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Westinghouse ABWR Subcompartment Analysis Methodology Using GOTHIC

Westinghouse

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1 INTRODUCTION AND BACKGROUND

Section 6.2.1.2 of NUREG-0800 requires design analyses be performed to demonstrate that the walls can withstand the short-term differential pressure pulse following a large, high energy line break (HELB) within each primary containment subcompartment. Westinghouse currently uses the Transient Mass Distribution code, TMD, code (Reference 2) to perform the subcompartment design analyses.

NRG Energy/South Texas Project Nuclear Operating Company (STPNOC) submitted a combined construction and operating license application (COLA) for two advanced boiling water reactor (ABWR) units at their South Texas site. Westinghouse is working with Toshiba and STPNOC to help license STP Units 3 and 4.

The code that was used by General Electric (GE) to perform the ABWR subcompartment design analyses for the design control document (DCD) (Reference 3) is not available to Westinghouse or Toshiba. Therefore, an alternative code/methodology is required to address potential future ABWR design changes.

A subcompartment design analysis methodology that uses the GOTHIC code is described in this report. Westinghouse is planning to use GOTHIC for future containment analysis work. Using a single code for containment analyses will simplify code maintenance and user qualification activities. Furthermore, TMD has modeling limitations that do not exist in GOTHIC.

The GOTHIC code qualification report (Reference 4) compares model results to a number of tests that represent conditions similar to those that would be observed in a typical subcompartment analysis. This provides a significant level of confidence that GOTHIC is a suitable tool for performing subcompartment analyses. To provide an additional level of confidence, Westinghouse performed a benchmark comparison to the approved TMD subcompartment analysis methodology using GOTHIC and TMD models of the ABWR steam tunnel subcompartment configuration that is described in the ABWR DCD.

The purpose of this report is to document and demonstrate the Westinghouse implementation of the GOTHIC subcompartment analysis methodology. This document provides:

1. A description of the GOTHIC subcompartment modeling methodology.

2. Benchmark comparison results from a GOTHIC subcompartment model and a TMD subcompartment model.

3. A comparison of the GOTHIC subcompartment modeling methodology to the Standard Review Plan Requirements (Reference 5).

4. Sample transient results for a representative ABWR steam tunnel subcompartment analysis.

2 SUBCOMPARTMENT MODELING METHODOLOGY

2.1 CONTROL VOLUMES

Control volumes (CV) are used in GOTHIC to represent the various rooms in the system being analyzed. Input data for control volumes is based on the room geometry. Once the room volumes are determined, they are conservatively reduced. This is done by subtracting the volume of major equipment and major piping, and then reducing the calculated volumes by an additional percentage. This additional reduction factor is typically [ ]^{a,c}, with some exception for rooms that have a large amount of small equipment, small piping, cable trays, etc. The typical GOTHIC control volume input values are calculated as shown in Equation 2-1.

[ ]^{a,c} 2-1

2.2 DROPS

The GOTHIC input for the drops can be adjusted to make the vapor region look like a homogeneous mixture of steam, water (as small drops), and gas. [ ]^{a,c} The GOTHIC code models the corresponding heat and mass transfer between the drops and atmosphere. Because the specified diameter of the incoming drops is very small, the drops quickly come into thermal and velocity equilibrium with the vapor phase.

2.3 VENT PATHS

Flow paths are used in GOTHIC to transfer mass, energy, and momentum between control volumes. Input data for flow paths is based on the flow path geometry.

Flow path area is based on the flow path geometric data, and similar to the control volume input, the total area is further reduced. This is done by reducing the calculated total flow area by subtracting major piping and insulation along with an additional [ ]^{a,c} reduction in available flow area.

Inertia lengths are calculated in accordance with GOTHIC guidance for calculating inertia lengths. The equation for inertia length is as follows:

[ ]^{a,c} 2-2

2-2

In Equation 2-2, L_I is the junction inertia length, A_j is the junction area, D_h is the junction hydraulic diameter, L_o is the orifice wall thickness, L_1 and L_2 are the distances from the attached cell centers to the area change (orifice, expansion, contraction, etc.) and A_1 and A_2 are the expanded areas on either side of the junction opening.

Loss coefficients for flow paths include form losses and friction losses. Reference 1 is the basis for all form losses used for flow paths. Using Reference 1, contributions to the overall loss coefficient from orifices, turns, contractions, and expansions are calculated. Because loss coefficients are a function of the relevant flow area in which they are associated, losses are then biased to the flow path flow area.

The friction loss portion of the loss coefficient is calculated using Equation 2-3.

$$K = \frac{f * L_{eq}}{D_h} \qquad 2\text{-}3$$

In Equation 2-3, f is the friction factor, L_{eq} is the equivalent length, and D_h is the hydraulic diameter. A constant value of [ ]^{a,c} is used for the friction factor, f, in Equations 2-3 and 2-4.

The equivalent length (L_{eq}) is calculated in the same manner as TMD (Reference 2). Equation 2-4 shows the method for calculating the equivalent length.

[ ]^{a,c} 2-4

(Note: the subscript 3 denotes the minimum flow area flow path)

In Equation 2-4, $f_{1\text{-}3}$ is the friction factor, L_1 is the length of the upstream room, L_2 is the length of the downstream room, L_3 is the length of the flow path between the rooms (i.e., door or wall length), D_1 is the hydraulic diameter of the upstream room, D_2 is the hydraulic diameter of the downstream room, D_3 is the hydraulic diameter of the flow path between the rooms, A_1 is the reduced flow area of the upstream room, A_2 is the reduced flow area of the downstream room, and A_3 is the reduced flow area of the flow path between the rooms.

All flow paths, with the exception of those attached to boundary conditions, account for compressibility effects within the flow paths. In addition, the homogeneous equilibrium choking model (HEM) is used in these flow paths. It considers a mixture of steam, water, and gas at equal temperature and velocity to calculate the choked flow rate through the flow paths.

A no slip condition between the liquid and vapor phases is assumed through the system. This assumption increases the calculated pressure drop through the vent system. [

]^{a,c}

2.4 INITIAL CONDITIONS

Consistent with the accepted methods for calculating the subcompartment peak pressure, [

]^{a,c}.

3 COMPARISON OF GOTHIC METHODOLOGY TO STANDARD REVIEW PLAN REQUIREMENTS

Table 3-1 Comparison of Gothic Methodology to Standard Review Plan Requirements a,c

Table 3-1 (cont.) Comparison of Gothic Methodology to Standard Review Plan Requirements

a,c

4 GOTHIC VALIDATION TESTING

As part of the GOTHIC Qualification Report (Reference 4), GOTHIC model results were compared with and benchmarked against the results from a variety of test facilities. Included in these tests are the Battelle-Frankfurt Test Facility (BFMC) and Heissdampfreaktor (HDR). Each of these test facilities contain a variety of different subcompartment configurations. Further information on these test facilities, along with comparisons to GOTHIC, may be found in Reference 4.

5 GOTHIC BENCHMARK MODEL DESCRIPTION AND RESULTS

Benchmark models were developed to compare GOTHIC results to those from the NRC approved subcompartment code (TMD). For this benchmark, a steam tunnel model, representative of the one described in the ABWR DCD analysis, was used as the basis for the TMD and GOTHIC benchmarking. Some calculated inputs that are required for TMD and GOTHIC were not provided in the ABWR DCD. For the TMD model, these calculated inputs were determined using TMD guidance. GOTHIC models are similar to the TMD models, with an exception in the areas that GOTHIC guidance deviates from TMD guidance.

Three sets of benchmark models were created and analyzed for both feedwater line breaks (FWLB) and main steam line breaks (MSLB). These three sets of models are intended to show the impact of parameter changes to provide an additional level of confidence in the code to code comparison. The three models are described as follows:

1. DCD Volume Model – These models are based on the volume data provided in the DCD. DCD flow path loss coefficients are used for flow paths without including the additional mechanical losses given in the DCD.

2. [ ][a,c] Calculated Volume Model without Additional Losses – These models use volume input data that is calculated from available drawings. DCD flow path loss coefficients are used for flow paths without including the additional mechanical losses given in the DCD.

3. [ ][a,c] Calculated Volume Model with Additional Losses – These models use volume input data that is calculated from available drawings. DCD flow path loss coefficients are used for flow paths including the additional mechanical losses given in the DCD.

The GOTHIC noding diagram for the benchmark analyses may be viewed in Figure 5-1. The key input data for the GOTHIC subcompartment benchmark models are presented in Tables A-1 and A-2 of Appendix A.

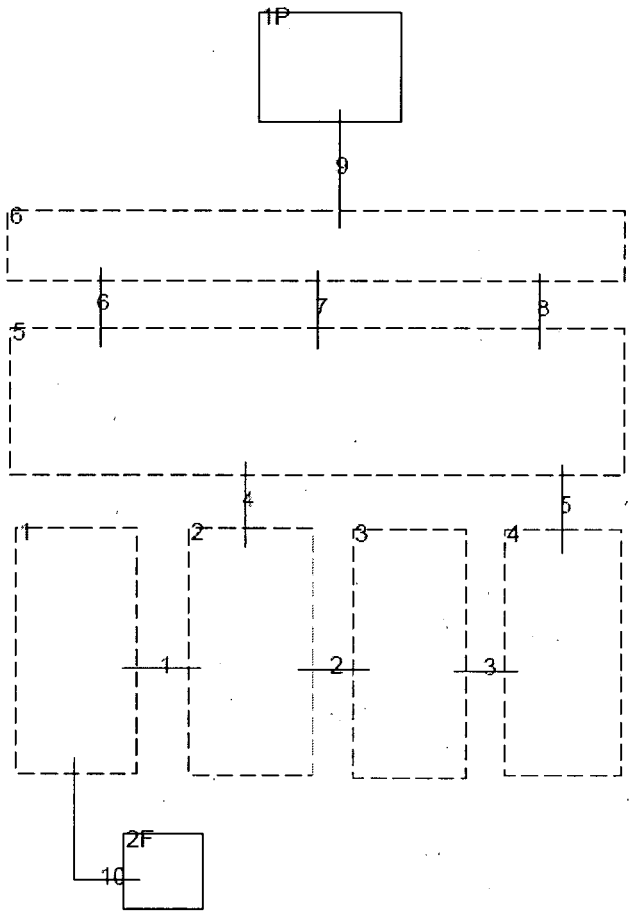

Figure 5-1 GOTHIC Benchmark Noding Diagram

5.1 MAIN STEAM LINE BREAK COMPARISON

The results of the MSL HELB in the reactor building steam tunnel are presented in Figures 5-2 through 5-4. Table 5-1 shows the "%" difference between the TMD and GOTHIC peak calculated pressures.

Note that the DCD results are shown only as a reference point to the original DCD analysis. The GOTHIC benchmark model is not intended to match the DCD results. Instead, the GOTHIC benchmark model is intended to be compared to the TMD results.

Table 5-1 Main Steam Line Break Benchmark Results			
Case	**TMD Result (psia)**	**GOTHIC Result (psia)**	**Difference (%)**
MSL DCD Volume	24.4	24.5	0.41
MSL [ ]^{a,c} w/o Add'l Losses	23.6	23.6	0.00
MSL [ ]^{a,c} w/ Add'l Losses	23.7	23.8	0.42

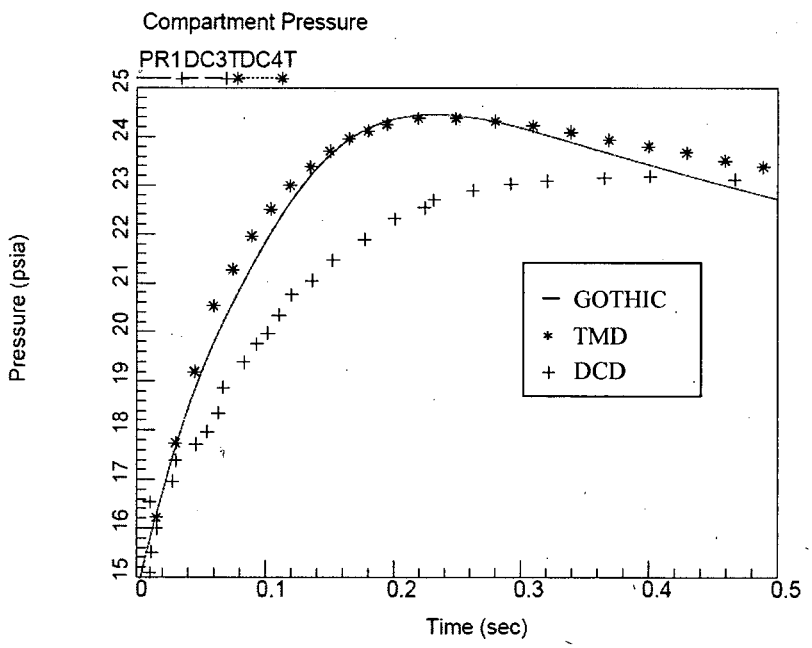

Figure 5-2 GOTHIC/TMD MSLB Pressure Comparison for DCD Volume Case

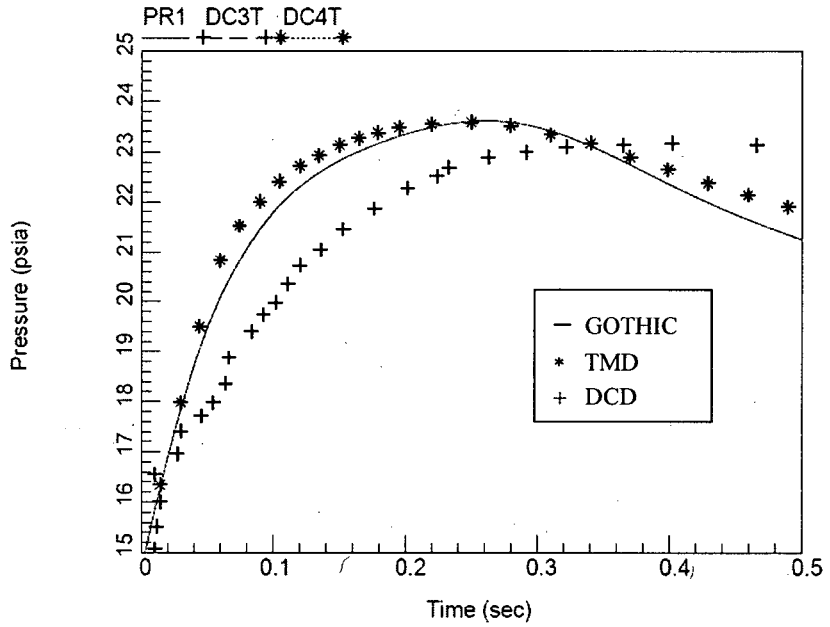

Figure 5-3 GOTHIC/TMD MSLB Pressure Comparison for [ ]^{a,c} Calculated Volume Case without Additional Losses

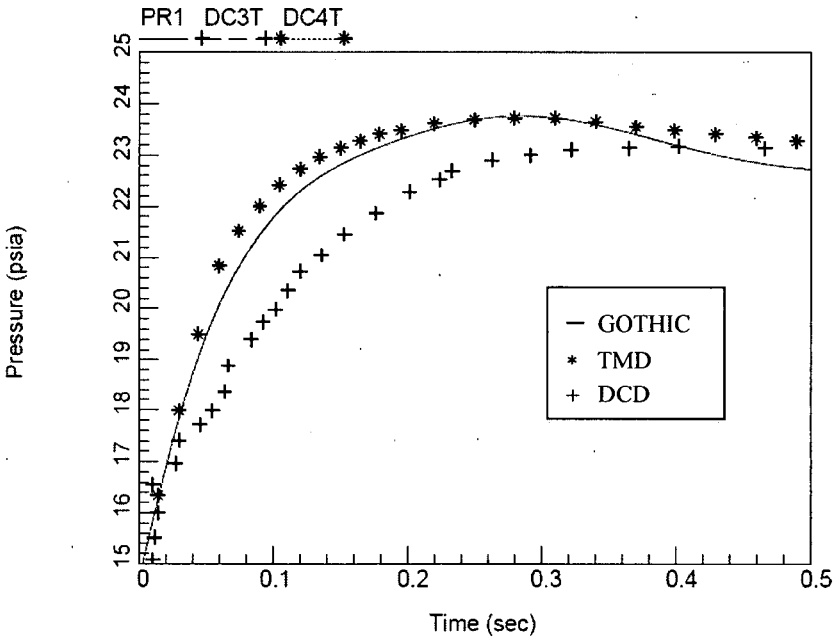

Figure 5-4 GOTHIC/TMD MSLB Pressure Comparison for [ ]^{a,c} Calculated Volume Case with Additional Losses

5.2 FEEDWATER LINE BREAK COMPARISON

The results of the FWL HELB in the reactor building steam tunnel are presented in Figures 5-5 through 5-7. Throughout these plots, the solid line represents the GOTHIC results and the dashed line represents the TMD results. Table 5-2 shows the "%" difference between the TMD and GOTHIC peak pressures. Unlike the steam line break, the DCD does not provide the transient results for the FWLB.

Table 5-2 Feedwater Line Break Benchmark Results

Case	TMD Result (psia)	GOTHIC Result (psia)	Difference (%)
FWL DCD Volume	16.2	16.6	2.47
FWL [ ]^{a,c} w/o Add'l Losses	16.0	16.2	1.25
FWL [ ]^{a,c} w/ Add'l Losses	16.0	16.2	1.25

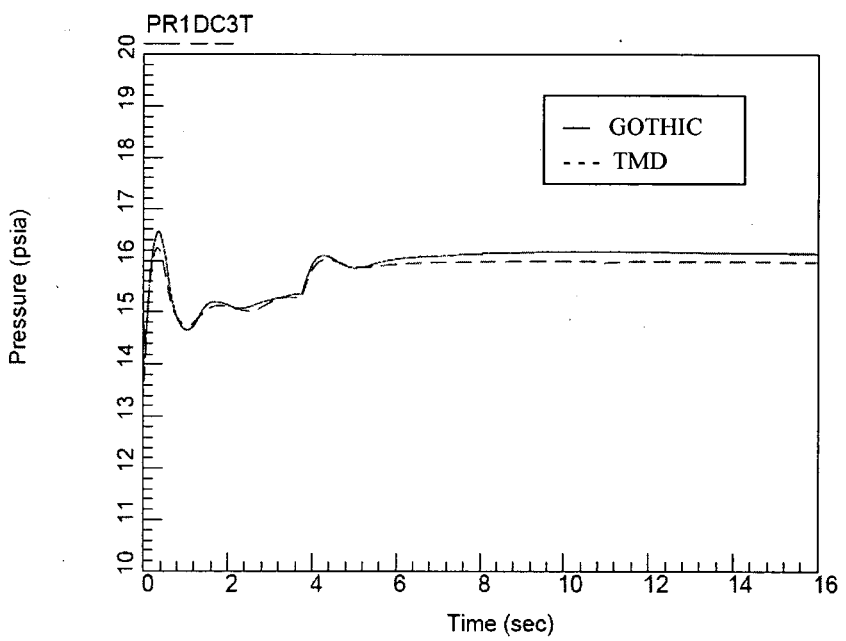

Figure 5-5 GOTHIC/TMD FWLB Pressure Comparison for DCD Volume Case

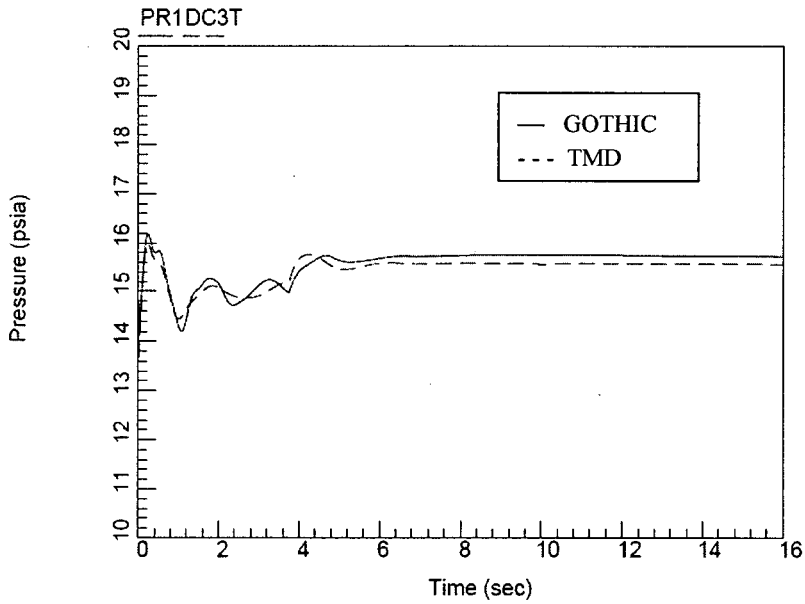

Figure 5-6 GOTHIC/TMD FWLB Pressure Comparison for [ ]^{a,c} Calculated Volume Case without Additional Losses

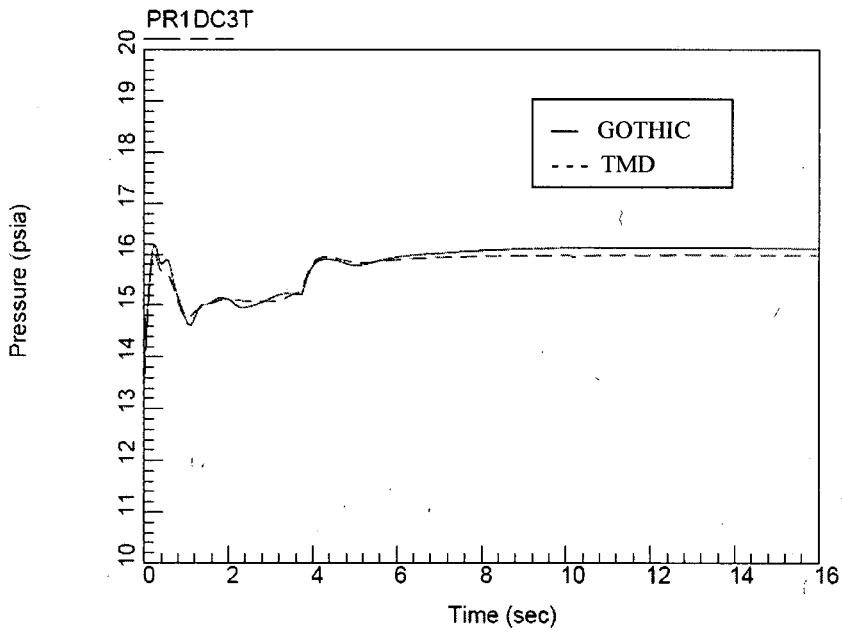

Figure 5-7 GOTHIC/TMD FWLB Pressure Comparison for [ ]^{a,c} Calculated Volume Case with Additional Losses

6 GOTHIC SUBCOMPARTMENT MODEL DESCRIPTION AND RESULTS

A GOTHIC model representative of an ABWR steam tunnel system was analyzed to show the application of the methodology described in Section 2.

6.1 STEAM TUNNEL MODEL DESCRIPTION

The ABWR steam-tunnel is a series of corridors that house both the main steam lines (MSL) and feedwater lines (FWL) as they run from the primary containment vessel to the turbines. This series of corridors includes portions of the reactor building, control building, and turbine building. In the event of a break within the steam tunnel corridors, the steam has two pathways to the atmosphere. One pathway is through a chimney system that connects the control building/turbine building interface region to the upper turbine building, where the steam can exit through flow paths to the atmosphere. The other flow path is from the control building/turbine building interface region into the lower turbine building, which then connects to the upper turbine building. Again, the steam can then exit the upper turbine building through flow paths to the atmosphere. The GOTHIC noding diagram for the steam tunnel high energy line break (HELB) analysis is shown in Figure 6-1.

[

]a,c

Breaks are postulated to occur in the reactor building steam tunnel, the control building steam tunnel, and the lower turbine building. Mass and energy releases are calculated using the Westinghouse boiling water reactor (BWR) loss of coolant accident (LOCA) mass and energy release code GOBLIN, as described in Reference 6.

The feedwater line break case shown in Section 6.3 is provided to demonstrate an application of the subcompartment methodology for a liquid line break. Because no flow occurs from the vessel, due to the

presence of check valves between the break and the vessel, just the pump side of the FWLB mass and energy releases from Reference 7 are used as input for this case.

The key input data for the GOTHIC steam tunnel subcompartment model are presented in Appendix A, Table A-3.

a,c

Figure 6-1 GOTHIC ABWR Steam Tunnel Model Noding Diagram

6.2 STEAM TUNNEL MODEL RESPONSE TO A MSLB

The peak pressure for the GOTHIC steam tunnel subcompartment analysis occurs during a main steam line high energy line break located in the reactor building section of the steam tunnel. The peak pressure occurs in the reactor building section of the steam tunnel. Figure 6-2 shows the pressure response in the reactor building section of the steam tunnel. Figure 6-3 shows the pressure response for the control building section of the steam tunnel. Figure 6-4 shows the pressure response curves for the lower turbine building and the upper turbine building. The peak pressure for this steam tunnel subcompartment analysis is 23.60 psia (8.9 psig).

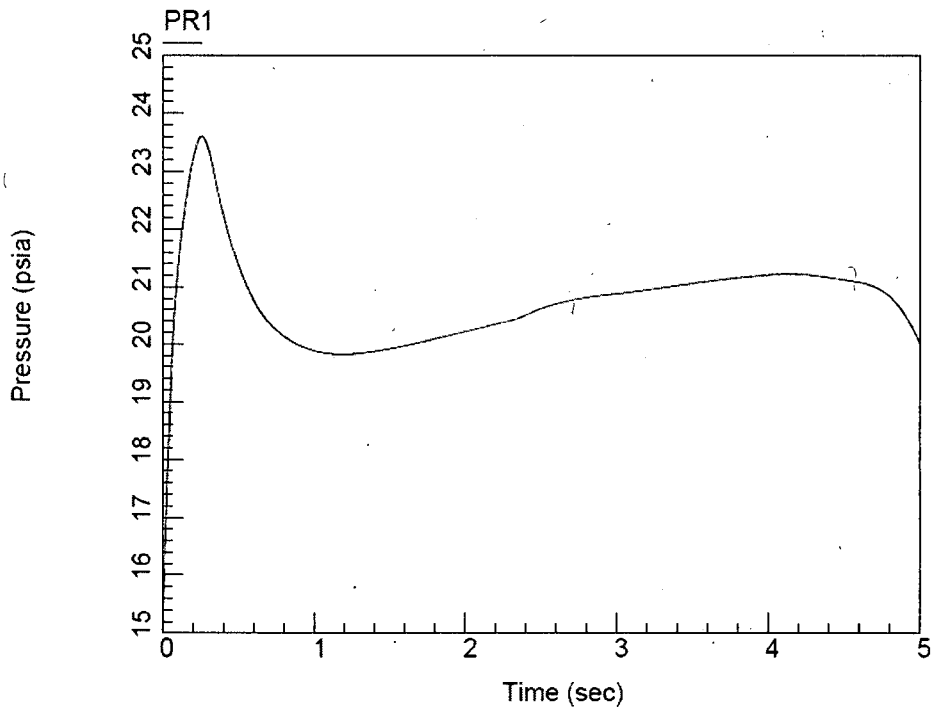

Figure 6-2 Reactor Building Pressure Response for a MSL HELB in the Reactor Building

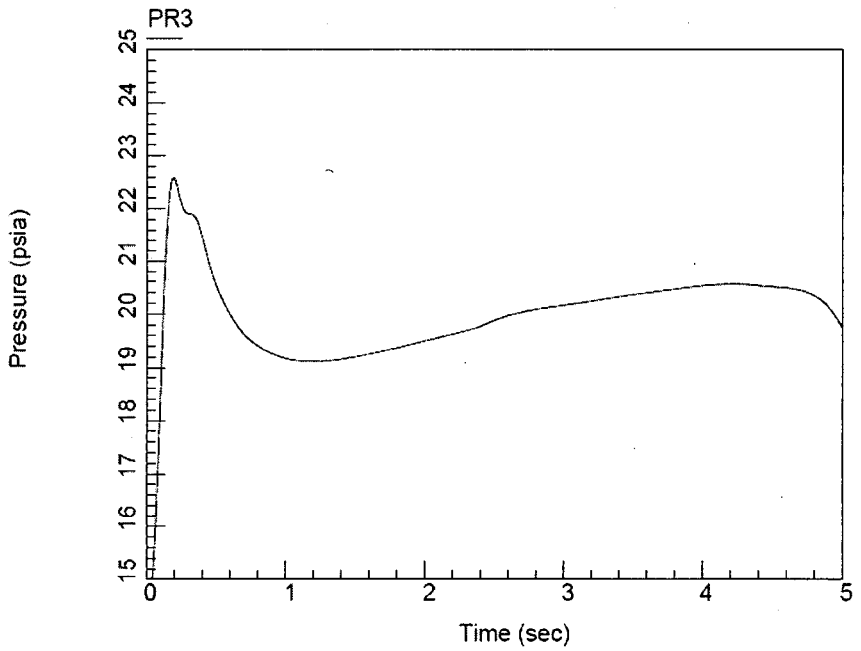

Figure 6-3 Control Building Pressure Response for a MSL HELB in the Reactor Building

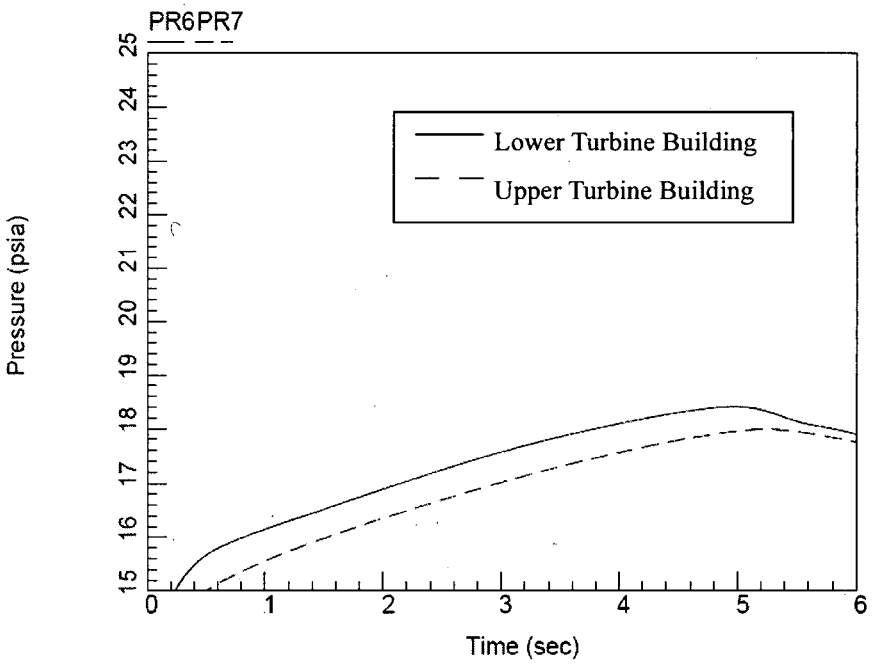

Figure 6-4 Upper and Lower Turbine Building Pressure Responses for a MSL HELB in the Reactor Building

6.3 STEAM TUNNEL MODEL RESPONSE TO A FWLB

A feedwater line break in the reactor building section of the steam tunnel was analyzed to demonstrate the behavior of the subcompartment model for a liquid line break. The calculated peak pressure in the FWLB analysis is well below the calculated peak pressure shown in the MSLB analysis. Figure 6-5 shows the pressure response in the reactor building section of the steam tunnel. The peak pressure for this steam tunnel subcompartment analysis is 17.81 psia (3.1 psig).

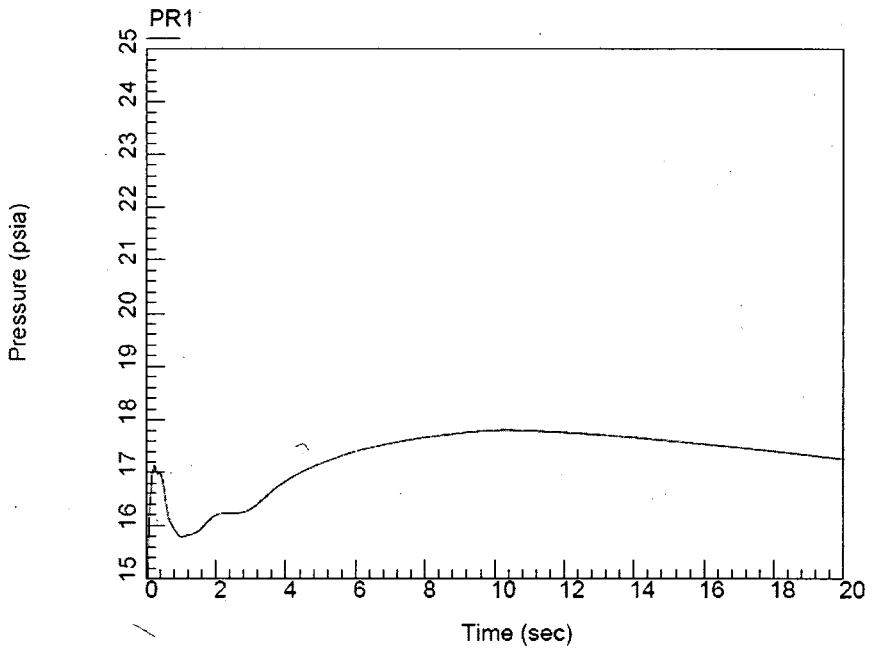

Figure 6-5 Reactor Building Pressure Response for a FWLB in the Reactor Building

6.4 STEAM TUNNEL MODEL NODING SENSITIVITY

As required by Standard Review Plan 6.2.1.2, a noding sensitivity was conducted to determine the effects of decreasing the noding size in the subcompartment analysis model. The noding sensitivity was performed for the HELB in the reactor building, which was shown to be the limiting case.

The control building section of the GOTHIC steam tunnel subcompartment model was selected for further subdivision, because it is a long corridor and may have an impact on the inertia effects observed in the model. Though the reactor building is the location of the peak pressure, it was not subdivided further for the noding sensitivity for two reasons. First, unlike the control building, which is a long narrow corridor, the reactor building is a large, open, cube-shaped volume. This open cube-shaped volume would not be subject to the same inertia effects as the control building. Second, further subdividing the volume of the break location will cause the pressure in the break node to continually increase as the node gets smaller and smaller. This will continue until the node is sufficiently small enough to act as the end of the broken pipe, and the pressure in the node will rise to the stagnation pressure of the broken pipe. This pressure is

not representative of the forces which would be seen on the subcompartment walls. For these reasons, a refined noding in the reactor building would not provide meaningful results in the noding sensitivity.

Figure 6-6 shows the noding structure used for a sensitivity case that breaks the control building section of the steam tunnel subcompartment model into two separate control volumes (Volumes 3 and 9).

a,c

[ ]

Figure 6-6 Steam Tunnel 2 Volume Noding Sensitivity Noding Diagram

The calculated peak pressure for a MSLB in the reactor building section of the steam tunnel was 23.60 psia. The calculated peak pressure with the revised control building noding structure was 23.81 psia. Therefore, increasing the number of nodes in the GOTHIC steam tunnel subcompartment model resulted in a small (less than 1%) increase in the calculated peak pressure.

Next, the control building section of the steam tunnel subcompartment model was broken into five control volumes (Volumes 8, 9, 10, 11, and 12), to evaluate the impact of a further increase in the number of nodes. The noding diagram for this sensitivity case is shown in Figure 6-7.

a,c

Figure 6-7 Steam Tunnel 5 Volume Noding Sensitivity Noding Diagram

The calculated peak pressure with this more detailed noding structure was 23.87 psia. This is only a 1.1% increase relative to the base case, and only a 0.25% increase relative to the two node variation. These small pressure changes are insignificant relative to the excess pressure due to the model conservatisms and the base case noding is judged acceptable.

7 CONCLUSIONS

A new analysis code/methodology is required to perform future subcompartment design analyses. The GOTHIC code has been selected to perform these analyses.

This Licensing Topical Report provides a description of the methodology intended to be used to perform the subcompartment design analyses with GOTHIC. The methodology is consistent with the SRP requirements listed in Section 6.2.1.2 of NUREG-0800.

The GOTHIC code qualification report (Reference 4) provides a comparison of the code results to subcompartment test data. The good comparison that is presented in the report demonstrates that the code contains the required modeling capabilities needed to perform subcompartment design analyses.

A benchmark transient comparison with the U.S. NRC approved subcompartment analysis code TMD further qualifies the application of the GOTHIC subcompartment design analysis methodology. The GOTHIC model results compare very well to the TMD benchmark analysis results.

The first application of this new subcompartment design analysis methodology is expected to be for the ABWR; however, this methodology could be used for subcompartment design analyses for any plant. The results from a representative GOTHIC ABWR steam tunnel model are provided to demonstrate the application of the methodology.

8 REFERENCES

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5. NUREG-800, "U.S. Nuclear Regulator Commission Standard Review Plan – 6.2.1.2 Subcompartment Analysis," March 2007.

6. WCAP-16608-P-A, Appendix B, "Westinghouse Containment Methodology," March 2009.

7. WCAP-17058, "Implementation of ABWR DCD Methodology using GOTHIC for STP 3 and 4 Containment Design Analyses," June 2009.

APPENDIX A

Table A-1 DCD Volume Benchmark Input Table

a,c

Table A-1 (cont.) DCD Volume Benchmark Input Table

a,c

Table A-2 Calculated Volume Benchmark Input Table a,c

Table A-2 (cont.) Calculated Volume Benchmark Input Table

a,c

Table A-3 Steam Tunnel Analysis Model Input Table

a,c

Table A-3 (cont.) Steam Tunnel Analysis Model Input Table

a,c