initial water level to the top of the wetwell.	The use of arbitrary values is acceptable because the flow of water occurs over a long-term analysis. As an example, this flow path was controlled to open at 75 s for the sample problem discussed in Section 2.2.3. Note that the flow is directed to the wetwell pool for simplicity. Alternatively, this flow could have been directed to the drywell and then overflowed to the wetwell pool. This was not done because of the additional, unnecessary modeling required.

Table 2-5. Input Guidelines for Modeling the Mark I Long-Term Analysis (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
Gas ENGVNT flow path between the RPV and the drywell (flow path #6 in Figure 2-11) to simulate the flow path created by the broken pipe.	Use the area of the broken pipe and arbitrary, but reasonable, values for the path inertial and turbulent loss coefficient parameters. No vena contracta factor is needed because the flow will be at low velocity. This flow path should open when the exchange of water between the wetwell and the RPV begins. The vent elevations should be set so the RPV (source) elevation is slightly higher than the drywell (sink) elevation, which should be at the initial RPV water level.	The use of approximate values is acceptable because the flow rates will be low. As an example, this flow path was controlled to open at 75 s for the sample problem discussed in Section 2.2.3.
Gas ENGVNT flow path between the wetwell and the drywell to model the vacuum pressure-relief valve that opens when the drywell pressure is lower than the wetwell pressure by a design value (see flow path "P relief@ 0.25 psi" in Figure 2-11).	This flow path should be initially closed, but its area should increase to be fully open when the pressure difference reaches its design value. The appropriate flow area and design pressure relief values should be used (e.g., from a SAR). Arbitrary, but reasonable, values can be used for the loss coefficient and elevations. For example, the vent elevations could be set to the elevation at the top of the wetwell.	The use of arbitrary values is acceptable because the pressure relief occurs only for only short periods of time. Note that the inertia term is not used for this CONTAIN flow option.

2.2.3 *Input Preparation and Calculated Results for the Mark I Long-Term Analysis*

This section discusses the preparation of CONTAIN input for a Mark I long-term analysis and presents sample input and calculated results for the Hope Creek plant based on data given in Reference 2. Input preparation for the long-term analysis should follow the recommended approach discussed above.

As an example, the input for the Hope Creek sample problem is given in Appendix D. The initial conditions and characteristics of the cells and flow paths used in this sample problem are shown in Tables 2-6 and 2-7, respectively. Note that the Appendix D input is annotated to further explain the basis for the input parameters.

Figures 2-8 through 2-10 present the CONTAIN-calculated and SAR values for important containment parameters in the no-restart case.[3] The parameters are the pressures, atmosphere temperatures and pool temperatures in the drywell, wetwell and the RPV. Values from the Hope Creek SAR are included. Figures 2-12 and 2-13 present the pressures and pool temperatures for the case with restart.

3. The CPU time on a DEC Alpha workstation for the calculation discussed was 210s

Table 2-6. Hope Creek Long-Term Analysis Initial Conditions and Geometry

Cell	Volume (m^3)	Area (m^2)	Height (m)	Cell+ Elevation (m)	Initial Conditions†
Drywell Atmosphere	4370.	158.6	27.55	Top, 35.19 Bottom, 7.64	T=330.4K P=1.1169e5 Pa Moles N2=96% Moles O2=4% RH=0.2
Vent System Atmosphere	416.2	72.52 (21.92)*	5.994	Top, 9.464 Bottom, 2.455	T=330.4K P=1.1169e5 Pa Moles N2=96% Moles O2=4% RH=0.2
Vent System Pool	20.02	21.92	0.914	Included in the above	T=308. K
Wetwell Atmosphere	4036.	992.2	4.068	Top, 7.277 Bottom, 0.0	T=308.K P=1.1169e5 Pa Moles N2=96% Moles O2=4% RH=1.0
Wetwell Pool	3184.	992.2	3.209 (LWL)	Included in the above	T=308. K
Reactor Pressure Vessel (RPV)	257.4	32.18	19.27	Top, 35.84 Bottom, 16.57	T=407.15# Moles H2OV=1.0 RH=1.0

+The elevation values are for the combined cell atmosphere and pool.
†T=temperature, P=pressure, RH=relative humidity.
*Note that the area reduces to 21.92 m^2 below an elevation of 3.877 m.
#Pressure will be at saturation for this temperature.

Table 2-7. Hope Creek Long-Term Analysis CONTAIN Flow Path Parameters

Flow Path	Area (m^2)	Area/Inertial Length[#] (m)	Elevation[†] (m)	Loss Coef.	Vena Contracta[‡]
Drywell to Vent System, POOL	21.92	2.0	From 9.464 To 9.464	2.3	0.7[*]
Drywell to Vent System, GAS	21.92	2.0	From 9.464 To 9.464	2.3	0.7
Vent System to Wetwell, POOL	21.92	19.2	From 2.455 To 2.455	0.5	0.7[*]
Vent System to Wetwell, GAS	21.92	2.3	From 2.455 To 2.455	0.5	0.7
RPV to Wetwell, POOL	0.307	2.5[+]	From 27.03 To 7.277	1. [+]	Default OK
RPV to Drywell, GAS	0.307	2.5[+]	From 28. To 27.	1. [+]	Default OK
Wetwell to Drywell Vacuum Breaker Area vs. Pressure Difference	Varies from 0. to 25.1 at 1.724×10^3 Pa	Not applicable for this flow path option	From 7.277 To 7.277	1. [+]	Default OK

[†]Relative to suppression pool bottom.
[*]The vena contracta parameter has no effect on a pool flow path.
[+]Arbitrary, but reasonable, value.
[#]Flow path area/inertial length.
[‡]See Appendix B.

Table 2-8. Hope Creek Long-Term Analysis SAR and CONTAIN Results for Case C: LOP – No containment spray

Result	Units	SAR	CONTAIN
Secondary peak wetwell pressure	MPa	0.22	0.23
Peak wetwell pool temperature	K	371	373

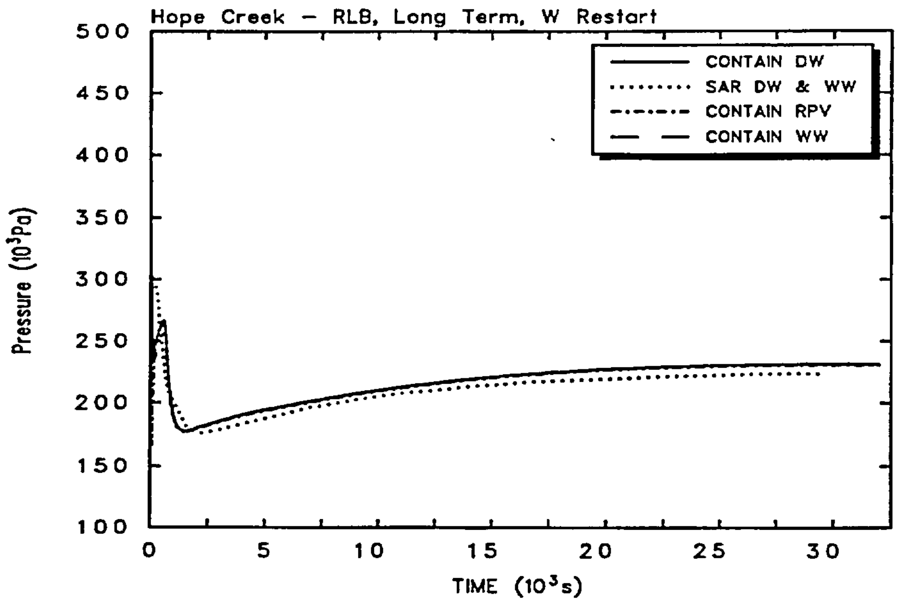

Figure 2-12. CONTAIN (With Restart) and SAR drywell and wetwell pressures for the Hope Creek recirculation line break Case C long-term analysis. The CONTAIN RPV-cell pressure also is presented.

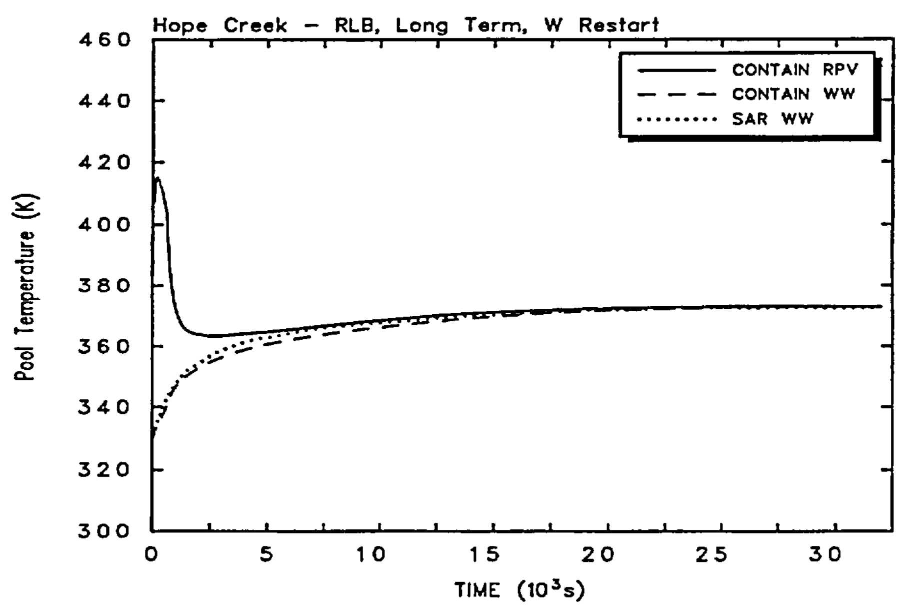

Figure 2-13. CONTAIN (With Restart) and SAR wetwell pool temperature for the Hope Creek Mark I BWR recirculation line break, Case C, long-term analysis. The CONTAIN RPV-cell pool temperature also is presented.

3.0 Mark II Containment Analysis

In this section we discuss methods that can be used to model the DBA response of Mark II BWR containments with CONTAIN. Figure 3-1 depicts the Mark II containment and shows the reactor pressure vessel, the drywell, the downcomers from the drywell to the wetwell, and the wetwell or suppression chamber.

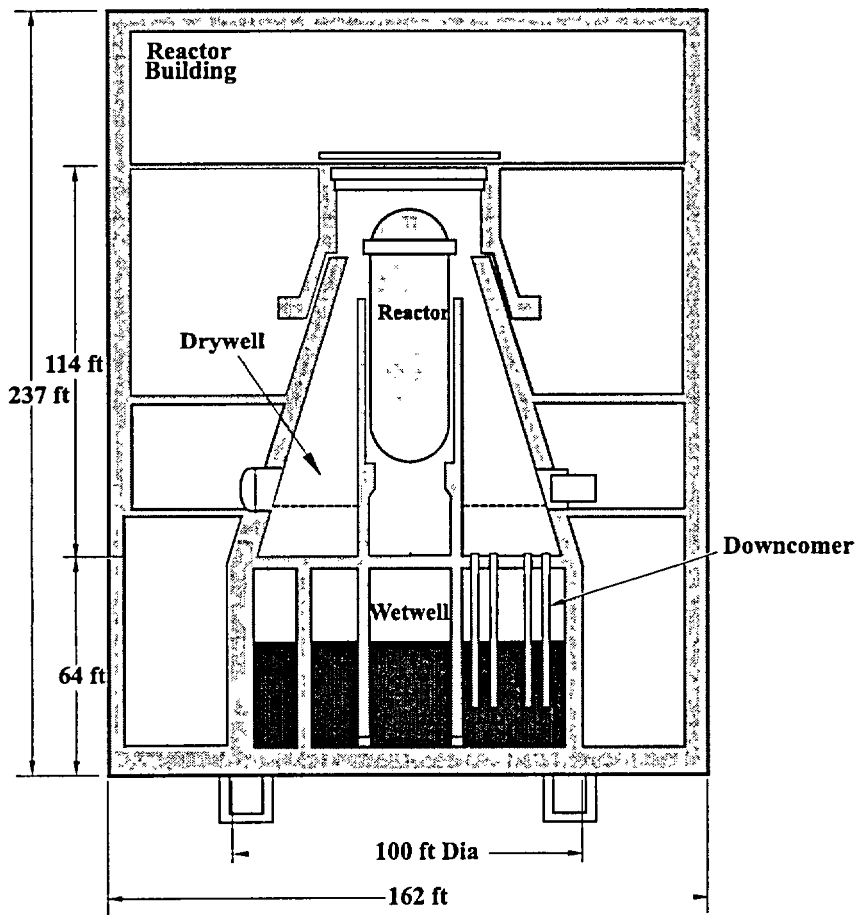

Figure 3-1. Mark II BWR containment showing the drywell, vent system downcomers, and the wetwell.

For the Mark II containment, two types of DBA-response calculations lie within the domain of CONTAIN: (1) The Mark II short-term scenario for evaluation of the maximum drywell pressure, drywell temperature and drywell to wetwell pressure difference, which occur during the blowdown. (2) The Mark II long-term scenario evaluation of the maximum suppression chamber (i.e., in the wetwell) pressure and pool temperature that occurs some hours after the initial blowdown. The short-term scenario is discussed in Section 3.1. For the long-term scenario, see Section 2.2 where recommendations for long-term analysis are described for the Mark I BWR.

3.1 Mark II Short-Term Accident Analysis

In Section 3.1.1, we describe the Mark II short-term scenario. Then, in Section 3.1.2 the recommended approach for Mark II short-term scenario modeling with CONTAIN is described. The objective of the recommended approach is to ensure that CONTAIN will predict conservative results, and that its predictions will be confirmed by traditional Mark II results. In Section 3.2, the preparation of the CONTAIN input for a Mark II short-term scenario is discussed. In addition, Section 3.2 discusses calculated results for the recirculation line break short-term scenario for the Limerick plant (arbitrarily selected as the Mark II demonstration plant), based on data in the plant's Safety Analysis Report (SAR) [3].

3.1.1 Mark II Short-Term Scenario

As for the Mark I, analysis of the spectrum of DBA accidents indicates that the maximum temperatures and pressures experienced inside the containment may not all result from a single accident. However, for demonstration purposes, only the recirculation line break scenario is analyzed in the Limerick sample calculation presented in Section 3.2 below. In addition, Figures 3-2 through 3-5, which were obtained from our Limerick sample problem analysis, will be used to illustrate the containment response calculated by CONTAIN for the recirculation line break short-term scenario.

3.1.2 Modeling Recommendations for the Mark II Short-Term Scenario

The recommended approach for modeling the suppression pool vents in the Mark II BWR is very similar to that discussed in Section 2.1.2 for the Mark I BWR. In particular, (a) the downcomers of a Mark II BWR should be represented as a separate cell, (b) flow communication between the drywell and the downcomers is modeled by two parallel flow paths, one a pool flow path and the other a gas flow path, and (c) flow communication between the downcomers and the wetwell should also be modeled by two parallel flow paths, one a pool flow path and the other a gas flow path.

The modeling recommendations for the Mark II short-term scenario analysis essentially are identical to the modeling recommendations for the Mark I short-term scenario analysis presented in Table 2-1 of Section 2.1. Therefore, the specific modeling recommendation for the Mark II short-term scenario are readily provided by Table 2-1. However, it is noted that the Mark II vent system uses only downcomers shown in Figure 3-1 in contrast to the Mark I vent system shown in Figure 2-1. The Limerick plant was arbitrarily chosen for the Mark II sample problem. The Appendix F input deck provides specific Mark II short-term scenario analysis modeling details.

3.2 Input Preparation and Calculated Results for the Mark II Short-Term Scenario

This section discusses the preparation of CONTAIN input for a Mark II short-term scenario and presents sample input and calculation for the Limerick plant based on data given in Reference 3. Input preparation for the short-term scenario should follow the recommended approach discussed above.

The Limerick sample problem input in Appendix F may also be consulted for examples of implementation of the recommended approach. The initial conditions and characteristics of the cells and flow paths used in this sample problem are shown in Tables 3-1 and 3-2, respectively. In addition, the Appendix F input is annotated to further explain the basis for the input parameters.

Figures 3-2 through 3-5 present the CONTAIN-calculated values for various containment parameters for the first 40 seconds of the blowdown.[4] The parameters include drywell and wetwell pressures and temperatures, the drywell to wetwell pressure difference and the drywell to wetwell flows. Comparisons with values from the Limerick SAR are made.

Table 3-3 compares the CONTAIN and SAR values for the vent clearing times, peak pressures, peak temperatures, peak drywell to wetwell pressure difference and the times at which the values occurred. In the CONTAIN calculations, vent clearing is assumed to occur when the initial liquid in the downcomer has reached the bottom of the downcomer. These results show that CONTAIN results compare favorably with the SAR values.

If the margin between the design values, e.g., pressure, and the peak calculated values are small, sensitivity studies of important parameters may be needed to understand the impact of inherent uncertainties. Key parameters for possible sensitivity study include those that affect the determination of the short-term peak drywell pressure. The peak pressure primarily is determined by the dynamic response of the vent system, i.e., the vent clearing time. As a result, key parameters that should be considered for sensitivity analysis are the vent-system water (pool) mass and the vent flow path characteristics, i.e., loss coefficients, inertial length, *vena contracta* value, and flow area.

4. The CPU time on a DEC Alpha workstation for the calculation discussed was 5 5s

Table 3-1. Limerick Short-Term Scenario Initial Conditions and Geometry

Cell	Volume (m^3)	Area (m^2)	Height (m)	Cell+ Elevation (m)	Initial Conditions†
Drywell Atmosphere	6662.	446.	14.93	Top, 31.35 Bottom, 16.42	T=339.0K P=1.0652e5 Pa Moles N2=96% Moles O2=4% RH=0.2
Downcomers Atmosphere	234.24	23.83	13.88	Top, 17.53 Bottom, 3.658	T=339.0K P=1.0652e5 Pa Moles N2=96% Moles O2=4% RH=0.2
Downcomers Pool	88.98	23.83	3.734	Included in the above	T=308. K
Wetwell Atmosphere	4181.	489.3	19.598	Top, 15.94 Bottom, 0.0	T=308.0K P=1.0652e5 Pa Moles N2=96% Moles O2=4% RH=1.0
Wetwell Pool	3722.	489.3 (513.2)*	7.607	Included in the above	T=308.0 K

+The elevation values are for the combined cell atmosphere and pool.
†T=temperature, P=pressure, RH=relative humidity.
*Note the area increases to 513.2 m^2 below an elevation of 3.658 m.

Table 3-2. Limerick Short-Term Scenario CONTAIN Flow Path Parameters

Flow Path	Area (m^2)	Area/Inertial Length[#] (m)	Elevation[†] (m)	Loss Coef.	Vena Contracta
Drywell to Downcomer POOL	23.83	3.2	From 17.526 To 17.526	0.615	0.7[*]
Drywell to Downcomers, GAS	23.83	3.2	From 17.526 To 17.526	0.615	0.7
Downcomers to Wetwell, POOL	23.83	2.3	From 3.734 To 3.734	0.5	0.7[*]
Downcomers to Wetwell, GAS	23.83	2.3	From 3.734 To 3.734	0.5	0.7

[†]Relative to suppression pool bottom.
[*]The vena contracta parameter has no effect on a pool flow path.
[#]Flow path area/inertial length.

Table 3-3. Limerick Short-Term Scenario SAR and CONTAIN Results

Result	Units	SAR	CONTAIN
Time of vent clearing	s	0.73	0.82
Peak drywell pressure	MPa	0.405	0.399
Time of peak drywell pressure	s	13.7	13.7
Peak drywell to suppression-chamber differential pressure	MPa	0.179	0.181
Time of peak differential pressure	s	0.85	0.85
Peak suppression-chamber pressure during blowdown	MPa	0.312	0.318*
Peak suppression-pool temperature during blowdown	K	331	328*

[*]These values were obtained by extending the CONTAIN calculation to 50 s.

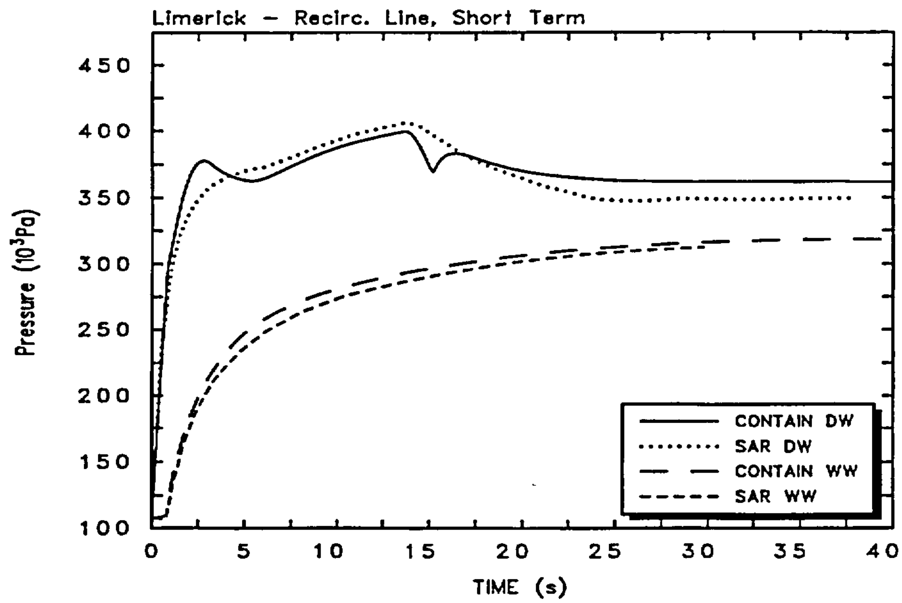

Figure 3-2. CONTAIN and SAR Drywell and Wetwell Pressures for the Limerick Recirculation Line Break Short-Term Scenario.

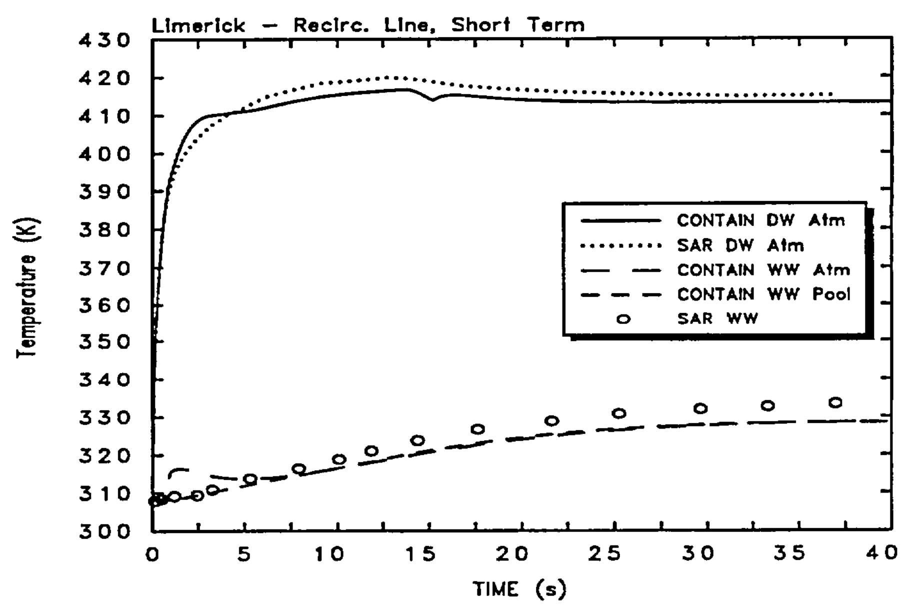

Figure 3-3. CONTAIN and SAR Drywell and Wetwell Temperatures for the Limerick Recirculation Line Break Short-Term Scenario.

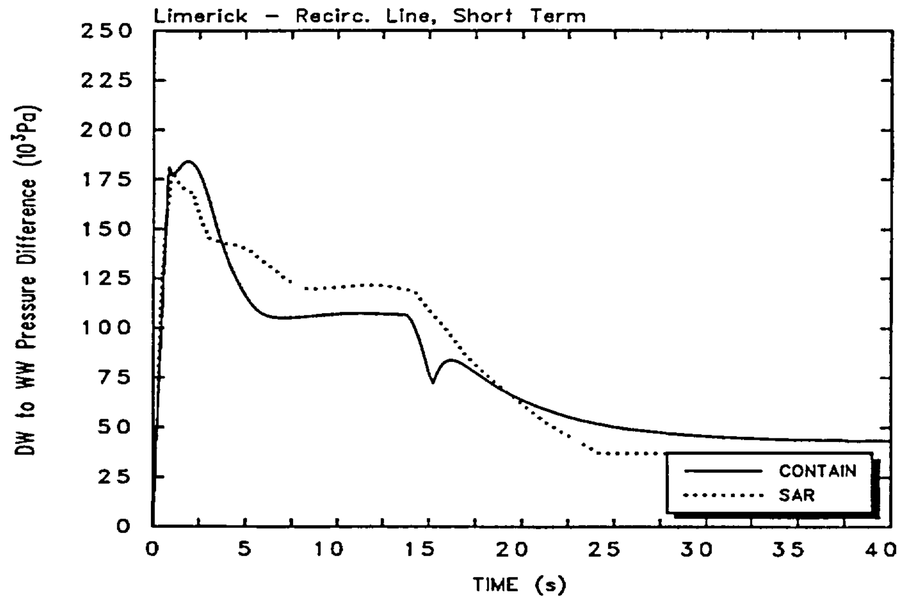

Figure 3-4. CONTAIN and SAR Drywell to Wetwell Pressure Difference for the Limerick Recirculation Line Break Short-Term Scenario.

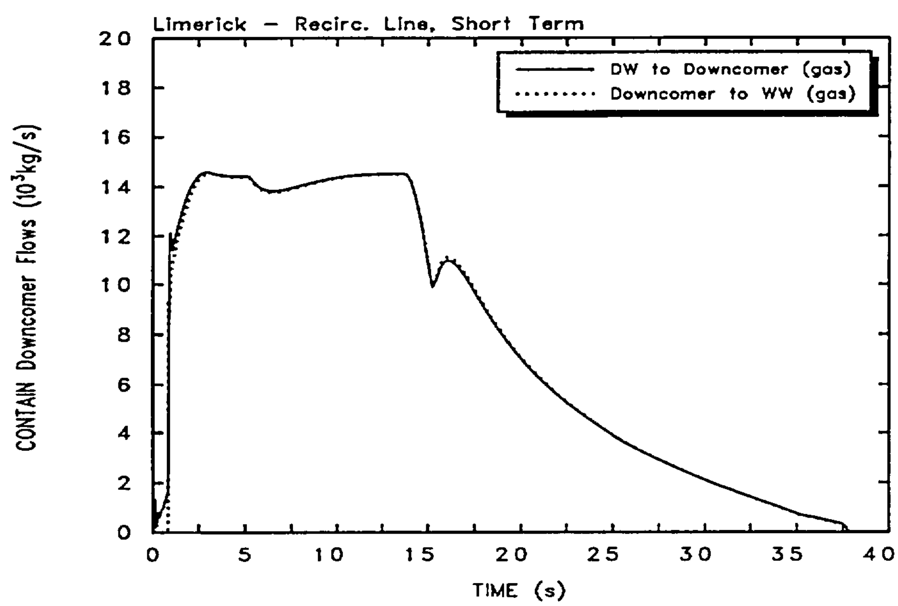

Figure 3-5. CONTAIN Mass Flow Rates from the Drywell to the Downcomer and from the Downcomer to the Wetwell for the Limerick Recirculation Line Break Short-Term Scenario.

4.0 Mark III Containment Analysis

In this section we discuss methods that can be used to model the response of BWR Mark III containments with CONTAIN during DBAs. This chapter will focus on methods for calculating the maximum pressure difference between the wetwell and the drywell. The peak containment boundary pressure can be calculated though a method similar to that used for evaluating the long-term response in Mark Is (see Section 2.2).

4.1 Mark III Short-Term Accident Analysis

In this section we first describe the recommended approach to be used for short-term blowdown modeling with CONTAIN, the purpose of which is to ensure that the code will predict conservative results, and that its predictions will be similar to traditional DBA codes. Second, the short-term containment pressure and temperature during a DBA is discussed in some detail for the Mark III demonstration plant, taken here to be Grand Gulf. Finally, the CONTAIN input parameter settings to model the short-term response are discussed in detail. CONTAIN and CONTEMPT vent clearing times are compared.

4.1.1 Mark III Short-Term Scenario

GE has done an analysis of various postulated primary system breaks, including double-ended recirculation line, double-ended main steam line, intermediate-sized liquid line, and small steam line breaks. Results of this analysis indicate that the double-ended main steam line break (MSLB) typically yields the maximum pressure difference in a Mark III. However, the recirculation line break produces comparable pressures, and this scenario will be used in the sample calculation presented below.

Figure 4-1, which was obtained from the Grand Gulf sample problem discussed in Section 4.3, illustrates the containment response calculated by CONTAIN for the recirculation line break scenario. The breaks in the slopes of the CONTAIN pressures in this figure are related to vent clearing in the top, middle, and bottom rows of suppression pool vents in the Mark III. It should be noted that the clearing of the top row of vents in the Mark III is not sufficient to terminate the short-term pressure rise in the drywell: the drywell pressure continues to rise while two-phase flow (a mixture of steam, air, and water) occurs in the top vent. The drywell pressure rise terminates only after the second (or in some cases, third) row of vents clear.

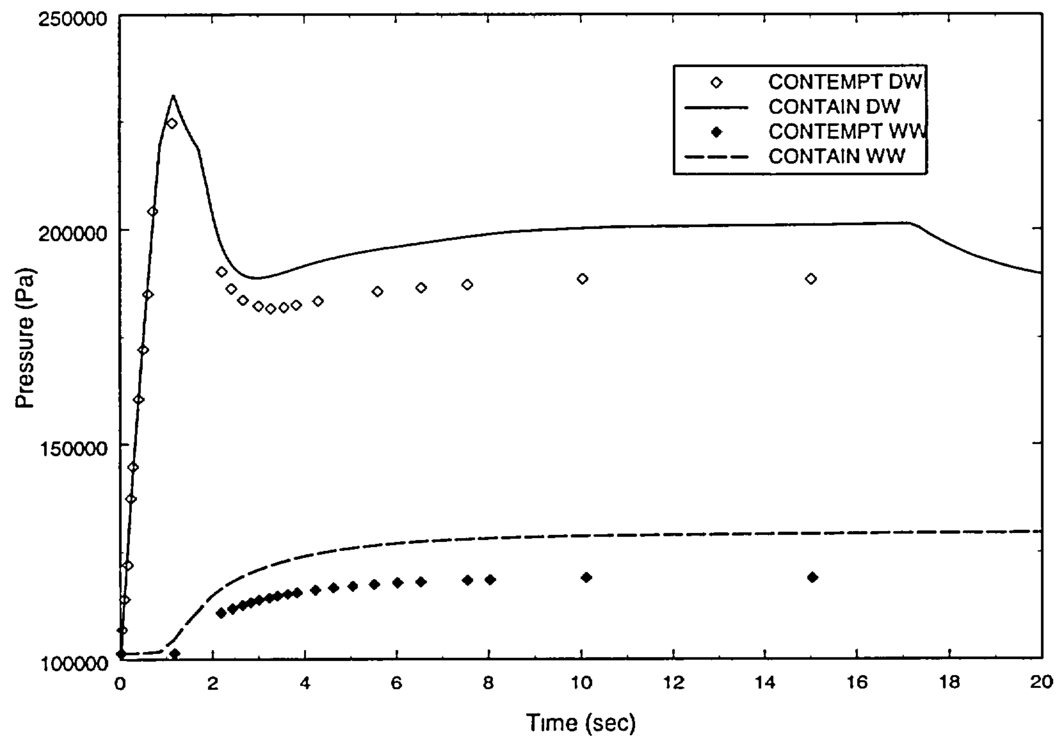

Figure 4-1. Comparison of CONTAIN and CONTEMPT predictions for the Grand Gulf recirculation line break scenario.

4.1.2 Modeling Recommendations for the Mark III Short-Term Scenario

The modeling recommendations for a Mark III short-term scenario are as presented in Table 4-1. Also see the annotated sample input deck in Appendix H.

Table 4-1. Input Guidelines for Modeling the Mark III Short-Term Scenario (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
Drywell, drywell-annulus, and wetwell free volumes based on a three-cell nodalization as shown in Figure 4-2.	Set to HWL (High Water Level). The drywell free volume is split between the drywell and annulus regions. Treat the drywell atmosphere as homogeneously mixed and in thermodynamic equilibrium to maximize density. Maximize the flow density and minimize the two-phase flow rate by avoiding use of DROPOUT or water aerosol options, which tend to remove liquid from the atmosphere.	Setting the free volume requires coordination of CELLHIST, GASVOL, and POOL mass input. Assume values are LWL (Low Water Level), if not otherwise specified, which was done for the (arbitrarily-chosen Grand Gulf) Mark III sample problem.
Drywell, annulus and wetwell pool volumes.	The pools defined in the annulus and wetwell should consist of the annulus, vent, and wetwell liquid inventories. For conservatism with respect to peak pressure, HWL volume for the suppression pool should be used. The annulus and wetwell water levels should be increased above HWL to include the water in the vents themselves (i.e., to give the correct HWL volume).	Set through the POOL mass input. Using the HWL volume is conservative with respect to the contribution to the suppression pool liquid head from cleared vents and serves to increase vent clearing times (for vents still in the process of clearing) and decrease two-phase flow rates. A drywell pool was not used because the blowdown coolant liquid was modeled to remained in suspension to maximize the calculated drywell pressure. The inclusion of the vent water is recommended because flow paths in CONTAIN only determine flow rates across a junction and do not have actual inventory associated with them.
Blowdown mass and energy rate.	Introduce blowdown mass and energy as a drywell atmosphere source. A homogeneous mixture of air, steam, and decompressed and/or condensed liquid water in thermodynamic equilibrium should be modeled in the drywell atmosphere. In addition, this liquid water should be allowed to remain suspended in the atmosphere, so that the liquid contributes to the flow density in the suppression vent system.	Sensitivity calculations have shown that retention of the liquid in the atmosphere is conservative overall in the short-term scenario when a well-mixed and equilibrated drywell is assumed. The resulting dominant effect is the reduction of the two-phase volumetric flow rate through the vent system because of the higher upstream flow density. Therefore, liquid dropout or aerosol modeling options for this liquid should not be used. The resulting atmosphere source is treated in a manner similar to the "temperature-flash" approximation because all of the mass and energy goes into the atmosphere.

Table 4-1. Input Guidelines for Modeling the Mark III Short-Term Scenario
(See the input deck annotations for specific examples of application of the recommended approach.)

Modeling Area	Recommended Approach	Comment
The following CONTAIN (pool and gas) ENGVNT flow paths should be used for the Mark III suppression pool vent clearing system shown in Figure 4-3.	The recommended CONTAIN three-node representation of the suppression pool vent clearing system for a Mark III is shown in Figure 4-3. This figure shows the lower regions of the annulus and wetwell in which the vent system is located. The dynamics of these paths should be based on constant effective inertial lengths. In addition, for conservatism, these lengths for the pool flow paths should be based on a effective liquid slug length for the vent system equal to 1.25 times the actual length of the original liquid in the flow path. The thermal hydraulic modeling of vent liquid and two-phase flow in the suppression vents for the Mark III should be based on standard gas and pool (ENGVENT) flow path options.	The vent system in a Mark III has three rows of round horizontal vents, with approximately 45 vents per row In the three-node suppression pool vent model, each row is represented by one pool and one gas flow path. The use of constant effective inertial lengths is conservative during the vent clearing process because the effective length actually decreases with time as the vent system water level decreases. The derivation of the inertial lengths appropriate for the vent system and vent geometry is discussed in more detail in Section 4.3 and Appendix G. Also, Appendix I (absent in non-proprietary version of this report) describes a validation of this approach to modeling the vent clearing transient in Mark IIIs, including comparison of CONTAIN predictions with GE Mark III vent clearing tests.
Drywell-annulus liquid flow vent (pool ENGVENT)	Use a pool flow path with a loss coefficient corresponding to contraction loss (VCFC = 0.2). The inertial length should be set to the distance between the top of the weir wall and the HWL.	This path is defined for completeness although it does not participate unless the drywell-wetwell pressure difference is negative. The loss coefficient is chosen for consistency with the parallel two-phase (gas) flow path, for which the forward loss is the most critical.
Drywell-annulus two-phase flow vent (gas ENGVENT).	Use a gas flow path with the same parameters as the corresponding pool flow path.	
Annulus-wetwell liquid flow vent (pool ENGVENT).	Use one pool flow path per vent row to model liquid flow. Set the path inertial length according to Table 4-2 for HWL, and set the turbulent loss coefficient VCFC = 1.5.	The inertial lengths are used to define the VAVL (area versus length) input parameter. The CONTAIN loss coefficients of CFC =1.5 (equivalent to conventional loss coefficients of 3.0) is recommended (for both liquid and two-phase flow). This is consistent with the range (2.5 – 3.5) of row-dependent conventional values given in the Grand Gulf SAR for the suppression vents.

Table 4-1. Input Guidelines for Modeling the Mark III Short-Term Scenario (See the input deck annotations for specific examples of application of the recommended approach.)		
Modeling Area	Recommended Approach	Comment
Annulus-wetwell vent two-phase flow vent (gas ENGVENT).	Use one gas flow path per vent row with the same parameters as for the corresponding pool flow path to model the two-phase flow that occurs after vent clearing. Use VCONTRA = 0.7 to account for possible choking. Sensitivity calculations are recommended to account for the uncertainty associated with an increased vent resistance due to two-phase flow and compressibility. These calculations should be made by increasing the CONTAIN loss coefficient by a factor of two and decreasing the vena contracta from 0.7 to 0.55.	The CONTAIN flow model is an incompressible formulation with a choked flow limiting value determined by adiabatic expansion without loss. As a result, a vena contracta factor of 0.7 is used when necessary to approximate the combined effects of expansion and loss. Sensitivity calculations for the Mark III gas vents are recommended based on the two-phase and compressibility analysis presented in Appendix B.
Wetwell compression.	Simply take the conservative approach of ignoring the wetwell pressure rise (compression) in determining the peak short-term drywell-wetwell pressure difference.	As discussed in the Section 2-Mark I and the Section 3-Mark II analyses, and in Appendix G, a significant difference between CONTAIN and traditional treatments of the wetwell involves the work done by compression as noncondensible gas is admitted to the wetwell atmosphere after bubbling through and equilibrating with the suppression pool. Traditional treatments either ignore this compression work or assume atmosphere-pool equilibration to reduce the superheating of the wetwell atmosphere that results from this compression work. Thus, in Sections 2 and 3, this superheating is removed in CONTAIN calculations of the short-term response for Mark Is and IIs by forcing equilibrium between the wetwell pool and atmosphere through a fictitious wetwell spray. In a Mark III the vent flow area and wetwell atmosphere volume are sized so that the wetwell pressure rise is relatively small at the time of peak drywell-wetwell pressure difference. Therefore, it is recommended that fictitious equilibrating wetwell sprays not be used for a Mark III; rather one should simply take the conservative approach of ignoring the wetwell pressure rise in determining the peak short-term drywell-wetwell pressure difference.

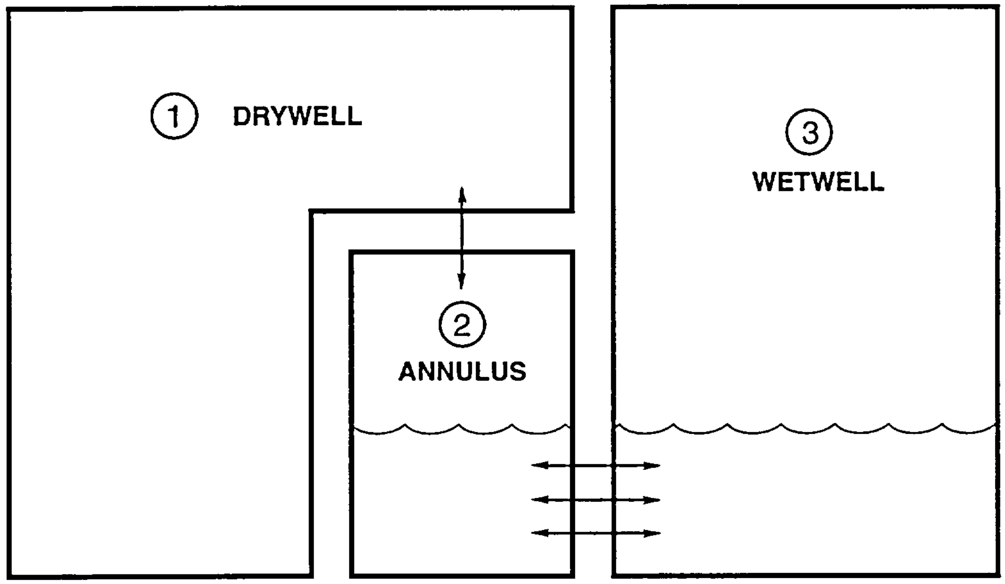

Figure 4-2. CONTAIN three-cell model of a Mark III BWR.

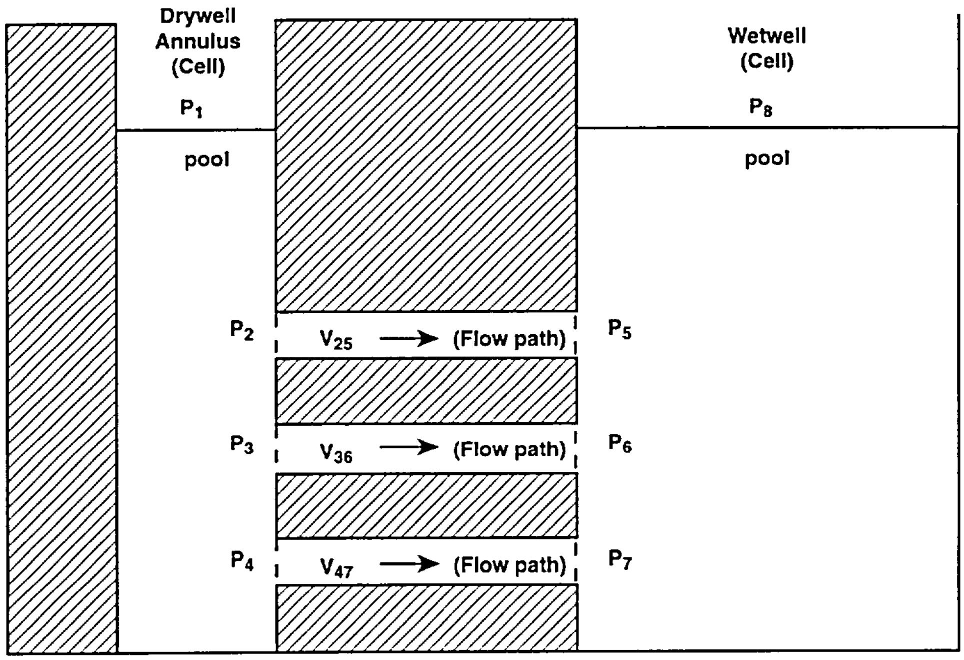

Figure 4-3. CONTAIN three-node representation of Mark III suppression vents.

4.2 Input Preparation and Calculated Results for the Mark III Short-Term Scenario

This section discusses how to prepare CONTAIN input for a Mark III short- term scenario and presents sample input and calculation for the Grand Gulf plant, based on data given in Reference 5. Input preparation for the short-term scenario should follow the recommended approach discussed above. This recommended approach is summarized and linked to specific input parameters in Table 4-2 below.

The inertial lengths to be used for the flow paths representing the suppression vents are given in Table 4-2, for various suppression pool water levels. These values were calculated according to the prescription discussed in Appendix G; i.e., as the time-independent effective lengths giving the same initial liquid accelerations in the vents as a 7-node model for the liquid flow. In this 7-node model, the liquid slug lengths for the horizontal vent nodes are taken to be 1.25 times the actual lengths of the horizontal vent tubes, to correct for end effects. Note that these inertial lengths depend on the initial vent submergence.

The input for the Grand Gulf sample problem is given in Appendix H. The initial conditions and characteristics of the cells and flow paths used in this problem are shown in Tables 4-3 and 4-4, respectively. The inertial lengths for the annulus and suppression vent flow paths correspond to HWL (i.e., a top-vent submergence of 2.28 m).

Figure 4-1 compares the drywell and wetwell pressures predicted by CONTAIN and CONTEMPT [Reference 4] for the first 20 seconds of the blowdown. The difference in the CONTAIN and CONTEMPT wetwell pressures results from the fact that CONTAIN models include compression of the wetwell atmosphere by the gas bubbled through the pool after vent clearing. CONTEMPT models this work only to the degree specified by the user, and this work is typically ignored. The CONTAIN treatment is physically correct during quasi-steady gas bubbling, provided level swell can be neglected. The CONTAIN peak drywell-wetwell pressure difference is clearly conservative compared to CONTEMPT's, especially when the wetwell pressure rise is neglected in evaluating this difference, as recommended in Section 4.2.

Table 4-5 compares the CONTAIN and CONTEMPT predictions for the vent clearing times. In the CONTAIN calculations, vent clearing is assumed to occur when the annulus level essentially reaches the vent centerline elevation. Use of the vent centerline elevation is consistent with the observations in Reference 6 that the top of a horizontal vent on the downstream side first clears when the annulus level on the upstream side is approximately at the vent centerline. These results show that CONTAIN is slightly conservative compared with CONTEMPT with respect to vent clearing time.

As indicated in Appendix B, the estimation of the Mark III vent loss coefficient and associated *vena contracta* is complicated by 1) allowance for two-phase flow entering the horizontal pathways through a bend or tee geometry and 2) compressibility effects in the vent. Appendix B discusses how the two-phase and compressibility effects can be addressed approximately in the CONTAIN flow input by increasing the vent gaseous loss coefficient and decreasing the *vena contracta* value. Sensitivity calculations should be considered when performing Mark III plant analysis to include the type of coefficient and *vena contracta* ranges suggested in Appendix B. Shown in Figure 4-4, for example, is an illustration of the type of sensitivity calculation recommended for the Mark III analysis. The case in Figure 4-4 with $C_{FC} = 1.5$ and $v = 0.7$

corresponds to the CONTAIN calculation presented in the CONTAIN/CONTEMPT comparison plot and tables. The upper curve in Figure 4-4, with $C_{FC} = 2.8$ and $v = 0.55$, corresponds to a *sensitivity* calculation that includes adjustments for two-phase flow and compressibility in the Mark III vents.[5]

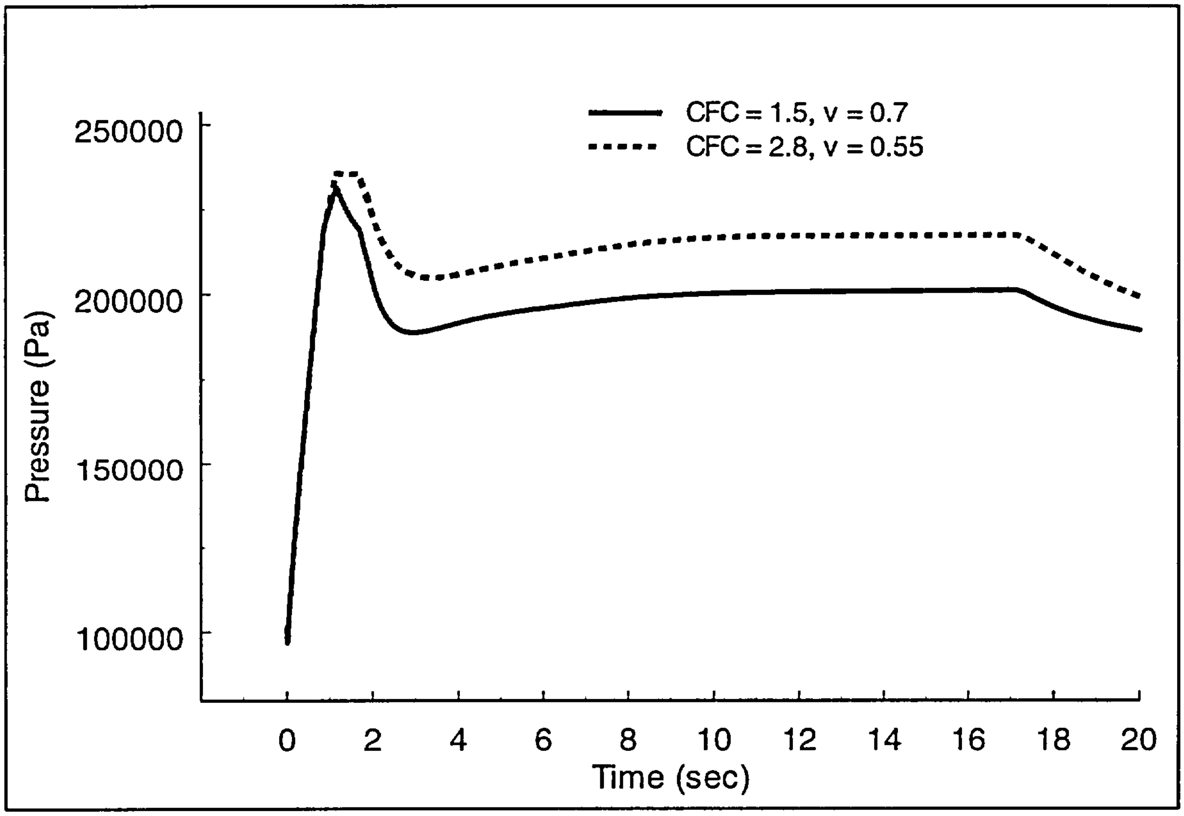

Figure 4-4. CONTAIN sensitivity calculations for the Grand Gulf recirculation line break scenario, where input for the gas vents between the downcomer and wetwell are varied to account for two-phase and compressibility effects.

5 CONTAIN validation calculations using GE Mark III tests have also suggested that the sensitivity calculation shown in Figure 4-4 may represent a better estimation of peak containment pressure than the calculation presented in the CONTAIN/CONTEMPT comparison (and listed in Appendix H). However, due to the uncertainties associated with the tests, a definitive statement concerning the most appropriate input for Mark III vents is difficult to recommend. As a result, sensitivity calculations based on vent input coefficient and *vena contracta* variation as suggested in Appendix B is strongly recommended.

Table 4-2. Effective Inertial Lengths for the Top, Middle, and Bottom Rows of Suppression Vents in a Mark III, as a Function of Water Level and Vent Separation. (All values are lengths in meters.)[6]

Top Vent Centerline Submergence	Vent Separation* = 1.27			Vent Separation = 1.37		
	Top Vent	Middle	Bottom	Top Vent	Middle	Bottom
2.43	3.82	5.43	6.69	3.79	5.50	6.88
2.28	3.70	5.26	6.48	3.67	5.33	6.67
2.13	3.58	5.09	6.28	3.56	5.16	6.46
1.98	3.46	4.92	6.07	3.44	4.99	6.24

*Refers to vertical distance between vent centerlines

Table 4-3. Grand Gulf Initial Conditions and Geometry

Node	Volume (m3)	Area (m2)	Height (m)	Cell Elevation (m)	Initial Conditions†
Drywell Atmosphere	7551.86	243.02	31.08	Top, 31.075 Bottom, 0.0	T=330.22 K P=1.0135e5 Pa RH=0.2
Annulus Atmosphere	80.02	51.47*	1.55	Top, 7.41 Bottom, 0.0	T=330.22 K P=1.0135e5 Pa RH=0.2
Annulus Pool	301.39	51.47	5.86	Included in the above	T=308.15 K
Wetwell Atmosphere	39479.12	619.29	63.75	Top, 69.604 Bottom, 0.0	T=299.67 K P=1.0135e5 Pa RH=0.6
Wetwell Pool	3626.34	619.29	5.86	Included in the above	T=308.15 K

†T=temperature, P=pressure, RH=relative humidity
*SAR value

6. These inertial lengths include a 1.25 multiplier applied to the horizontal vent section lengths to correct for end effects and are used to determine the CONTAIN VAVL term (flow area/inertial length).

Table 4-4. Grand Gulf Flow Path Characteristics

Flow Path	Area (m2)	Inertial Length (m)	Area/Inertial Length (m)	Elevation† (m)	CONTAIN Loss Coef.
Annulus Entry	51.44*	1.68	30.62	7.41	0.25
Top Vents	17.88	3.70	4.832	3.45	1.5
Middle Vents	17.88	5.26	3.399	2.18	1.5
Bottom Vents	17.88	6.48	2.759	0.91	1.5

†Relative to suppression pool bottom
*Note that this value is three times the value for each vent row as described in Appendix G and is insignificantly different from the SAR value for the annulus pool area in Table 4-3.

Table 4-5. Grand Gulf Vent Clearing Times (sec)

Event	CONTEMPT	CONTAIN
Top Row Clears	0.75	0.86
All 3 Rows Clear	1.34	1.68
Bottom Row Closes	21.5	22.6
Middle Row Closes	33.0	33.5

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, 1997.

2. Hope Creek Generating Station Updated Final Safety Analysis Report (UFSAR), Revision 0, April 11, 1988.

3. Limerick Generating Station Updated Final Safety Analysis Report (UFSAR), Revision 5 April 1996.

4. D. W. Hargroves and L. J. Metcalfe, "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, March 1979.

5. K. Almenas, F. J. Munno, N. Ennaciri, and H. Esmaili, "Recomputation of Selected CONTEMPT Code Design Basis Containment Transients Using the CONTAIN Code," ERI/NRC93-209, Energy Research, Inc., Rockville, MD, 1993.

5. 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.

APPENDIX A
Comparison of CONTAIN with CONTEMPT for BWR Analysis

Introduction

To understand the implications of using CONTAIN for DBA studies in place of traditional DBA codes, it is important to compare the specific models in the codes. It is not expected that the models would be the same—on the contrary, the benefits of making the transition to CONTAIN arise from the differences in the models. But an understanding of the differences, and their implications, will help in understanding the degree of continuity in code predictions that is possible under various accident and plant conditions. It is sometimes possible to predict with some confidence the implications of certain types of model differences, but more often it is not possible to make general statements about the direction of differences (e.g., degree of conservatism) in results that would result from the differences. That is why it is important to carry out specific comparisons of code results, as in the main body of this report.

In this appendix the CONTAIN modeling of the drywell, vent system, and wetwell of a BWR is discussed and compared to CONTEMPT LT/28.[1] This comparison is summarized in Tables A-1 through A-3, and assumes that the user guidelines in the main body of this report are followed.

Drywell Modeling

Table A-1 summarizes the drywell thermal hydraulic modeling approach in CONTAIN and CONTEMPT. CONTAIN assumes homogeneous mixtures of steam, air, and water are present in the drywell, in calculating the drywell thermodynamic response and the composition of flow into the vents during the two-phase flow period. CONTEMPT, however, allows the user to specify the flow composition, although typically it is set to the homogeneous mixture. As indicated in the table, CONTAIN differs from CONTEMPT in that drywell free-volume expansion effects, from depression of water levels in the vent system prior to vent clearing, is taken into account. This tends to reduce the drywell pressure slightly prior to vent clearing.

Table A-1. Modeling Comparisons Between CONTAIN and CONTEMPT for Drywell Conditions

Modeling Item	CONTAIN	CONTEMPT
Number of volumes	2 (drywell and downcomer/annulus)	1
Atmosphere thermodynamics	Homogeneous mixture†	Homogeneous mixture
Flow density	Homogeneous	User-specifiable
Heat transfer	Adiabatic	Adiabatic
Free volume expansion prior to vent clearing	Yes	No

† Refers to the steam, air, and suspended blowdown water present in the drywell.

Table A-2. Modeling Comparisons Between CONTAIN and CONTEMPT for Vent Clearing

Modeling Item	CONTAIN	CONTEMPT
Model type	Incompressible inertial formulation with loss	Incompressible inertial formulation with loss
Number of nodes	1* (Mark I, II); 3* (Mark III)	2 (Mark I, II); 7 (Mark III)
Loss coefficient type	Form	Form; Fanning
Back-pressure effects	Hydrostatic†	Hydrostatic; wetwell pool acceleration††
Built-in conservative bias	Fixed inertial lengths equal to initial; vent slug length =1.25 x actual length	Neglect of drywell free volume increase during vent clearing

*Number of CONTAIN pool flow paths.

†From the wetwell gas pressure plus static liquid head on wetwell side.

††From the upward acceleration of the wetwell pool by the accelerating liquid flow in uncleared. vents

Vent Clearing

Table A-2 summarizes the vent clearing modeling in the CONTAIN and CONTEMPT approaches. The number of nodes used in the CONTAIN approach refers to the number of pool flow paths used to model the vent clearing. Note that the 3-node model for the Mark III uses effective inertial lengths determined from a 7-node model, as described in Appendix G. Inspection of the CONTEMPT documentation[1] for a Mark III shows that there is no simple correspondence between the form loss coefficients used in the CONTEMPT model and the CONTAIN loss coefficient. The difficulty is that some of the CONTEMPT loss coefficients are applied to the annulus and wetwell nodes and not the vent nodes in the 7-node CONTEMPT representation of the vent system. Thus, evaluation of conservatism must be based on actual calculations.

The back-pressure effects in Table A-2 refer to static and dynamic pressurization effects in the wetwell that can impede flow through the vents. The hydrostatic effects are related to the wetwell gas pressure and to the liquid head on the wetwell side that must be overcome before flow can proceed or continue into the wetwell. The dynamic back-pressure effects are related to the fact that both accelerating liquid (vent clearing) flow in the vents and the expansion of the gas bubble formed at the vent exit just after clearing create local pressure fields that cause the wetwell pool to accelerate outward and upward. In particular, bubble expansion back-pressure may be quite important in limiting both liquid flow in uncleared vents (in a Mark III) and the two-phase flow that occurs in a vent just after vent clearing. However, neither CONTAIN or CONTEMPT model the bubble inertia effect.

The built-in conservative bias indicated in Table A-2 is based on the documentation of the models. The bias for CONTAIN is based on time-independent effective inertial lengths, calculated for conservatively chosen water levels in the downcomer/annulus and wetwell. Since the effective inertial length actually decreases with time when the vents are clearing and the water level in the downcomer/annulus is decreasing, using a time-independent value based on initial levels tends to give a conservative vent clearing time.

Table A-3. Modeling Comparisons Between CONTAIN and CONTEMPT for Two-Phase Flow and Wetwell Conditions

Modeling Item	CONTAIN	CONTEMPT
Flow model type	Incompressible inertial, with loss and choked flow limit	Compressible quasi-steady with loss and choking
Loss coefficient type	Form	Branching; form
Back-pressure effects†	Hydrostatic	Hydrostatic; wetwell pool acceleration
Free volume compression prior to vent clearing	Yes	Unknown
Wetwell pool level swell modeled	No	No
Bubble gas conditions	Temperature and vapor pressure equilibrium attained over short distance (by default, 1 cm)	Temperature equilibrium; all water and steam removed; user-specifiable work done on wetwell atmosphere

†See Table A-2

Two-Phase Flow and Wetwell Modeling

Table A-3 summarizes the modeling of two-phase flow and wetwell conditions. With regard to pressurization effects prior to vent clearing, CONTAIN calculates the compression of the wetwell atmosphere resulting in the change in the wetwell pool height during the vent clearing process. It is not clear whether CONTEMPT takes this into account. If not, the omission is slightly nonconservative with regard to vent clearing times. With regard to pool swell, both CONTAIN and CONTEMPT assume that the bubble velocity of gas in a pool is effectively infinite, and consequently pool swell is ignored. In CONTAIN and CONTEMPT, pressurization of the wetwell atmosphere by pool swell prior to bubble breakthrough is therefore not modeled. Both these codes do model pressurization as the result of the admittance of vented gases into the wetwell atmosphere, a process that also does work on the atmosphere. CONTAIN models this work, in a manner appropriate for conditions of quiescent gas bubbling. However, CONTEMPT allows the user to specify the fraction of this work to be applied to the wetwell atmosphere in the calculation; typically, however, this work is ignored. If this work is ignored the wetwell conditions calculated by CONTEMPT will be cooler and less pressurized than the conditions calculated by CONTAIN, given the same bubble conditions.

While CONTAIN calculates the wetwell conditions properly under quasi-steady bubbling conditions, the initial part of a vent clearing transient cannot be characterized as a quasi-steady. For example, prior to bubble breakthrough, the work done on the wetwell atmosphere is the result of pool swell, which may be mitigated by pool inertia, and not by gas admittance, and after bubble breakthrough the atmosphere heating resulting from the work done may be mitigated by the water entrained into the atmosphere during the breakthrough process. The CONTAIN treatment of gas bubbling is typically conservative, but for the maximum drywell-wetwell pressure difference during vent clearing transient for a Mark III it could be nonconservative. In this case, an increase in the pressurization rate of the wetwell atmosphere pressure with time tends to reduce the maximum pressure difference attained. For this reason, it is recommended that the relatively small pressure rise in the wetwell be ignored when the maximum drywell-wetwell pressure difference is evaluated for a Mark III.

References

1. D. W. Hargroves and L. J. Metcalfe, "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, March 1979.

APPENDIX B
CONTAIN Flow Model for BWR Design Basis Applications

Introduction

Modeling fluid flow behavior in the containment of a BWR-type plant during a design basis accident can involve many complicated models for a variety of processes. These processes include both single and two phase fluid flow through channels and singularities such as contractions, expansions, bends, and flow divisions (tees). Due to the severity of the blowdown injections, two phase flows may be considered as compressible flows and under some conditions exhibit critical flow behavior. A detailed analysis of the flow behavior is often beyond the scope of a systems code, like CONTAIN, which has limited capability for a precise treatment of two-phase compressible flow. However, reasonable approximations to a complex fluid behavior can be utilized to provide conservative results that may be used for licensing applications. In the following discussion, methods used to obtain conservative approximations for two-phase compressible fluid flow are described. In the first section, two-phase flow (incompressible) is discussed in terms of the CONTAIN homogeneous flow modeling approach. The second section discusses modeling issues related to compressibility of the two-phase mixture. Included in this discussion on compressibility are those issues related to the prediction of two-phase critical flow in the containment vent pathways.

Two-phase, incompressible flow modeling with the CONTAIN code

During design basis accidents, line breaks (main steam line, recirculation lines, etc.) can produce a two–phase injection of steam and liquid water into the drywell of the containment. These injections, in turn, generate a pressurized, dispersed gas/liquid mixture that will clear flooded vents leading from the drywell to the wetwell suppression pool and overlying gas volume. The maximum pressure obtained in the drywell is determined by the flow rate of the two-phase mixture through these vents. Each BWR plant type (Mark I, II, III) has a different geometric configuration for the vent system. In the CONTAIN code, the two-phase flow modeling is formulated as a homogeneous model; that is, a model where the gas and liquid move at the same velocity.[1] For discussion purposes, only the steady state form of the homogeneous model equations will be referred to here, but it should be noted that the code uses the transient form of the momentum equation where fluid inertia in a pathway is included.

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[1] For the blowdown period, the CONTAIN default treatment for condensed water in the atmosphere is recommended. The default setting (FLOW block input) retains all condensed liquid water in the atmosphere (no dropout). In the flow models, no slip between phases is assumed. The fluid mixture of gas/liquid therefore flows as a homogeneous fluid through pathways.

When fluid flowing through a pathway is two-phase, a two-phase loss coefficient is often used to account for unrecoverable pressure losses. The pressure loss for a singularity (contraction, expansion, bend, etc.) may be written in terms of the single-phase loss ΔP_{Lo} times a two-phase multiplier Φ^2_{Lo} as

$$\Delta P_{TP} = \Delta P_{Lo} \Phi^2_{Lo} \qquad \text{(B-1)}$$

The single-phase pressure loss is the loss that occurs if the total mixture flows as liquid only (subscript *Lo*), in this case. The liquid pressure loss for a singularity is

$$\Delta P_{Lo} = C_{FC} G^2 / \rho_L , \qquad \text{(B-2)}$$

where C_{FC} is the single-phase CONTAIN loss coefficient, G is the mass flux, and ρ_L is the liquid density. In the case of homogeneous mixtures, the two-phase multiplier is typically written as

$$\Phi^2_{Lo,H} = \frac{\rho_L}{\rho_H} = 1 + x \frac{(\rho_L - \rho_G)}{\rho_G} \qquad \text{(B-3)}$$

with the subscripts H and G referring to the homogeneous and gas (air/steam) mixture, and x is the dryness or mixture quality. The homogeneous model for two-phase pressure loss can be formulated simply by including the single-phase loss coefficient in the Equation (B-1), such that

$$\Delta P_{TP} = C_{FC} G^2 / \rho_H \qquad \text{(B-4)}$$

For many singularities (e.g., sudden contractions or expansions), Equation (B-4) is a reasonably good approximation to the two-phase pressure loss where the single phase loss coefficient is unchanged for two-phase pressure drops. However, there are situations observed experimentally where the pressure drop calculated using Equation (B-4) either over or under predicts two-phase pressure drops. In these cases, the assumption of no phase slip (homogeneous flow) is drawn into question. If the pressure drop is determined as an over prediction, the homogeneous model would be considered a conservative model for design basis analyses. In such situations the two-phase multiplier would be measured *lower* than values estimated by Equation (B-3). Flows through orifice type pathways generally will be predicted conservatively using the homogeneous model [1]. For contractions or expansions the measured and calculated (homogeneous) two-phase multipliers are approximately equal, and therefore Equation (B-4) would be considered a "best-estimate" model [2]. Where there are bends or divided flows (branches) homogeneous modeling tends to under predict two-phase pressure losses; such that, the two-phase multiplier obtain using Equation (B-3) is calculated lower than measured values [3]. It has been noted in the literature that bends or tees function as phase mixers or separators, significantly affecting the slip between phases and therefore also pressure losses. For this type of singularity, found in the Mark III vent configuration (bend or tee), the multiplier for the bend portion of the vent can, alternatively, be approximated using an empirical equation developed by Chisholm [3]. Chisholm's equation is often referred to as the "B-type" equation,

$$\Phi_{Lo}^2 = 1 + \left(\frac{\rho_L}{\rho_G} - 1\right)\left[Bx(1-x) + x^2\right]. \qquad \text{(B-5)}$$

Experimental ***B*** values have ranged from 1.8 to 4.5 for bends or tees having various ratios of radius of curvature to pipe diameter R/D and single-phase conventional loss coefficients (K_{Lo}) ranging from 0.17 to 1.25. As a reference, a smooth surface, miter bend or branch tee (divided flow) has conventional loss coefficient of approximately 1.0. During blowdown periods, flow qualities of 0.4 to 0.6 are typical (Figure B-1); and, the two-phase pressure losses for the bend or tee-divided flow is calculated to be 1.5 to 2.25 times the two-phase loss multiplier determined with the homogeneous model. Here we define a "two-phase loss factor"

$$F_{2-phase} = \frac{\Phi_{Lo}^2}{\Phi_{Lo,\text{homo}}^2}, \qquad \text{(B-6)}$$

where $F_{2-phase}$ is equal to ~ 2 for bends or branch tees during blowdowns. The two-phase loss factor $F_{2-phase}$ is plotted in Figure B-2 for a range of qualities and two B values typical of bends or tees. Equation (B-4) can be modified to include the phase factor,

$$\Delta P_{TP} = F_{2-phase} C_{FC} G^2 / \rho_H \qquad \text{(B-7)}$$

or written using an adjusted loss coefficient, $C_{FC}^* = F_{2-phase} C_{FC}$, as

$$\Delta P_{TP} = C_{FC}^* G^2 / \rho_H \ . \qquad \text{(B-8)}$$

Compressible flow modeling using the CONTAIN code

The CONTAIN flow model is based on an incompressible flow formulation with a user-specified loss coefficient except when the resulting flow rate exceeds the choked flow limit imposed by adiabatic expansion in the absence of loss. In the latter case the limiting flow rate is used. This treatment disregards the fact that in general both friction loss and expansion effects limit the flow rate. The CONTAIN model may be compared with a model that takes both effects into account, namely, the GE Analytic Model [4] for steady-state flow of gas and suspended liquid in the suppression vent system of a BWR. It is shown that the CONTAIN treatment can be made to approximate the results for the GE Analytic Model for moderate total loss coefficients if a *vena contracta* factor of approximately 0.7 is used in the CONTAIN model. Two cases are examined: the first assumes the vent system (when cleared of pool liquid) is described by a single gas flow path, and the second assumes that the vent system downcomer (in a Mark I or II) is represented as a cell and the vent system is modeled in terms of two gas flow paths, the first connecting the drywell to downcomer cell and the second connecting the downcomer cell to the wetwell. The reader should note that the second, two-flow-path configuration is used to model the vent systems of Mark I's and II's in the body of this report. In the case of the Mark III vent configuration, a third method for addressing compressible flow using modified loss coefficients greater than what is proposed for the Mark I's and II's is discussed.

The GE Analytic Model

The GE model is based on standard differential expressions [5] relating the change of pressure P and velocity v with distance x for adiabatic flow of gas in a duct with a constant area A and constant loss coefficient k = 4f/D per unit length, where f is the friction factor and D is the hydraulic diameter. The standard differential expression can be generalized to include two-phase mixtures within the assumptions of the GE Analytic Model. These assumptions are cumbersome to state and will not be repeated here, except to note that no slip and no thermodynamic coupling is present between the gas and condensed phases in this model. The resulting momentum equation has the form

$$\frac{dP}{P}+\frac{\gamma M^2}{2}kdx+\frac{\gamma M^2}{2}\frac{dv^2}{v^2}=0 \qquad \text{(B-9)}$$

where γ is the specific heat ratio for the gas only, v is the mixture velocity, M is the effective Mach number = $(\rho_{t0}/\rho_{g0})^{1/2}v/c_g$, where c_g is the speed of sound for the gas only. Note that the subscript 0 denotes upstream conditions, which for simplicity are assumed stagnant in the comparisons below.

The above expression can be integrated by using similar generalizations of the mass and energy equations[5] to give, first, the relation between the local pressure and the pressure P_s that would be present at unit Mach number (M = 1)

$$\frac{P}{P_s}=\frac{1}{M}\left[\frac{\gamma+1}{2\left(1+\frac{\gamma-1}{2}M^2\right)}\right]^{1/2} \qquad \text{(B-10)}$$

and, second, the indefinite integral of the loss coefficient

$$\int kdx=\frac{1-M^2}{\gamma M^2}+\frac{\gamma+1}{2\gamma}\ln\left[\frac{(\gamma+1)M^2}{2\left(1+\frac{\gamma-1}{2}M^2\right)}\right]+\text{const} \qquad \text{(B-11)}$$

In order to relate the above expressions for a constant area duct to the upstream and downstream flow conditions, one must allow for both entrance and exit effects. We do this by assuming (1) that the entrance pressure is governed by a lossless adiabatic expansion process between the assumed stagnant upstream conditions and the entrance of the duct and (2) that the pressure at the duct exit is equal to the specified downstream pressure. Note that entrance losses, if any, are assumed to be incorporated into k, but the exit expansion loss is not, since the exit loss occurs downstream of the duct exit.

The lossless adiabatic expansion process assumed at the entrance is governed by standard expressions [3] relating the upstream conditions and the conditions at a downstream point with pressure P and gas density ρ. For assumed stagnant upstream conditions, the pressure ratio between upstream and downstream conditions is given by

$$\frac{P_0}{P} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}} \qquad \text{(B-12)}$$

and the gas density ratio is given by

$$\frac{\rho_{g0}}{\rho_g} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{1}{\gamma - 1}} \qquad \text{(B-13)}$$

In terms of the above expressions, the pressure ratio between the stagnant upstream conditions and the duct exit can be written as

$$\frac{P_0}{P_2} = \frac{P_1/P_s}{P_2/P_s}\left[\frac{P_0}{P_1}\right]_{\text{lossless}} \qquad \text{(B-14)}$$

where points 1 and 2 are at the entrance and exit of the duct, respectively, and the ratio P_0/P_1 is evaluated using the lossless adiabatic expression given by Equation (B-12). Note that the Mach numbers M_1 and M_2 implicit in Equation (B-14) are related through the total loss coefficient K defined through the definite integral

$$\int_{x_1}^{x_2} k\,dx = K \qquad \text{(B-15)}$$

which can be evaluated through Equation (B-11).

For comparison purposes, it is convenient to define a normalized two-phase flow rate w per unit area

$$w = W/(A\sqrt{\gamma \rho_{t0} P_0}) = M\sqrt{\frac{\rho_g P}{\rho_{g0} P_0}} \qquad \text{(B-16)}$$

where W is the total mass flow rate.

The CONTAIN Single Flow Path Model

The CONTAIN flow model, under steady-state conditions, is based on an incompressible flow formulation with loss and an adiabatic formulation without loss. The incompressible pressure ratio under steady state conditions can be expressed as

$$\frac{P_2}{P_0} = 1 - C_{FC}\gamma(w_{incomp})^2 \qquad \text{(B-17)}$$

Note that the pressure P_2 used in the CONTAIN model is a stagnation pressure, whereas the pressure P_2 in the GE Analytic Model is in general a static pressure. This difference can be neglected if we assume for simplicity that the downstream receiving volume has a very large cross-section compared to the duct. In this case, C_{FC} is simply related to K: $C_{FC} = (K+1)/2$.

The CONTAIN lossless adiabatic expression is

$$w_{lossless} = \nu M \sqrt{\frac{\rho_{g2} P_2}{\rho_{g0} P_0}} \qquad \text{(B-18)}$$

where the expressions given in Equations (B-12) and (B-13) are used to evaluate the right hand side, and the user-specified factor ν has been introduced to allow for area reduction through a *vena contracta.*[2]

The flow rate used in CONTAIN under steady-state conditions is the minimum of the lossless flow and the incompressible flow rate,

$$w = \min(w_{lossless}, w_{incomp}) \qquad \text{(B-19)}$$

(assuming that $P_0 > P_2$).

Comparisons Between the CONTAIN and GE Analytic Models

Mark I and II vent configurations

Figure B-3 shows a comparison of flow rates from the various models above for ν = 0.7 for a total loss coefficient K = 1.23, excluding exit loss, and a value for γ = 1.4, a value corresponding to air. (This loss coefficient is a value typical of Mark II vent systems.) Since the CONTAIN single flow path model uses the minimum of the indicated lossless adiabatic and incompressible flow rates, good agreement is found between the CONTAIN and GE Analytic models. Figure B-4 shows a comparison with the same value of υ but with a loss coefficient of K = 4.6 (a value typical of Mark I vent systems). In this case the CONTAIN flow rate is substantially greater than that of the GE Analytic Model at large pressure ratios.

---

[2] The user-specified factor ν accounts only for jet contraction and is not associated with any flow loss resulting from neglected friction; hence, the term "lossless adiabatic."

The above comparisons show that the CONTAIN flow model can be considerably less conservative than the GE model. However, note that this comparison assumes that the losses in the CONTAIN flow model are lumped into a single flow path, whereas in practice the losses can be spread over a number of flow paths. The lower flow rates in the GE model are presumably the result of the fact that the variation of gas pressure (and, implicitly, temperature) along the downcomer are taken into account in Equation (B-10). This variation can be taken into account in CONTAIN by dividing a single flow path into a number of sections and placing CONTAIN cells between sections to represent the flow path volume. This approach of subdividing the downcomer is the one taken in the Mark I and II models discussed in the body of this report.

In the CONTAIN Mark I and II input files in this report, the downcomers are represented by an upper and a lower flow path, each with $\upsilon = 0.7$. In addition, a cell is placed between the upper and lower paths to represent the downcomer volume. In these input files, the total downcomer loss coefficient is split between the upper and lower flow paths - the exit loss is nominally assigned to the lower path and the remainder is assigned to the upper path. The steady state flow resulting from such a two flow path configuration has been evaluated by using a simplified three-cell CONTAIN model, and the results are given in Figures B-3 and B-4. One can conclude that the CONTAIN vent system gas flow model as implemented in the Mark I and II input files should closely approximate or be more conservative than the GE model.

For Mark I and II drywell to wetwell vent configurations, the singularities are limited mainly to sudden contractions and expansions; therefore, the homogeneous model for two-phase flow is expected to produce a "best-estimate" of pressure losses when using conventional single-phase loss coefficients. Therefore, no two-phase adjustment is required, as indicated in Equation (B-8), since $F_{2-phase} \approx 1$.

Mark III vent configuration

In the case of the Mark III, the horizontal vent configuration does not readily lend itself to the two-cell flow path model discussed for Mark I and II to address compressibility effects. Furthermore, the configuration of the vent (including the bend pathway) would suggest that the single-phase loss coefficient should be increased to account for the two-phase flow behavior. In this discussion, both the two-phase behavior and compressibility effects are treated.

For a vent configuration similar to the Mark III horizontal vents, the single-phase conventional loss coefficient reported is K* = 3 (90 deg. directional change, sudden contraction, and sudden expansion), which gives a CONTAIN loss coefficient of $C_{FC} = 1.5$. If the correction for the two-phase pressure drop is applied, a portion of the total CONTAIN single phase loss coefficient for the vent (bend) is increased, as indicated in Equation (B-8). Using $F_{2-phase} = 2$ for the bend, the two-phase loss coefficient for the vent is estimated to be $K^* = 4$ (includes the exit loss, K = 3 otherwise).

To make the adjustment for compressibility, we again consider the comparison between the GE analytical model and the CONTAIN lossless adiabatic and incompressible flows. However, in these comparisons we adjust both the *vena contracta* υ and the loss coefficient to provide a reasonable match between models. Shown in Figure B-5 is a comparison between models which indicates that good agreement with the GE analytic model can be obtained by increasing the effective CONTAIN loss coefficient by ~ 40% (C_{FC}*1.4) and by using a vena contracta $\upsilon = 0.55$.

References

1. H. C. Simpson, et al., "Two-phase flow through gate valves and orifice plates," Paper presented at International Conference on the Physical Modelling of Multiphase flow, Coventry, England, Paper A2, 25-40, 1983.

2. B. Harshe, et al., Two-phase pressure drop across restrictions and other abrupt area changes," Cincinnati Univ. Ohio., Report NUREG-0062., 1976.

3. D. Chisholm, Two-Phase Flow in Pipelines and Heat Exchangers, Pitman Press Ltd., Bath England, 1983.

4. A. P. Bray, "The General Electric Pressure Suppression Containment Analytical Model," NEDO-10320, General Electric Co., San Jose, CA, 1971.

5. A. H. Shapiro, The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. 1, Ronald Press, New York, 1953.

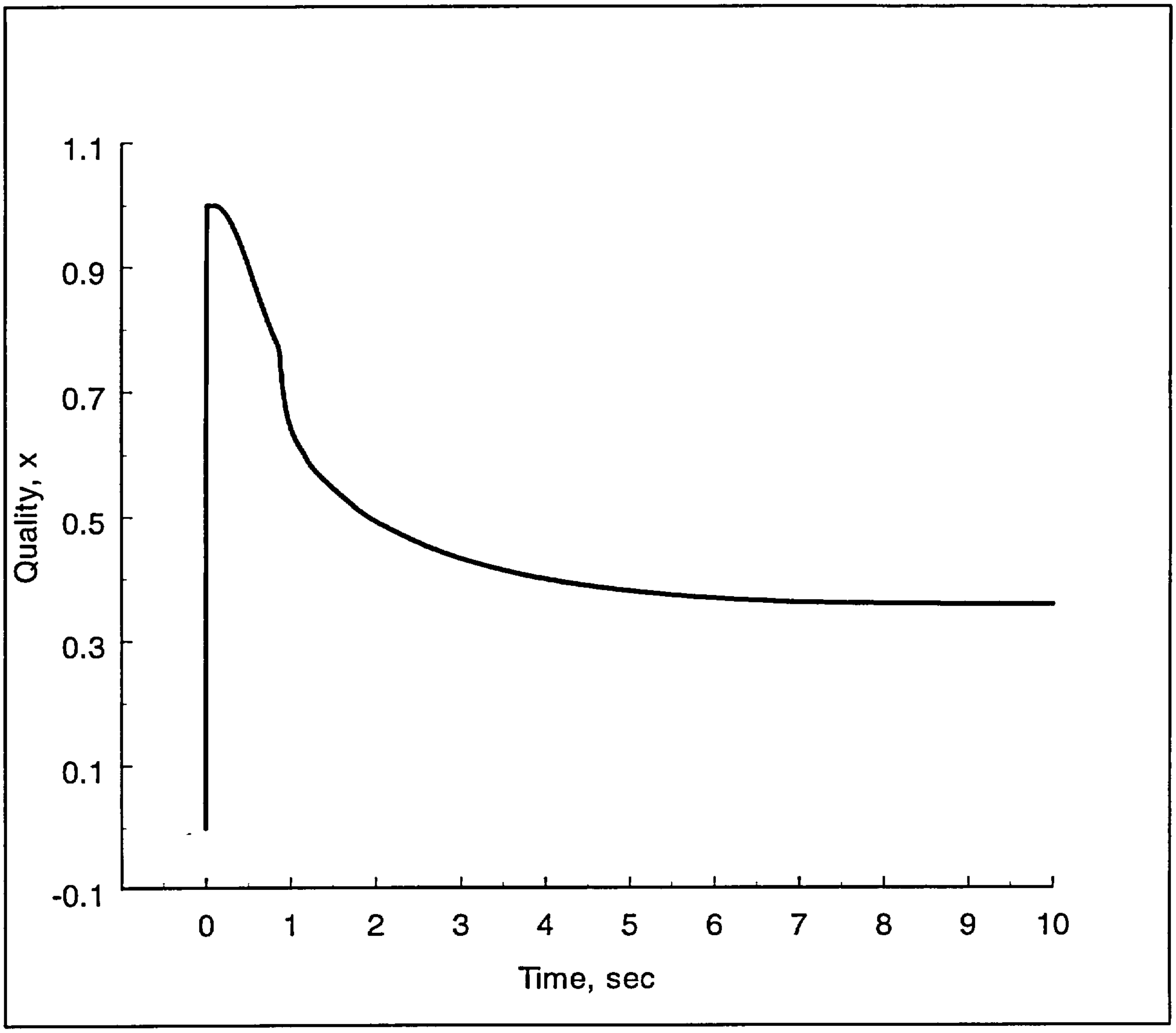

Figure B-1. CONTAIN calculated flow quality in the downcomer of the Grand Gulf plant during a recirculation line break event.

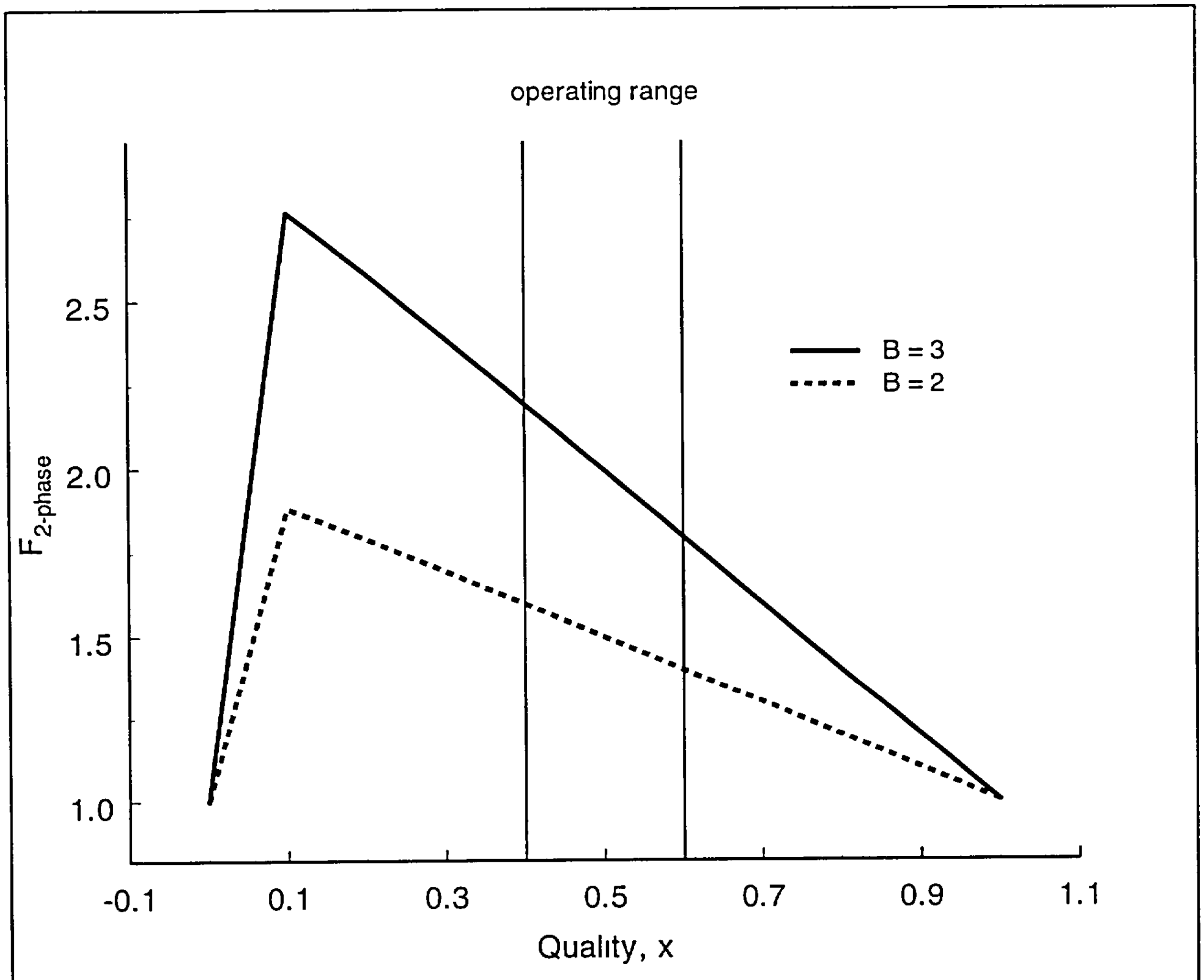

Figure B-2. Calculated two-phase loss factor $F_{2\text{-phase}}$ for miter-bend using the B-type empirical correlation of Chisholm [3].

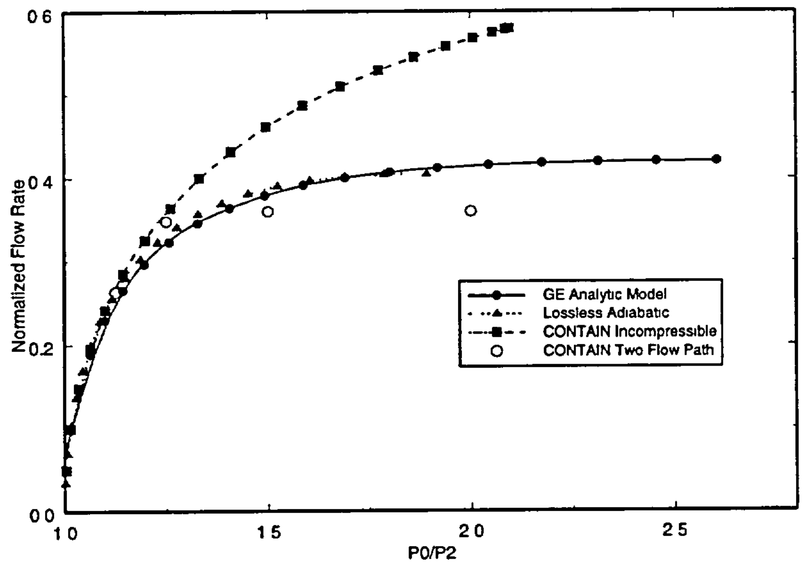

Figure B-3. Comparison of the CONTAIN and GE Analytic Model Flow Rates as a Function of the Upstream to Downstream Pressure Ratio (P_0/P_2), for ν = 0.7 and K = 1.23.

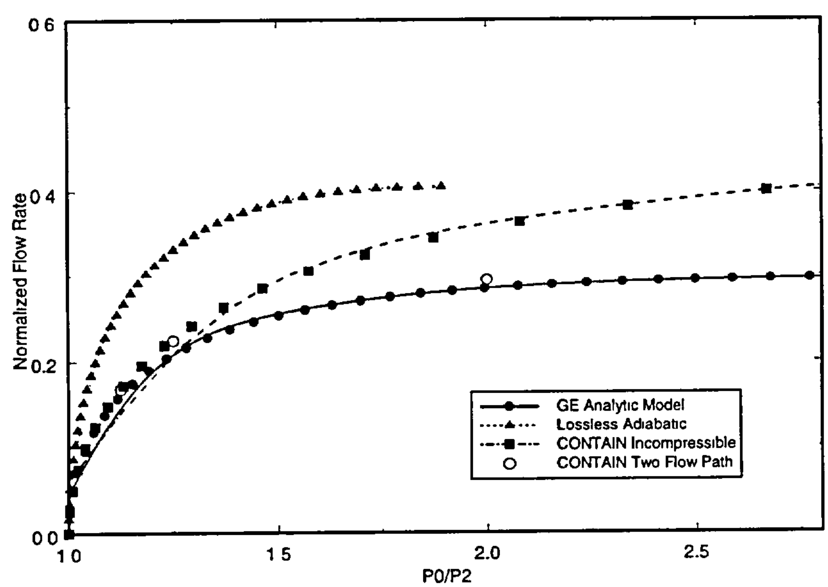

Figure B-4. Comparison of the CONTAIN and GE Analytic Model Flow Rates as a Function of the Upstream to Downstream Pressure Ratio (P_0/P_2), for ν = 0.7 and K = 4.6.

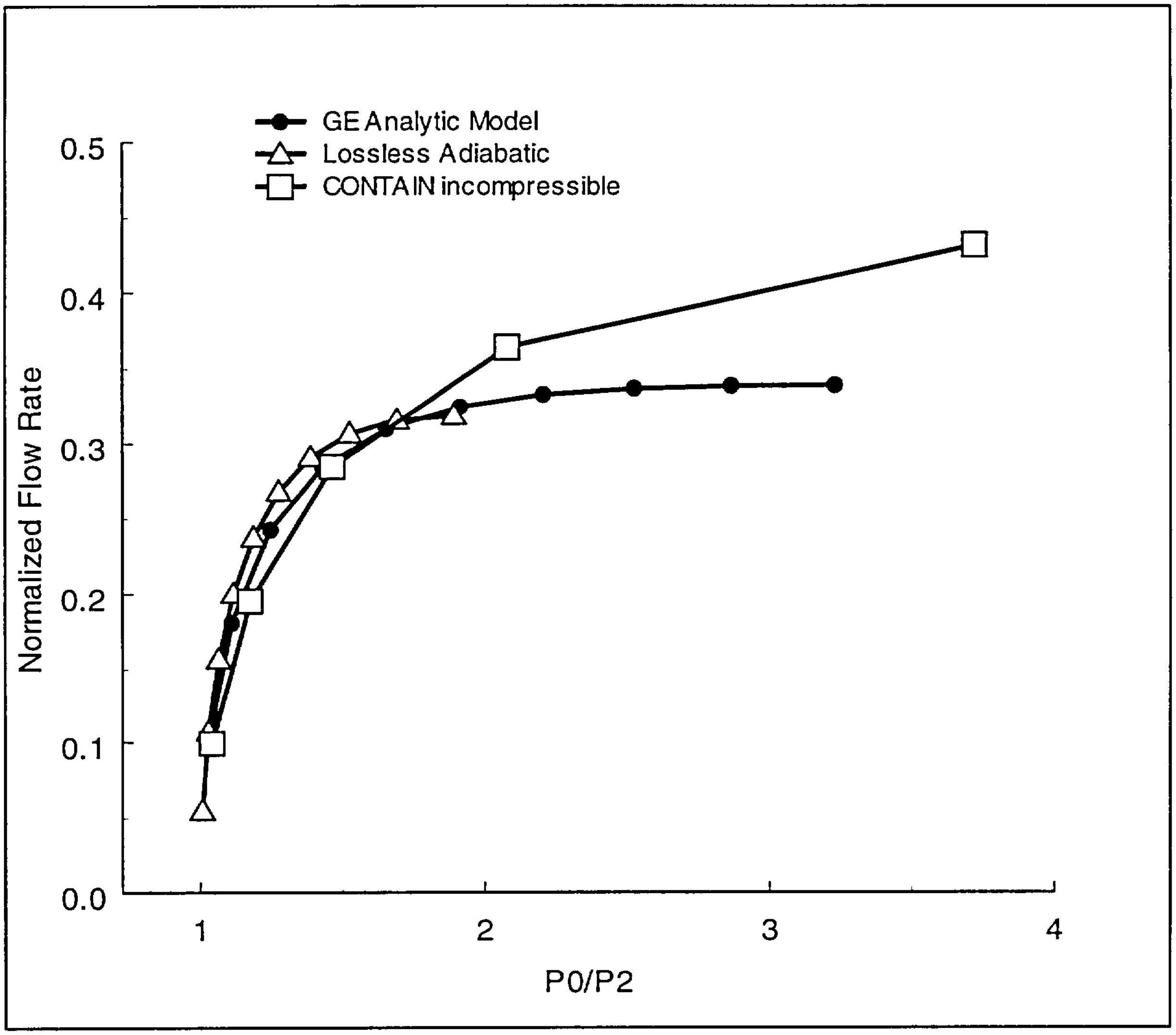

Figure B-5. Comparison of CONTAIN and GE Flow Rates as a function of Upstream to Downstream Pressure Ratio (P_0/P_2), for ν = 0.55 and K = 3 * 1.4.

APPENDIX C
Hope Creek (Mark I) Recirculation Line Break, Short-Term Analysis CONTAIN Input Deck

The CONTAIN calculated values resulting from the use of this deck are presented and compared with values given in Hope Creek SAR in Section 2.1. Section 2.1 also discusses the important input-deck parameters, including the basis for the parameter values used.

```
&& ********** GLOBAL CONTROL BLOCK

control                 && Global storage allocation specification
  ncells=3              && # of cells
  ntitl=3               && # of lines in the title
  ntzone=4              && # of time zones
  nengv=4               && # engineered vents, of which there are 4
                        &&    for the vent system, see discussion
                        &&    in main body
eoi                     && eoi for control

&& ********** MATERIAL BLOCK

material                 && Initiate material block
  compound h2ol h2ov n2 o2

&& ********** TITLE BLOCK

title
Mark I Short-Term Analysis Sample Problem
 Hope Creek Plant - Recirc. Line Break, vent system modeled as a
 cell and 4 engineered vents&& ********** TIME ZONES

times 50000.  0.0        && cpu time and start time
  0.0005    .01   0.3    && time step, plot interval, zone end time
  0.0005    .05   2.0
  0.001     .02   5.0
  0.02      .10  10.0    && Calculation ends at 10 s

&& ********** PRINT OPTIONS

shortedt=300             && # of time steps between short edits
longedt=10               && # of edit steps between long edits, but a
                         &&   long edit also at the time-zone end
prheat                   && Print output options
prlow-cl
prflow
prengsys
prenacct

flows implicit           && Implicit for engineered vents

&& ********** ENGINEERED VENTS

engvent                  && designation for CONTAIN flow paths
```

```
&& Drywell (Cell 1) to Mark I vent system (Cell 2) uses 2
&&   engineered vents, one a pool and the other a gas flow path.

&& The flow area is SAR net free vent area of 235.9 ft**2

&& Loss coefficient is SAR conventional value of 5.51 less 1.0
&&   applied at the vent system exit which leaves 4.51      conventional,
&&   i.e., a CONTAIN value of 2.3, to be applied here, the vent
&&   system entrance

&& The inertial A/L term is based on an L/A sum as follows
&&   (L/A)1-2 = (L/A)1 + (L/A)2. For L1, the DW height of 27.4 m
&&   over 2 was used. The resulting L is 27.4/2=13.7 m.
&&   The area A1 is ~ the DW area used in cellhist,
&&   which is 159 m**2. Thus, (L/A)1 = 13.7/159 = 0.086.
&& For L2, ½ of the Cell 2 (vent system) flow path length of
&&   19.4 m we calculated will be used. For A2, the vent system
&&   area of 21.9 m**2 is used. Thus (L/A)2=19.4/2/21.9=0.44
&& The sum of the L/A is 0.53 (=0.086+0.44) so the CONTAIN
&&   A/L input is 1.9 (=1/0.53).

&& velevb (the back of this vent)is assumed to be the top of the
&&   vent system where it exits the DW at the elevation 9.464 m.
&& Also, velevf (the front of this vent) is assumed to be at the
&&   same value elevation.

&& A vena contracta value of 0.7, which has no effect on a pool
&&   path, is used, see discussion in main part of this report

  from 1 to 2
    varea=21.92 vavl=1.9  type=pool vcfc=2.3  velevb=9.464
    velevf=9.464 vcontra=0.7
eoi                          && eoi for this engineered vent

  from 1 to 2
    varea=21.92 vavl=1.9  type=gas  vcfc=2.3 velevb=9.464
    velevf=9.464 vcontra=0.7
eoi                          && eoi for engineered vent

&& vent system (cell 2) to wetwell (cell 3)

&& Flow area is 21.92 m**2 the area of the vent bottom,
&&   i.e., the bottom of the vertical sections of the 80 downcomers
&&   with their internal diameter of 0.591 m.

&& Inertial length for the liquid is based on previous experience
&&   that indicated a value of 1.25 times the submergence length
&&   is appropriate. The submergence length is ~3 ft (0.9 m), so
&&   the inertial length used is 1.25*0.9=1.14 m.
&& Therefore, for the liquid vent, the a/l=21.92/1.14=19.2 m.
&& For the gas vent a/l, an L/A sum was calculated in a manner     like
&&   that described above. The resulting vavl is 2.3.

&& For these exit vents a conventional loss of 1.00 is applied.
&& The remainder of the FSAR total loss of 5.51 is applied at the
&&   inlet as discussed above.
&& Note that the CONTAIN value of 0.5 is used to represent the
&&   conventional loss coefficient of 1.0..
&&
&& velevb, the elevation of the back of this vent, is assumed to be
&&   at the bottom of the vent system, i.e., the bottom of the
```

```
&&   downcomers located at 2.455 m.
&& velevf is assumed to equal velevb

  from 2 to 3
    varea=21.92 vavl=19.2  type=pool vcfc=0.5 velevb=2.455
velevf=2.455 vcontra=0.7
eoi                        && eoi for engineered vent

  from 2 to 3
    varea=21.92 vavl=100.  type=gas  vcfc=0.5 velevb=2.455
    velevf=2.455 vcontra=0.7
eoi                        && eoi for engineered vent

&& ****************** CELL #1- DRYWELL *********************

cell=1                     && Beginning of cell 1 input
control
  jpool=1
  nsoatm=2                 && Two coolant blowdown sources
  nspatm=25                && To allow 25 blowdown vs. time points
eoi                        && eoi for cell control

geometry
  gasvol=4371.             && 169,000ft3 less vent system gas volume
  cellhist=1 7.64 158.6 35.20
                           && cellhist area and bottom estimated from
                           &&  SAR drawings of plant
eoi                        && eoi for geometry

atmos=2
  pgas=1.1169e5            && 1.5 psig (SAR)
  tgas=330.4               && 135F (SAR)
  molefrac o2=0.04 n2=0.96
                           && Atmosphere is inerted
  satrat =0.2              && Humidity = 20% (SAR)
eoi                        && eoi for atmos

condense

source=2                   && Two sources

h2ov=25                    && The first source
  iflag=2
  t=
   0.0     0.002197   1.313   1.314   2.125   3.563
   4.421   4.422     13.79   17.03   17.04   18.28
  19.6    21.15      22.53   23.78   25.15   26.78
  28.53   30.50      33.37   37.37   42.87   48.31    48.43
  mass=
   19159.  22836.  22023. 15009.  14845. 15473.
   16091.  10150.  10595. 10568.   4659.  4255.
    3851.   3439.   3086.  2786.   2484.  2157.
    1841.   1543.   1235.  1144.    954.1  516.8  0.0
  enth=
   1.2688e+6  1.2688e+6   1.2653e+6  1.2653e+6  1.2644e+6      1.2681e+6
   1.2728e+6  1.2728e+6   1.2965e+6  1.2951e+6  1.2951e+6      1.273e+6
   1.2481e+6  1.2193e+6   1.1928e+6  1.1681e+6  1.1409e+6      1.1086e+6
   1.0735e+6  1.0323e+6   9.686e+5   8.4744e+5  6.807e+5       5.6465e+5
   5.6256e+5
eoi                        && eoi for source
```

```
h2ov=17                 && The second source
  iflag=2
  t=
    0.0    17.03    17.04  18.28  19.65
   21.15   22.53    23.78  25.15  26.78  28.53
   30.50   33.37    37.37  42.87  48.31  48.43
  mass=
      0.0     0.0  1827.  1782.  1720.
   1639.  1557.   1480.  1394.  1290.
   1179.  1042.    815.   364.    72.4   12.4   0.0
  enth=
   .0         2.7651e+6  2.7651e+6  2.7721e+6  2.7767e+6
  2.7837e+6  2.7884e+6  2.7907e+6  2.7953e+6  2.7977e+6  2.8e+6
  2.8023e+6  2.8e+6     2.7907e+6  2.7581e+6  2.7256e+6  2.7256e+6
eoi                     && eoi for source

ht-tran off off off off off
                        && None of these heat-transfer mechanisms
                        &&   needed for this cell
low-cell
  geometry  158.6 bc=330.4
                        && Area from SAR figure, bc temperature
                        &&   same as atmosphere
  pool
    compos=1 h2ol 1.e-6  temp=330.4
                        && Essentially no initial DW water and there
                        &&   will be no additional water
    physics
      boil
    eoi                 && eoi for physics
  eoi                   && eoi for pool
eoi                     && eoi for low-cell

&& ****************** CELL #2- Vent System (VS)

cell=2
control
  jpool=1
eoi
&&
geometry
&&
&& The total VS volume was calculated to be 436.4 m**3 based on SAR
&&   drawings.
&& At HWL, the downcomer is submerged 1.015 m.
&& The 80 downcomer pipes ID is 591 m so their area is 21.92 m**2
&& Thus, the liquid in the downcomers takes up ~22.25 m**3.
&& The VS gas volume is (436.4-22.52=) 414.2 m**3.
&& Note that this volume is used to determine the Cell 1 gasvol

  gasvol=414.2

&& The cellhist for this volume is modeled in two parts as shown
&&   in the main body of this report.
&& The lower part is only the downcomers area of 21.92 m**2 that
&&   goes between the elevations 2.455 m to 3.877 m
&& The downcomers thus account for 31.17 m**3.
&& The remainder of the volume (436.4-31.17=405.2 m**3) is accounted
&&   for by the remainder of the VS elevation going from the downcomer
&&   top (3.877 m) to where the VS exits the DW at 9.464 m.
&& Thus the area for this elevation change is 72.52 m**2
```

```
&&   (405.2/(9.464-3.877).

  cellhist=2 2.455 21.92 3.877 72.52 9.464

eoi                        && eoi for geometry

atmos=2                    && Same as the DW (Cell 1)
  pgas=1.1169e5 tgas=330.4
  molefrac o2=0.04 n2=0.96
  satrat =0.2
eoi                        && eoi for atmos

ht-tran off off off off off

low-cell
  geometry 21.92           && Downcomer area for 80 0.591 m ID pipes
  bc=308.2                 && Same temp as WW pool 95 F
  pool

                           && From the discussion above, the liquid in the
                           &&   downcomer at HWL is ~22.52 m**3, which at
                           &&   ~1000 kg/m**3 is 2.252e+04 kg.
    compos=1  h2ol=2.252e+04 temp=308.2
                           && Temp is same as WW 95 F
    physics
      boil
    eoi                    && eoi for physics
  eoi                      && eoi for pool
eoi                        && eoi for low-cell

&& *******************  CELL #3- WETWELL

cell=3
control
  jpool=1
  naensy=1                 && For engineered system spray
eoi    && eoi for control

geometry
  gasvol= 3758.0           && SAR HWL 133,500 ft**3 less liquid in
                           &&   downcomer
  cellhist=1 0. 995.  7.27
                           && cellhist for (SAR) pool area of 10,710ft2
                           &&   exposed to WW free space and total volume
                           &&   of gas and liquid
eoi                        && eoi for geometry

atmos=2
  pgas=1.1169e5 tgas=308.2
                           && 1.5 psig, 95 F
  molefrac o2=0.04 n2=0.96
                           && Inerted atmosphere
  satrat=1.0               && 100% humidity
eoi                        && eoi for atmos

engineer wwpspry 4  3  3  0.0
                           && Above specifies an engineered safety system
                           &&   with 4 components (as described below)
                           &&   with coolant coming from this cell (#3)
                           &&   and returning to this cell.
                           && The safety system 4 components are a spray,
```

```
                              &&     a dummy tank that has no water, a
                              &&    pump, and a dummy heat exchanger that
                              &&    does not change the pumped water
                              &&    temperature
   spray
     spstpr=1.13e+05          && Spray to come on when WW press increases a
                              &&    little
   eoi                        && eoi for spray

   tank
     0.0                      && No water mass in the tank
     308.2                    && Pool and atmosphere temperature
     5000.                    && Same as pump flow

   pump
     5000.                    && Arbitrary value to simulate mixing of pool
                              &&    and atmosphere by bubbles bursting above
                              &&    pool

   hex
     user=0.0                 && hex to not change pool-water temperature
eoi                           && eoi for engineer

condense                      && Enables condensation

ht-tran off off off on off
                              && 4th of these on to have heat transfer
                              &&   between pool and atmosphere

low-cell
  geometry   995.0   bc=308.2
  pool
    compos=1 h2ol  3.455e6 temp=308.2
                              && Pool mass based on SAR HWL water volume of
                              &&    122,000ft3, 1000 kg/m**3.
                              && Temperature is SAR value of 95F
    physics
      boil
    eoi                       && eoi for physics
  eoi                         && eoi for pool
eoi                           && eoi for low-cell

eof                           && end of input
```

APPENDIX D

Hope Creek (Mark I) Recirculation Line Break, Case C, Long-Term Analysis, No Restart Option CONTAIN Input Deck

The CONTAIN calculated values resulting from the use of this deck are presented and compared with values given in Hope Creek SAR in Section 2.2.3. Section 2.2.2 also discusses the important input-deck parameters, including the basis for the parameter values used.

```
&& ********** CONTROL BLOCK
control                  && Global storage allocation
  ncells=4               && # of cells
  ntitl=3                && # of lines in the title
  ntzone=14              && # of time zones
  nengv=7                && # engineered vents - 4 for the vent system,
                         &&   1 for the RPV overflow, 1 for the RPV to
                         &&   DW flow path, and 1 for the WW to DW
                         &&   pressure relief area vs. Press. Diff
  numtbg=1               && For engvnt table of area vs. Press. Diff.
  maxtbg=10              && Max # of entries for above table
eoi                      && eoi for control

&& ********** MATERIAL BLOCK

material                 && to initiate material block
  compound h2ol h2ov n2 o2

&& ********** TITLE BLOCK

title
 Mark I Long Term Analysis Sample Problem
Hope Creek Plant- Recirc. Line Break, CASE C
    Without restart,

&& ********** TIME ZONES

times  1200.  0.0        && Maximum cpu time and start time
                         && Time step, plot interval, zone end time
  0.0005     .01         0.3
  0.0005     .05         2.0
  0.001      .02         5.0
  0.02       .10        10.0
  0.10      1.00        50.0
  0.10      5.00       100.0
  0.10     20.00       600.0
  0.10     20.00       700.0
  0.20     20.00      1000.0
  0.50     50.00      2000.0
  1.00    100.00      5000.0
  2.00    100.00     10000.0
  2.00    100.00     20000.0
  2.00    100.00     32000.0
                         && Calculation end time is 32000 s

&& ********** PRINT OPTIONS

shortedt=300             && # of time steps between short edit
longedt=10               && # of time steps between long edits, but a
                         &&   long edit at time-zone end
```

```
prheat                   && Print output options

prlow-cl
prflow
prengsys
prenacct

flows implicit           && Implicit for engineered vents

&& ********** ENGINEERED VENTS

engvent                  && designation for CONTAIN flow paths

&&

&& The following 4 vents describe the 2 flow paths from the DW to

&&   the vents system (VS) and the 2 flow paths from the VS to the WW.
&& Details of the basis for these flow paths is presented in the
&&   main text and the Hope Creek short-term input deck referenced
&&   in Section 2.1.

  from 1 to 2

    varea=21.92 vavl=2.0  type=pool vcfc=2.3  velevb=9.464
    velevf=9.464 vcontra=0.7
eoi                      && eoi for this engineered vent

  from 1 to 2

varea=21.92 vavl=2.0   type=gas  vcfc=2.3 velevb=9.464

velevf=9.464 vcontra=0.7
eoi                      && eoi for this engineered vent

  from 2 to 3
    varea=21.92 vavl=19.2  type=pool vcfc=0.5 velevb=2.455
    velevf=2.455 vcontra=0.7
eoi                      && eoi for this engineered vent

  from 2 to 3
    varea=21.92 vavl=2.3  type=gas  vcfc=0.5 velevb=2.455
    velevf=2.455 vcontra=0.7
eoi                      && eoi for this engineered vent

&& This flow path simulates the RPV liquid overflow to the wetwell

  from 4 to 3            && Area of recirc. line used
type=pool  varea=0.307

vavl=2.5   vcfc=1.  && Approximate values

velevb=27.03        && This is the initial RPV water level
                         &&   above which we want the RPV pool water
                         &&   to flow directly to the WW pool
                         && Note that the DW is bypassed
    velevf= 7.277        && The top of the WW was used because the
                         &&   liquid is added to the WW pool.

    vtopen=75.           && Prevents any flow until vessel is

&&   reflooded at 75 s.
```

```
eoi                         && eoi for this engineered vent

&& The following vents model the flow path between the RPV and the
&&   DW resulting from the broken recirc. line

   from 4 to 1              && Area of recirc. line used

type=gas   varea=0.307

vavl=2.5   vcfc=1.  && Approximate values
    velevb=28.              && This elevation intentionally made a
                            &&   little higher than the 27.03 m
                            &&   elevation at which the liquid (pool)
                            &&   will flow out to minimize possible
                            &&   flow oscillation
    velevf=27.00            && DW elevation slightly lower
    vtopen=75.              && Prevents any flow until
                            &&   vessel is reflooded at 75 s.
eoi                         && eoi for this engineered vent

&& The following vent models the vacuum breakers between the
&&   WW and DW that open when the DW pressure becomes 0.25 psia
&&   (1.724e3 Pa) lower than the WW pressure..
&& There are 8 24 in valves so the full-open area is 25.1 m**2.

  from 3 to 1
    type=gas
    vstatus=closed          && Initially closed
    vdpb=1.e6               && High pressure to prevent back flow from
                            &&   DW to the WW

vdpf=1.724e3        && 0.25 psi opens vacuum relief valves
    rvarea-p                && This table will control the vent area
                            &&   as a function of press. diff.
      flag=2                && flag=2 required by code for this table
      x=5                   && The WW to DW Press. Diffs.
      -1.e20  0.0  1.724e3   3.5e3   1.e20

y=5                 && The flow path area for each P Diff

0.0     0.0   25.1     25.1     25.1

eoi                 && eoi for rvarea-p table

    vavl=2.5   vcfc=1.  && Approximate values
    velevb=7.277            && Top of the wetwell
    velevf=7.277            && Top of the wetwell
eoi                         && eoi for this engineered vent

&& ****************** CELL #1- DRYWELL

cell=1                      && Beginning of Cell 1 input
control
  jpool=1
  nsoatm=2                  && 2 blowdown sources
  nspatm=25                 && 25 blowdown vs. time points
  naensy=1                  && 1safety system, a spray
eoi                         && eoi for cell control

geometry

gasvol=4370.               && SAR value including VS free volume is
                            &&   169,000ft**3 (4786 m**3.
```

```
                        && For a VS free (gas) volume (see Cell 2
                        &&   below, of ~416 m**2, we get
                        &&   4786 - 416 = 4370. m**3
 cellhist=1 7.64 158.6 35.19
                        && Estimated from SAR figures

eoi                     && eoi for geometry

atmos=2

pgas=1.1169e5         && 1.5 psig from SAR
  tgas=330.4            && 135 F from SAR
  molefrac o2=.04 n2=.96
                        && Atmosphere inerted
satrat =0.2           && Humidity=20% from SAR

"

eoi                     && eoi for atmos

engineer rpvdwwws  4  4  3  16.57

&& The above defines a 4 component
                        &&   engineer safety system named rpvdwwws

&&   that will pump water from the RPV (Cell 4)
                        &&   pool through the DW as a spray with the
                        &&   water added to the WW pool (Cell 3).
                        && The change of elevation delev is from the
                        &&   bottom of Cell 4 (16.57) to the bottom of
                        &&   Cell 3 (0.0)

&& The flow modeled is arbitrarily taken as
                        &&   the non-RHR flow of 11950 gpm, which is
                        &&   ~754 kg/s.

&& There is no heat exchanger so user=0.0
                        &&   was used
                        && This reflood overflow does not occur until
                        &&   the RPV is reflooded at 75 s so the tank
                        &&   will be modeled to stop its negligible
                        &&   flow at 75 s after which the spray flow
                        &&   will come from the pool of Cell 4 (iclin).
                        && The tank water temperature was assumed to be
                        &&   the RPV initial temperature.

&& The resulting input follows
   spray
     spdiam=0.0190      && 0.75 in spray diameter larger than default
                        &&   to minimize oscillation because of
                        &&   coupling with atmosphere.

eoi                  && eoi for spray
   tank
       0.75             && Water mass in tank
     407.2              && Tank water temperature
       0.01             && Water flow rate from tank so tank mass is
                        &&   gone at 75 s after which the pump will
                        &&   start
pump

754.                 && The assumed overflow
```

```
hex

user=0.0            && A required heat exchanger that does nothing

eoi                     && eoi for engineer

source=2                && Two sources

h2ov=25                 && Low-enthalpy (water) source
  iflag=2
  t=
    0.0     0.002197 1.313   1.314  2.125  3.563
    4.421   4.422    13.79   17.03  17.04  18.28
   19.65   21.15     22.53   23.78  25.15  26.78
   28.53   30.50     33.37   37.37  42.87  48.31
   48.43
  mass=
   19159.  22836. 22023. 15009.  14845.  15473.
   16091.  10150. 10595. 10568.   4659.   4255.
    3851.   3439.  3086.  2786.   2484.   2157.
    1841.   1543.  1235.  1144.  954.1   516.8
       0.0
  enth=
   1.2688e+6  1.2688e+6  1.2653e+6  1.2653e+6  1.2644e+6     1.2681e+6
   1.2728e+6  1.2728e+6  1.2965e+6  1.2951e+6  1.2951e+6     1.2730e+6
   1.2481e+6  1.2193e+6  1.1928e+6  1.1681e+6  1.1409e+6     1.1086e+6
   1.0735e+6  1.0323e+6  9.6860e+5  8.4744e+5  6.8070e+5     5.6465e+5
   5.6256e+5
eoi                     && eoi for source

h2ov=17                 && High enthalpy (steam) source
  iflag=2
  t=
    0.0    17.03   17.04  18.28  19.65
   21.15   22.53   23.78  25.15  26.78  28.53
   30.50   33.37   37.37  42.87  48.31  48.43
  mass=
       0.0    0.0  1827.  1782.  1720.
    1639.  1557.   1480.  1394.  1290.  1179.
    1042.   815.    364.   72.4   12.4    0.0
  enth=
    0.0        2.7651e+6  2.7651e+6  2.7721e+6  2.7767e+6
    2.7837e+6  2.7884e+6  2.7907e+6  2.7953e+6  2.7977e+6  2.8e+6
    2.8023e+6  2.8e+6     2.7907e+6  2.7581e+6  2.7256e+6  2.7256e+6
eoi                     && eoi for source

condense                && Enables condensation

ht-tran off off off off off
                        && None of these heat transfer mechanisms
                        &&   needed in this cell

low-cell
  geometry  158.6       && Approx. area from SAR
  bc=330.4              && Same as atmos. temp
  pool
    compos=1 h2ol 1.e-6  temp=330.4
                        && No water, same temp
    physics
      boil
    eoi                 && eoi for physics
  eoi                   && eoi for pool
eoi                     && eoi for low-cell
```

```
&& ****************** CELL #2- Vent System (VS)

cell=2
control
  jpool=1
eoi                     && eoi for control

geometry
&& The development of the vents system (VS) is described more
&&   completely in the Hope Creek short-term input deck.
&&

  gasvol=416.4

  cellhist=2 2.455 21.92 3.877 72.52 9.464

eoi                     && eoi for geometry

atmos=2
  pgas=1.1169e5 tgas=330.4
  molefrac o2=.04 n2=.96
  satrat =0.2
eoi                     && eoi for atmos

ht-tran off off off off off

low-cell
  geometry 21.92        && 80 0.591 m ID downcomer pipes
  bc=308.               && Same temp as WW pool 95 F
  pool

    compos=1  h2ol=2.004e+04 temp=308.
                        && Water mass for LWL, temp is for 95 F
    physics
      boil
    eoi                 && eoi for physics
  eoi                   && eoi for pool
eoi                     && eoi for low-cell

&& ****************** CELL #3- WETWELL

cell=3
control
  jpool=1
eoi                     && eoi for control

geometry
  gasvol= 4036.         && gasvol based on the SAR LWL value
&&                      &&   137,000 ft**3 (3879 m**3) increased
                        &&   by the 1.573e2 m**3 decrease of the
                        &&   pool volume (& mass) discussed below.
  cellhist=1 0. 992.2 7.277
                        && For LWL pool A=10,680 ft**2 (992.2 m**2)
                        && gasvol=4036 & water vol=3184 m**3, i.e.
                        &&   a total volume of 7220 m**3
eoi                     && eoi for geometry

atmos=2
  pgas=1.1169e5 tgas=308.0
                        && SAR gives 1.5psig, 95F, 100% hum
  molefrac o2=.04 n2=.96
                        &&   inerted atmosphere
  satrat=1.0
```

```
eoi                         && eoi for atmos

condense   && Want for WW HT (albeit slow) between pool and atmosphere

   ht-tran off off off on  off
                            && 4th set to on for heat transfer between
                            &&   pool and atmosphere

low-cell
  geometry   992.2   bc=308.0
                            && Area for SAR LWL A=10680 ft**2
  pool
    compos=1 h2ol  3.184e6
                            && Based on LWL V=118,000 ft**3, which is
                            &&   3341 m**3 & ~ 3.341e6kg, less ~ECCS flow
                            &&   of 7700 lm/s from 30 s to 75 s, i.e.,
                            &&   less 3.465 lm (1.573e5 kg).
                            && Total mass is then 3.184e5 kg
      temp=308.0            && 95 F

    physics
    eoi                     && eoi for physics
  eoi                       && eoi for pool
eoi                         && eoi for low-cell

&& ******************* CELL #4- RPV

cell=4
control
  nsopl=3  nsppl=50         && 3 pool sources, 50 points max
  naensy=2                  && For 2 engineered safety (spray) systems
  jpool=1
eoi                         && eoi for control

geometry
  gasvol=  257.4            && From SAR Table 6.2-3, RPV initial condition,
                            &&   steam volume is 9089 ft**3 (257.4 m**3)
                            && Also, from Table 6.2-3, the RPV liquid
                            &&   volume is 11,885 ft**3 (336.5 m**3)
                            && However, the liquid volume for the initial
                            &&    condition was found to be 362.7 m**3,
                            &&    which also will be used
                            && The total RPV volume is then (336.5+362.7)
                            &&  = 620.1 m**3).
                            && From SAR the Fig. 3.8-1 cross section, the
                            &&  approx. RPV ID is 21 ft (6.40 m).
                            && The corresponding area is 346.4 ft**2
                            &&   (32.18 m**2), which for the total
                            &&   volume of 620.1 m**3 results in a RPV
                            &&   height of 19.27 m (63.22 ft).
                            && This height is confirmed by scaling the RPV
                            &&    height in SAR Fig. 3.8-1.
                            && The RPV cellhis parameter can now be
                            &&   specified, but first a bottom elevation
                            &&   is needed.
                            && From Fig. 3.8-1, the difference in elevation
                            &&   from the DW bottom to the RPV bottom is
                            &&   approx. 28.3 ft (8.925 m).
                            && Therefore, for the DW bottom elevation of
                            &&   7.64 m used above for Cell 1,
                            &&   the RPV bottom cellhist elevation is
                            &&   16.57 m.
  cellhist=1 16.57  32.18 35.84
```

```
                         && Total V=620.1 m**3, as desired
eoi   && eoi for geometry

atmos=3                  && Others had 2, this cell needs h2ov=1.0
&& The RPV conditions, which will enter the calculation at 75 s,
&&   are set to the DW conditions after the short-term analysis.
&& To get the conditions, the ST analysis was run to 50 s, when
&&   nothing else will happen

   tgas=407.15           && Code will determine corresponding saturation
                         &&   pressure
                         && Note that attempts to specify press. &
                         &&   temp. values may have been an over
                         &&   specification because we had problems
                         && Note that the h2ov molefrac must be given
                         &&   if only T & no P given

  molefrac o2=0.0 n2=0.0 h2ov=1.0
                         && Saturated steam only
  satrat=1.0
eoi                      && eoi for atmosphere
&&
engineer wwtphso  4  3  4  -16.57

                         && The above defines a 4 component engineer
                         &&   system named wwtphso.
                         && Its main purpose is to pump coolant from the
                         &&   WW (Cell 3) through a cooling heat
                         &&   exchanger followed by a spraying of the
                         &&  coolant into the RPV (Cell 4) atmosphere.
                         && The specification includes the difference in
                         &&   elevation of the bottom of Cell 3 (0.0)
                         &&   minus the bottom of Cell 4 (16.57), i.e.,
                         &&   -16.57 m.
                         && However, the spray is not activated until
                         &&   600 s, so the tank will be modeled to stop
                         &&   spraying its negligible flow at 600s after
                         &&   which the spray flow will be drawn from
                         &&   the pool of Cell 3 (iclin)
                         && The following discusses the basis for
                         &&   the 4 components.
&&   The 4 components are
&&      (1) a dummy tank (required by the code) with liquid mass so
&&          the flow from the tank stops at 600 s after which the
&&          spray flow will come from Cell 3
&&      (2) a pump for the Hope Creek, Case C, RHR flow rate of
&&          10,000 gpm (630.8 kg/s)
&&      (3) a heat exchanger of the type=shell, with cooling water at
&&         308 K (95 F). a cooling water flow rate of 567.7 kg/s
&&         (9000 gpm), heat transfer area of 329.8 m**2 (3550 ft**2),
&&         and a heat transfer coefficient of 66.04 W/m**2-K
&&         (375 Btu/hr-ft**2-F/unit
&&      (4) a spray to model the recirculation flow to the RPV pool.
&& The resulting input follows
   spray
     spdiam=1.           && Very large spray drop size used because this
                         &&   flow actually goes to the RPV pool and a
                         &&   large drop essentially will simulate this.
   eoi                   && eoi for spray
   tank
       0.6               && water mass in tank
     308.0               && tank water temperature
       0.001             && water flow rate from tank so tank mass is
```

```
                            &&   gone at 600 s
   pump
     630.8                  && The RHR flow rate that will start after the
                            &&   tank is empty
   hex
     shell   308.   567.7   329.8   2130.
                            && See above discussion
eoi                         && eoi for engineer

engineer wwtrvrf  4  3  4  -16.57

&& The above defines a 4 component engineer
                            &&   system named wwtphso.
                            && Its only purpose is to pump coolant from the
                            &&   WW (Cell 3) pool to the RPV as a spray of
                            &&   the coolant that then goes to the
                            &&   the RPV pool to which decay-heat, heat-
                            &&   structure sensible, and pump
                            &&   energy is added and this pool flows
                            &&   the heated water to the WW pool.
                            && The flows modeled are, from SAR Table 6.2-6
                            &&   for Case C, the core spray rate of
                            &&   6350 gpm and the (newly-modeled and
                            &&   believed to be conservative) HPCI
                            &&   5600 gpm, which totals 11950 gpm
                            &&   (*3.785e-3 m**3/gal * 1000 kg/m**3 /
                            &&    60 s/m =) 753.8 kg/s.
                            && There is no heat exchanger so user=0.0 will
                            &&   be used.
                            && The specification includes the difference in
                            &&   elevation of the bottom of Cell 3 (0.0)
                            &&   minus the bottom of Cell 4 (16.57), i.e.,
                            &&    -16.57 m.
                            && However, this additional reflood is not
                            &&   activated until 75 s, so the tank will be
                            &&   modeled to stop spraying its negligible flow
                            &&   at 75 s after which the spray flow will
                            &&   come from the pool of Cell 3 (iclin).
                            && This additional reflood flow rate was
                            &&   assumed to be the Table 6.2-6 core
                            &&   spray rate of 6350 gal/min (400.6 kg/s).
                            && A temperature of 308. K was assumed.
&& The following discusses the basis for the 4 components.
&&   The 4 components are
&&       (1) a dummy tank (required by the code) with liquid mass so
&&           the flow from the tank stops at 75 s after which the
&&           pump will provide the spray flow from the WW (Cell 3) pool
&&       (2) a pump to provide 753.8 kg/s)
&&       (3) a required heat exchanger that does nothing
&&       (4) a spray for the desired additional reflood flow rate

&& The resulting input follows
   spray
     spdiam=0.003           && Spray diameter larger than default to reduce
                            &&   oscillations because of coupling with
                            &&   atmosphere and thereby avoid possible
                            &&   instabilities
   eoi                      && eoi for spray
   tank
       0.75                 && Water mass in tank
     308.                   && Tank water temperature
       0.001                && Tank water flow rate so spray will start
                            &&   at 75 s.
```

```
   pump
     753.8                  && The additional reflood and HPCI rate
   hex
     user=0.0
eoi                         && eoi for engineer

condense                    && Want in RPV for HT between spray, atm. &
                            &&   pool

   ht-tran off off off on  off
                            && 4th set to on for heat transfer between
                            &&   pool and upper cell (atmosphere)

low-cell
  geometry   32.18   bc=308.0
                            && RPV area as discussed above.

  pool
    compos=1 h2ol  3.365e5
                            && Mass from Table 6.2-3 value for volume of
                            &&   liquid in vessel=11885 ft**3 (336.5 m**3)
                            &&   at 1000 kg/m**3.
        temp=407.15         && Same as atmos. temp.
physics
&&      boil                && NOTE boil not used

&& Following sources to the RPV pool are from the Hope Creek SAR
&& However, the pump heat is from the Limerick FSAR

   source=3

&& Decay heat source table for Hope Creek, 0-100000 sec,
&&   including fuel relaxation energy
&&
&& Note that the following table of decay heat originally provided
&&   values (which are retained) starting at time=0.0.
&& However, we only are interested in the energy after 75 s
&&   because the energy before that time is accounted for in the
&&   blowdown energy and mass added to the containment.
&& Because the original values were given based on the iflag=2
&&   format, two times, one at 75 s and one shortly thereafter, were
&&   required.

  h2ol=22  iflag=2

  t=
&&   0.        2.        6.        10.    20.       30.
&&  60.      120.      200.       600.   800.     1000.
     0.        2.        6.        10.   20.        75.
   75.001   120.      200.       600.   800.     1000.
  2000.    4000.     6000.      8000.    1.e4      2.e4
     4.e4      6.e4      8.e4      1.e5

  mass=
    0.e-5     0.e-5     0.e-5     0.e-5     0.e-5     0.e-5
    1.e-5     1.e-5     1.e-5     1.e-5     1.e-5     1.e-5
    1.e-5     1.e-5     1.e-5     1.e-5     1.e-5     1.e-5
    1.e-5     1.e-5     1.e-5     1.e-5

  enth=
&&   59.0e11 1839.0e11 1817.2e11 1270.4e11  393.3e11  274.1e11
&&   40.1e11  128.0e11  113.0e11   86.6e11   79.4e11   74.9e11
      0.0       0.0       0.0       0.0       0.0       0.0
```

```
    137.1e11  128.0e11  113.0e11   86.6e11   79.4e11   74.9e11
     61.8e11   50.8e11   45.4e11   42.2e11   40.3e11   33.9e11
     27.3e11   24.8e11   22.3e11   21.0e11
  eoi    && eoi for 1st source

&& Source table with   48 points
&& Integrated mass = 5.54384E-02  integrated enthalpy = 1.25557E+11
&& Init. int. mass = 5.54384E-02  init. int. enthalpy = 1.25557E+11

   h2ol=48 iflag=1

&& Note that the following table of sensible heat originally provided
&&   values (which are retained) starting at time=0.0.
&& However, we only are interested in the energy after 75 s
&&   because the energy before that time was accounted for in the
&&   blowdown energy and mass added to the containment.
&& Because the original values were given based on the iflag=1
&&   format, the 75 s value is the same as that for the time in
&&   the table before 75 s.
   t=
&&     4.98610E+01  6.12520E+01  7.08260E+01  8.18970E+01  9.70190E+01
       4.98610E+01  6.12520E+01 75.          8.18970E+01  9.70190E+01
       1.12180E+02  1.28160E+02  1.49990E+02  1.69290E+02  1.86500E+02
       2.05460E+02  2.26350E+02  2.52400E+02  2.74720E+02  3.02650E+02
       3.29410E+02  3.49960E+02  3.76320E+02  3.99790E+02  4.24730E+02
       4.62290E+02  4.91120E+02  5.28120E+02  5.74810E+02  6.10670E+02
       6.56660E+02  6.97630E+02  7.50170E+02  8.06680E+02  8.46690E+02
       9.10460E+02  9.67260E+02  1.04010E+03  1.11840E+03  1.20270E+03
       1.29320E+03  1.40760E+03  1.53200E+03  1.66750E+03  1.85940E+03
       2.04840E+03  2.28420E+03  2.60940E+03  2.94520E+03  3.40560E+03
       3.84370E+03  4.55340E+03  5.59370E+03

   mass=
&&     1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05
       0.0          0.0          1.00000E-05  1.00000E-05  1.00000E-05
       1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05
       1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05
       1.00000E-05  9.99999E-06  1.00000E-05  1.00000E-05  9.99999E-06
       1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05  9.99999E-06
       1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05
       1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05
       1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05  1.00000E-05
       1.00000E-05  1.00000E-05  1.00000E-05

   enth=
&&     0.00000E+00  2.05226E+12  1.24237E+13  1.29937E+13  1.29602E+13
       0.00000E+00  0.0          1.24237E+13  1.29937E+13  1.29602E+13
       1.22960E+13  1.17012E+13  1.22170E+13  1.14172E+13  1.13998E+13
       1.12871E+13  9.80570E+12  1.14443E+13  1.05526E+13  8.81122E+12
       9.56156E+12  1.04357E+13  9.20920E+12  9.45415E+12  7.32393E+12
       8.17857E+12  7.96582E+12  7.15427E+12  8.21905E+12  6.83591E+12
       7.19391E+12  5.98371E+12  5.56334E+12  7.36653E+12  5.23810E+12
       5.53493E+12  4.85560E+12  4.51701E+12  4.19552E+12  3.69097E+12
       3.26339E+12  3.00105E+12  2.75521E+12  2.25262E+12  2.28719E+12
       1.49992E+12  1.14800E+12  8.19195E+11  5.97495E+11  4.93356E+11
       2.76863E+11  1.88872E+10  1.88872E+10
  eoi                     && eoi for 2nd source

&& Pump heat from Limerick FSAR that probably is for 2 pumps, but the
&&   energy amount is small.

   h2ol=4    iflag=1
```

```
   t=
     0.        75.      600.       1.e6
   mass=
      0.0        1.e-5    1.e-5    1.e-5
   enth=
      4.58e+11   4.58e+11  4.58e+11  0.
  eoi                     &&  eoi for 3rd source

    eoi                   && eoi for physics
  eoi                     && eoi for pool
eoi                       && eoi for lower cell
&&
eof                       && End of input file
```

APPENDIX E
Hope Creek (Mark I) Recirculation Line Break, Case C, Long-Term Analysis, Restart Option Modeling

This CONTAIN restart deck mainly removes the wetwell spray model be used to equilibrate the wetwell pool and atmosphere temperatures. All other modeling will be as used in the with-restart input deck.

It should be noted that the CONTAIN restart capability is easy to use.

```
&&

restart

&&

&& ********** TIME ZONES

times 01200.  50.

0.0005     .01        0.3

0.0005     .05        2.0

  0.001      .02        5.0
  0.02       .10       10.0
  0.10      1.00       50.0
  0.10      5.00      100.0
  0.10     20.00      600.0
  0.10     20.00      700.0
  0.20     20.00     1000.0
  0.50     50.00     2000.0
  1.00    100.00     5000.0
  2.00    100.00    10000.0
  2.00    100.00    20000.0
  2.00    100.00    32000.0
&&
cell=3                      && Cell with changes

&& This is original deck format except the flows are zero and,
&&   as a result, the spray will do nothing for the remainder of the
&&   long-term analysis.

engineer wwpspry 4  3  3  0.0

    spray

      spstpr=1.13e+05
    eoi

    tank

      0.0                   && the water in the tank

308.0                 && same as pool & atm. temp.
```

```
      0000.             && same as pump flow

    pump
      0000.             && WAS 5000

    hex
      user=0.0          && hex to not change water temp.
eoi

eof
```

APPENDIX F

Limerick (Mark II) Recirculation Line Break, Short-Term Analysis CONTAIN Input Deck

The CONTAIN calculated values resulting from the use of this deck are presented and compared with values given in Limerick SAR in Section 3.1. Section 3.1 also discusses the important input-deck parameters, including the basis for the parameter values used.

```
&& ********** GLOBAL CONTROL BLOCK

control                 && Global storage allocation specification
  ncells=3              && # of cells
  ntitl=3               && # of lines in the title
  ntzone=5              && # of time zones
  nengv=4               && # engineered vents, of which there are 4
                        &&    for the downcomers, see discussion
                        &&    in main body
eoi                     && eoi for control

&& ********** MATERIAL BLOCK

material                && Initiate material block
  compound h2ol h2ov n2 o2

&& ********** TITLE BLOCK

title
Mark II Short-Term Analysis Sample Problem
 Limerick Plant - Recirc. Line Break, downcomers modeled as a
 cell and 4 engineered vents

&& ********** TIME ZONES

times 50000.  0.0       && cpu time and start time
  0.01     .01   2.0    && time step, plot interval, zone end time
  0.02     .02   5.0
  0.05     .10   10.0
  0.10     .20   20.0
  0.10     .20   40.0   && Calculation ends at 10 s

&& ********** PRINT OPTIONS ********************************

shortedt=300            && # of time steps between short edits
longedt=10              && # of edit steps between long edits, but a
                        && long edit also at the time-zone end

prheat                  && Print output options
prlow-cl
prflow
prengsys
prenacct

flows implicit          && Implicit for engineered vents

&& ********** ENGINEERED VENTS

engvent

&& Drywell (Cell 1) to Mark II downcomers (Cell 2) uses 2
&&   engineered vents, one a pool and the other a gas flow path.
&& The flow area is SAR net free vent area of 256.5ft**2 = 23.830m**2
```

```
&& Loss coefficient is SAR conventional value of 2.23 less 1.0
&&   applied at the downcomers exit which leaves 1.23 conventional,
&&   i.e., a CONTAIN value of 0.615, to be applied here, the vent
&&   system entrance

&& The inertial A/L term is based on an L/A sum as follows
&&   (L/A)1-2 = (L/A)1 + (L/A)2. For L1 use the DW height over 2.
&& The area A1 is ~ the DW area used in cellhist.
&& For L2, use ½ of the Cell 2 (downcomers) flow path length
&& The area is the downcomer flow area.
&& velevb (the back of this vent)is assumed to be the top of the
&&   downcomers where it exits the DW.
&& Also, velevf (the front of this vent) is assumed to be at the
&&   same elevation.
&& A vena contracta value of 0.7, which has no effect on a pool
&&   path, is used, see discussion in main part of this report

  from 1 to 2
    varea=23.830 vavl=3.2  type=pool vcfc=0.615 velevb=17.526
    velevf=17.526 vcontra=0.7
eoi                        && eoi for this engineered vent

varea=23.830 vavl=3.2  type=gas  vcfc=0.615 velevb=17.526
    velevf=17.526 vcontra=0.7
eoi                        && eoi for engineered vent

&& downcomers (cell 2) to wetwell (cell 3)

&& Flow area is 256.5ft**2 = 23.830m**2
&& Inertial length for the liquid is based on previous experience
&&   that indicated a value of 1.25 times the submergence length
&&   is appropriate.
&& For the gas vent a/l, an L/A sum was calculated in a manner like
&&   that described above. The resulting vavl is 2.3.
&& For these exit vents a conventional loss of 1.00 is applied.
&& The remainder of the SAR total loss is applied at the
&&   inlet as discussed above.
&& Note that the CONTAIN value of 0.5 is used to represent the
&&   conventional loss coefficient of 1.0.
&& velevb and velevf are at the downcomer bottom

from 2 to 3
    varea=23.830 vavl=2.3  type=pool  vcfc=0.5 velevb=3.734
    velevf=3.734 vcontra=0.7
eoi                        && eoi for engineered vent

  from 2 to 3
    varea=23.830 vavl=2.3  type=gas  vcfc=0.5 velevb=3.734
    velevf=3.734 vcontra=0.7
eoi                        && eoi for engineered vent

&& The DW & WW volumes below need to be adjusted to account
&&   for the volume of the vent system air space.
&& In particular, this air space is included in
&&   the SAR value for the DW (cell below) volume.
&& Similarly, the WW volume must recognize the vent system
&&   in the WW cellhist vertical area profile.
&& Our vent-system air space determination starts with the
&&   suppression pool SAR volume of 134,600ft**3 (3811.45m**3).
&& This is the HWL value that is used because there is more
&&   liquid water in the downcomer (DC) that must be accelerated,
&&   which delays the time of vent opening and maximizes the
&&   calculated peak pressure.
```

```
&& The corresponding water mass, at 1000kg/m**3, is 3.8114e+06 kg.
&& To get the pool area, the HWL pool depth of 24.25 ft is
&&   used.
&& For the volume of 134600 ft**3, the pool area is 5550.5 ft**2
&&   (515.66m**2).
&& Note that this is close to the SAR table 6.2-4a total pool area
&&   of 5267ft**2.
&& For the WW pool area 5550.5ft**2 and the table 6.2-4a wet well
&&   air space volume (including vent system) at HWL of
&&   147,670 ft**2, the WW height above the pool of this air space
&&   is 26.605 ft (8.1092 m).
&& Adding an additional 3 ft for the floor thickness gives us
&&   the increment of elevation of the vent system air space that
&&   is not in the DW to be 29.605 ft (9.024 m).
&& We can now determine the volume of the vent system air space
&&   included in the DW volume.
&& It is the vent area (256.5 ft**2) times 29.605 ft = 7,593.7 ft**3
&&    (215.03 m**3).
&& Note that the above analysis establishes elevations used below:
&&   WW top is at 50.855 ft (25.25+26.605) (15.501 m)
&&   DW bottom is at 53.855 ft (50.855+3.) (16.415 m)
&&   DC bottom (at HWL) is at 12.00 ft (3.658 m) based on it being
&&      12.25 ft below the pool height of 24.25 ft

&& ********** CELL #1- DRYWELL

cell=1                   && Beginning of cell 1 input
control
  jpool=1
  nsoatm=2               && Two coolant blowdown sources
  nspatm=25              && To allow 25 blowdown vs. time points
eoi                      && eoi for cell control

geometry
 gasvol=6662.0           && This is the SAR table 6.2-1 value of
                         &&   242,860 ft3 corrected for the included
                         &&   vent system downcomer (DC) gas volume
                         && From the above analysis, the DC volume is
                         &&   7,593.7 ft**3. thus the DW volume is
                         &&   242,860-7593.7=235,266 ft**3
                         &&   (6662.0 m**3.)
 cellhist=1 16.415 446. 31.352
&& For an approximate DW cross sectional
                         &&   area of 4800 ft2, gasvol and the above
&&   determined DW bottom height
eoi                      && eoi for geometry

atmos=2
  pgas=1.0652e5          && 0.75 psig (SAR)
  tgas=339.0             && 150 F (SAR)
  molefrac o2=0.04 n2=0.96
                         && Atmosphere is inerted
  satrat =0.2            && Humidity = 20% (SAR)
eoi                      && eoi for atmos

condense

source=2                 && Two sources

h2ov=18                  && The first source
  iflag=2
  t=
   0.0      0.733   1.03    1.53   3.16   4.16
```

```
   5.16     6.16     8.16    10.16   13.66   15.16
   18.16   20.16    25.0     30.0    35.0    37.5
  mass=
   21645.  21645.  21645. 21645.   14677.  14718.
   14759.  14800.  14864. 14905.   14873   6436.
    4764.   3872.   2176.  1085.   1215.   1139.
  enth=
   1.2793e+6  1.2777e+6   1.277e+6  1.2767e+6  1.2733e+6  1.2767e+6
   1.2774e+6  1.2793e+6   1.284e+6  1.2872e+6  1.2842e+6  1.2523e+6
   1.1842e+6  1.1342e+6   1.0135e+6  9.012e+5   6.948e+5   6.135e+5
eoi                      && eoi for source

h2ov=9                   && The second source
iflag=2
  t=
    0.0    15.15  15.16  18.16   20.16
   25.0    30.0   35.0   37.5
  mass=
       0.0   0.0  2225.  2017.  1843.
    1327.  841.4   277.   121.
  enth=
    0.0          2.774e+6   2.774e+6   2.7893e+6  2.7963e+6
    2.8037e+6  2.7963e+6  2.7626e+6     2.74e+6
eoi                      && eoi for source

ht-tran off off off off off
                         && All heat-transfer processes turned off

low-cell
  geometry  446.0 bc=339.0
                         && Area from SAR figure, bc temperature
                         &&   same as atmosphere
  pool
    compos=1 h2ol 1.e-6  temp=339.0
                         && Essentially no initial DW water and there
                         &&   will be no additional water
    physics
      boil
    eoi                  && eoi for physics
  eoi                    && eoi for pool
eoi                      && eoi for low-cell

&& ********** CELL #2- Downcomers (DC)

cell=2
control
  jpool=1
eoi
&&
geometry
&&
&& Total DC volume is its area (256.5 ft**2, 23.830 m**2)) times
&&   its length (45.5 ft, 13.868 m). a value of 11,671 ft**3
&&   (330.47 m**3) results
&& However, the HWL DC submergence is 12.25 ft (3.734 m), so the
&&   DC gas volume is (44.5-12.25)*256.5=8272.1 ft**3 (234.24 m**3).

  gasvol=234.24

&& DC cell top elevation is its bottom elevation (3.658) plus the
&&   vent length 45.5 ft (13.868 m), i.e., 17.526 m

  cellhist=1 3.658 23.830 17.526
```

```
eoi                        && eoi for geometry

atmos=2                    && Same as the DW (Cell 1)
  pgas=1.0652e5 tgas=339.0
  molefrac o2=0.04 n2=0.96
  satrat =0.2
eoi                        && eoi for atmos

ht-tran off off off off off

low-cell
  geometry 23.830           && Downcomer area
  bc=308.                  && Pool temp
  pool
                           && Mass in downcomer based on 1000 kg/m**3
&&   volume for 12.25 ft (3.734 m) HWL DC
                           &&   submergence and area of 256.5 ft**2
                           &&   (23.830 m**2) is 3,142.1 ft**2
                           &&   (88.975 m**3)
    compos=1  h2ol=88.975e+3 temp=308.
    physics
      boil
    eoi                    && eoi for physics
  eoi                      && eoi for pool
eoi                        && eoi for low-cell

&& ********** CELL #3- WETWELL

cell=3
control
  jpool=1
  naensy=1                 && For engineered system spray
eoi                        && eoi for control

geometry
&& The SAR HWL suppression chamber air
                           &&   volume is 147,670 ft**3 (4181.5 m**3),
                           &&   which includes an accounting for the
                           &&   downcomer vent system in the air space.
  gasvol=4181.5
                           && cellhist accounts for the change in WW
                           &&   cross section
  cellhist=2 0.0 513.2 3.658 489.3  15.94
&& Note that the cellhist values give a total
                           &&   cell volume of
                           &&   513.2*(3.658-0.0)+489.3*
                           &&   (15.94-3.658)=7887
                           && The otherwise-specified total WW volume is
                           &&   the sum of the above
                           &&  gasvol volume of 4181.5 m**3 plus the below
                           &&   water-pool volume of about 3722.5 m**3.
                           &&   the resulting total is 7904,
                           &&   which is "close enough" to the
                           &&   cellhist based total volume.
atmos=2
  pgas=1.0652e5 tgas=308.0
                           && 0.75 psig, 95 F
  molefrac o2=0.04 n2=0.96
                           && Inerted atmosphere
  satrat=1.0               && 100% humidity
eoi                        && eoi for atmos
```

```
engineer wwpspry 4  3  3  0.0
                        && Above specifies an engineered safety system
                        &&   with 4 components (as described below)
                        &&   with coolant coming from this cell (#3)
                        &&   and returning to this cell.
                        && The safety system 4 components are a spray,
                        &&     a dummy tank that has no water, a
                        &&    pump, and a dummy heat exchanger that
                        &&    does not change the pumped water
                        &&    temperature
    spray
      spstpr=1.075e+05  && Spray to come on when WW press increases a
                        &&   little
    eoi                 && eoi for spray

    tank
      0.0               && No water mass in the tank
      308.0             && Pool and atmosphere temperature
      5000.             && Same as pump flow

    pump
      5000.             && Arbitrary value to simulate mixing of pool
                        &&    and atmosphere by bubbles bursting above
                        &&    pool

    hex
      user=0.0          && hex to not change pool-water temperature
eoi                     && eoi for engineer

condense                && Need for heat transfer between pool and
                        &&    atmosphere

low-cell
  geometry   489.3   bc=308.0
  pool
    compos=1 h2ol  3.722e6 temp=308.0
                        && Above water mass is based on 1000 kg/m**3
                        &&   and the SAR WW water volume 134,600 ft**3
                        &&   (3811.5 m**3) corrected by the submerged
                        &&   downcomer volume.
                        && The submerged downcomer volume is the vent
                        &&   area (256.5 ft**2) times the vent
                        &&   submergence (12.25 ft). which gives a
                        &&   volume of 3,142.1 ft**3 (88.98 m**3)
                        && Therefore, the WW water volume is
                        &&   3811.5-88.98=3722.5 m**3, or about
                        &&   3.722e+06 kg
                        && Temperature is SAR value of 95F
    physics
      boil
    eoi                 && eoi for physics
  eoi                   && eoi for pool
eoi                     && eoi for low-cell

eof                     && end of input
```

APPENDIX G
Derivation of Inertial Lengths for the CONTAIN Mark III Vent Clearing Model

Introduction

The usefulness of the standard CONTAIN flow path configuration for the modeling of vent clearing in a Mark III depends on the proper assignment of the inertial lengths to the pool and gas paths. These are not immediately obvious because the annulus has a cross-section comparable to that of all of the vents, and thus the inertia of the fluids in the annulus must be taken into account. The following discussion gives a prescription for calculating the effective inertial lengths for the pool paths, using the seven-node representation of the vent system in Figure G-1. The same prescription is also used for the gas paths, although the inertial lengths for these are typically not critical. Note that in the seven-node representation, the flow of liquid is assumed to be governed by standard hydraulic equations, within the approximation that plug flow is present in each node.

Derivation

The effective inertial lengths of the three flow paths in Figure G-1 may be determined by matching the initial liquid acceleration rates in that configuration with those in the configuration of Figure G-1, for a unit step change in the drywell-wetwell pressure difference. It is assumed that the system is initially at rest, with the same pool levels and gas pressures in the drywell and wetwell. Note that effective inertial lengths based on the initial acceleration rates should result in a slightly conservative vent clearing time, since the mass of liquid in the annulus and thus the effective inertial lengths decrease with time. The seven-node representation uses six velocities (V12, V23, V34, V25, V36, V47), six dynamic pressures (P_2', P_3', P_4', P_5', P_7'), and two hydrostatic pressures, P_1 and P_8. The vertical velocities in the wetwell are relatively small and are therefore neglected. Consequently, the dynamic pressures P_5', P_6', and P_7' at the downstream end of the vents are related hydrostatically to P_8. The liquid in each of the six remaining nodes is assumed to move as a coherent slug, and force-balance and conservation equations can be written in the usual manner. For a constant density liquid, these equations are given by

$$\Delta P'_{ij} A_{ij} = \rho_\ell L'_{ij} A_{ij} \frac{dV_{ij}}{dt} \tag{G-1}$$

$$A_{12}V_{12} = A_{25}V_{25} + A_{23}V_{23} \tag{G-2}$$

$$A_{23}V_{23} = A_{36}V_{36} + A_{34}V_{34} \tag{G-3}$$

$$A_{34}V_{34} = A_{47}V_{47} \tag{G-4}$$

where $\Delta P'_{ij}$ is equal to $\Delta(P'_i - P'_j)$, the change in pressure difference between points i and j, from the initial (hydrostatic) values; Aij is the flow area between points i and j; $\rho\ell$ is the liquid density;

L'_{ij} is the inertial length of liquid between points i and j; and dVij/dt is the acceleration of liquid mass from point i to j. Note that P'_1 is equal to P_1 and P'_8 is equal to P_8. These equations neglect the change in liquid level within a node, as is appropriate for determining the initial liquid acceleration rates. Note that the time-derivatives of the velocities are the key quantities in the following discussion, and therefore the time-differentiated forms of Equations (G-2) through (G-4) are used in the following discussion.

With the CONTAIN multi-node representation, the corresponding initial acceleration equations have the form

$$\Delta P_{ij} A_{ij} = \rho_\ell L_{ij} A_{ij} \frac{dV_{ij}}{dt} \qquad \text{(G-5)}$$

where [i,j] is either [2,5], [3,6], or [4,7]; ΔP_{ij} is equal to $\Delta(P_i - P_j)$, the change in hydrostatic pressure difference between points i and j, relative to the initial values; and Lij is the effective inertial length for liquid between points i and j. Note the hydrostatic pressures Pi are calculated as if the fluid velocities are identically zero and are used in the CONTAIN representation because momentum convection is ignored in a cell.

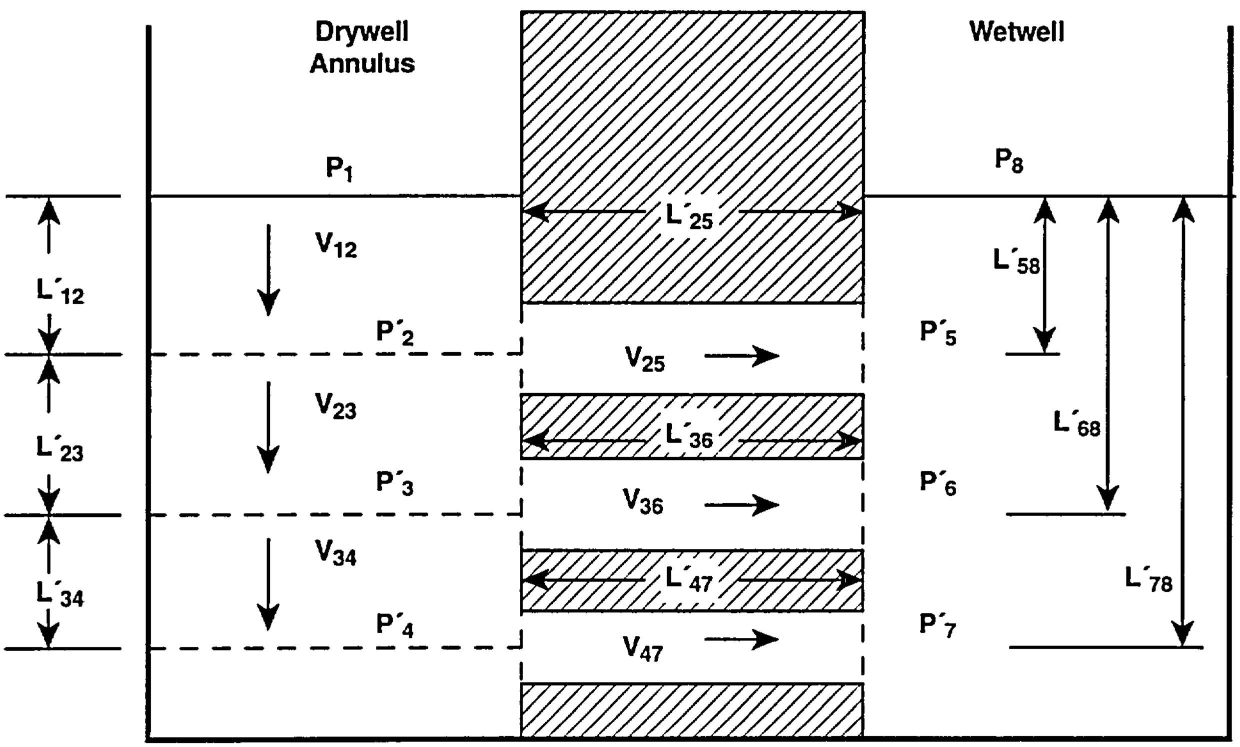

Figure G-1. Illustration of the Seven-Node Representation of Mark III Suppression Vents Used in the Inertial Lengths Derivation. Note that L'_{12} is the top vent submergence, L'_{23} is the vent centerline separation, and L'_{25} is the vent horizontal length.

To compute Lij, a unit step change in hydrostatic pressure, $\Delta(P_1 - P_8) = 1$, is imposed on the system and the initial time derivatives of V_{25}, V_{36}, and V_{47} are assumed to be equal in Equations (G-1) and (G-5). It should be obvious that Lij is independent of the magnitude of the pressure change.

One can start by solving Equation (G-1) and the time-derivatives of Equations (G-2) through (G-4) for the unit step change in pressure. Since P'_5, P'_6, and P'_7 are hydrostatically related to P_8 by a liquid depth that can be taken as fixed with respect to calculating initial accelerations and $P'_8 = P_8$, one can set

$$\Delta\left(P'_5 - P'_8\right) = \Delta\left(P'_6 - P'_8\right) = \Delta\left(P'_7 - P'_8\right) = 0 \qquad \text{(G-6)}$$

Substituting these into Equation (G-1) leaves six independent pressure differences and three time-derivatives, dVij/dt, which must be determined by the nine equations represented by Equations (G-1) through (G-4). Since L'_{ij} is assumed fixed at the initial value, these equations are linear and can be solved by standard methods. After the time derivatives are obtained, they are substituted into Equation (G-5), which is then solved for Lij using the hydrostatic pressure relations

$$\Delta\left(P_1 - P_8\right) = \Delta\left(P_2 - P_5\right) = \Delta\left(P_3 - P_6\right) = \Delta\left(P_4 - P_7\right) \qquad \text{(G-7)}$$

Such relations hold for horizontal vents within a constant density liquid. The solution of these equations are shown in the Mathcad file displayed in Figure G-2, for the annulus and vent areas and lengths characteristic of the Grand Gulf plant.

Calculation of Inertial Lengths for a Mark III BWR

CASE: Grand Gulf

Define liquid density

$\rho := 1000$

Define annulus area

$A_{an} := 51.44$

Define individual vent area

$A_v := 17.88$

Define top vent submergence

$L_1 := 2.28$

Define vent vertical separation

$L_2 := 1.27$

Define vent horizontal length

$L_3 := 1.521.25$

Solve system of equations (see Code Manual, Fig 11-3).

$\Delta P_{12} - \rho \cdot L_1 \cdot \alpha_{12} = 0$

$\Delta P_{23} - \rho \cdot L_2 \alpha_{23} = 0$

$\Delta P_{34} - \rho \cdot L_2 \cdot \alpha_{34} = 0$

$-\Delta P_{12} + \Delta P_{18} - \rho \cdot L_3 \cdot \alpha_{25} = 0$

$-\Delta P_{23} - \Delta P_{12} + \Delta P_{18} - \rho \cdot L_3 \cdot \alpha_{36} = 0$

$-\Delta P_{23} - \Delta P_{12} - \Delta P_{34} + \Delta P_{18} - \rho \cdot L_3 \cdot \alpha_{47} = 0$

$A_{an} \cdot \alpha_{12} - A_v \cdot \alpha_{25} - A_{an} \cdot \alpha_{23} = 0$

$A_{an} \cdot \alpha_{23} - A_v \cdot \alpha_{36} - A_{an} \cdot \alpha_{34} = 0$

$A_{an} \cdot \alpha_{34} - A_v \cdot \alpha_{47} = 0$

Figure G-2. Mathcad Worksheet for Computation of Effective Inertial Lengths.

where a is the acceleration.

Solve a 9x9 set of linear equations of the form M *ans = f, for a unit step change in pressure where

ans = $(\Delta P_{12}, \Delta P_{23}, \Delta P_{34}, \alpha_{12}, \alpha_{23}, \alpha_{34}, \alpha_{25}, \alpha_{36}, \alpha_{47})$ and $\Delta P_{18} := 1$

$$f := \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 - \Delta P_{18} \\ 0 - \Delta P_{18} \\ 0 - \Delta P_{18} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

and

$$M := \begin{bmatrix} 1 & 0 & 0 & -(\rho \cdot L_1) & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & -(\rho \cdot L_2) & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -(\rho \cdot L_2) & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & -(\rho \cdot L_3) & 0 & 0 \\ -1 & -1 & 0 & 0 & 0 & 0 & 0 & -(\rho \cdot L_3) & 0 \\ -1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & -(\rho \cdot L_3) \\ 0 & 0 & 0 & A_{an} & -A_{an} & 0 & -A_v & 0 & 0 \\ 0 & 0 & 0 & 0 & A_{an} & -A_{an} & 0 & -A_v & 0 \\ 0 & 0 & 0 & 0 & 0 & A_{an} & 0 & 0 & -A_v \end{bmatrix}$$

ans := lsolve(M, f)

Figure G-2. Mathcad Worksheet for Computation of Effective Inertial Lengths (cont'd)

$$
ans = \begin{bmatrix} 0.487 \\ 0.152 \\ 0.068 \\ 2.135 \cdot 10^{-4} \\ 1.197 \cdot 10^{-4} \\ 5.361 \cdot 10^{-5} \\ 2.701 \cdot 10^{-4} \\ 1.901 \cdot 10^{-4} \\ 1.542 \cdot 10^{-4} \end{bmatrix}
$$

Compute top inertial length

$$L_4 := \frac{\Delta P_{18}}{\rho \cdot ans_7}$$

Compute middle length

$$L_5 := \frac{\Delta P_{18}}{\rho \cdot ans_8}$$

Compute bottom length

$$L_6 := \frac{\Delta P_{18}}{\rho \cdot ans_9}$$

Summary

$L_4 = 3.703$

$L_5 = 5.261$

$L_6 = 6.484$

Figure G-2. Mathcad Worksheet for Computation of Effective Inertial Lengths (concluded)

APPENDIX H

Grand Gulf (Mark III) Short-Term Accident CONTAIN Deck

The following CONTAIN input file models the short-term recirculation line break scenario in the Grand Gulf plant, a Mark III BWR:

```
&&*********************************************************************
&&                    Mark III Short Term DBA Sample Problem
&&              Recirculation Line Break DBA in the Grand Gulf Plant&&
***********************************************************************

&& *********************** CONTROL BLOCK********************************
&&
control                      && global storage allocation
  ncells=3                   && # of cells
  ntitl=2                    && # of lines in the title
  ntzone=5                   && # of time zones
  nengv=8                    && # of engineered vents
eoi

&& *********************** MATERIAL BLOCK*******************************
material                                && material block
  compound h2ol h2ov n2 o2

&& *********************** TITLE BLOCK**********************************
title
  Grand Gulf-Mark III- Recirculation Line Break - Short Term Pressure

&& *********************** TIME ZONES***********************************
times 50000.  0.0
  0.01    .01    0.3
  0.005   .005   2.0
  0.02    .02    5.0
  0.03    .10   10.0
  0.03    .20   40.0

&& *********************** PRINT OPTIONS********************************
longedt=1                    && # of timesteps between longedits
shortedt=300                 && # of timesteps between shortedits

&& *********************** PRINT OPTION FLAGS***************************
prheat                       && heat transfer structure output
prlow-cl                     && lower cell output
prflow                       && flow output
prengsys                     && engineered system output
prenacct                     && energy and mass accounting output
&& ********************** FLOW OPTIONS INPUT****************************
flows implicit               && implicit should always be used

&& *********************** ENGINEERED VENTS*****************************
engvent
&& Flow path from drywell to annulus at top of weir wall
&&   Elevation reference is the bottom of the suppression pool
&&   Pool conditions assumed to be at HWL = 5.73 m. (18.81 ft) This is
&&     the SAR suppression pool volume at HWL (125398 ft3) divided by SAR
&&     wetwell pool area (6666 ft2)
&&   Flow area = annulus area = 51.47 m2(554 ft2) from SAR.
&&   vavl is annulus area/inertial length at HWL. Inertial length is based on
&&     distance from top of weir wall to pool surface at HWL.  Top of weir
```

```
&&     wall
&&     = 7.41 m (24.31 ft).  Therefore the inertial length = 1.68 m (5.51 ft)
at
&&     HWL.
&&   Loss coefficient vcfc = 0.25 corresponds to contraction loss
&&   (conventional
&&     value = 0.5)
  from 1 to 2
    varea=51.47 vavl=30.62  type=pool vcfc=0.25 velevb=7.41
    velevf=7.41
   eoi
   from 1 to 2
    varea=51.47 vavl=30.62  type=gas  vcfc=0.25 velevb=7.41
    velevf=7.41
   eoi

&& Top row of vents represented as one gas and one pool path
&&   Vent area = 17.88 m2 (577.3 ft2 divided by 3) taken from SAR
&&   Inertial length = 3.70 from Table 4-2 for submergence of 2.28 m.
&&   Loss coefficient vcfc = 1.5 corresponds to nominal loss (conventional
&&     value = 3.0)
&&   Vent elevation = 3.45 m (11 ft 4 in) taken from SAR.
  from 2 to 3
    varea=17.88 vavl=4.832 type=pool vcfc=1.5 velevb=3.45
    velevf=3.45
   eoi
   from 2 to 3
    varea=17.88 vavl=4.832 type=gas vcfc=1.5 velevb=3.45
    velevf=3.45 vcontra=0.7
   eoi
&& Middle vents represented like the top vents except
&&   inertial length = 5.26 (17.26 ft) at HWL from Table 4-2
&&   Vent elevation = 2.18 m (7 ft 2 in) taken from SAR.
    from 2 to 3
     varea=17.88 vavl=3.399 type=pool vcfc=1.5 velevb=2.18
     velevf=2.18
   eoi
  from 2 to 3
    varea=17.88 vavl=3.399 type=gas vcfc=1.5 velevb=2.18
    velevf=2.18 vcontra=0.7
   eoi

&& Bottom vents represented like the top vents except
&&   inertial length = 6.48 (21.26 ft) at HWL from Table 4-2
&&   Vent elevation = 0.91 m (3 ft 0 in) taken from SAR.
  from 2 to 3
    varea=17.88 vavl=2.759 type=pool vcfc=1.5 velevb=0.91
    velevf=0.91
   eoi
  from 2 to 3
    varea=17.88 vavl=2.759 type=gas vcfc=1.5 velevb=0.91
    velevf=0.91 vcontra=0.7
   eoi
&& ****************** CELL #1- DRYWELL **********************
cell=1                        && beginning of input for drywell cell,
                              &&   which excludes the annulus region
control
  jpool=1                     && flag indicates pool is present
  nsoatm=2                    && number of source tables
  nspatm=25                   && max. number of table points
eoi
geometry
```

```
  gasvol=7551.86                   && SAR drywell gas volume of 7645.55 m3
                                   &&   (270000 ft3) less a gas volume of 93.69 m3
                                   &&   at LWL in the annulus.  Note the water
                                   &&   level corresponding to the stated drywell
                                   &&   gas volume is not specified, so we
                                   &&   conservatively assume it corresponds to
                                   &&   LWL.  The annulus pool volume at LWL is
                                   &&   (LWL wetwell pool volume)x(annulus pool
                                   &&   area)/(wetwell pool area) or 287.70 m3.
                                   &&   The total volume of the annulus cell is
                                   &&   given by a cross-section of 51.47 m2 (554
                                   &&   ft2) times a height of 7.41 m (24.3125 ft),
                                   &&   which equals 381.39 m3.  This leaves a LWL
                                   &&   annulus gas volume of 93.69 m3.
   cellhist=1 0. 243.02 31.075 && bottom elevation, nominal cross-section, and
                                   &&   top elevation.  Note that total implied
                                   &&   cellhist volume should be equal to the
                                   &&   total gas and pool volume, otherwise a code
                                   &&   diagnostic is issued
eoi

atmos=2                            && refers to number of noncondensible gases
pgas=1.0135e5 tgas=330.22          && corresponds to 1 atm and 120 F
  molefrac o2=.21 n2=.79           && noncondensible gas mole fractions
satrat =.2                         && water vapor saturation ratio
eoi

source=2                           && number of source tables, representing steam
                                   &&   and liquid water in this case
h2ov=15                            && material, number of points in table
  iflag=2                          && linear interpolation indicated
  t=                               && time values (s)
    0.0         17.25       17.26       20.37       25.12
    30.         35.         40.         45.         50.
    54.6        54.7        57.4        59.1        59.4
  mass=                            && mass rate values (kg/s)
    0.0         0.0         1987.66     1816.66     1495.51
    1121.75     692.19      403.7       190.51      75.75
    33.11       94.35       48.08       11.34        0.0
  enth=                            && specific enthalpy values (J/kg)
    0.0         0.0         2.7639e+6   2.7802e+6   2.7969e+6
    2.8039e+6   2.7995e+6   2.7837e+6   2.7581e+6   2.7323e+6
    2.7125e+6   2.7125e+6   2.6997e+6   2.6958e+6   0.0
  eoi                              && terminator for first table
h2ol=20                            && beginning of second source table
  iflag=2
  t=
    0.0         0.794988     1.450008    1.888992    1.905012
    2.264004    3.99996      6.00012     7.99992     10.24992
    17.25012    17.25984     20.36988    25.12008    29.99988
    34.99992    39.9996      45          50.0004     54.6012
  mass=
    13812.0294 13784.3096  13775.4896 13780.5296 11525.9004
    11535.9723 11630.2277  11725.4831 11793.5226 11829.8104
    11725.4831 5139.25429  3995.30779 2674.45846 1677.80499
    1148.96126 909.00843   871.813481 768.846956 637.303819
  enth=
    1.2814e+6  1.28e+6    1.2793e+6  1.2792e+6  1.2793e+6
    1.2802e+6  1.2893e+6  1.2829e+6  1.3007e+6  1.3039e+6
    1.2937e+6  1.2937e+6  1.233e+6   1.1344e+6  1.0267e+6
    9.1037e+5  7.9192e+5  6.7544e+5  5.8427e+5  5.2262e+5
  eoi                              && terminator for second table
```

```
ht-tran off off off off off
                            && turn off all heat transfer
low-cell                    && define lower cell geometry for drywell sump
  geometry 243.02             && area of pool substrate layers
  bc 330.22                 && boundary condition temperature for
                            &&   bottom-most layer, if any
  pool
     compos=1 h2ol 0.0       && pool assumed dry for now
     temp=330.22
     physics
       boil                  && pool boiling enabled
     eoi
  eoi
eoi

&& ******************* CELL #2- ANNULUS ********************
cell=2
control
  jpool=1
eoi
geometry
  gasvol=80.02              && volume at HWL, less volume of water added
                            &&   to the annulus to make up for the fact
                            &&   that CONTAIN does not keep track of the
                            &&   water in the vent flow paths (see below)
   cellhist=1 0. 51.47 7.41  && bottom elevation, annulus cross-section (554
                            &&   ft2) and height of top of weir wall
                            &&   (24.3125 ft)
eoi

atmos=2
  pgas=1.0135e5 tgas=330.22
  molefrac o2=.21 n2=.79
  satrat=.2
eoi

ht-tran off off off off off

low-cell
  geometry 51.47            && area of non-pool layers, if any
  bc 308.15                 && corresponds to 95 F
  pool                      && annulus pool
    compos=1 h2ol=2.9952e5  && annulus water mass at HWL, plus allocation of
                            &&   water that should be in the vent flow paths
                            &&   but is ignored by CONTAIN. Since the vent
                            &&   volume is ignored the annulus and wetwell
                            &&   pool levels are increased so that the
                            &&   correct HWL liquid inventory of 3927.57 m3
                            &&   (13303 + 125398 ft3) is present.  This
                            &&   gives an annulus pool volume of 301.37 m3
                            &&   and a wetwell pool volume of 3626.20 m3
                            &&   when apportioned by the respective areas of
                            &&   51.47 m2 (554 ft2) and 619.29 m2 (6666
                            &&   ft2). The pool mass assumes a water
                            &&   density = 993.86 kg/m3 at 308.15 K

    temp=308.15             && initial temperature
    physics
      boil
    eoi
  eoi
```

```
eoi

&& ****************** CELL #3- WETWELL ********************
cell=3
control
  jpool=1
  numtbc=1
  maxtbc=10
  naensy=1
eoi
geometry
  gasvol=39479.12             && gas volume at HWL less allocation of
                              &&   the water volume that should
                              &&   be in the vents (see below)
  cellhist=1 0. 619.29 69.604 && bottom elevation, area (6666 ft2),
                              &&   and top elevation set to give a
                              &&   total volume of 43105.32 m3
                              &&   (1400000 ft3 + 122250 ft3 for gas
                              &&   and water respectively).  Note as
                              &&   in calculating the drywell volume,
                              &&   the SAR wetwell gas volume is assumed to
                              &&   correspond to LWL
eoi

atmos=2
  pgas=1.0135e5 tgas=299.82   && set to 1 atm and 80 F
  molefrac o2=.21 n2=.79
  satrat=.6
eoi

low-cell
  geometry 619.29             && area of non-pool layers, if any
  bc=308.15                   && boundary condition temperature
  pool                        && pool in wetwell proper
      compos=1 h2ol 3.60393e6  && water in wetwell at HWL, plus wetwell
                              &&   fraction of water in the vents. The total
                              &&   wetwell water volume is given in the
                              &&   discussion of the annulus pool as 3626.20
                              &&   m3 and this water is assumed to be at the
                              &&   same density as that of the annulus pool
    temp=308.15               && initial temperature 95 F
    physics
      boil
    eoi
  eoi
eoi
eof
```