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MELCOR DBA Containment Audit Calculations for the ESBWR Plant
(Final)

Jack Tills*
Dept. 6862
Sandia National Laboratories
Albuquerque, NM
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* Jack Tills & Assoc., Inc.

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1 Introduction

The MELCOR code (1.8.6 YN) has been applied to the containment analysis of a design basis accident (DBA) occurring in the General Electric Hitachi (GEH) ESBWR plant, Figure 1. This report documents calculations for a main steam line break (MSLB) scenario that results in the greatest challenge to the containment design pressure limit. The *audit* calculation is based on set of bounding initial conditions and model inputs consistent with information provided in the ESBWR Design Control Document (DCD Revision 6)[1] and numerous letters sent to the NRC by GEH in response to requests for additional information (RAIs) concerning design and operating procedures. When these calculations are compared to TRACG code results presented in the DCD, based on the same modeling (design) and operation conditions, the calculations are also referred to as *confirmatory*. Both the audit and confirmatory aspects of the MELCOR calculations are discussed in this report.

The context for selection of DCD Revision 6 as the informational basis for the final audit report needs some explanation since at the time of this report preparation Revision 8 is nearing completion. A progression of design and TRACG model changes since the first certification submittal has provided the NRC with a number of DCD bounding cases to review, where peak containment pressure, as a figure of merit, varies from one DCD revision to the next, Table 1. DCD Revision 6, however, represents an appropriate set of design/operation specifications for the final ESBWR DBA analysis that compares MELCOR audit and confirmatory calculations with DCD reported containment response. Therefore, the auditing basis for this report is now established using DCD Revision 6 information. In terms of the confirmatory aspect of this report, some additional qualification for a portion of the TRACG DBA calculation listed in DCD Revision 6 (post-3day intervention) is still undergoing some review by GEH. Consequently, a part of the confirmatory effort may need further attention and require additional documentation as an addendum to this report. At the present time, the degree of adjustment to the TRACG DBA calculations presented in DCD Revision 6 is expected to be minor, and therefore both audit and confirmatory efforts can be reported here based specifically on information provided in DCD Revision 6.

Previous validation reports, reflecting on the applicability of MELCOR modeling for ESBWR containment calculations, have referenced MELCOR modeling performance for integral test calculations using PANDA facility tests (ISP42, GEH program tests P-series) as well as separate effects testing performed in the GEH PANTHERS facility (steam and steam/air mixtures).[2] Table 2 lists code validation reporting in a PIRT-type format, recognizing the three time periods that characterize the ESBWR passive operation that must be analyzed in order to predict the DBA maximum containment pressure that occurs at the end of the passive period. Some validation reports for the CONTAIN code are also referenced in the Table 2 for single tube PCCS tests performed at University of California Berkley (UCB) and Massachusetts Institute of Technology (MIT). These single tube test references are listed since the tube condensation model (by heat and mass transfer analogy) is essentially identical in these instances for both CONTAIN and MELCOR. Table 2 also

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[1] ESBWR Design Control Document/Tier 2, 26A6642A Revision 6, August 2009.

[2] "MELCOR Code Calculations for the PANDA Facility," proprietary information, July 2005, ADAMS – ML080920009.

indicates an interim report on the MELCOR application to ESBWR DBA analysis (MELCOR ESBWR Containment Performance Study) based on earlier DCD revisions; this report can be found in the NRC ADAMS archive.

In the following sections, a description of the MELCOR ESBWR containment model is presented and its application to ESBWR containment response is discussed for both the passive (0-3 days) and intervention (post-3 days) periods. Section 2 discusses the MELCOR containment model and setting of input parameters for each period, passive and intervention. Section 3 covers the MELCOR audit calculation results specifically for the passive period. Audit and confirmatory calculations for the intervention period are presented and discussed in Section 4 together with a sensitivity calculation where PARs are not credited during the intervention period.[3] Conclusions based on the auditing effort using the MELCOR code for passive and intervention periods are presented in Section 5.

A number of appendices are included within the report, mainly for documentation purposes. Appendix A discusses issues related to drywell gas trapping during the blowdown portion of the ESBWR passive period, showing blowdown peak pressure increases as additional amounts of initial gas are trapped within the drywell via nodalization selection. Appendix B presents various sensitivity cases performed with MELCOR showing variability of pressure profiles to bypass leakage and PARs credit during the passive period. Appendix C documents discussions with NRC staff/GEH/ACRS concerning TRACG upper drywell nodalization and impact on post-3 day pressure response. Finally, Appendix D provides a response to supplemental information documented by GEH for the intervention period, which updateed DCD Revision 6 TRACG calculations for inclusion into DCD Revision 7. This last appendix discusses a revised TRACG ESBWR application methodology for treating variable fan discharge submergence during the post-3day period.

[3] Based on the DCD Rev 6 scenario specification, PARs are not credited during the ESBWR passive period (0 to 3 days) but are credited (100% effective) during the intervention period (3 to 30 days). When the PARs are credited, the source of radiolytic gas to the reactor vessel/drywell is terminated. The sensitivity case that does not credit PARs extends the radiolytic gas sources out to 30 days.

2 MELCOR ESBWR Model

The MELCOR ESBWR model was adapted from an early severe accident (SA) input deck provided by ERI.[4] The model was extensively modified to conform to the needed detail and conservative licensing guidelines recommended when performing DBA containment analysis.[5] Additionally, the early SA input was updated to reflect plant design changes and clarification of data provided in various GEH responses to NRC issued RAIs. The current ESBWR model, Figure 2, reflects the most recent plant design changes as referenced in the DCD Revision 6 submittal. Specially, important updates to the design affecting the passive containment response are 1) added isolation valves for the feedwater balance-of-plant lines, and 2) replacement of spill-over pipes to the suppression pool with retained holes that now connect the drywell annulus region to the vent pipes, located well above the expected pool level in the drywell annulus. Together, these changes have eliminated the feed-water line break (FWLB) as an initiating event that results in the smallest margin of safety as drywell pressure approaches the containment design pressure limit (411.7 kPa)[6]. Due to these design changes, there has been a shift in the DBA event of most interest first reported in DCD Rev0/Rev1 as the FWLB to the MSLB event discussed here.

The ESBWR modeling is divided into five input groupings by component location and connection as follows: 1) reactor vessel and isolation condensers (IC), 2) containment (drywell DW, wetwell WW, and passive cooling condensers PCC), 3) external pools (IC/PCCS, expansion, and storage tanks), 4) intervention components (vent fans and PCC tank pumps), and 5) environmental regions. The following paragraphs describe plant modeling for these groupings.

Reactor Vessel. Shown in Figure 3 is the reactor pressure vessel (RPV) model that includes lower plenum, core, downcomer, chimney, separator/dryer, and steam dome regions. The core region contains three radial fuel sections that are, in turn, vertically segmented into three axial regions. The fuel rods are modeled as simple cylindrical heat structures with a prescribed internal heat source consistent with the power profile and magnitude associated with the reactor rating and decay heating subsequent to scram. Structural steel in the vessel and vessel walls are included in the reactor vessel model. Initialization of the reactor water level (collapsed), flows, fuel and structure temperatures are obtained by running the model for a pre-conditioning time period of 300 seconds. Due to difficulty in modeling two-phase flow and heat transfer regimes during steady state periods, some adjustment of reactor power prior to scram is required to prevent non-physical excursions of fuel temperature in high void regions under full power conditions. The pre-conditioning has two important goals required for blowdown analysis; 1) establishment of water inventory (collapsed level) at operational pressure and temperature,

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[4] MELCOR 1.8.5 Modeling of ESBWR, ERI/NRC 06-201, January 2006

[5] Pertinent licensing documents are Standard Review Plan, chapter 6.2.1.1.C and Regulatory Guide 1.203.

[6] Early versions of the ESBWR DCD reported an absolute design pressure limit of 413.7 kPa. The revised limit of 411.7 reflects on a containment structural analysis performed for a gauge pressure of 45 psig or 310.3 kPa gauge.

and 2) an approximate calculation of fuel and other structure temperatures at full power rating. These pre-conditioning values are required for a prediction of blowdown water releases to the containment from vessel and response of the balance-of-plant (prior to containment isolation), and later for predicting the start of steam quenching during the GDCS draindown. Some sources of water injections to the reactor subsequent to scram are specified, not calculated. These include the feedwater inlet coastdown flow (for ~ 5 seconds) and the injection from the standby liquid control system (SLCS). External liquid water rates and temperatures defining these sources are obtained from GEH's responses to issued RAIs.

For the sequencing of ADS/SLCS and GDCS valve actuation, the model is consistent with the most recent design information where actuation is dependent on a Level 1 signal with associated time delays. Level 1 signal time is calculated in the code based on the collapsed water level in the downcomer. The time delay for isolation of the reactor vessel from the balance-of-plant is specified accordingly to the 13 seconds value listed in the DCD.

Modeling for the IC condensers is included in the MELCOR input decks. However, for the bounding calculations presented here, heat removal is neglected as indicated in the DCD. The initial inventory of water in the IC units is transferred to the reactor vessel by gravity during the blowdown period.

Radiolysis in the core continuously generates hydrogen and oxygen gas in the reactor vessel which then, along with RPV exit steam, enters the drywell through open DPVs and breaks in the reactor cooling system. The radiolyic gas sources are included in the model using external tables for gas rates and temperature versus time, out to 3days. These gas rates were provided by GEH in a separate transmittal[7], and are plotted in Figure 4. Gas rates are assumed terminated for post-3day operation since PARs are credited as 100% effective during the intervention period. For evaluating a sensitivity case where PARs may not be effective (Section 4), the radiolyic gas generation was extended to 30 days through extrapolation based on the decay heat of the core during the intervention period.

Containment. The containment model shown in the sketch of Figure 2 is used to model both the passive and intervention periods during accidents. Significant to the modeling is the characterization of the drywell as a single volume cell. The single cell includes the drywell head, upper drywell, shield annulus, and lower drywell regions. The three GDCS tanks are separately modeled with individual cells that include both open space and associated pools. The reason for treating the drywell region as a single volume is the conservative licensing guidelines that recommend this modeling approach in order to maximize noncondensable gas transfers to the wetwell during the blowdown period; thereby minimizing trapping of gases in the drywell. Minimization of drywell gas trapping produces the maximum pressure increase during the time that the main vents are cleared, and also tends to increase maximum drywell pressure late in the passive period after the vents close. Gas volumes above the falling GDCS pool surface level in each

[7] MFN-06-364 Supp 1 RAI Response 6.2-61 Supp 1 Complete File, January 17, 2007.

GDCS tank are connected by double pathways between the GDCS and drywell in order to allow steam and gas circulation between the tanks and drywell volume. This treatment for dead-ended gas spaces also minimizes gas trapping and represents a conservative modeling methodology.

The three main vents connecting the drywell to wetwell suppression pool are modeled using a prescription for a conservative estimation of inertia lengths as defined in the CONTAIN code's user guideline for BWR plant modeling.[8] ESBWR vent pipes are lumped together and modeled as a single cell volume, including pool. Figure 5 is a representation of the main vent and wetwell model. Conservative treatment for temperature stratification in both the suppression pool and gas space is included in the MELCOR modeling following the procedures outlined in the ESBWR pre-application certification submittal. These modeling procedures that enhance stratification are indicated in Figure 5, where [[

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Heat sink structures are limited in the model, providing a conservative treatment with respect to early and late time heat removal. Containment structures that are exposed only to the wetwell gas and pool regions are included. These structures are defined as inner and outer walls, and prescribed using information provided in response to NRC RAI 6.2-62 (MFN 06-364, date 10/3/2006). The most important structure affecting containment response is the outer wetwell wall above the pool surface. This wall region is thermally connected directly to the ambient environment, and provides a relatively large surface area for long-term condensation and cooling of vapor and gases in the wetwell.

A composite model for PCC condensers connected via expansion tank to the storage/dryer pool and reactor well is included in the MELCOR input deck. Each condenser model is connected to a single volume expansion tank that contains excess water inventory for a split of two and four condensers units, respectively.[9] The overlying atmospheric pressure in the tank volumes is connected to an environmental volume at atmospheric pressure. Shown in Figure 6 is the nodalization for one of the two composite PCC units used in the ESBWR plant model. The smaller tube volumes in the upper level are included to better resolve heat removal rates during initial uncovering and reflooding of tubes during the long-term cooling period. Heat removal from the gas/steam mixture in the tubes to inner tube walls is calculated in a mechanistic manner

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[8] CONTAIN Code Qualification Report/User Guide for Auditing Design Basis BWR Calculations, SMSAB-03-02, ML030700335, March 2003.

[9] The physical layout of the plant shows two expansion tanks, one each servicing a ICS tank and three PCCS tanks on either side of the containment drywell; these tanks however communicate through a storage tank connected to each expansion tank after the liquid level in the expansion tanks reaches a low level set point. Both MELCOR and [[ ]] Early MELCOR models incorporated two tanks and showed no asymmetry in expansion tank water levels during an accident event.

using the MELCOR wall condensation modeling for forced internal flow with film tracking on tubes inner walls. Heat transfer to the PCC pools is modeled using an empirical nucleate boiling equation (Rohsenow correlation) in the MELCOR code. PCC pools are modeled with multi-layered levels or cells to allow tracking pool level and associated time varying saturation temperatures along tube outer walls. The PCC modeling approach has been validated using single and multiple condenser tube test data generated for the GEH design. These validation efforts have been reported for models exercised using the CONTAIN and MELCOR codes (integral tests ISP42, P1 and P2 in the PANDA facility, pure steam and steam/air tests in the PANTHERS facility, and single tube tests in both the USB and MIT testing facilities).[10] The most recent reporting is for the MELCOR code, which includes both PANDA and PANTHERS facility tests.[11]

Bounding values for loss coefficients, heat transfer multipliers (wetwell walls and PCCS inner tube walls), and decay heat rates were included according to listed values in the DCD Revision 6, and include here as Table 3. A leakage or bypass value between the drywell and wetwell was set to the ESBWR specification for bounding analysis, 2.0 cm^2 ($A/\sqrt{K}$). Two of the three vacuum breakers were credited for the analysis (conservative assumption regarding maximum WW/DW gas transfers and single failure analysis).

PCC, Expansion, and Storage Pools. Shown in Figure 7 is the layout for the PCC, expansion, and storage pools. The IC tank volumes are included in the expansion tank volumes which are connected directly to the PCC tanks. When the collapsed pool level decreases to 29.6 meters, valves connecting the storage and expansion tanks open transferring water to the expansion pool.

Intervention components. Connected to the vent line of each PCCS condenser is an exhaust line which is connected to a fan that exhausts PCCS gas/steam through an exit pipe in a designated GDCS tank. The fans operate only during the intervention period starting at 3 days. Fan performance characteristics are derived from the Semiscale pump model in the TRACG code. For this specific application, the fan rated head and flow are 2000 m^2/s^2 and 0.5 m^3/s. Table 4 provides fan minimum performance requirements.[12]

Exhaust lines terminate in trays or drain pans located in the GDCS pools, Figure 8. The trays are kept full of water by the PCCS condensate drain lines. The fan exhaust line exit is located from 9 to 10 inches below the lip of the tray. Consequently, the approximate static head at the exit of the fan exhaust is ~ 10 inches, even though the GDCS tank level may drop below the tray lip elevation. The MELCOR model uses a 10 inch minimum static head assumption that is consistent with post-3day analysis

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[10] The heat and mass transfer correlations used in the CONTAIN and MELCOR code are essentially identical in that both use a heat and mass transfer analogy methodology to correct steam condensation for the presence of noncondensable gases.

[11] J. Tills, "MELCOR Code Calculations for the PANDA Facility," SNL Letter Report, July 2005, ADAMS ML080920009.

[12] Table 4 (6.2-49) has been updated in subsequent DCD revisions (additional row of Head/Flow entry, and footnote to indicate that the range of fluid densities associated with values in the table is 1.81 to 3.81 kg/m^3).

reported in GEH response to RAI 6.2-140 S06 (MFN 09-023 Supp. 4, dated 2/27/2010).

The re-flood of the PCC tank at 3 days is by a constant 200 gpm flow of external water added to the expansion tanks. No level control of water in expansion/PCC tanks is assumed except for over-flow at the approximate level of the tank exit to the environment or return line to the storage tank. As indicated in Figure 7, the PCC condenser units are divided according a 2/4 split. This configuration is necessary in order to model the post-3day operation period with 4 of 6 fans operational, according to conservative requirements noted in DCD Revision 6.

Environment. Two environment cells are included in the ESBWR plant model. One cell is connected to the expansion and storage pool volumes providing a constant ambient pressure boundary and a reservoir for any water overflow from the expansion tank during re-flooding. The other environment cell is thermally connected to the outer surfaces of the wetwell wall.

3 MELCOR Bounding Audit Calculation (0-3days)

The MELCOR audit calculation for the containment response to a MSLB initiated event in the ESBWR plant is reported here for bounding initial conditions and conservative model parameters and biases as described in the DCD Revision 6 submittal. The audit calculation includes radiolytic gas (H2/O2) input to the containment as a result of radio-chemical processes occurring in the reactor vessel (no PARs), and assumes the failure of 1 DPV during the accident. Shown in Figure 9 is the MELCOR calculated drywell pressure profile for the bounding MSLB scenario. On the upper portion of the figure the time periods representing the passive and intervention periods are shown. At the bottom of the figure the passive period is divided into three sub-periods: blowdown, GDCS draindown and recovery, and long-term cooling. These divisions indicate periods where various phenomena or processes dominate. At the start of the accident, the blowdown period is dominated by the rapid release of primarily steam from a main steam line break which pressurizes the drywell, and is moderated by main vent clearing. The large dip in pressure starting at ~ 0.2 hours is the result of GDCS draindown causing a quenching of RPV steaming. At ~ 0.4 hours, the PCC efficiency is reduced due to an increased concentration of non-condensables in the condensers from open vacuum breakers. Coincident with this effect is an increase in steaming from the RPV resulting from a reduced quenching rate as the GDCS pool level drops. The combination of these events (PCC efficiency decline and reduced quenching) gives rise to the DW pressure increase or recovery. With the vacuum breakers closing as the DW pressure rises, PCCS heat removal efficiency also increases and eventually at the point referred to as “PCCS start-up” the DW pressure flattens as the pressure is controlled mainly through passive heat removal. With the continued generation of non-condensable radiolytic gases, a significant amount of these gases are drawn into the PCCS with the steam flow, accumulating in the lower portion of PCCS condenser tubes. The accumulation of gases produces a condition whereby the PCCS self-regulates, matching the inlet steam flow by condensation in the PCCS tubes. Self-regulation is possible when small amounts of accumulated gases are vented to the wetwell suppression pool; the venting provides the self-regulation where heat removal by condensation and reactor decay heat in the form of steam to the PCCS is essentially matched.

The self-regulation effect, however, is accompanied by a pressure drop between the DW and WW gas spaces. The pressure differential is the additive effect of 1) the irreversible pressure drop in the PCC inlet pipe, and 2) the larger static pressure head of the submerged PCCS vent pipe in the WW suppression pool. The pressure difference between drywell and wetwell spaces forces bypass steam to enter the wetwell via bypass leakage. Bypass steam adds to the vapor content of the wetwell open space, and additionally, the hot bypass steam entering the wetwell also heats the wetwell gases during mixing. The bypass steam is therefore the cause of the nearly constant pressure rise observed during the majority of the long-term cooling period. A fixed DW/WW pressure differential as indicated in Figures 10, during the long-term cooling period, is a characteristic signature of a self-regulating PCCS that is dependent on a nearly constant source of noncondensable gas generated in the RPV and transferred to the PCCS via the drywell transport. Consequently, the radiolytic gas source is an important factor that forces the passive heat removal process into a self-regulation mode that results in the type of DW/WW pressure rise that is observed above. A further explanation of self-regulation and partial-regulation without radiolytic gas generation is provided in Appendix B. It should also be noted that when the PCCS is in a self-regulation mode with excess capacity, a very accurate modeling of the PCCS heat removal efficiency during the long-term period is not critical since bypass leakage is the dominating phenomenological process affecting pressurization.

The pressure profile presented in DCD Revision 6, Figure 11, is calculated using the TRACG code and the TRACG ESBWR containment nodalization model, as shown in Figure 12. During the passive period, except for the some modeling choices that cause significant differences in drywell gas trapping during the blowdown (see Appendix A), the MELCOR and TRACG models present similar modeling approaches for the ESBWR design and operation (vent path clearing, valve signals, etc.). Therefore, the MELCOR audit calculation is also a confirmatory calculation for the TRACG results.

There are three pressure values that are important for making comparison to the TRACG calculated pressure profile for the passive period: 1) peak blowdown pressure, 2) pressure at time of "PCCS start-up," and 3) pressure at the end of the passive period (259200 seconds, 72 hours, 3 days). The approximate time locations of these pressures are indicated in the pressure profile plotted in Figure 13. Table 5 provides a comparison of the MELCOR and TRACG pressure values at these times. Very good comparisons are indicated for the pressure comparisons at the "PCCS start-up" and end of the passive period. During the blowdown period, the MELCOR calculated peak pressure is significantly higher than the TRACG value. The MELCOR DW modeling follows the Standard Review Plan for calculating peak pressure in a BWR-type containment[13]; that is, in the sense that the model is physically appropriate and conservative – using a single DW control volume that maximizes gas transfers from DW to WW during the blowdown period. Because the TRACG model includes a number of control volumes (symmetrical rings) to model the DW, gas trapping during the blowdown period causes a reduced DW pressure rise early in the transient. Since the long-term pressure rise exceeds the blowdown pressure peak, this non-conservative aspect of the TRACG model is noted but not considered a safety issue for this specific application. Included appendices more fully address this point with a series of MELCOR sensitivity cases for blowdown gas trapping (Appendix A) and long-term cooling (Appendix B).

Shown in Figure 14 are the long-term drywell pressure comparisons for the MELCOR and TRACG models in the passive period of operation. Comparisons for the DW gas/steam mixture temperatures during the short and long-term operation periods are plotted in Figures 15 and 16, respectively. The slightly smaller pressure increase for the TRACG model in Figure 14, at the end of the passive period (72 hours), is believed to be due to a small amount of gas trapping in the DW head region compared to the "no-trapping" response of the MELCOR single-volume DW model. The DCD includes a discussion for a number of separate "add-on" calculations for DW pressure. One case includes a "hand" calculation where all air in the DW at 72 hours is transferred to the WW, see DCD

[13] Standard Review Plan (SRP) section 6.2.1.1C, Revision 7.

Table 6.2-5a of chapter 6.2. In this case, the DW pressure at the end of the passive period is increased from 396.25 to 400.3 kPa. The higher pressure value can be compared to the MELCOR maximum long-term pressure of 400.65 kPa. The safety margin[14], expressed in percentage below design limit (gauge), in both cases is 4% for a peak pressure of ~ 400 kPa.[15]

[14] Safety margin (%) = (1-(gauge pressure for calculation / design gauge pressure)) * 100
[15] ESBWR containment design pressure = 411.7 kPa, with ambient pressure = standard atmosphere

4 MELCOR Bounding Audit Calculation (3-30days)

According to the DCD discussion of post-LOCA containment cooling and recovery, starting at 3 days or 72 hours, the ESBWR plant credits nonsafety-related Structure, System, or Components (SSC) to rapidly reduce containment pressure and temperature to a level where there is an acceptable margin, and then continues to function to maintain these conditions indefinitely. This post-3day operation and control is accomplished by the following:

1) SSCs to refill the IC/PCCS pools;
2) PCCS Vent Fans;
3) PARS; and
4) Power supplies to the PCCS Vent Fans and the IC/PCCS pool refill pumps.

For the post-3day period, the audit calculation is performed with the design and operation procedures specified in the DCD and clarified in telephone conferences with GEH and through the formal RAI process. The containment cooling and recovery analysis reported in the DCD takes credit for 4 of 6 PCCS Vent Fans. Presented below are MELCOR calculations for containment pressure where the MSLB (1 DPV failure) event is extended past the passive period of 3 days out to 30 days. The extended period is referred to in this report as the *intervention* period. At the start of the intervention period the GDCS pool levels are at the top lip of the GDCS drain pans, with the fan exhaust line submerged 10 inches below the top lip of the pan. Based on RAI responses, the IC/PCCS pool is refilled at a constant rate of 200 gpm, with no level control. The drain pan design maintains fan outlet submergence of 10 inches minimum, and the operational procedures, as communicated, specify no level control via variable pump flow. Therefore, IC/PCCS pool depth will remain relatively fixed once the expansion tank overflow or backflow pipe to the storage tank has been reached. These are the design and operational parameters that are known to be correct at the time of the DCD Revision 6 release.

While performing the calculation for the DCD Revision 6 using the TRACG model, GEH ran the calculation 1) without including a drain pan, and 2) with IC/PCCS pool level control (limiting the pool level to the top of the PCC condenser tubes). Because these modeling assumptions do not adhere to the design and operational procedures for the intervention period, a direct comparison to an audit calculation that follows design and operating procedures would not be appropriate. Therefore, in the discussion below two MELCOR calculations are presented: 1) a confirmatory calculation setup to adhere to the TRACG model where the neglect of a drain pan and IC/PCCS pool level control is included and 2) an audit calculation, where the design and operational features of the SSCs are appropriately modeled.

Confirmatory calculation. Shown in Figure 17 is the IC/PCCS refill water level calculated with the TRACG code, where the level control during re-flood is clearly indicated. A low pool level in this calculation effectively holds the saturation temperature along the submerged tubes to a lower value due to a reduced static head compared to a case where the pool level is allowed to increase to a higher expansion pool depth, raising static pressure along the tube and also saturation temperature. The lowering of the pool saturation temperature along the condenser outer tube wall effectively increases the heat removal capacity of the condenser and, in turn, lowers the containment pressure.

Another design adjustment in the confirmatory calculation involves the removing the effect of that the GDCS drain pan has on vent fan performance. The GDCS pool level is shown to decrease during the intervention period for the TRACG model, Figure 18. Without the drain pan modeled, the static head associated with a submerged fan outlet continues to decreases as the outlet submergence also decreases, approaching the point of complete uncovery. Reduced fan discharge submergence decreases the static head at the fan outlet, and results in a higher fan flow than a case where the submergence had been kept at a larger fixed value (drain pan effect included). Higher fan flow decreases the time delay for gas/steam cycling (re-circulation). Shorter cycling times increases heat removal over a given time period, and therefore excluding the drain pan effect has a tendency to slightly increase the rate of containment pressure reduction. The MELCOR modeling of GDCS pool level also show a decreasing level during the intervention period, Figure 19. Without the drain pan accounted for, the fan outlet submergence decreases as the GDCS pool level drops in this model also. In both MELCOR confirmatory and TRACG DCD calculations, the fan outlet elevation is set at 10 inches of submergence at the start of the intervention period, beginning at72 hours. (See Appendix D for additional discussion on the TRACG GDCS drain pan simulation modification for DCD Revision 7.)

Shown in Figure 20 are the post-3day DW pressure response comparisons for the MELCOR and TRACG codes. Both codes calculate similar trends with the TRACG results trending below the MELCOR curve throughout the intervention period. The offset in the pressures between the codes occurs is generated during the first few hours after the fans start-up and the offset is maintained at approximately 40 kPa out to 720 hours (30 days). Both predictions however show a slight continued drop in pressure late in the intervention period. The behavior exhibited suggests that intervention measures as modeled in the confirmatory case (IC/PCCS pool refill and PCCS vent fan operation) results in a sustained reduction of containment pressure out to 30 days.

A couple of sensitivity calculations have been performed in an attempt to identify the cause of the early offset in containment pressure between models when the pressure "cliff" (i.e., rapid pressure drop) occurs, approximately 72 to 75 hours in Figure 20. The sensitivity calculations explored DW pressure variation for small non-condensable gas concentrations in the condenser tubes by isolating the vacuum breakers, and in another case by increasing the effective PCCS condenser heat removal efficiency using a multiplier (1.7) on the heat and mass transfer correlations. These studies indicated that the DW pressure is very sensitive to small transient changes in the non-condensable gases in the condensers, and not very sensitive to large increases in the heat and mass transfer coefficient. Because the early period in the intervention period is attended by somewhat erratic fan flows due to large flow variability at the time of highest fan head (fan chatter), the "cliff" phenomenon is extremely difficult to model. Consequently, further investigation into the magnitude of the "cliff" response calculation was determined not to be a fruitful pursuit without the insight that may be available from experimental testing.

However, further investigation of the possible causes for the lower TRACG DW pressure prediction during the late intervention period led to issues involving the condenser efficiency modeling and accuracy of the TRACG model for gas trapping within the DW. For example, although the TRACG empirical method for condenser heat and mass transfer generally predicts slightly higher condenser efficiencies at low flow and low inlet gas concentrations than MELCOR's mechanistic condenser model, late in the intervention period the condenser flows and the gas inlet concentrations are both increased, and the difference between predicted efficiencies between codes are relatively minor (few %). Differences however in gas trapping between codes is more problematical. At the start of the intervention period, the TRACG calculation has some trapped noncondensable gas in the upper head region of the DW. Although separate calculations were performed to eliminate this effect, as noted above, the TRACG calculation for intervention actually begins the intervention period with some trapped gas in the DW resulting in a lower DW pressure than MELCOR (~ 4 to 6 kPa lower at 72 hours) at the beginning of the period.

Additionally, variation in gas trapping during the intervention period, affected by modeling errors associated with characterization of the upper DW and DW head region has been addressed by GEH. The errors, associated with the artificial pathways connecting GDCS and DW head regions was explored in a corrected TRACG model by GEH (Appendix C). The corrected model resulted in a slower pressure decrease; i.e., higher DW pressure in the late intervention period, calculated 72 to 192 hours. Although GEH did not completely resolve the gas trapping tendency for a re-calculation out to 30 days, the ~40 kPa difference shown in Figure 20 would be expected to be reduced with a corrected GDCS, upper DW and DW head model. Given the long intervention period, a ~ 40 kPa or less pressure difference between DCD reported values and the confirmatory calculation is considered of less importance than the pressure trends that are in reasonable agreement. The confirmatory calculation thus confirms 1) a rapid pressure drop even though the magnitude is not matched, and 2) a maintained pressure control out to 30 days, as reported in the DCD. These conclusions however are dependent on the intervention modeling assumptions used to perform the TRACG calculation and applied also for confirmation (PCCS pool level control and no simulation of GDCS drain pan), and must be revised for the audit case considered below.

Audit calculation. The audit calculation for the post-3day intervention period is setup to represent all of the design and operational aspects of the ESBWR plant. Primarily, this includes PARs at 100% efficiency (no radiolyic gas addition post-3days), IC/PCCS pool refill without level control other than overflow, and PCCS Vent Fans with a minimum vent outlet submergence of 10 inches (GDCS drain pan simulation).

The curve labeled "MELCOR reference calculation" in Figure 17 shows the post-3days PCC water level calculated for the audit. The pool level reaches a maximum level of ~ 31.5 meters elevation at approximately 200 hours, and maintains this level through the remainder of the intervention period. The late time PCC pool level is about 1.5 meters above the top of the condenser tubes, and consequently 1.5 meters above the level control in the confirmatory case discussed above. Shown in Figure 21 are calculated vent fan flows versus fan head. This figure shows that the MELCOR fan performance model follows the performance curve specified in the DCD, Table 4. Figure 22 shows the fan head as a function of elapse time. The main contributors to the fan head calculation are shown in Figure 23.[16] During fan start-up, there is notable stability (fan chatter) arising from induced flows during brief periods of rapid variations in condensation rates within the condenser tubes as accumulated noncondensable gases are being purged from the condensers. Feedback from the condensation rate changes is manifested as fluctuations in condenser heat removal, and correspondingly PCC inlet pressure losses.[17] As time progresses, the condensation rates tend to reduce and stabilize, such that the fan head losses correspondingly reduce and the fan flow stabilizes, Figure 22, following smoothly the fan performance curve, as indicated in Figure 21.

Shown in Figure 24 is the MELCOR audit calculation for the period 0 to 30 days. The intervention period is characterized by a "rapid" reduction in containment pressure due to the operation of vent fans (4 fans operational) and PCC pool re-flood. These non-safety measures are determined in this calculation to be adequate for maintaining containment pressure control. The MELCOR audit calculation has therefore confirmed the stated function of the plant intervention measures, which is to maintain containment pressure below the design pressure out to 30 days. The resulting late time containment pressure value however is notably higher than the TRACG prediction[18] and is shown to have a flat profile at late time compared to the slight decreasing slope presented in the DCD.

Non-safety sensitivity calculation.

One of the key non-safety feature that is credited during the intervention period is operating PARs functioning at100% efficiency to remove any additional radiolyic gas generated in the RPV post-3days. For the purpose of this sensitivity calculation, it is assumed that for the low hydrogen concentration and high steam conditions in the DW during the intervention period prevent PARs from removing RPV generated radiolyic gases post-3days. The generation rate for post-3day radiolyic gas generation is shown in Figure 4. Shown in Figure 25 is the MELCOR calculated containment pressure, where PARs are not credited for either the passive or intervention periods.[19] In the sensitivity calculation, the containment pressure is "rapidly" reduced early in the intervention period, as in the audit case, but pressure control is not maintained and the pressure response shows a continued rise with time. At 30 days the safety margin is ~ 10% and is decreasing, as compared to the 24% safety margin that is being maintained with PARs 100% effective.

[16] Fan head = PCC inlet loss + condenser tube loss + fan line loss + fan outlet static head – GDCS to DW loss.

[17] The strong positive feedback to fan flow is a consequence of operating on the fan curve in a region where the performance curve is relatively flat; that is, where very small pressure variations result in large flow changes.

[18] Safety margin at 30 days is 24% for the audit calculation and 48% for the TRACG DCD Rev6 calculation

[19] PARs are not credited during the passive period since the PARs are non-safety features of the plant design.

5 Conclusions from the MELCOR ESBWR Audit Calculations

At the time this report was written, the most current submittal for the ESBWR plant DBA was DCD Revision 6, documented in August 2009. The audit calculation performed with the MELCOR 1.8. 6 code was based on design and operational information obtained from DCD Revision 6, with numerous RAI responses, and joint JTA/NRC/GEH telephone conferences to clarify those responses. The MELCOR audit calculation has evolved over the years since the original DCD Revision 0 submittal to accommodate changes in the design and recently added intervention period. A number of reports and presentations of MELCOR calculations have been documented throughout this submittal process. This report summarizes and concludes reporting through the DCD Revision 6 submittal.[20] Some additional plant design changes may be anticipated to accommodate concerns related to beyond DBA or severe accident issues, those design modifications are not addressed in this report.

The DBA audit calculation reported here follows an accident scenario (MSLB with single DPV failure) that poses the greatest threat to the ESBWR containment design.[21] For the passive period (0 to 3 days), the audit calculation shows that the maximum containment pressure occurs at the end of the passive period just prior to activation of non-safety features that reduce containment pressure and maintain pressure control throughout the intervention (3 to 30 days) period. The maximum pressure is calculated with both MELCOR and TRACG to occur in the DW at 3 days. The MELCOR maximum pressure calculated is **400.65 kPa**, resulting in a margin of safety of **4%**. The MELCOR audit calculation confirms the DCD TRACG post-blowdown containment response trends and the reported **4%** margin of safety at 3 days. For the ESBWR containment post-blowdown analysis, the MELCOR audit and DCD TRACG model results show very good agreement during the long-term passive period, and the audit calculation for this period is therefore also confirmatory.

Significant differences in DW gas trapping amounts during the blowdown period between the MELCOR and TRACG containment models exist, causing the calculated maximum blowdown pressure predicted with TRACG to be lower than the MELCOR calculated peak pressure. This difference is due to retained DW gases in the TRACG model. However, since the post-blowdown containment pressure response exceeds the pressure calculated during the blowdown (MELCOR or TRACG values) for this design, the audit analysis focused on phenomenon dominant during the post-blowdown period where maximum pressure occurs. During this portion of the accident, and only this portion, differences in gas trapping is minimized between the two containment models, and both MELCOR and TRACG codes calculate essentially identical pressure response profiles.

The purpose of the non-safety features activated at 3 days is to rapidly reduce the containment pressure and maintain pressure control indefinitely. Following the DCD

[20] For completeness some RAI responses that go beyond the DCD Revision 6 documentation have been included and discussed in Appendix D. These discussions however do not impact the conclusions of the MELCOR audit as stated in this report.

[21] The MSLB with either single DPV or SRV failure are essentially equivalent scenarios, and represent the maximum challenge to the containment integrity.

described intervention design features and operation, the 3 to 30 days audit calculation confirms this purpose, although there are noted differences in modeling between the MELCOR and TRACG models that affect the magnitude of the rapid pressure decline during the first few hours of intervention. The MELCOR audit pressure calculation shows that the margin of safety of **4%** at 3 days is increased to **24%** with intervention and maintained at that level out to 30 days.

A direct comparison of the MELCOR audit calculation to the DCD TRACG calculation during the intervention period is negated by the particular assumptions made in the TRACG modeling – assumptions noted to be in conflict with the DCD specified non-safety components design and operation. Consequently, a separate MELCOR confirmatory calculation was performed to demonstrate the containment pressure trends reported in the DCD as determined with the TRACG model that neglected GDCS drain pan effects and PCCS pool re-flood procedures. The MELCOR confirmatory calculation verified that the containment pressure trends observed in the DCD Revision 6 submittal could be recreated by including particular TRACG model assumptions. An updated TRACG calculation for the intervention period discussed in a response to NRC RAI that addressed DCD Revision 6 model deficiencies were reviewed in Appendix D to this report. That review does not alter the conclusions of this report with respect to the audit and confirmatory aspects of the MELCOR ESBWR containment analysis.

Finally, a sensitivity calculation for the intervention period was performed with the MELCOR audit model where the specification for PARs operating at 100% effectiveness during the post-3day period was removed (no PARs). Although the MELCOR adjusted audit calculation did indicate a rapid reduction in containment pressure shortly into the intervention period, pressure control could not be maintained, and the safety margin at 30 days was reduced from 24 to 10%, with a slightly rising pressure profile.

Table 1. Bounding pressure changes for DCD versions from first submittal (Revision 0) to Revision 6, showing a stabilization of bounding peak pressure values with Revision 6.

DCD Version	Bounding Event	Peak Pressure, kPa
Rev 0 (8/2005)	FWLB*	342.0
Rev 1 (2/2006)	FWLB	344.0
Rev 2 (11/2006)	FWLB MSLB**	406.1 375.4
Rev 3 (2/2007)	FWLB MSLB	338.9 384.2
Rev 4 (9/2007)	FWLB MSLB	351.7 384.6
Rev 5 (5/2008)	FWLB MSLB	369.63 396.25
Rev 6 (8/2009)	FWLB MSLB	369.63 396.25

*feed water line break (1 SRV failure)
**main steam line break (1 DPV failure)
*** noncondensible adjustment; 408.06 kPa
+noncondensible adjustment; 400.3 kPa

Table 2. MELCOR validation matrix for modeling the ESBWR passive period.

Event: Phenomena/Process Modeling	Validation type (Code-to-Code) (Integral Effects Test – IET) (Separate Effects Test – SET)	MELCOR References [Related]
Blowdown:		
Break & Main vent clearing	Code-to-Code GE TRACG (ESBWR break discharge)/GE Analytical Model (Grand Gulf licensing)	ESBWR Performance Study Report(1) Presentation to MCAP(2) on Mark III type blowdowns
Wetwell pressurization		
GDCS:		
Drywell mixing/purging	IET – ISP-42: Phase A – PCCS start-up Phase B – GDCS Discharge IET – GE Tests, P-Series P1	PANDA Report (3) Presentation to CSARP (4) on PANDA Modeling and Calculations for ISP42
Vacuum breaker operation		
PCCS start-up		
GDCS draindown		
RPV Quenching and Steaming		
Long-term:		
PCCS degradation/noncondensables	SET – PANTHERS PCC/MIT/UCB (Note: PANTHERS is a prototypical component test of PCC unit; whereas, MIT/UCB tests are single tube tests)	PANDA Report(3) PANTHERS Analysis Appendix (3) [CONTAIN MIT & UCB Single tube (5), CONTAIN PANTHERS Rpt (6)]
PCCS "bounding"	IET – ISP-42 Phase C – Long-term decay heat removal Phase D – Overloaded PCCS IET – P1	PANDA Report (3)
PCCS venting	IET – ISP-42/P8	
PCCS tank boil-down/reflooding	IET – P8 SET – PANTHERS	
DW trapping & distribution noncondensables	IET – ISP-42 Phase E – Release of hidden air IET -- P7 (helium)	
Wetwell Pool Interface HMT	IET – ISP-42: Phases A-E	
Wetwell wall heat and mass transfer (HMTA)	SET – Dehbi tests (MIT), IET – CVTR	MELCOR CVTR Report & Appendices (7)
Bypass leakage	Code-to-Code, analytic assess	---

1. "MELCOR ESBWR Containment Performance Study (Draft)," J. Tills, November2006, ADAMS ML063180380, Proprietary Information.
2. "Short-term Containment Analysis for MARK III Containments with Emphasis on Main Vent Critical Flow," J. Tills, MELCOR Cooperative Assessment Program (MCAP) Meeting, September, 2006.
3. "MELCOR Code Calculations for the PANDA Facility," J. Tills, July 2005, ADAMS ML080920009 (including Appendix C: Analysis of the GE PANTHERS Tests using the MELCOR code).
4. "Post-test Analysis of ISP-42 (PANDA Tests) using the MELCOR code," J. Tills MELCOR Cooperative Assessment Program (MCAP) Meeting, September 2005.
5. "Letter Report on PCCS Modeling for SBWR," J. Tills, SNL Letter report to NRC, March 1994.
6. "Analysis of the GE PANTHERS Tests using the CONTAIN Code," J. Tills, SNL Letter Report to NRC, June 1996.

7. "An Assessment of MELCOR 1.8.6: Design Basis Accident Tests of the Carolinas Virginia Tube Reactor (CVTR) Containment (including selected Separate Effects Tests)," J. Tills, A. Notafrancesco, and P. Longmire, SAND2008-1224, February, 2008.

Table 3. Model parameters for the containment bounding calculation [DCD, Revision 6].

No.	Model Parameter	Base value	Distribution	Uncertainty (1 sigma)	Bounding case	Bounding value used
1	Critical Flow* (PIRT84)	1.0	Normal	9.5%	- 2 sigma	0.81
2	Decay Heat Multiplier	1.0	Normal	~0.05	+ 2 sigma	Decay Heat +2 sigma
3	Surface Heat Transfer** (PIRT07)	100	Uniform	1 to 200	Lower bound	1
4	Passive Containment Cooling inlet Loss (k/A^2)	1065 m^{-4} 9.192 ft^{-4}	Normal	260.0 m^{-4} 2.244 ft^{-4}	+ 2 sigma	1585 m^{-4} 13.68 ft^{-4}
5	Passive Containment Cooling Heat Transfer (PIRT78)	1.0	Normal	7.9% (bias – 6.0%)	- 2 sigma	0.902
6	Vacuum Breaker Loss (k/A^2)	747 m^{-4} 6.45 ft^{-4}	Normal	93.6 m^{-4} 0.81 ft^{-4}	+ 2 sigma	934.1 m^{-4} 8.06 ft^{-4}

* A model multiplier (PIRT84) of 1.0 is applied to the critical flow for the nominal cases for all breaks. The choked flow uncertainty in the TRACG model (Reference 6.2-1) has been determined to be 1 sigma (9.5%) uncertainty, or + 2 sigma (+0.19) variance. For long-term containment pressure, uncertainty analysis shows that a smaller critical flow multiplier results in higher DW pressure. Hence for all bounding cases, a smaller model multiplier (PIRT84) of 0.81 (=1-0.19) is applied to the critical flow model to account for the lower uncertainty range (-2 sigma value) for the choked flow.

** Free surface to vapor heat transfer in WW.

Table 4. PCC Vent fan minimum performance requirements [Table 6-2-49, DCD Revision 6].

Normalized Fan Head ΔP/ρ m^2/s^2 (ft^2/s^2)	Flow m^3/s (CFM)
2,410 (25,900)	0.071 (150)
2,380 (25,600)	0.141 (300)
2,290 (24,600)	0.283 (600)
2,050 (22,100)	0.472 (1,000)
1,880 (20,200)	0.566 (1,200)

[The inlet losses for the PCCS are described in DCD Tier 2, Revision 6, Table 6-2-8, Item 4. The outlet losses shall not exceed a k/A^2 value of 1500 m^{-4}.]

Table 5. MELCOR and TRACG pressure point comparisons for the bounding MSLB (1 DPV failure) event in the ESBWR plant.

Pressure Point*	MELCOR		TRACG (DCD Revision 6)	
	Time, hours	Pressure, kPa	Time, seconds	Pressure, kPa
Blowdown peak	0.02	336.8	0.02	255
“PCCS start-up”	1.5	307	1.5	312
End passive period	72	400.65	72	396.25

*Times for pressure point selections are indicated in Figure 9.

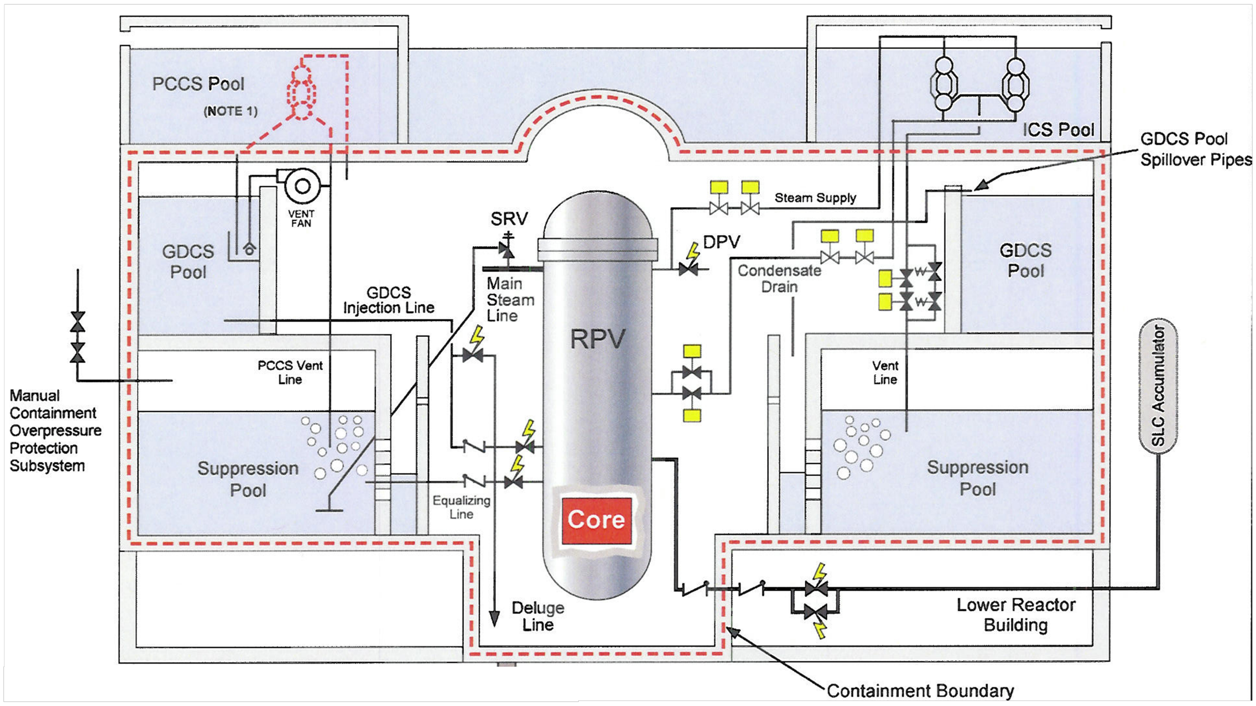

Figure 1. Sketch of the ESBWR containment layout [DCD Revision 6].

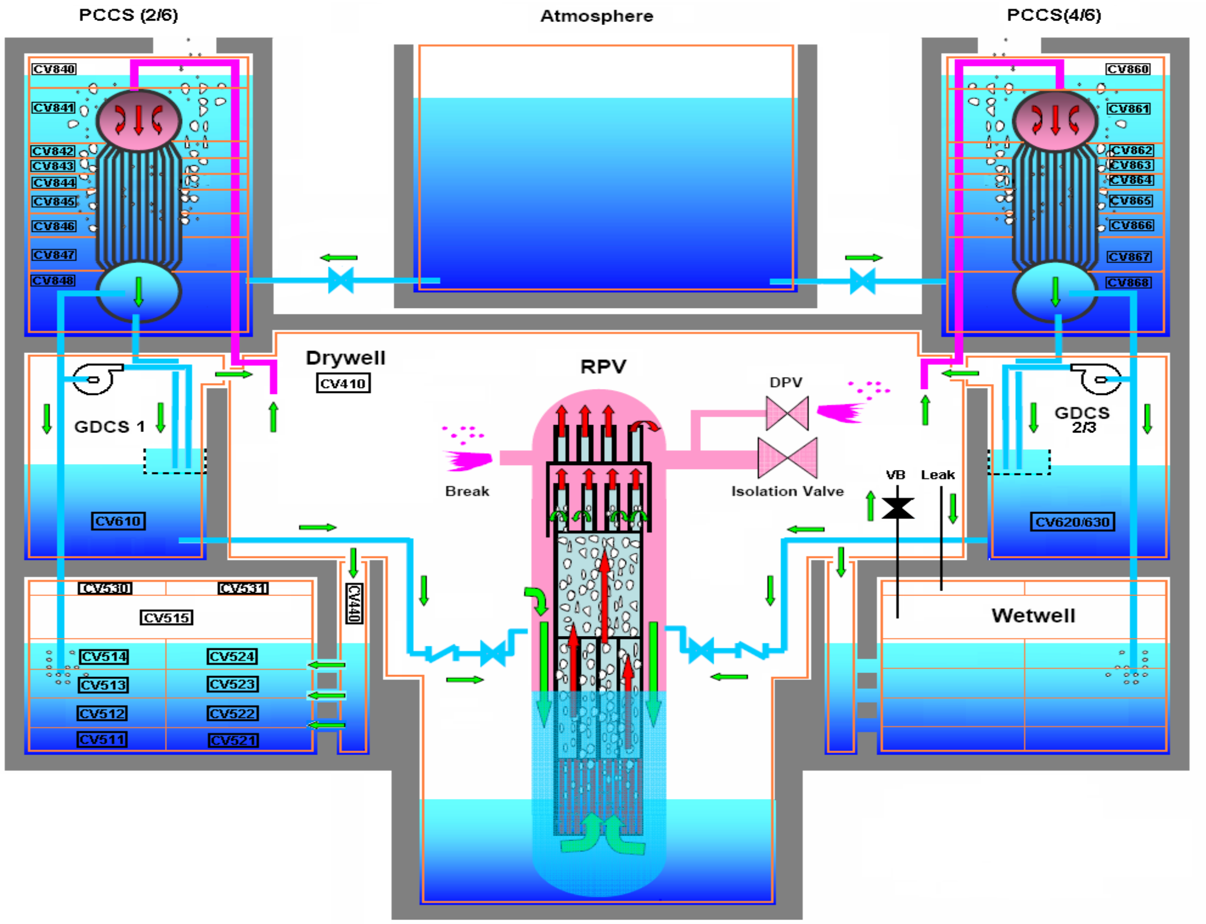

Figure 2. MELCOR containment model for the ESBWR plant.

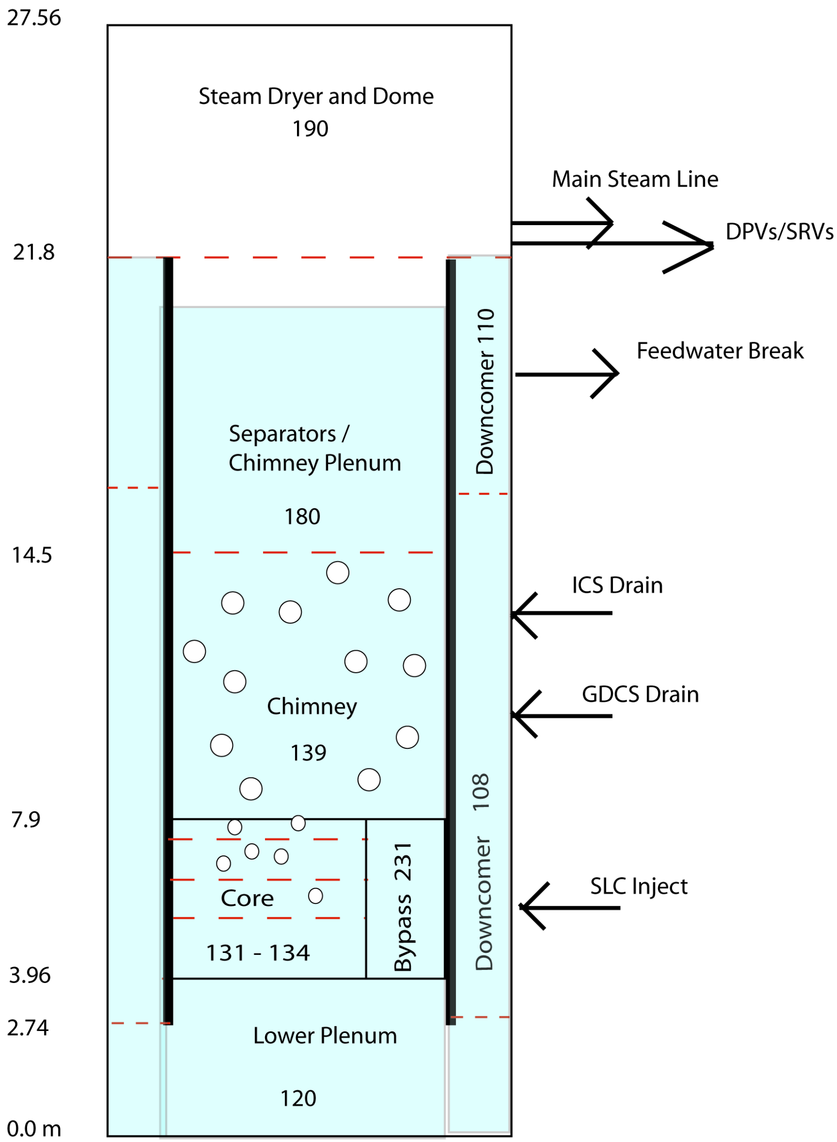

Figure 3. MELCOR representation of the ESBWR reactor pressure vessel (RPV).

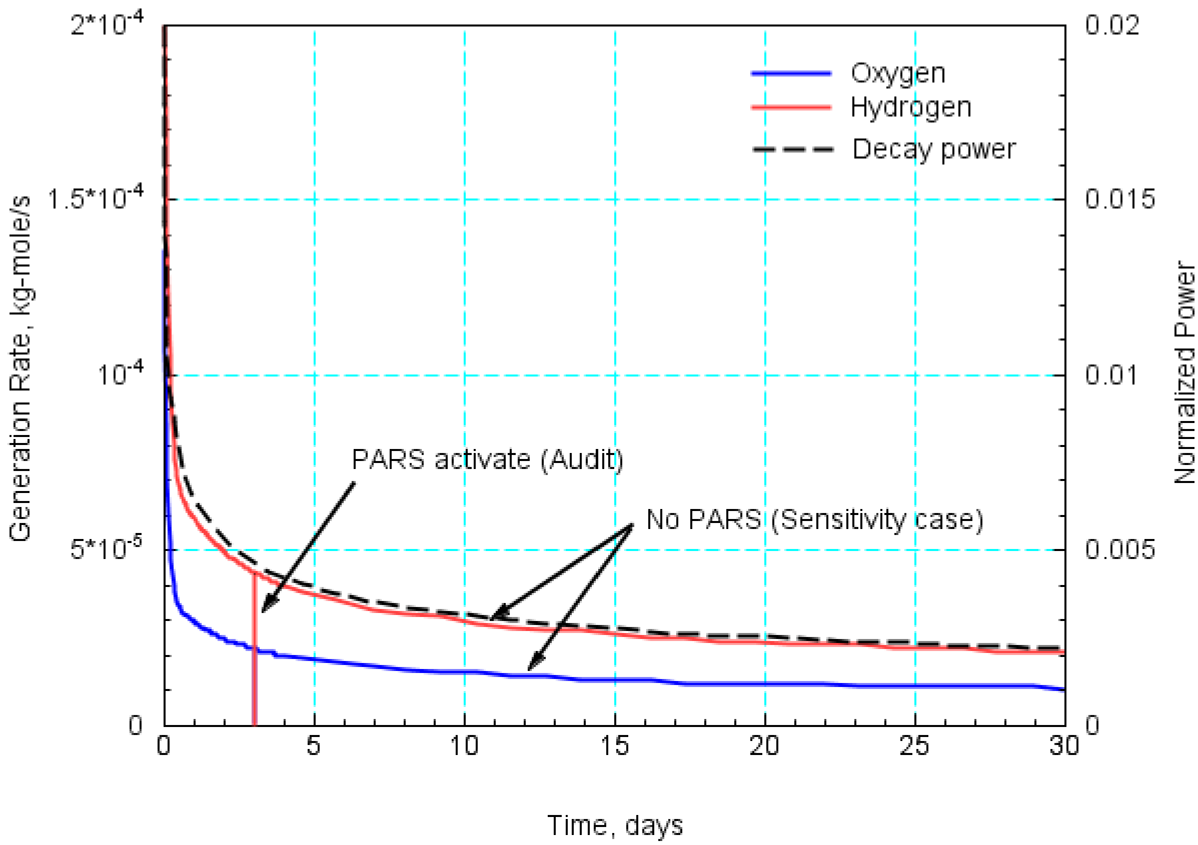

Figure 4. Radiolysis release rates used in the MELCOR bounding DBA calculation (0-3 days) as supplied by GEH. Extension from 3 to 30 days is determined by extrapolation consistent with the ESBWR decay rate.

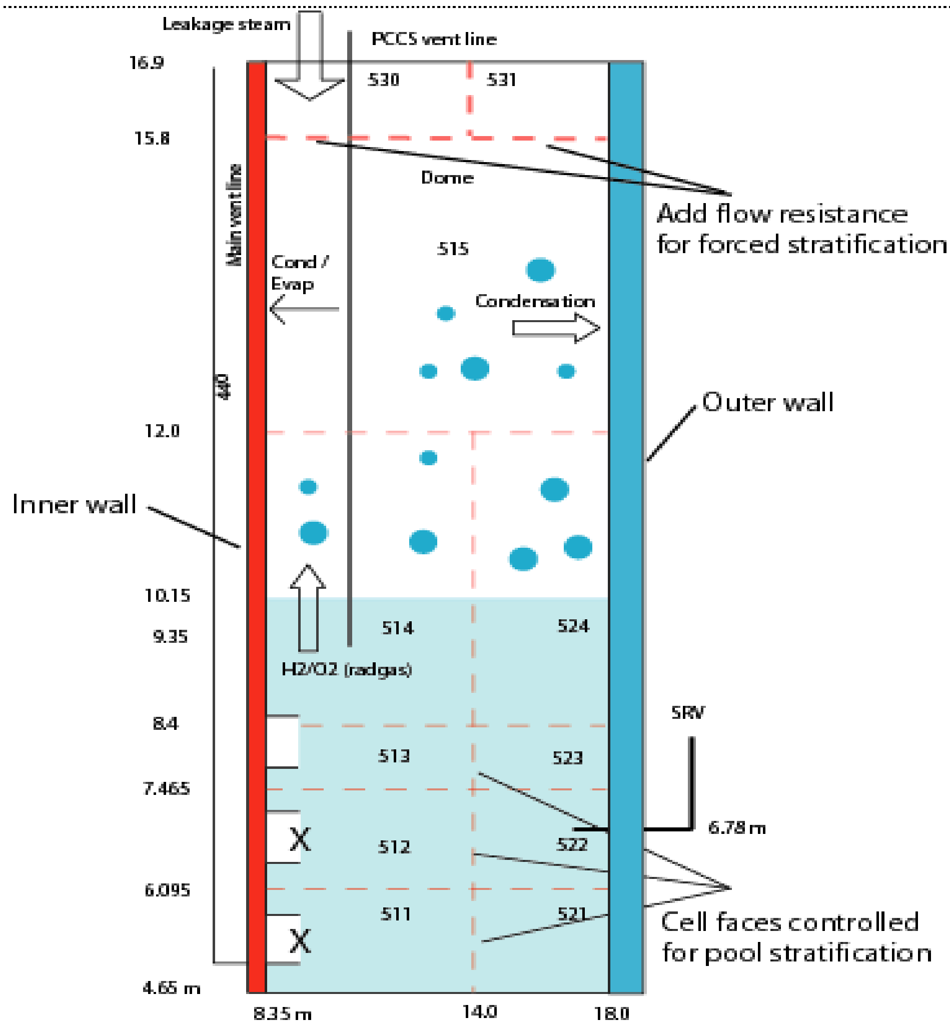

Figure 5. MELCOR model of the ESBWR wetwell (WW).

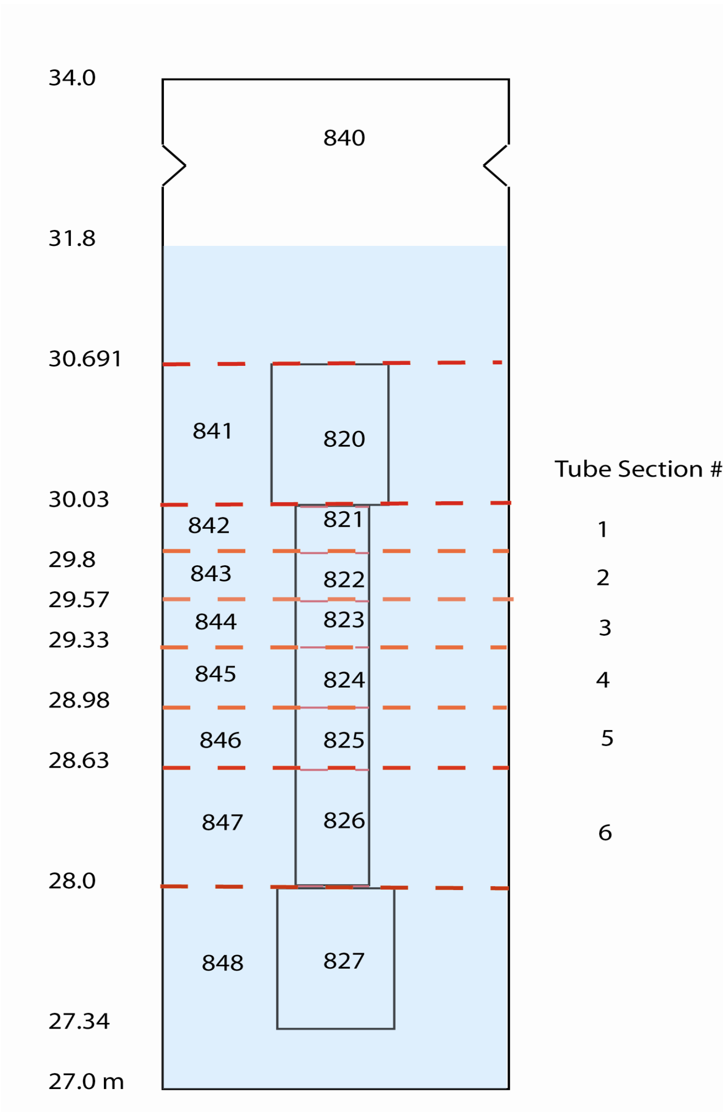

Figure 6. MELCOR model of a PCCS unit of the ESBWR plant. In the plant model, two composite units are modeled, where the 6 units are configured according to a 2/4 unit split (2 unit in one composite unit, and 4 units in an additional composite unit.

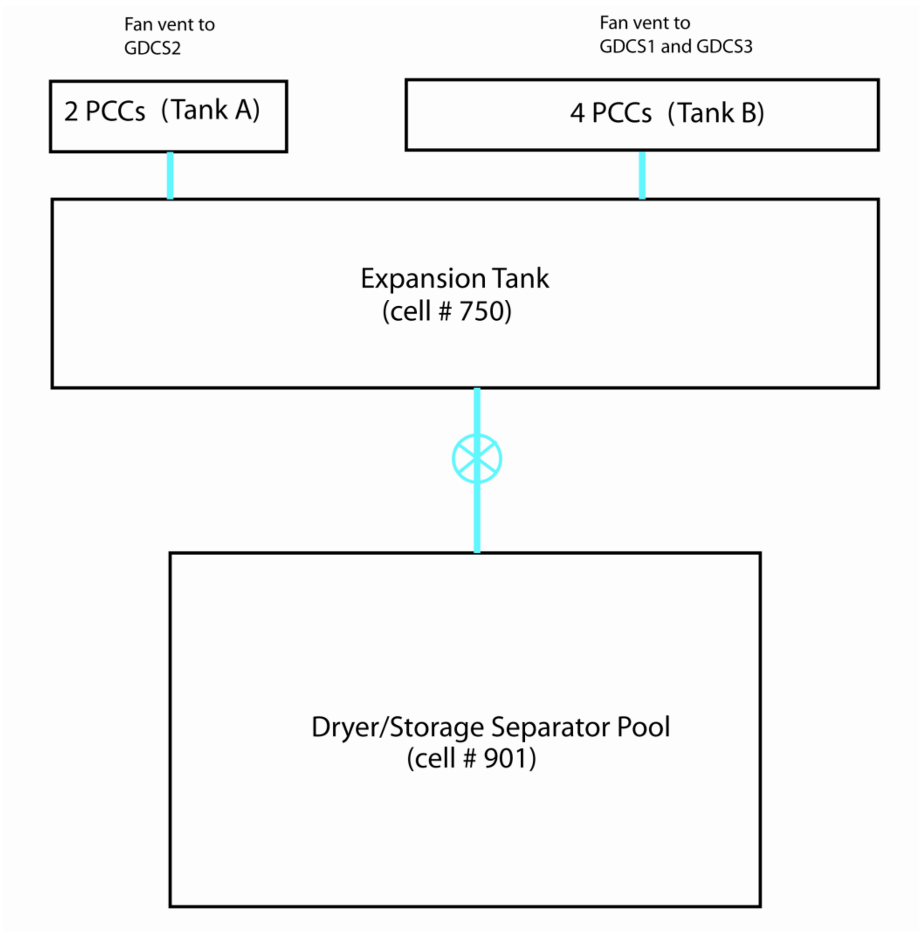

Figure 7. MELCOR model of external water tanks for the ESBWR plant.

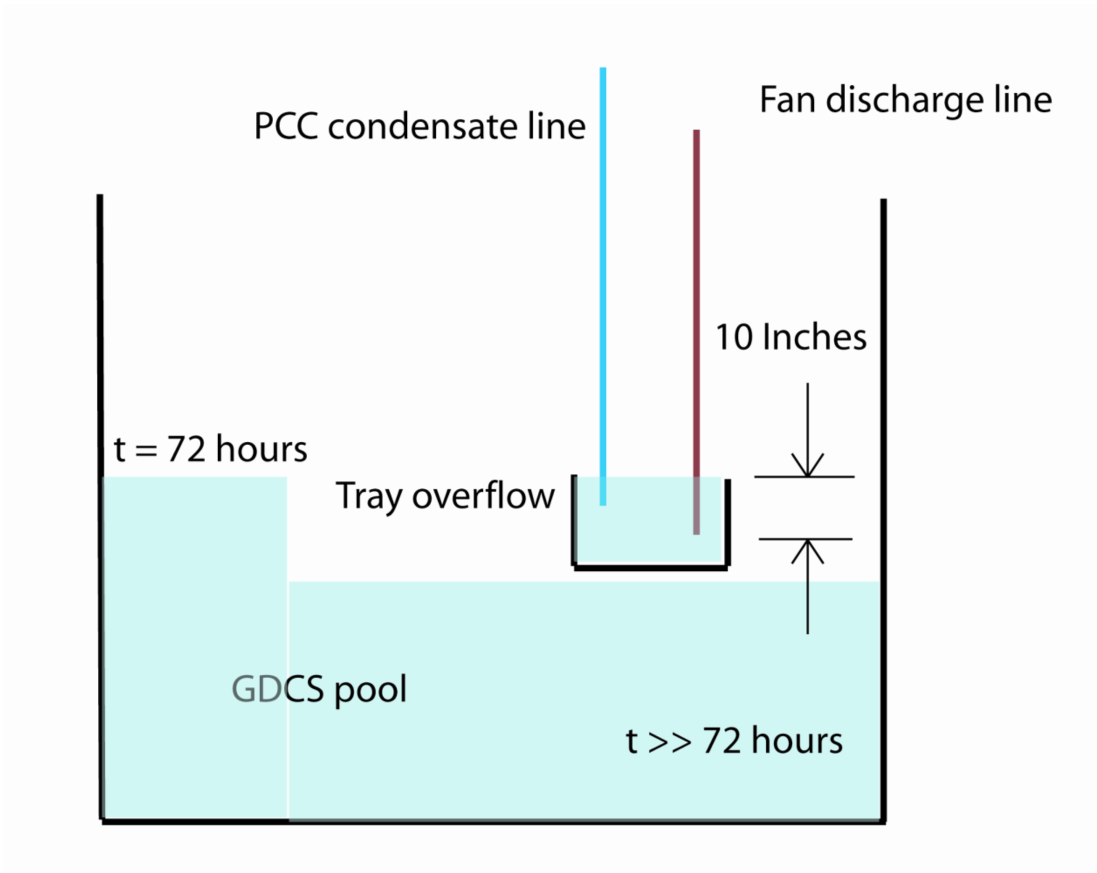

Figure 8. MELCOR model of the GDCS pool and discharge tray for the PCC condensate and fan discharge line.

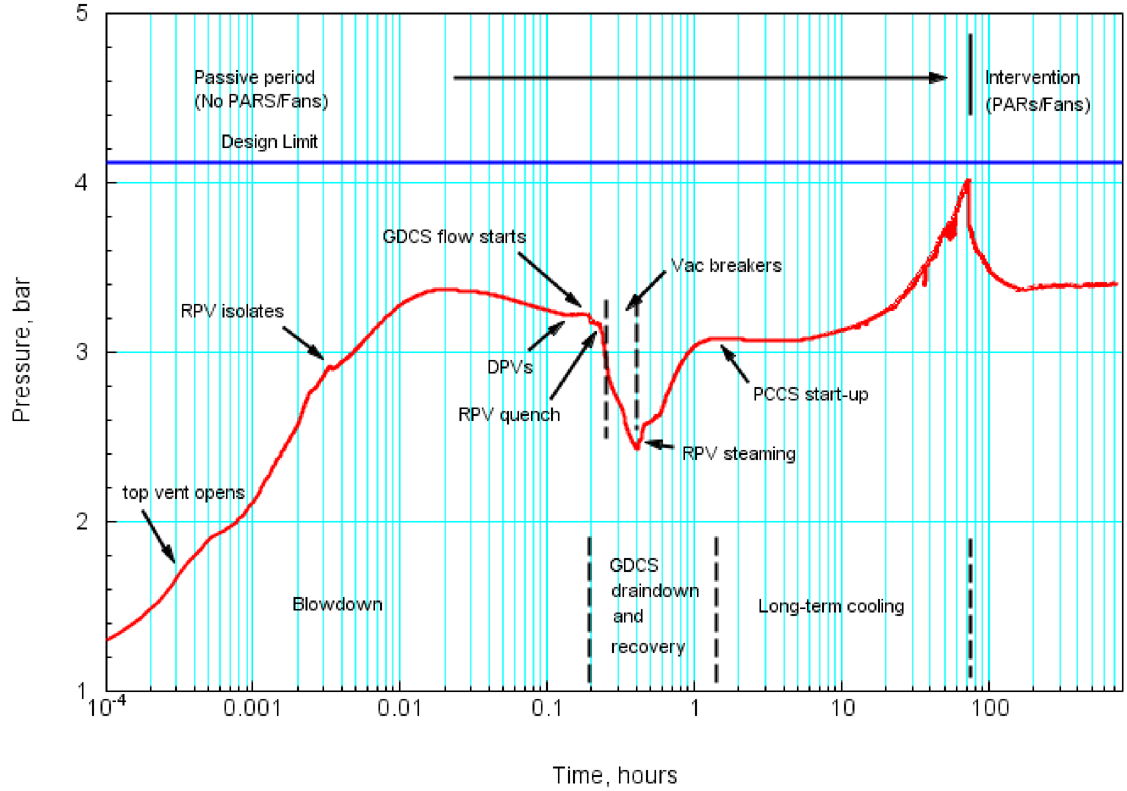

Figure 9. MELCOR audit calculation of the MSLB event (1 DPV failure) in the ESBWR containment.

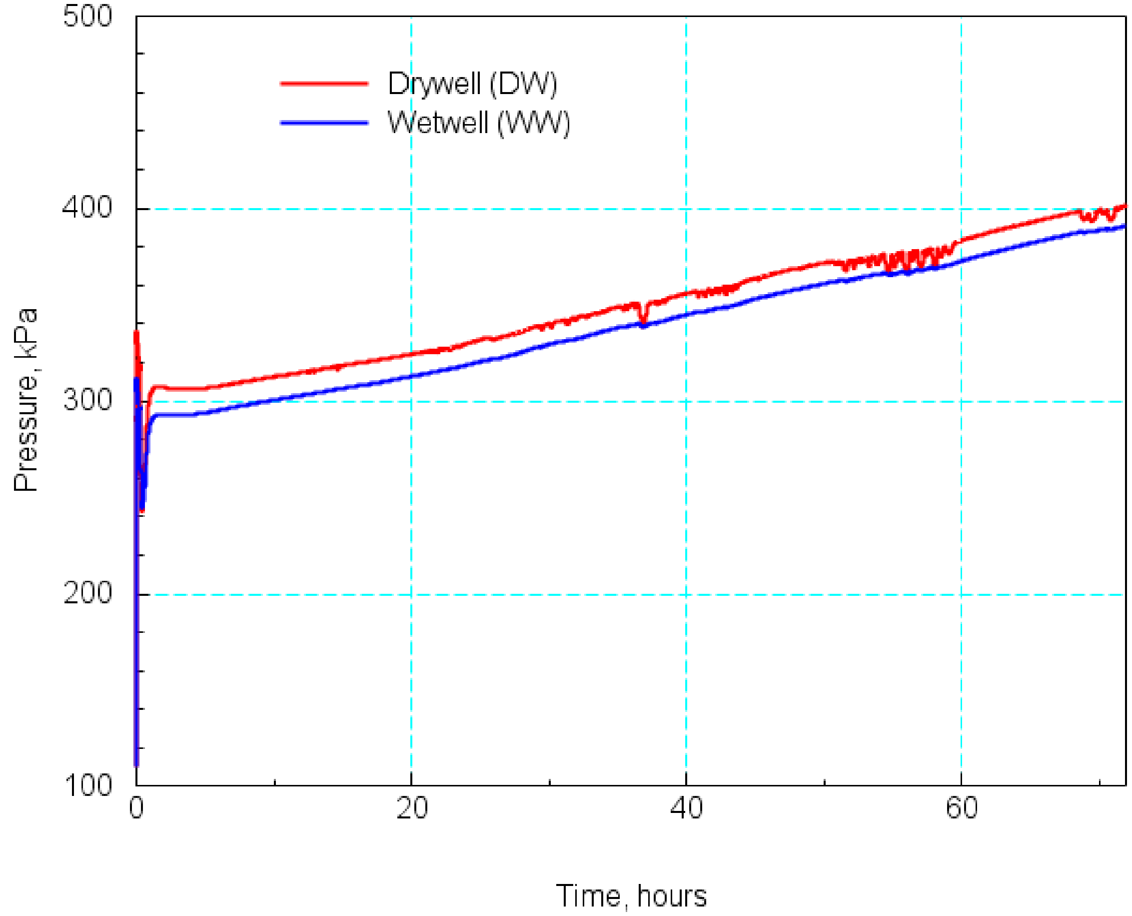

Figure 10. MELCOR calculated containment pressure (drywell/wetwell) for ESBWR MSLB (1 DPV failure) – passive period.

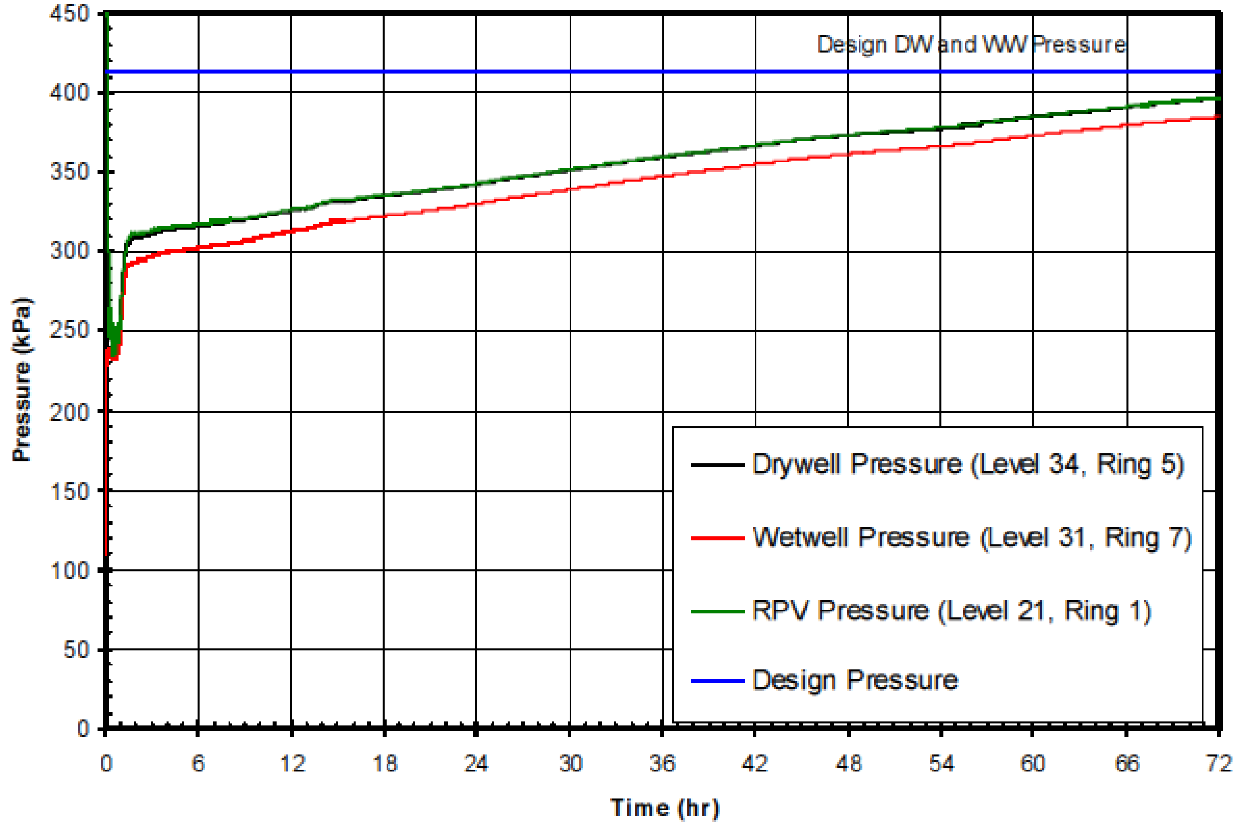

Figure 11. TRACG calculated pressure responses for the ESBSR plant for a MSLB (1 DPV failure) event.

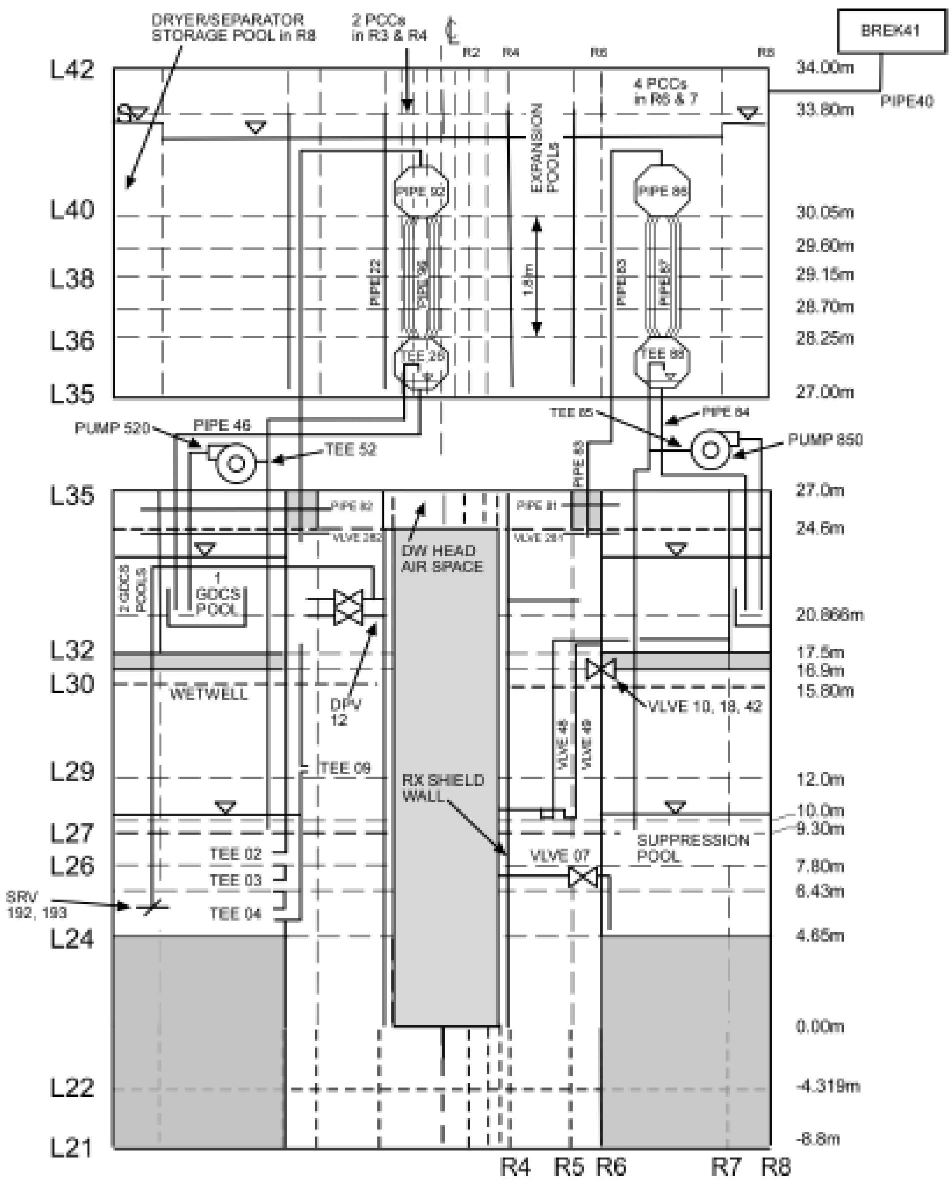

Figure 12. TRACG model of the ESBWR containment [DCD Revision 6].

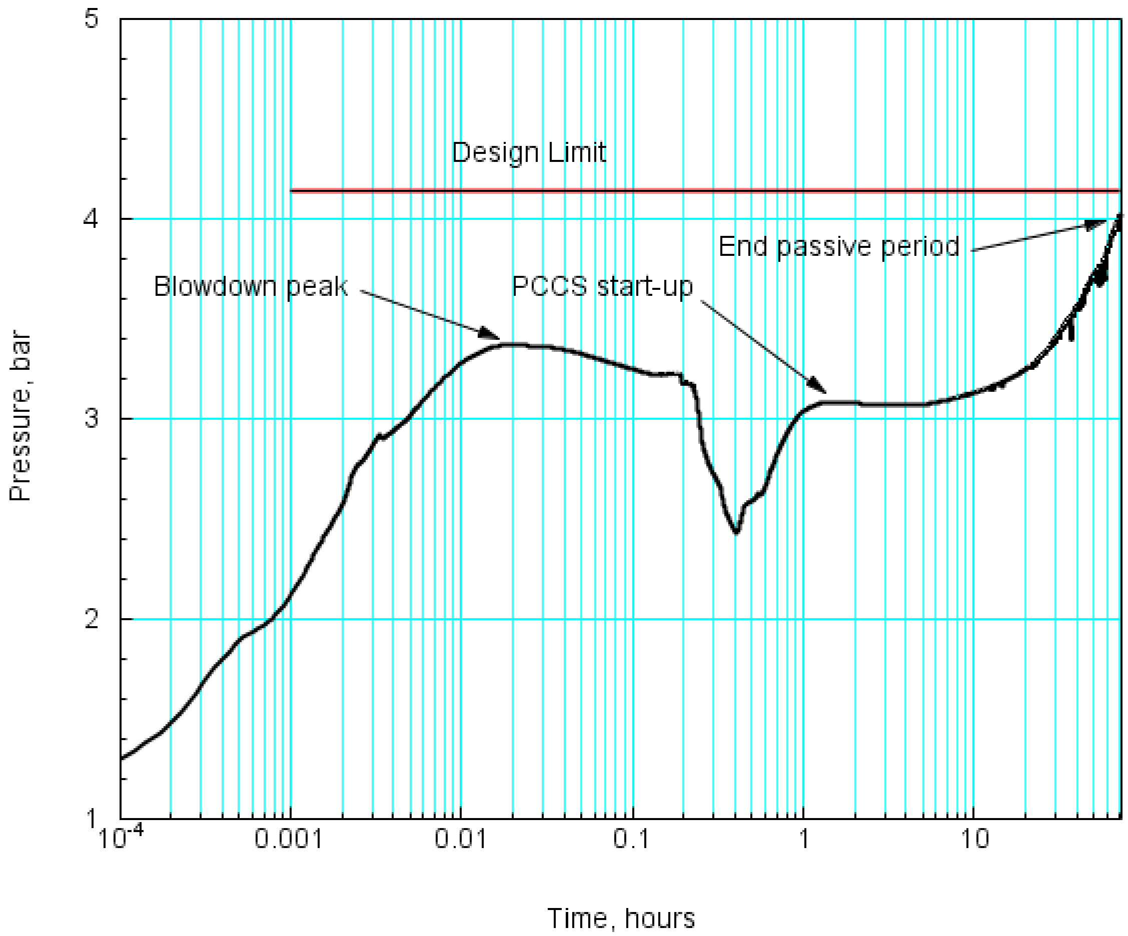

Figure 13. MELCOR calculated containment drywell pressure showing the time points for key pressure response.

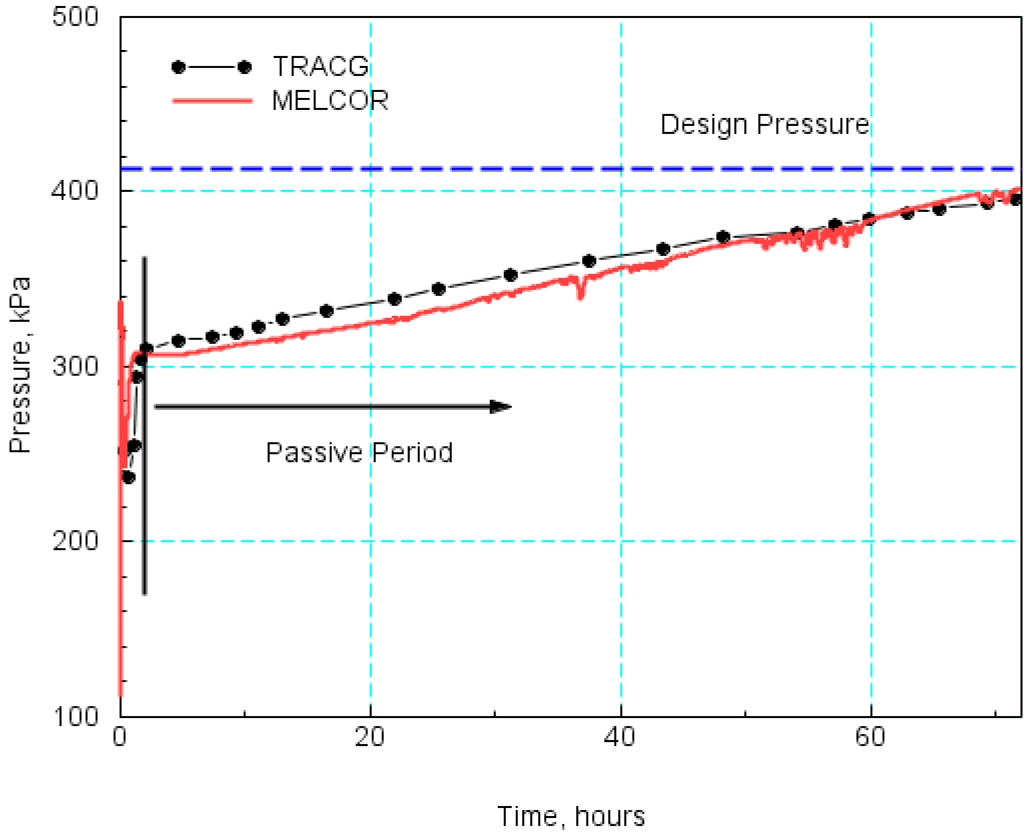

Figure 14. Comparison of the MELCOR and TRACG [DCD Revision 6] pressure rise in the ESBWR drywell during the MSLB (1 DPV failure) event.

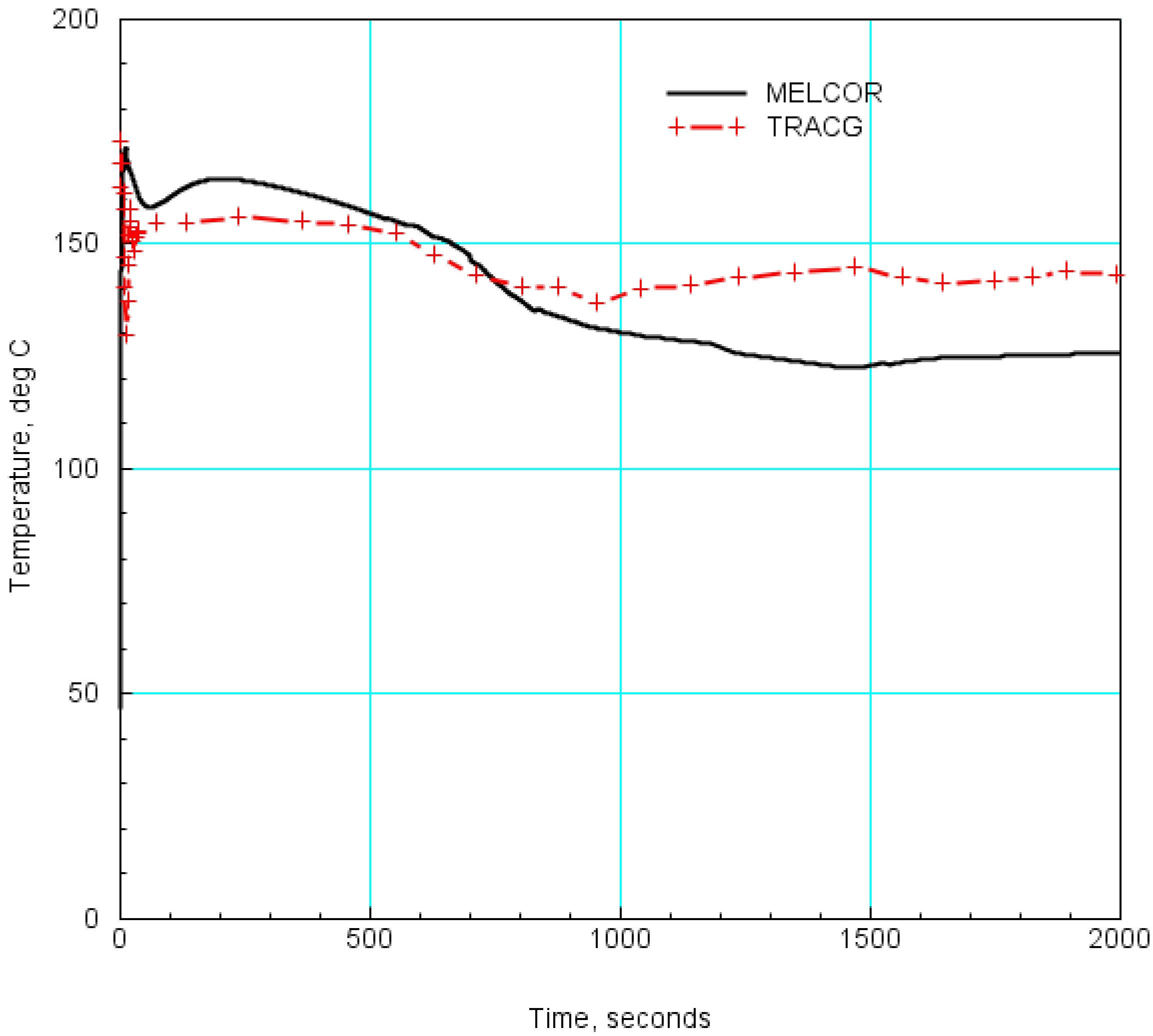

Figure 15. Comparison of the MELCOR and TRACG gas temperature response during the 2000 seconds following a MSLB (1 DPV failure) in the ESBWR plant. The TRACG temperatures are average temperatures (bulk) for the drywell open space.

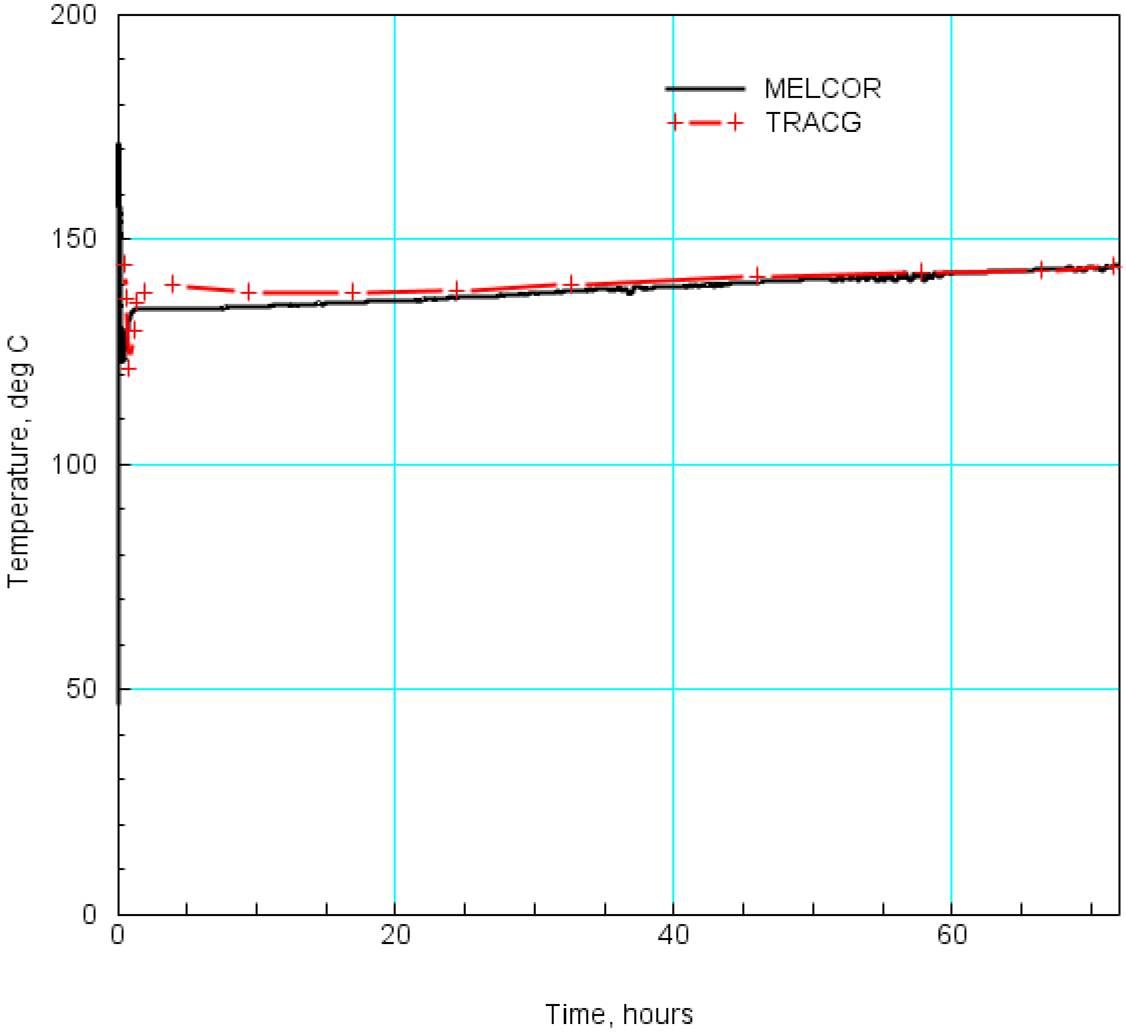

Figure 16. Comparison of the MELCOR and TRACG gas temperature response during the 72 hour passive period following a MSLB (1 DPV failure) in the ESBWR plant. The TRACG temperatures are average temperatures (bulk) for the drywell open space.

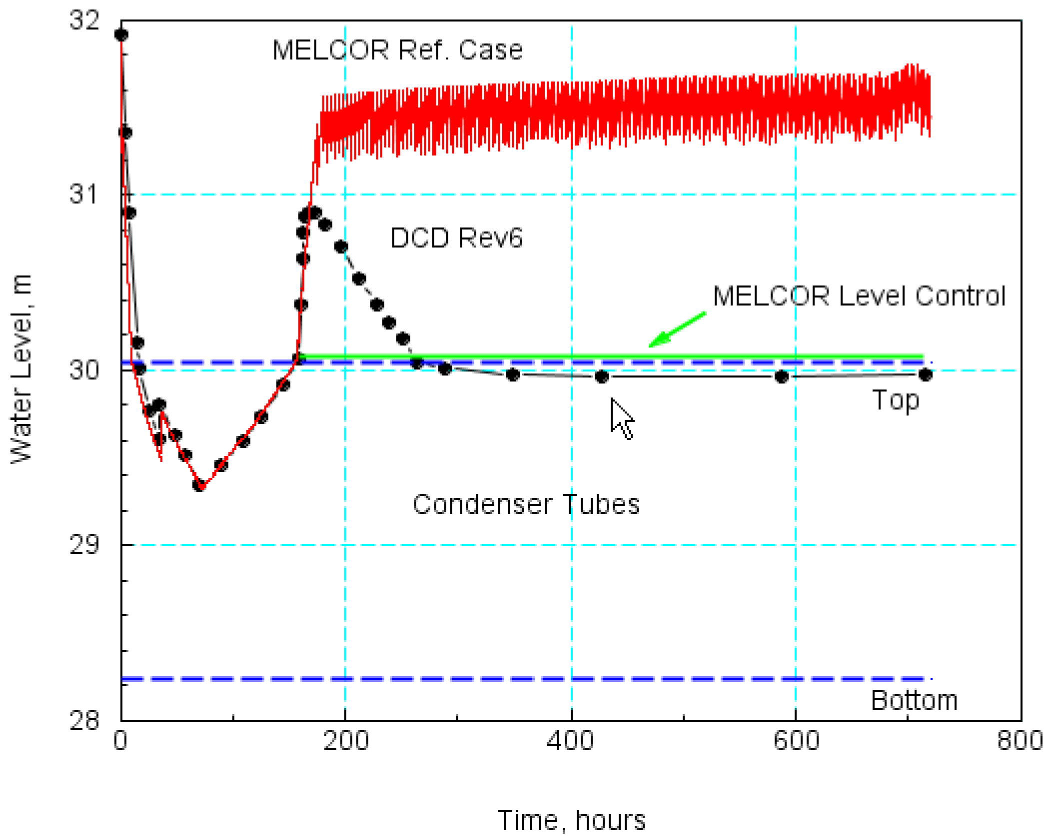

Figure 17. TRACG PCC pool level control [DCD Revision 6] compared to the MELCOR level control model used in the confirmatory calculation.

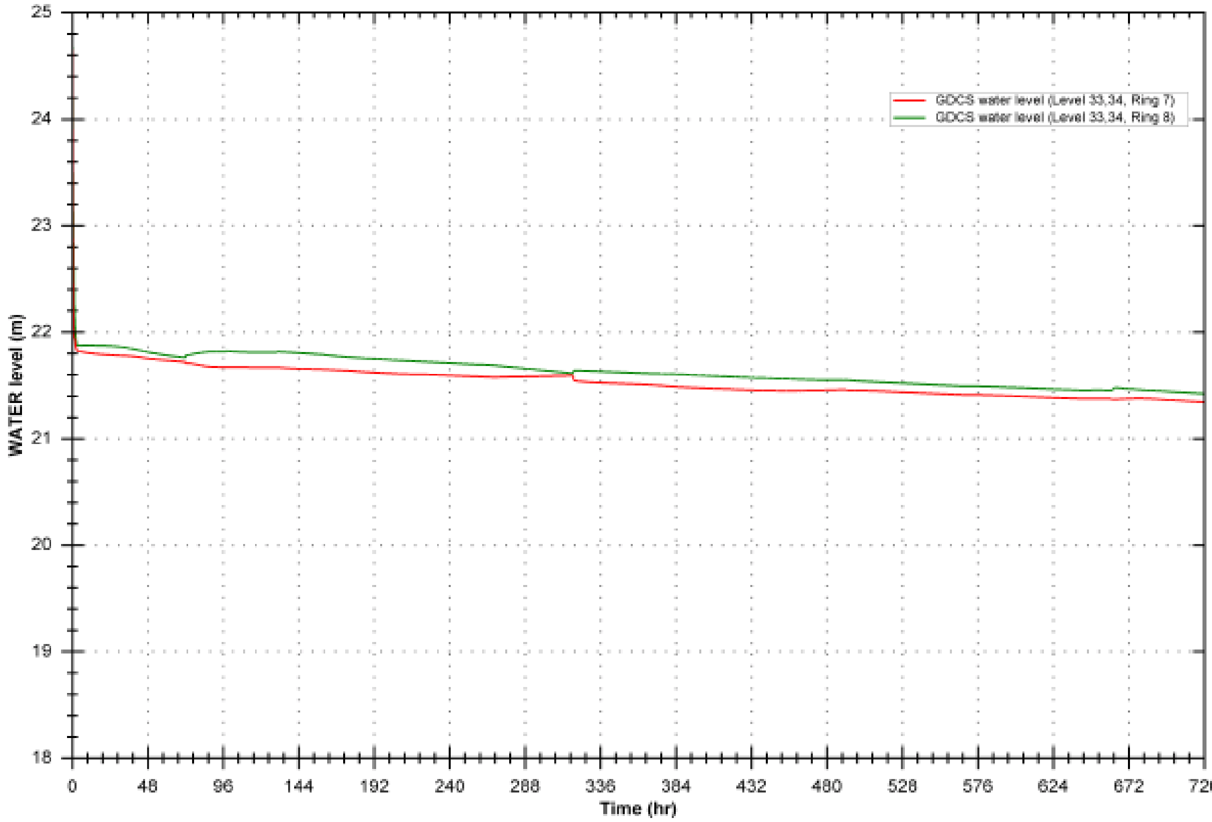

Figure 18. TRACG calculated GDCS pool levels [DCD Revision 6].

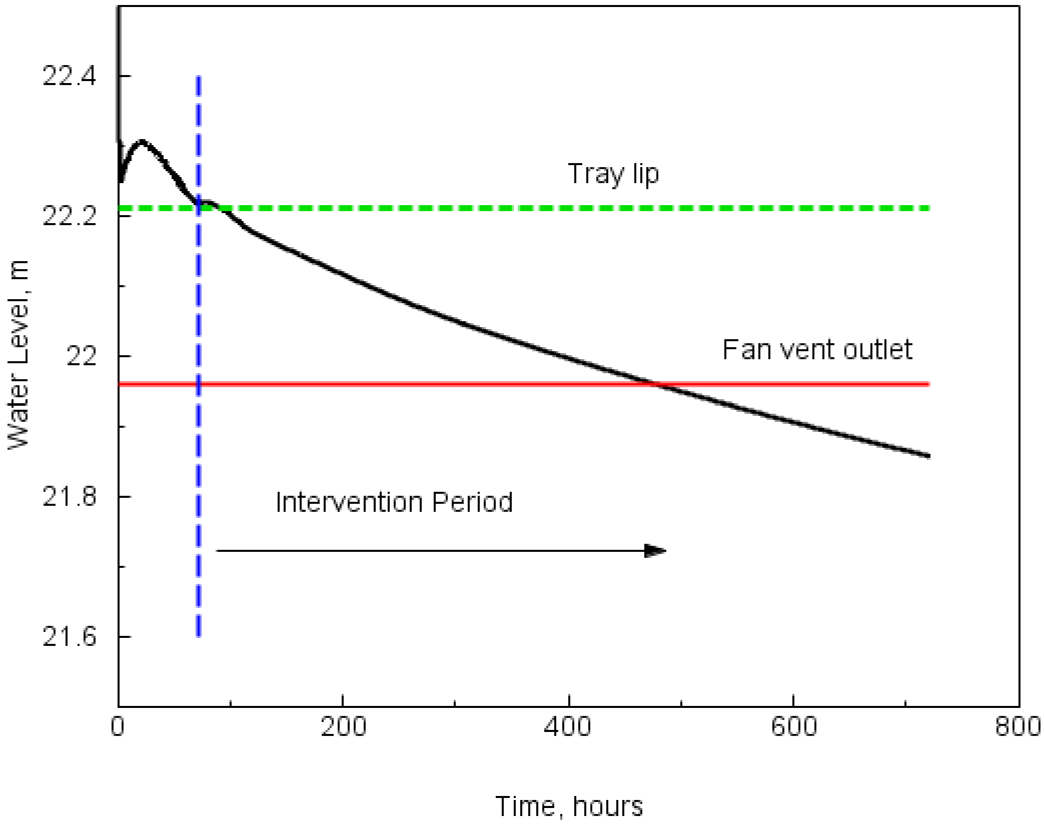

Figure 19. MELCOR calculated GDCS pool level during the intervention period – the confirmatory calculation does not recognize the drain pan (tray) lip effect on submergence; whereas, the audit calculation maintains submergence at the height of the lip above the fan vent outlet at 72 hours, 10 inches.

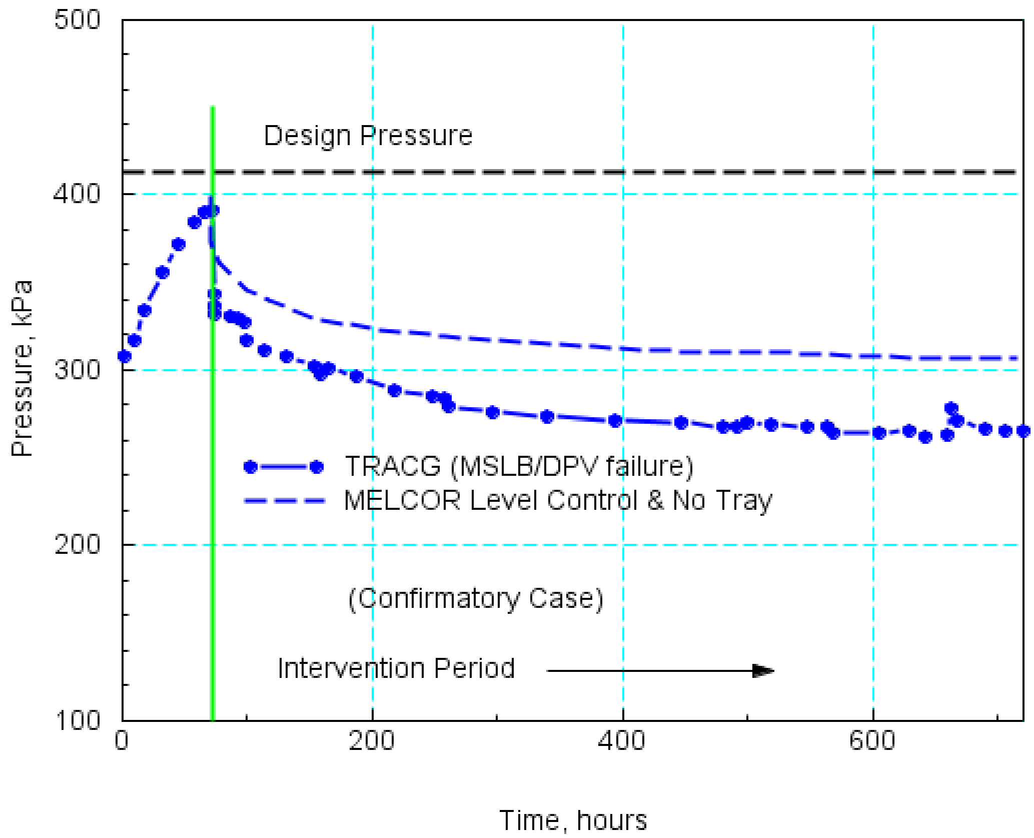

Figure 20. Comparison of DW pressure response for the TRACG [DCD Revision 6] and MELCOR (confirmatory) calculation during the intervention period.

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Figure 21. MELCOR calculated fan flow for the ESBWR audit of the MSLB (1 DPV failure) event during the intervention period.

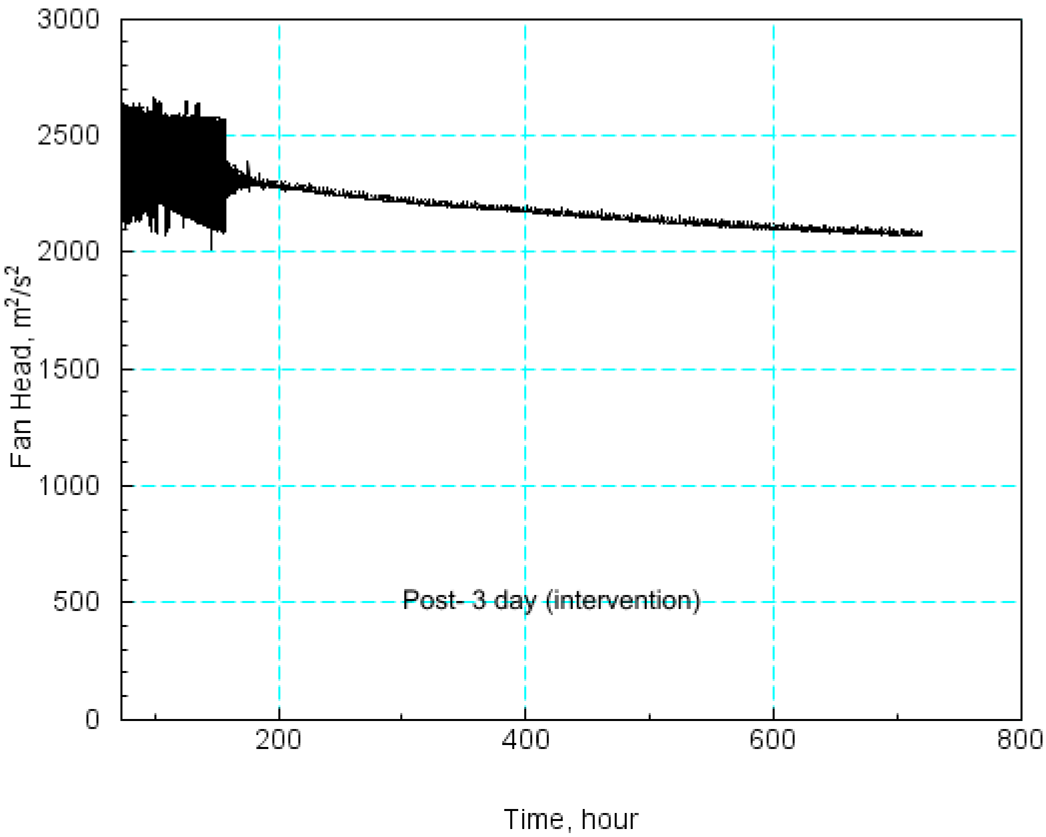

Figure 22. Fan head time history calculated with the MELCOR post-3day intervention model, showing the initial instability period as a result of operation in a highly sensitive region of fan performance (head vs. flow), experienced during the fan start-up period.

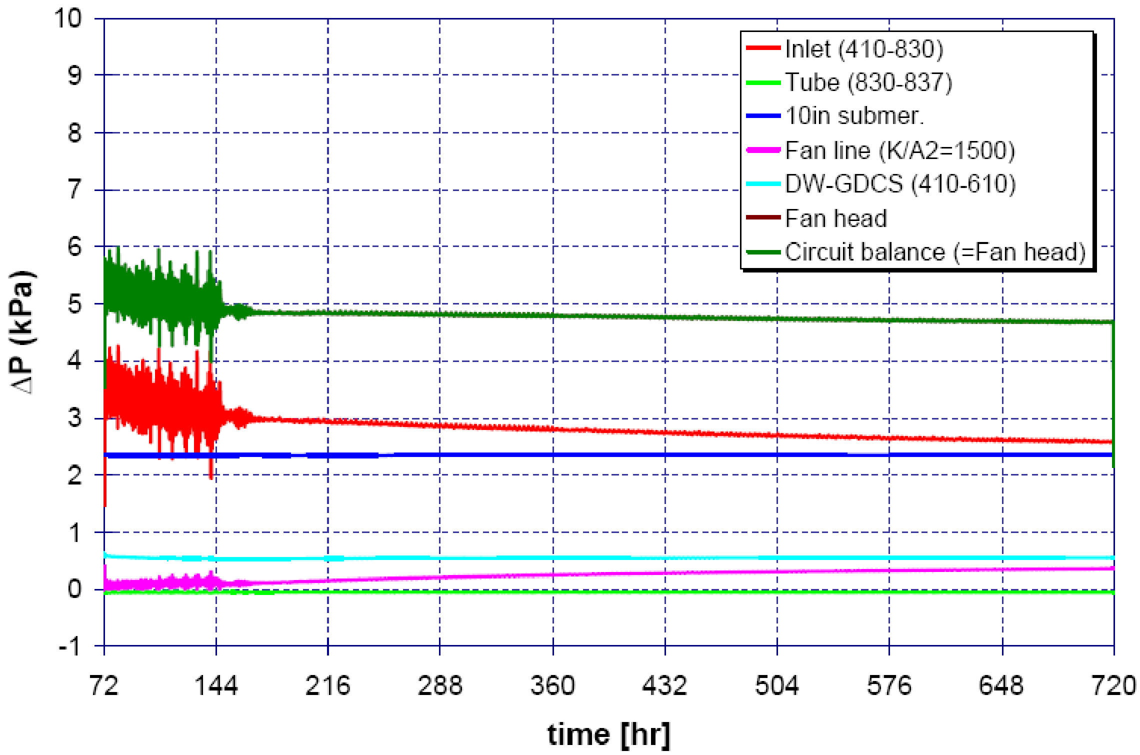

Figure 23. Calculated pressure loss components for the total fan head calculation used in the fan performance curve to determine fan flow for the MELCOR audit.

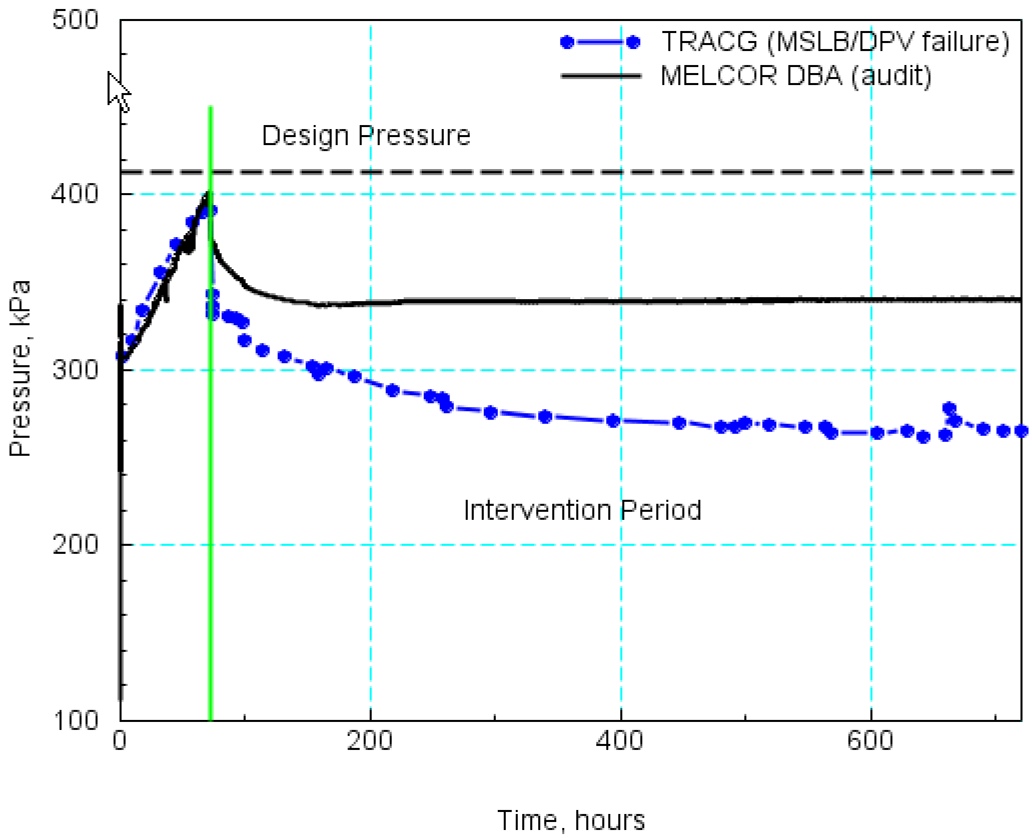

Figure 24. Comparison of the MELCOR audit and DCD Revision 6 reported containment pressure for the MSLB (1 DPV failure) in the ESBWR plant.

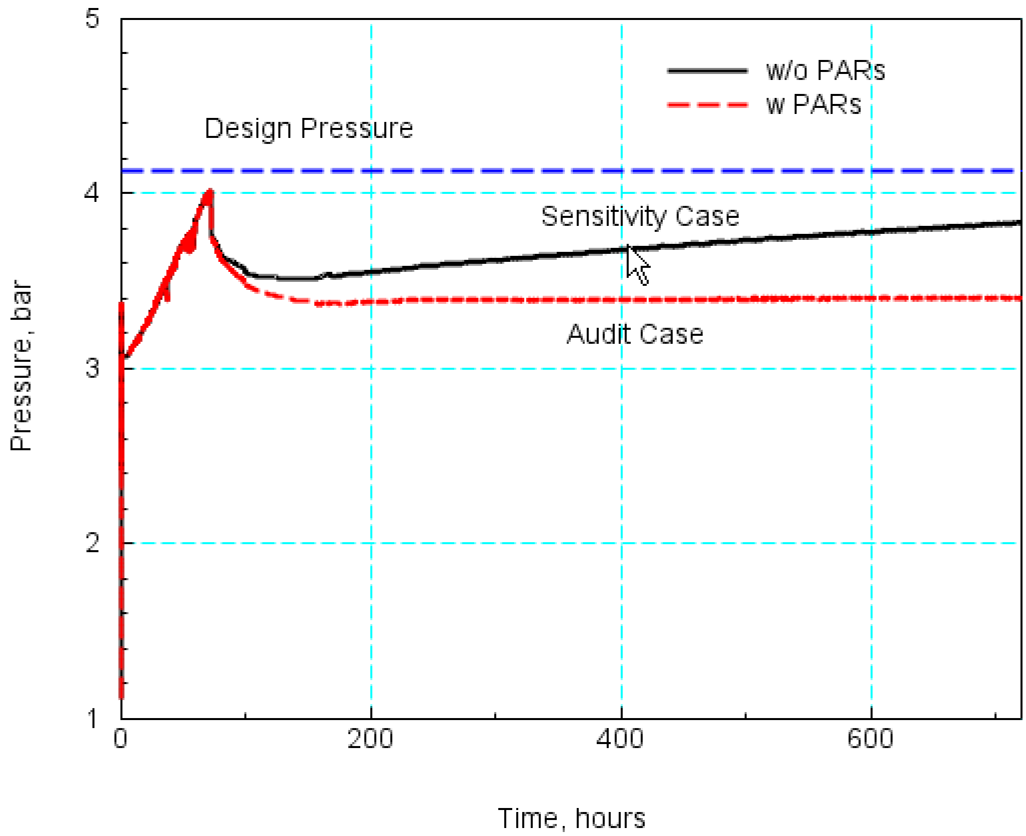

Figure 25. MELCOR calculated sensitivity (no PARs) and audit (PARs during intervention) containment pressure for the ESBWR plant during a MSLB (1 DPV failure) event.

Appendix A

ESBWR Containment Pressure Sensitivity
To Drywell Gas Trapping
[Blowdown Period]

During the blowdown period of a design basis accident (DBA), the break injection into the drywell (DW) region is very dynamic (with multiple jet-structure interactions), causing the entire region to approach a well-mixed condition. This type of mixing behavior is critical to obtaining a conservative prediction of peak blowdown pressure. With a well-mixed DW, noncondensable gas transfer rates from DW to wetwell (WW) via the main vent pathway are maximized. The rapid transfer of noncondensable gases to the WW partially reduces steam flow in the main vents and increases the WW back pressure for which the DW pressure must exceed to continue main vent steam/gas flow. Consequently, treating the DW as a well mixed region during the blowdown period has, as applied to current BWR-plants (e.g., Grand Gulf), been considered an appropriate and conservative modeling approach that produces maximum short-term containment pressures

The reference MELCOR model for the ESBWR containment includes a single control volume for representing the open space DW region – excluding the GDCS tank regions which are modeled as individual control volumes, mostly filled with water during the blowdown period. Sensitivity calculations were conducted using MELCOR to simulate various reduced gas transfer cases, with DW gas trapping modeled using a second control volume for the DW open space, as shown in Figure A-1. In this figure, the cases with two control volumes are configured with the steam injected into the top volume. The top volume is also connected to the main vent pipes leading into the WW. The two volume configurations will trap gas in the lower volume during the blowdown, with the amount trapped being dependent on the size of the lower volume below where the injection is assumed.

Shown Figures A-2 to A-4 are the MELCOR calculated DW pressure profiles for a feed water line break (FWLB) scenario that was the focus of the early ESBWR review. The location for the FWLB injection is near the top of the annulus region that extends from elevations of approximately 6.4 meters to 17.5 meters (see Figure A-5). This injection location is within the narrowed region in the drywell sketches shown in Figure A-1. In the case of a main steam line break (MSLB), the blowdown injection would be at a higher elevation, extending into the upper drywell region that ranges from elevation 17.5 meters to 24.6 meters. This location is in the larger DW volume region adjacent to the GDCS tanks. A comparable TRACG calculated FWLB pressure profile is shown in Figure A-6 for the MELCOR configuration (b) in Figure A-1. With the FLWB injection in the drywell annulus region, the lower drywell region below the annulus represents a region of trapped gas for either the two volume MELCOR model or the TRACG nodalization model shown in Figure A-5. As indicated in the sensitivity calculation for lower drywell gas trapping (Figure A-3), the MELCOR pressure profile for this case is in good agreement with the TRACG predicted pressure profile; whereas, for the MELCOR case with minimal gas trapping, configuration (a) in Figure A-1, the TRACG peak blowdown pressure is significantly lower than the MELCOR value. Comparisons between the MELCOR cases and the TRACG result therefore indicate the approximate degree of non-conservatism associated with the TRACG nodalization model for predicting *blowdown* pressure in the ESBWR containment. However, since the maximum pressure for the ESBWR DBA event is predicted with MELCOR single volume DW to occur after the blowdown period in later DCD revisions, the focus for a conservative estimate of containment pressure shifted away from phenomena modeling during the blowdown to the long-term period or phase of the accident. During the long-term period that extends out to the end of the passive period at 3 days where the peak pressure is calculated to occur, most of the DW gases in the TRACG model are transferred to the WW, and the MELCOR and TRACG predictions for maximum pressure at 3 days are in relatively good agreement.

In summary, this appendix points out that the TRACG nodalization model for the ESBWR DW would arguably not represent an appropriate and conservative modeling approach for situations where the DBA peak pressure occurs during the blowdown period. Further, it should be noted that such a case, with blowdown pressure as the DBA peak pressure, was reported in DCD Revision 0 for the worst case DBA FWLB event, Figure A-7. However, with subsequent DCD revisions, the issue concerning TRACG DW nodalization affecting short-term gas trapping was eliminated as a major concern. This result was a consequence of the MELCOR conservative blowdown calculations for these later cases that indicated peak DW pressure occurs during the long-term phase of the accident for the worst case DBA event.

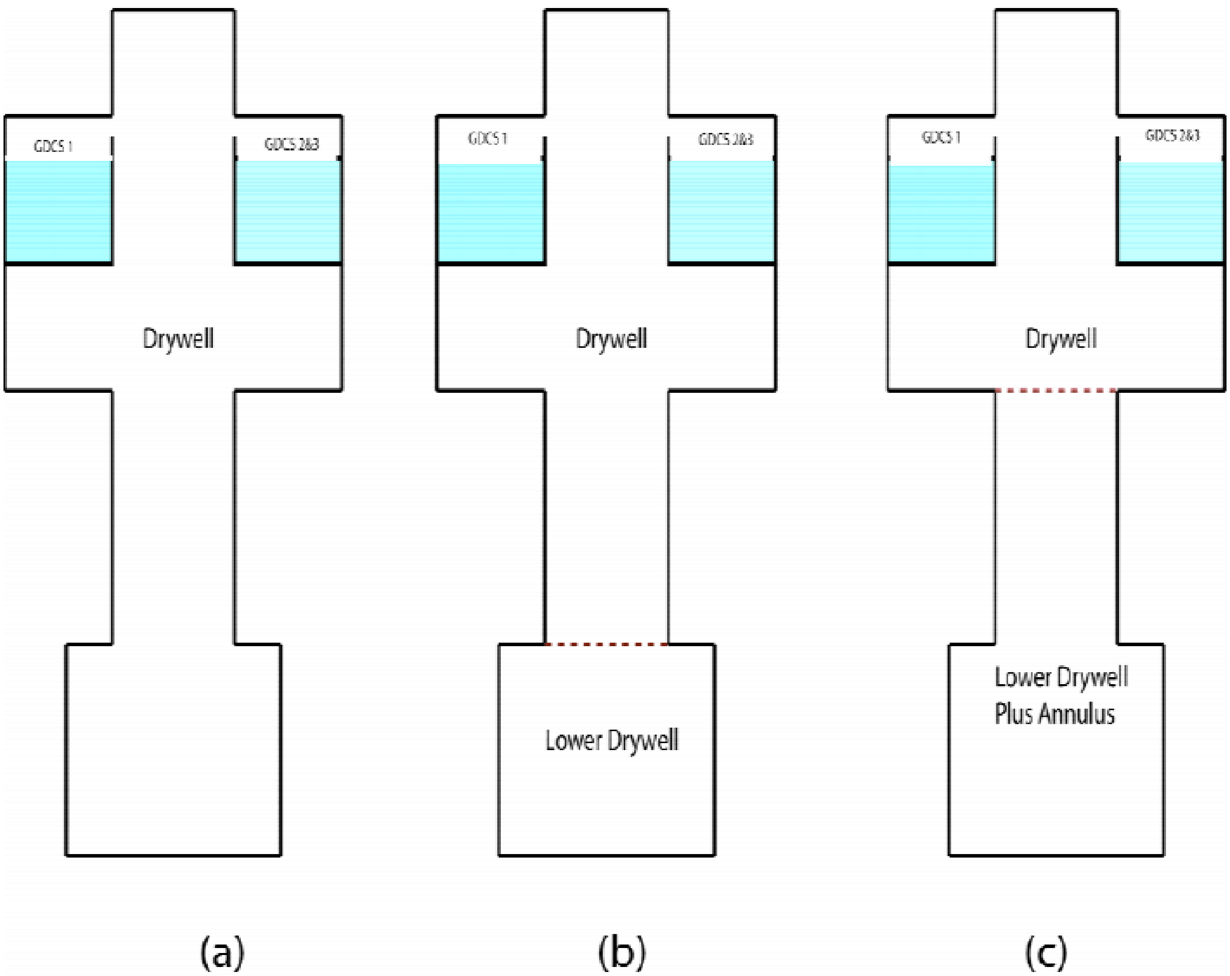

Figure A-1. Various drywell nodalizations used to explore the effects of noncondensable gas trapping in the ESBWR containment during the blowdown period: a) reference case, b) lower drywell trapping, and c) lower drywell and annulus trapping.

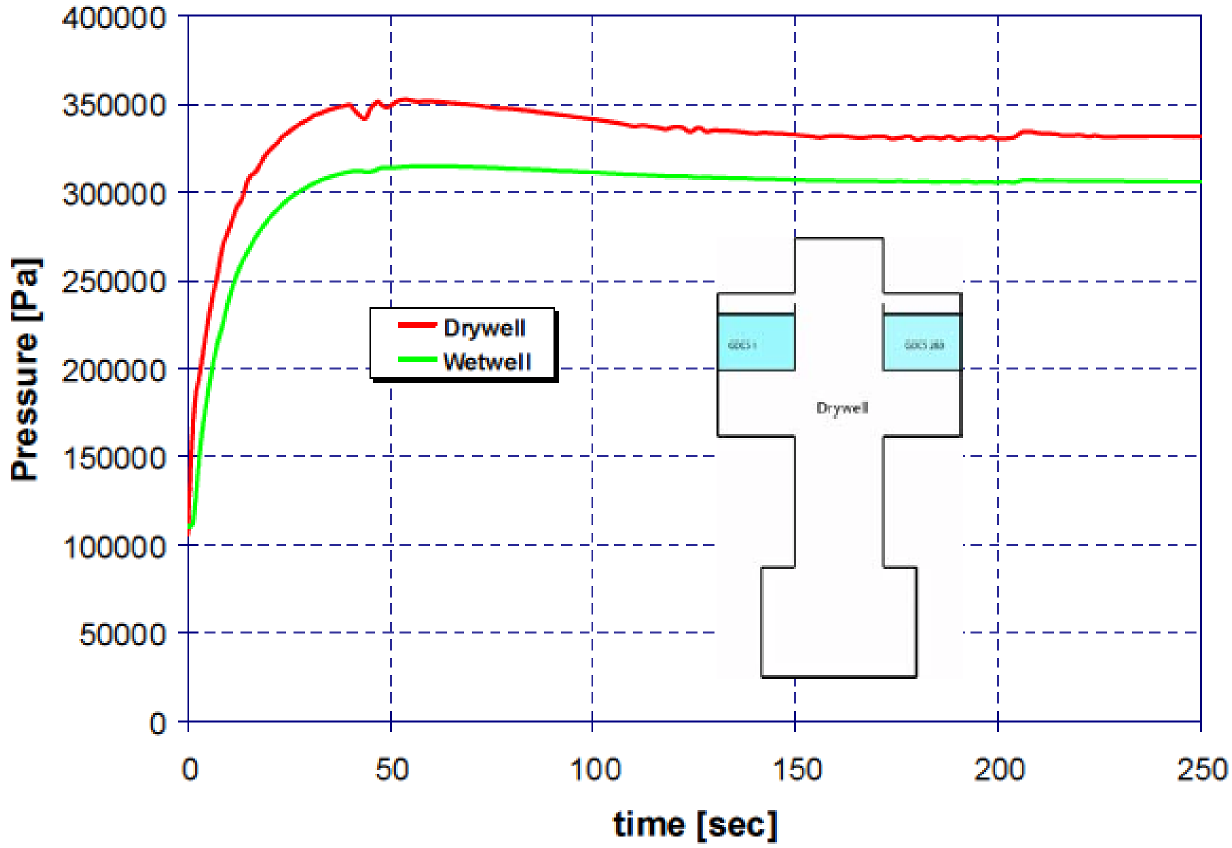

Figure A-2. MELCOR calculated drywell/wetwell pressure profile for the reference case (single drywell volume) during the blowdown period of a ESBWR FWLB (1 SRV failure) scenario [DCD Rev 3 conditions].

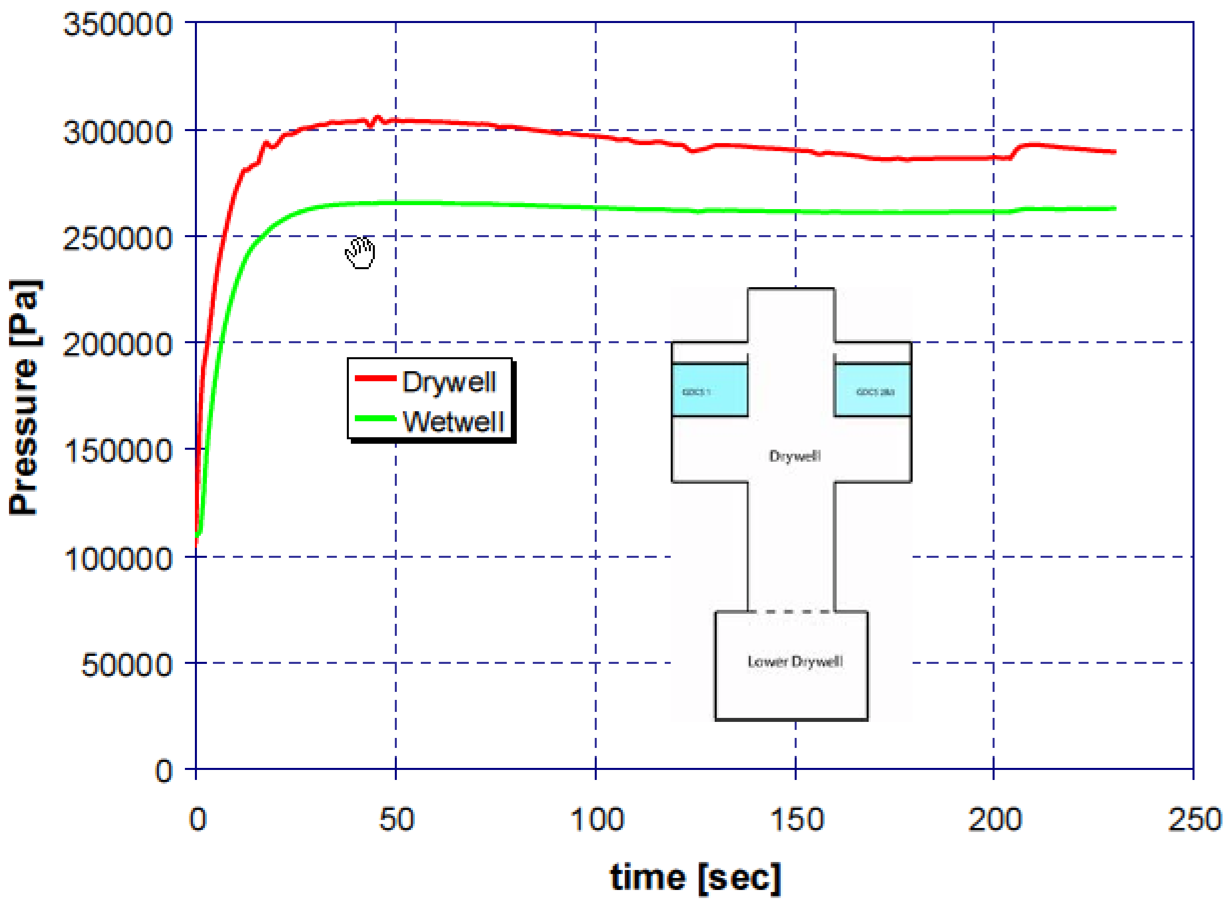

Figure A-3. MELCOR calculated drywell/wetwell pressure profile for the case with lower drywell gas trapping during the blowdown period of a ESBWR FWLB (1 SRV failure) scenario [DCD Rev 3 conditions].

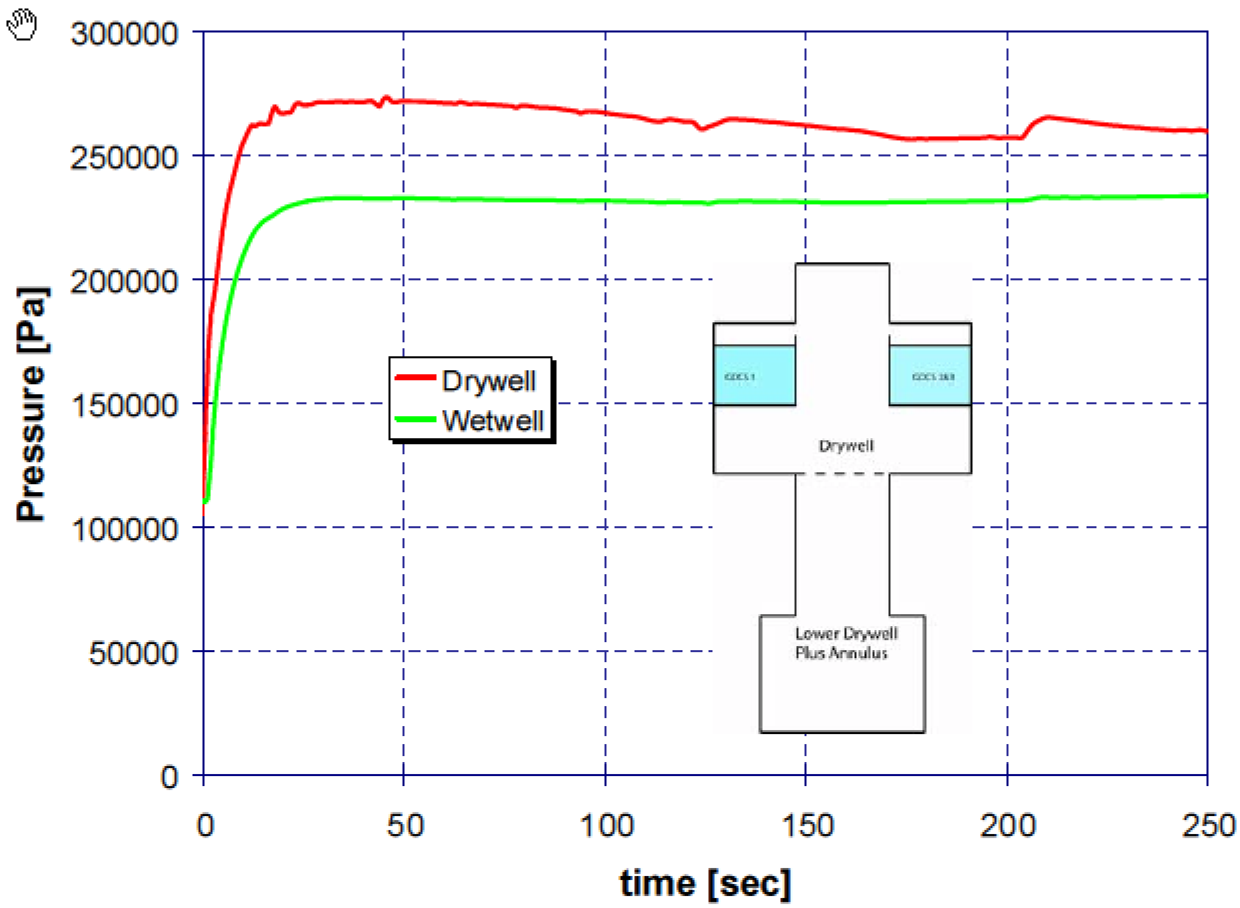

Figure A-4. MELCOR calculated drywell/wetwell pressure profile for the case with lower drywell and annulus gas trapping during the blowdown period of a ESBWR FWLB (1 SRV failure) scenario [DCD Rev 3 conditions].

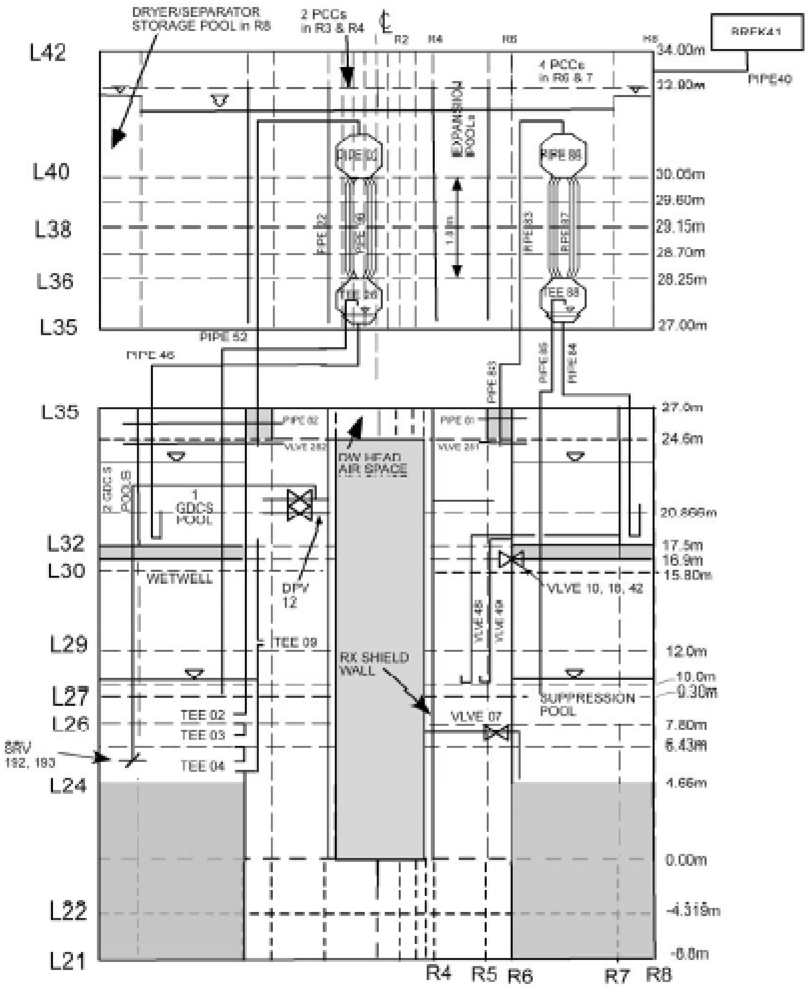

Figure A-5. TRACG Nodalization of the ESBWR Containment [DCD Rev 3].

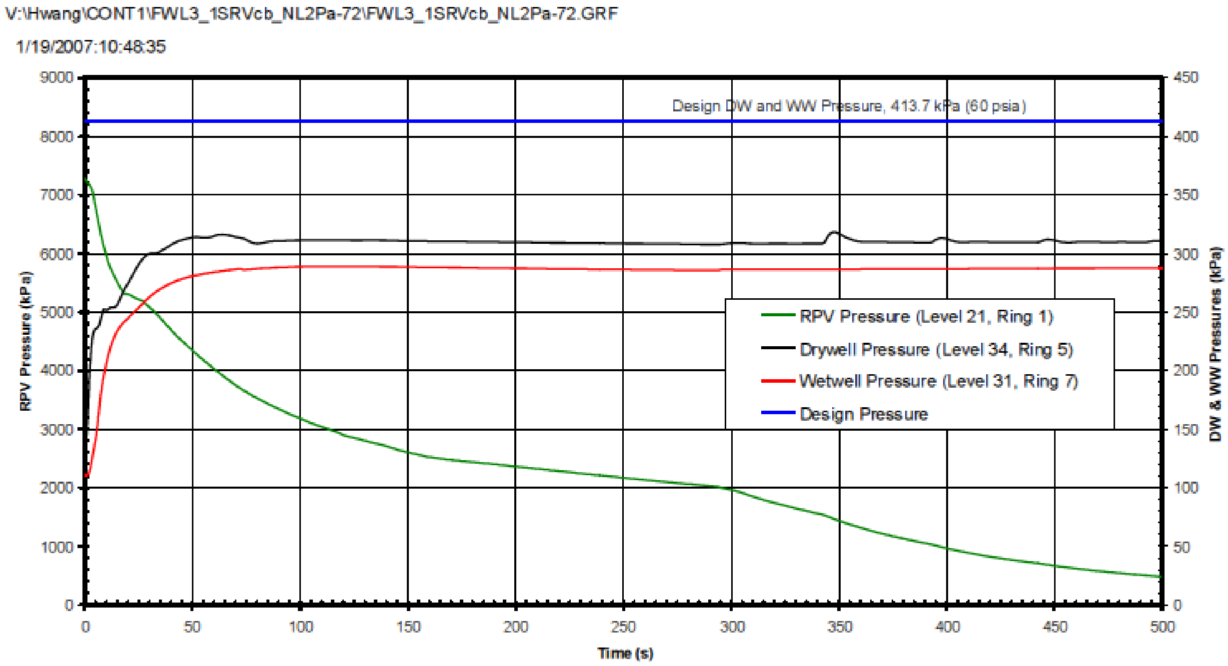

Figure 6.2-13a2. Feedwater Line Break (Bounding Case) – Containment Pressures (500 s)

Figure A-6. TRACG calculated blowdown pressures for FWLB [DCD Rev 3]. Note: GEH changed the DW and WW design pressures to 411.7 kPa (59.7 psia) in later ESBWR DCD revisions.

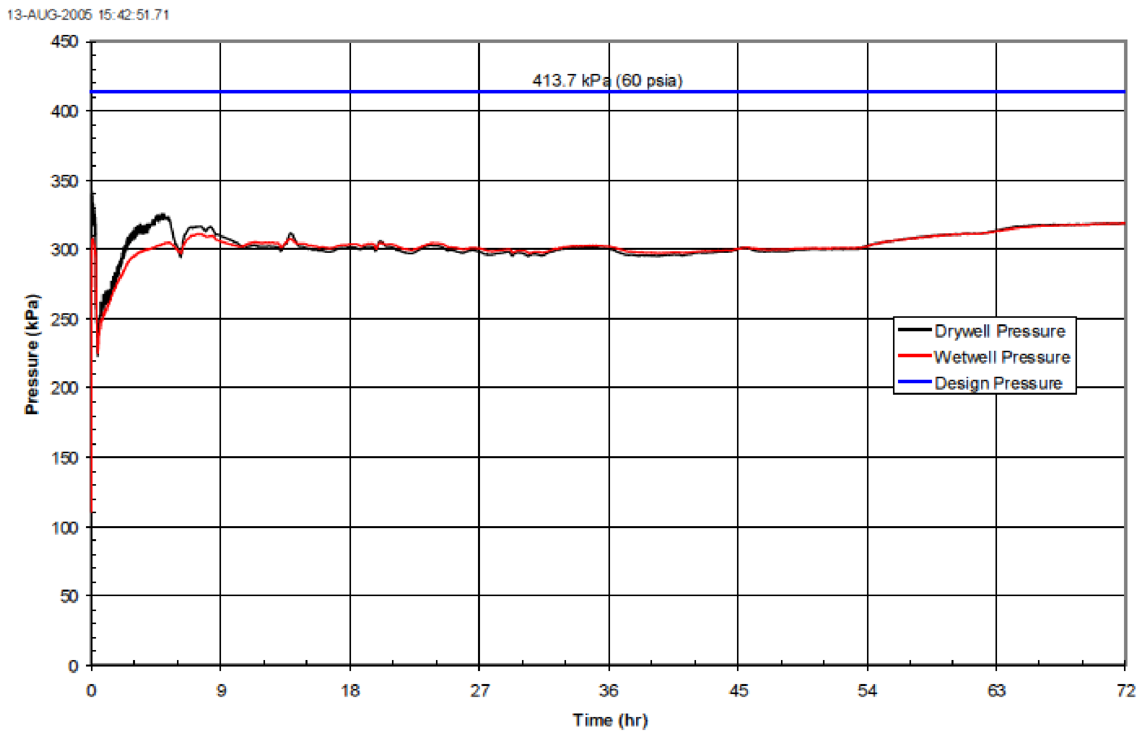

Figure 6.2-12. Feedwater Line Break (Bounding Case) — Containment Pressures

Figure A-7. TRACG FWLB bounding containment pressure calculation, DCD Rev 0. Note: GEH changed the DW and WW design pressures to 411.7 kPa (59.7 psia) in later ESBWR DCD revisions.

Appendix B

ESBWR Containment Pressure Sensitivity
To PARs and Bypass Leakage
[Passive Period (0-3days)]

Following the GDCS draindown and recovery period the PCCS heat removal rate is able to match the reactor decay heat as represented by steam exiting the reactor vessel and condensing within the PCCS condensers. When this state of steam generation and condensation first match the PCCS is considered to be in the "start-up" mode. Through much of the long-term cooling period, even with steaming and condensing rates essentially matched, the drywell (DW) and wetwell (WW) pressures are observed in the calculations (MELCOR and TRACG results) to rise with near constant slope to the end of the passive period when intervention is necessary to prevent the containment pressure exceeding the design limiting pressure. This behavior, continuous pressure rise, is a consequence of small amounts of steam bypassing the PCCS and directly entering the wetwell through leakage paths between the drywell and wetwell regions. The main contributor to the leakage pathway is leakage passed through vacuum breaker seals near the top of the wetwell space. The constant rate of pressure increase is, in turn, the result of the near constant leakage resulting from a fixed pressure differential between the drywell and wetwell. It is observed that the pressure differential during the long-term period is mainly determined by the hydrostatic head of the submerged PCCS vent pipe in the wetwell pool. The full static head however is imposed on the system only when small amounts of a steam/gas mixture are released into the wetwell pool from the PCCS vent pipes. This pressure differential condition (i.e., with a continuous and fixed bleed-off of small amounts of steam/gas mixtures) can be caused by the nearly constant source of radiolyic gas from the reactor pressure vessel (RPV). Without the radiolytic gas source a smaller pressure rise is expected due to the cycling of vacuum breakers, where sporadic amounts of noncondensable gases are released back into the drywell when full PCCS heat removal capacity is approached. The cycling occurs as follows: 1) momentarily, condensation in the condensers exceed the steaming rate in the RPV, and the drywell pressure drops below the WW pressure and the vacuum breakers open; 2) WW gases are transferred back to the drywell and effectively reduce the condensation rate in the condensers; 3) increasing DW pressure occurs with the reduced PCCS condensation and the vacuum breakers close; 4) bleeding of noncondensibles returns the system to condition (1), and so forth.

From the explanation above regarding the long-term pressure rise during the passive period, there are two DW/WW pressure signatures that are characteristic of the manner that noncondensable gases are introduced into the DW: 1) fixed DW/WW pressure differential characteristic of nearly constant radiolytic gas source with continuous bleeding of gas from vent pipe to suppression pool, and 2) variable DW/WW pressure differential characteristic of a variable gases source introduced into the DW from the repeated cycling of the vacuum breakers. The first condition is an example of the often referred to self-regulating response of the PCCS. Self-regulation indicates power matching, where a constant source of gas introduced into the PCCS feed results in a "bounding" state for the heat removal capacity; and, where steam entering the PCCS feed line matches steam condensed. Bounding here indicates that gases have accumulated and bled-off in the lower portions of the condenser tubes producing the self-regulating response through a slowly varying blanketing of portions of the condenser tubes inner surfaces. Phenomena such as "bounding" and/or variable purging as the vacuum breakers cycle have been observed in tests performed and modeled with MELCOR in the PANDA facility.

The reference MELCOR calculation for the MSLB vent is an example of a self-regulating response driven by a near constant source of gases (radiolytic) injected into the DW, Figure B-1. In a similar modeling approach with the TRACG code, GEH has also replicated this "bounding" response of the PCCS as shown in the MSLB scenario case reported in DCD Rev 6, Figure B-2.

A containment pressure signature for the variable purging case is simulated by assuming that the radiolytic gases released to the DW are effectively removed by PARs. Shown in Figure B-3 is same DBA portrayed in Figure B-1, except the radiolytic gas source is eliminated. The variations in drywell pressure are a result of intermittent vacuum breaker actuation. Note that the margin to design limit presented in Table 1 increases from 4 to 13 % by assuming 100% PARs efficiency.

Early in the DCD certification process the bypass leakage was defined with a leakage of 1 cm^2 ($A/\sqrt{K}$) – Rev 0 through Rev 2. Figure B-4 is a plot of the MSLB scenario calculated with MELCOR for a bypass leakage area set to 1 cm^2. In subsequent DCD versions, the chosen value for modeling leakage was changed to twice the measured leakage, 2 cm^2. The larger leakage value effectively increased the maximum DW pressure at 3 days in comparison to the original value of 1 cm2, as indicated in the comparisons of Figures B-1 and B-4. The comparisons of MELCOR calculations show that the margin to design decreases from 15 to 4 % when bypass leakage increases from 1 to 2 cm2. This change explains most of the variation in MSLB bounding cases between DCD Rev 2 and later versions.

In the initial DCD Rev 0 submittal the bounding calculation for the FWLB (worst case for Rev 0) showed a pressure profile where the peak pressure occurred during the blowdown, Figure B-5. From the signature of the pressure trace (minimal drywell-to-wetwell pressure differential) and relatively low 72 hour pressure, it was initially postulated, based on early audit reviews that did not include radiolytic gas sources, that early TRACG calculations may have not included these sources. The relatively good agreement between the early audit case, Figure B-6, and the DCD Rev 0 pressure profile raised this issue. This postulation however was dispelled by GEH in checking the TRACG input for Rev 0 and other pre-application cases, where GEH verified that these early cases did include radiolytic gases even though no mention of this gas source was indicated in the documentation. A part of the audit review process was to investigate possible oversights that may explain differences or similarities in code results. In this case, GEH performed a post-calculation review to eliminate the possibility that radiolytic gases were missing from TRACG Rev 0 calculations. Other explanations for relative agreement in pressure profiles between TRACG and MELCOR calculations that excluded radiolytic gases were complicated due to additional modeling differences since uncovered (e.g., WW wall heat transfer surfaces modeled, WW gas space forced stratification, DW flood water transfer to WW, etc). Later, these other modeling differences were eliminated, the limiting case also changed from FWLB to MSLB, and the agreement between TRACG and MELCOR pressure calculations (including radiolytic gases for all cases) were observed to be in relatively good agreement both in terms of trend or signature and magnitude.

Table B-1. Peak drywell pressure for ESBWR MSLB event.

Calculation	Peak Pressure (72 hours)	Margin to Design Limit (%)
TRACG (DCD Rev 6)	396.25 (1 DPV failure)	5
TRACG (DCD Rev 6)	397.45 (1 SRV failure)	5
MELCOR (Reference) [bypass leakage = 2 cm2, No PARs]	400.65 (1 DPV failure)	4
MELCOR [bypass leakage = 1 cm2, No PARs]	364.96	15
MELCOR [bypass leakage = 2 cm2, PARS]	370.01	13
MELCOR [bypass leakage = 1 cm2, PARs]	343.92 (peak blowdown pressure = 336 kPa)	21

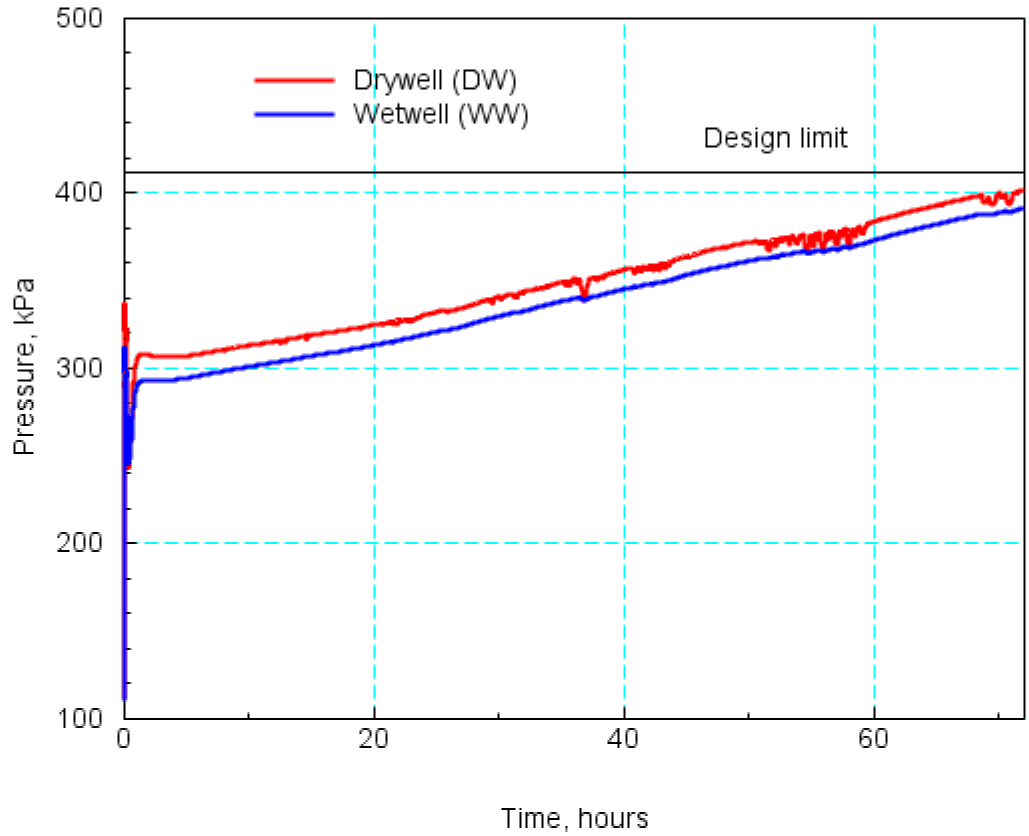

Figure B-1. MELCOR calculated drywell/wetwell containment pressure for the ESBWR during a MSLB break event (bypass leakage = 2 cm^2, no PARs).

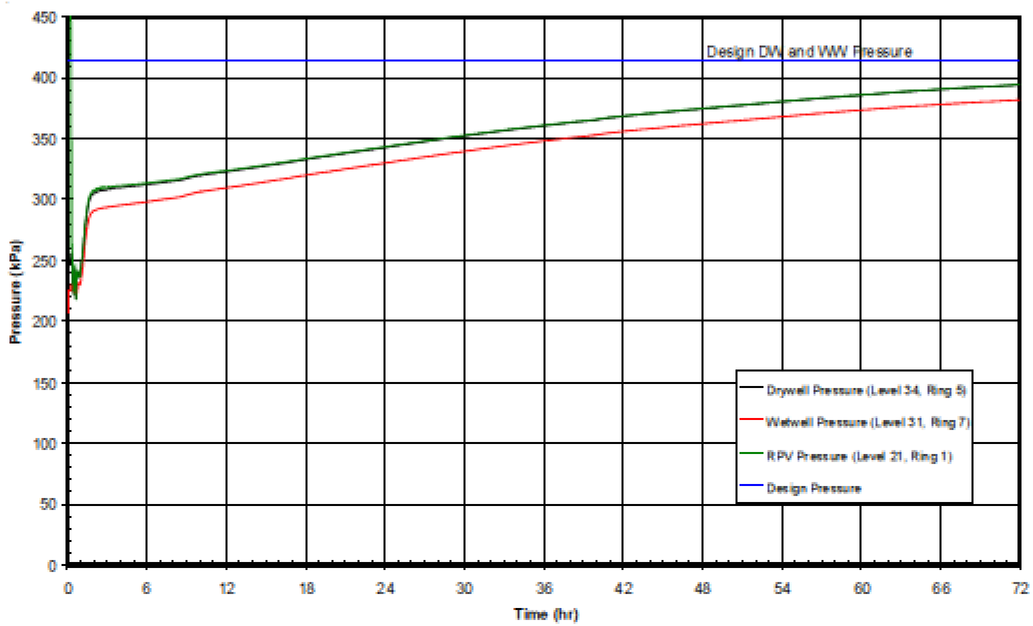

Figure 6.2-14j1. Main Steam Line Break, 1 SRV Failure (Bounding Case, with Offsite Power) – Containment Pressures (72 hrs)

Figure B-2. TRACG calculated drywell/wetwell containment pressure for the ESBWR during a MSLB break event (bypass leakage = 2 cm2, no PARs).

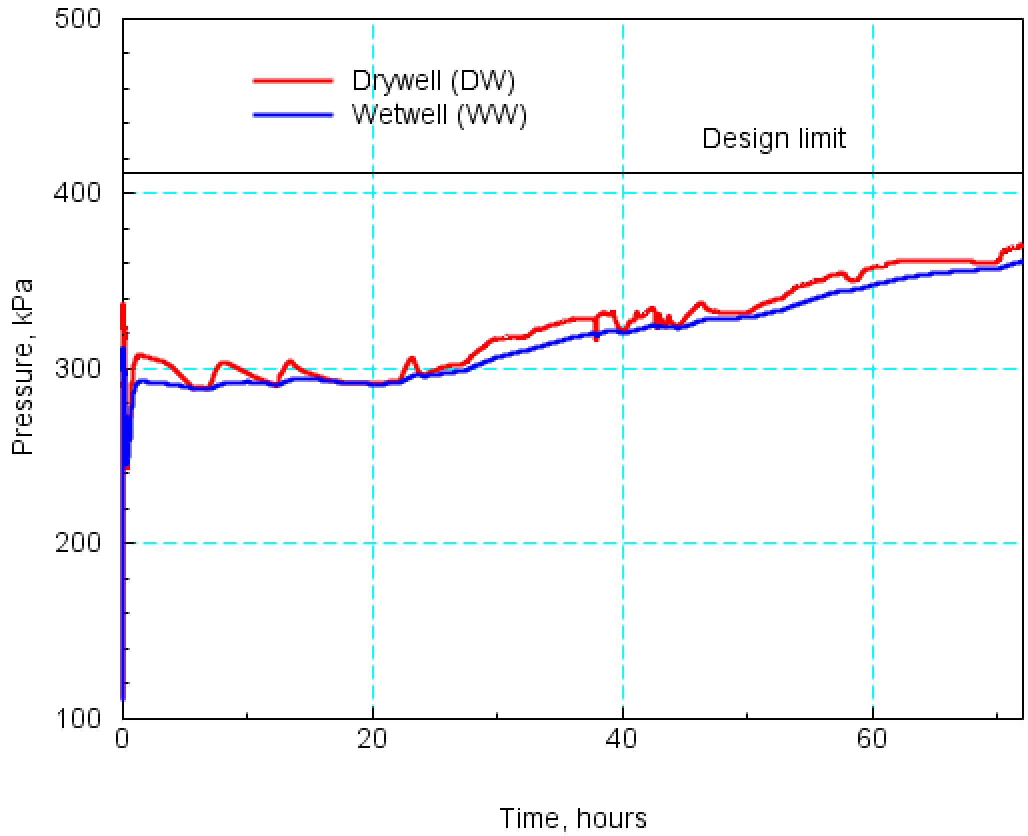

Figure B-3. . MELCOR calculated drywell/wetwell containment pressure for ESBWR during the MSLB event, excluding the radiolytic gas sources (bypass leakage = 2 cm^2, PARs).

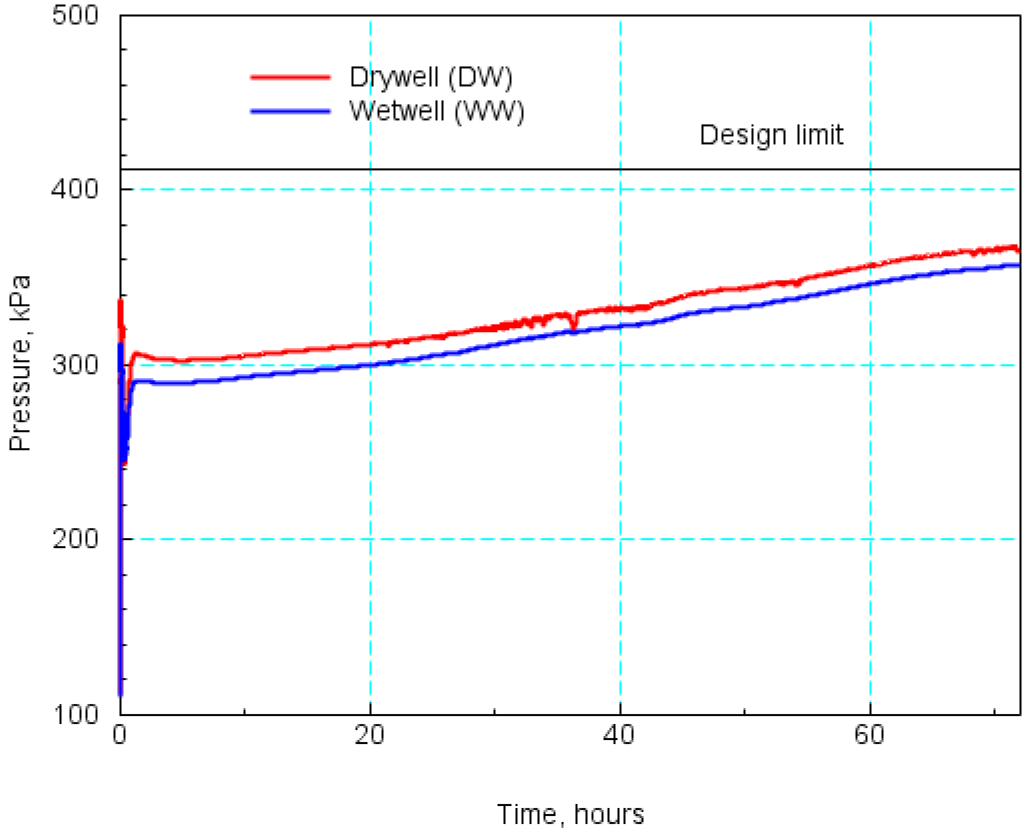

Figure B-4. MELCOR calculated drywell/wetwell containment pressure for the ESBWR during a MSLB break event with bypass leakage area set to 1 cm^2 (no PARs).

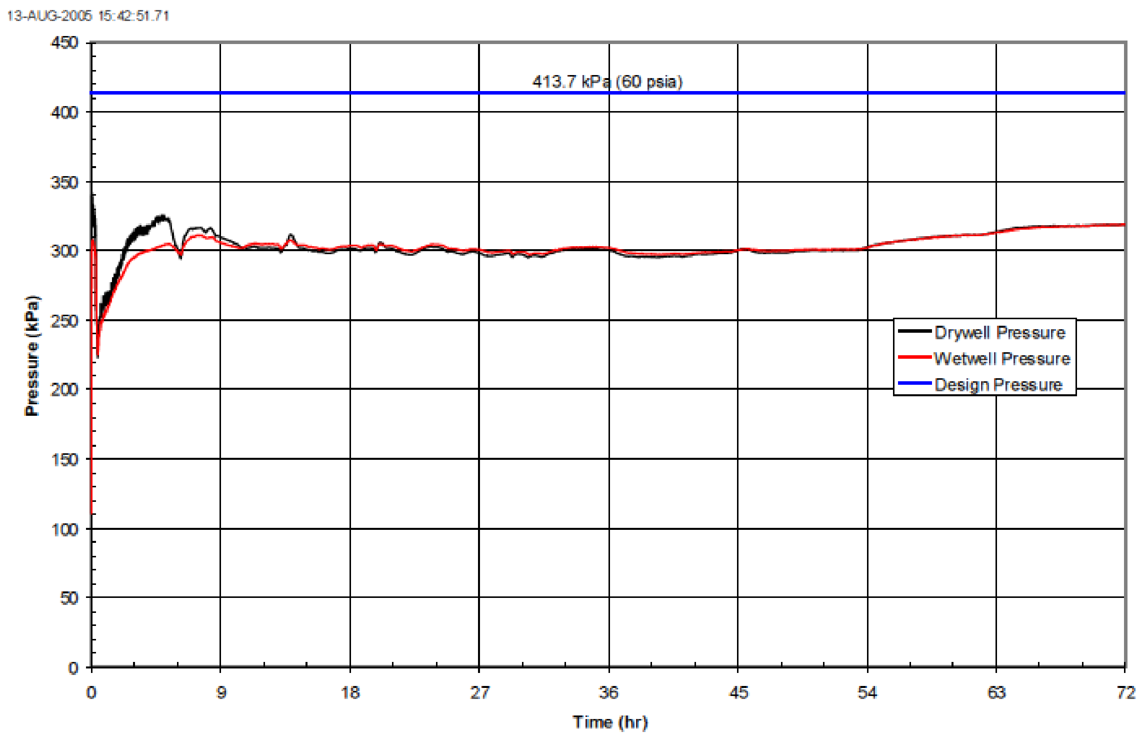

Figure 6.2-12. Feedwater Line Break (Bounding Case) — Containment Pressures

Figure B-5. TRACG FWLB bounding containment pressure calculation, DCD Rev 0. Note: GEH changed the DW and WW design pressures to 411.7 kPa (59.7 psia) in later ESBWR DCD revisions.

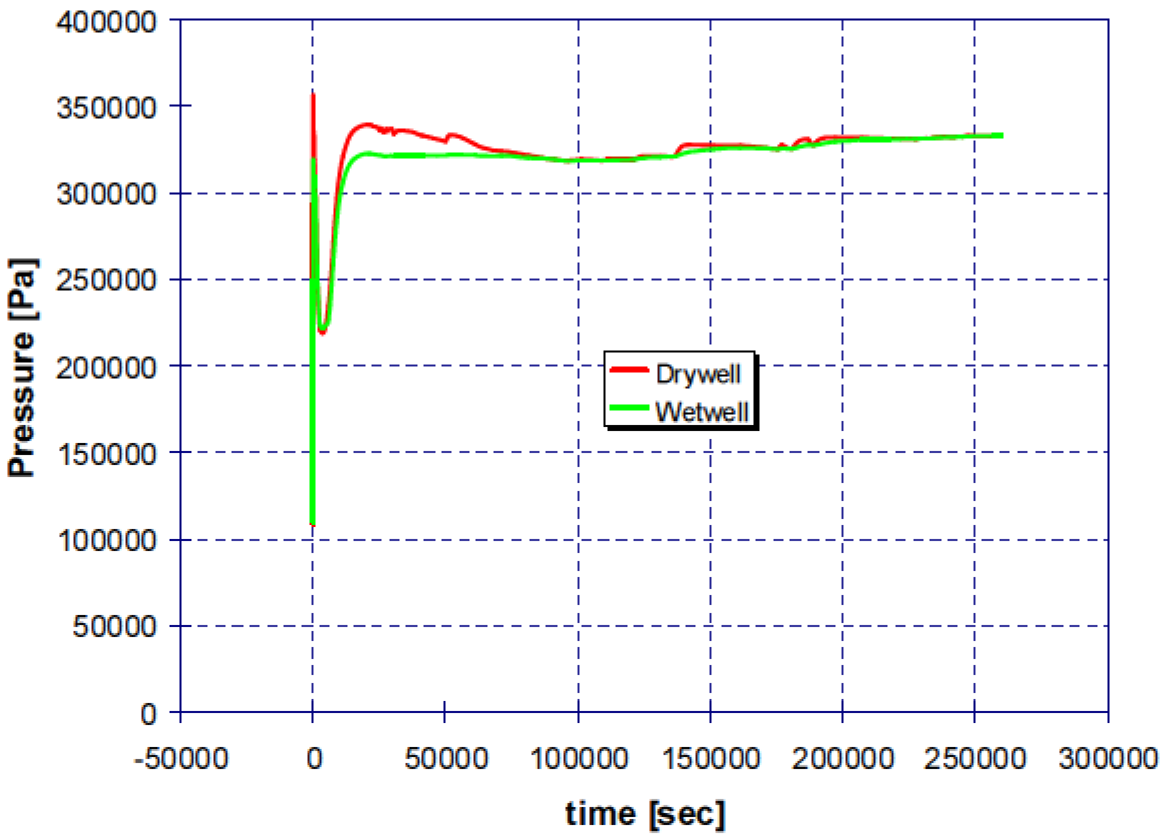

Figure B-6. MELCOR calculated drywell/wetwell containment pressure for ESBWR during the FWLB event, excluding the radiolytic gas sources with bypass leakage set to the original leakage area of 1 cm^2 ("MELCOR ESBWR Containment Performance Study (Draft)," J. Tills, November, 2006, ADAMS ML0631803801, Proprietary Information.)

Appendix C

TRACG ESBWR Nodalization Modification [Post-3day Intervention Period]

In performing the MELCOR audit/confirmatory calculations for the ESBWR containment, comparisons between the MELCOR and TRACG containment pressure response are documented as included in the body of the report. Explanations for difference observed with these responses initiated a review of model variations between each code's input. One area of noted difference involves the methodology employed in nodalizing the containment, specifically the drywell region. In the case of the MELCOR code, the drywell region (excluding GDCS tanks) is modeled as a single lumped control volume, that is, where steam and noncondensable gases are assumed to be uniformly mixed through asymmetric steam injections into the region. This well-mixed assumption has been shown to produce conservative containment pressure response for both blowdown and long-term cooling periods, transferring most noncondensable gases to the wetwell gas space. Appendix A provides a discussion concerning MELCOR blowdown pressure response versus various amounts of drywell gas trapping simulated with a multi-cell representation of the drywell (excluding GDCS tanks). The impact of gas trapping with multi-cell models for long-term peak containment pressure is addressed in the GEH DCD Rev 6 chapter 6 documentation via side calculations (DCD Tier 2 Revision 6, Table 6.2.5b), where drywell gas trapping (mainly in the drywell head region) is eliminated and the TRACG peak pressure at 72 hours is adjusted by transferring TRACG predicted trapped drywell gases to the wetwell gas space. In this appendix, however, the TRACG containment nodalization is critically reviewed for pressure response sensitivity during the post-3day intervention period which is also sensitive to noncondensable gas distributions within the drywell/wetwell spaces.

Shown in Figure C-1 is the 2-D representation of the ESBWR containment with various elevations indicated. Accuracy in geometric modeling would necessitate a 3-D representation, as dictated by asymmetries in design components and open spaces; for example, asymmetry due to placement of GDCS tanks and main steam lines (breaks), and other transfer lines (PCCS supply lines). Figure C-2 shows the asymmetric placement of GDCS tanks and steam lines within the upper drywell region. Although the TRACG code can represent 3-D component placement, the ESBWR TRACG model is described using a 2-D layout of the containment (R/Z coordinates), Figure C-3. Consequently, for the upper drywell, steam injections to this region are input symmetrically in a ring just exterior to the RPV, and the GDCS tanks are also symmetrically modeled in two outer rings. Both of these modeling characteristics can introduce non-realistic artifacts into the mixing processes simulated, specifically unknown inaccuracies into amounts of noncondensable gases trapped in the drywell. However, there are also other modeling concerns beyond the symmetry issues. These concerns deal with modeling errors associated with gas space placement (elevation errors) and volume-to-volume connections, as described below.

Figure C-4 shows the translation of the drywell head (dome and cylinder) and upper drywell/GDCS tank regions into the TRACG nodalization scheme. Elevations of the drywell head regions are not preserved in the TRACG model, and the GDCS tank gas spaces are modeled outside of the containment boundary. More importantly, in the TRACG nodalization the GDCS upper gas space is connected directly to the drywell head; however, in the containment design the GDCS tanks connect only to the upper drywell region below the head. These modeling concerns were raised during the 17 June 2009 ACRS subcommittee meeting on ESBWR containment topics. GEH responded later to these concerns with a sensitivity calculation that addressed modeling distortions in the TRACG nodalization. On the basis of this sensitivity calculation, GEH revealed at the 17 November 2009 ACRS subcommittee meeting that correction of the TRACG nodalization to the actual physical design of the upper head and drywell region resulted in less pressure reduction for the post-3day period than was apparent in the figures presented in DCD Rev 6. Figure C-5, although listed as unverified, is the basis for that statement where now the GDCS tank to drywell connection is adjusted to represent the containment design. As indicated in the figure, the corrected model shows a slight increase in containment pressure compared to the DCD documented pressure response curve (DCD Rev 6). However, the calculation is terminated at 192 hours, well short of the 720 hours that represents the end of the post-3day intervention period. [[

]][1] We can conclude from the GEH sensitivity calculation referenced in the GEH ACRS presentation that a corrected TRACG drywell nodalization model would increase post-3day maximum pressure slightly and tend to flatten the pressure response profile compared to the DCD documented pressure calculation.

[1] MELCOR ESBWR 30 day intervention calculations are completed in ~ 5 days.

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Figure C-1 ESBWR containment (layout taken from GEH internal documentation to support ESBWR Containment Configuration Data Book -- figure corresponds to DCD Rev 6 Figure 6.2-1 with vertical dimensioned included).

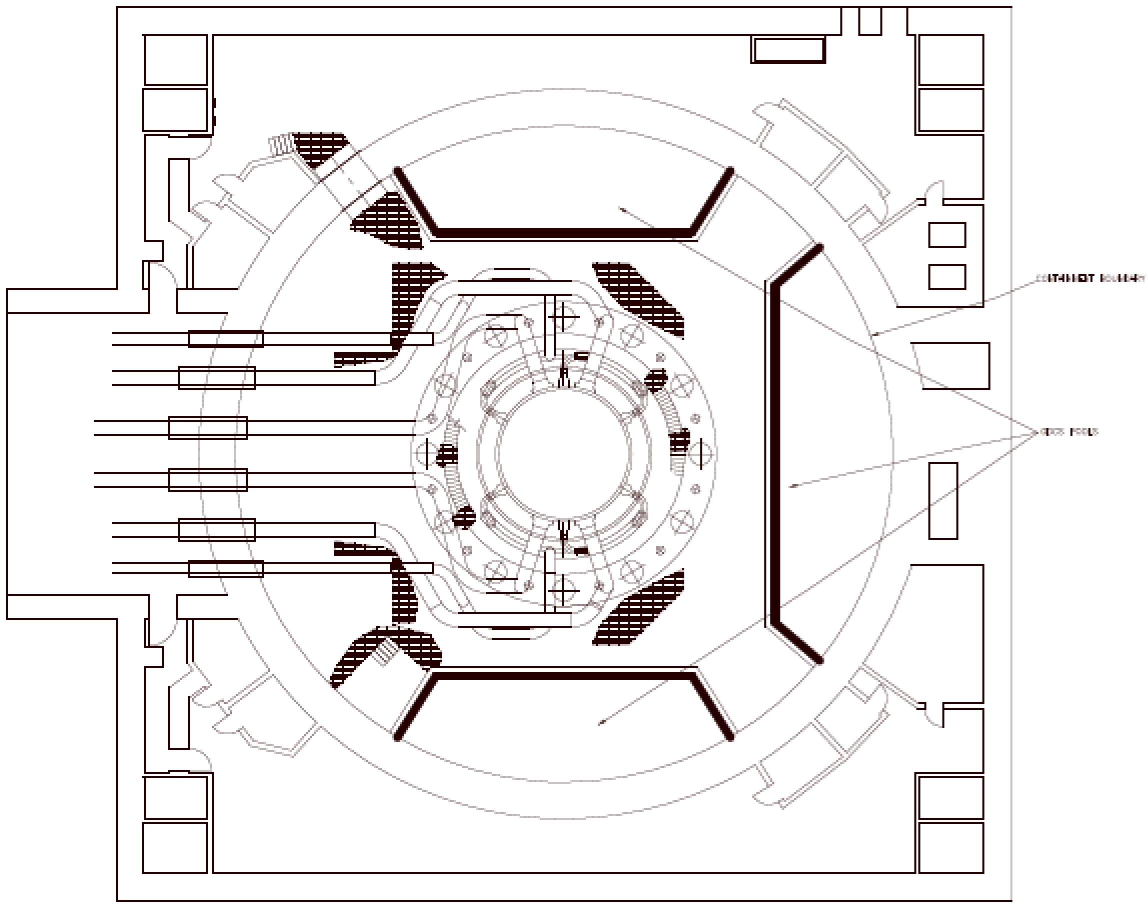

Figure C-2 ESBWR containment elevation in the upper drywell region (elev. 22500), DCD Rev 6, Figure 6.2-3.

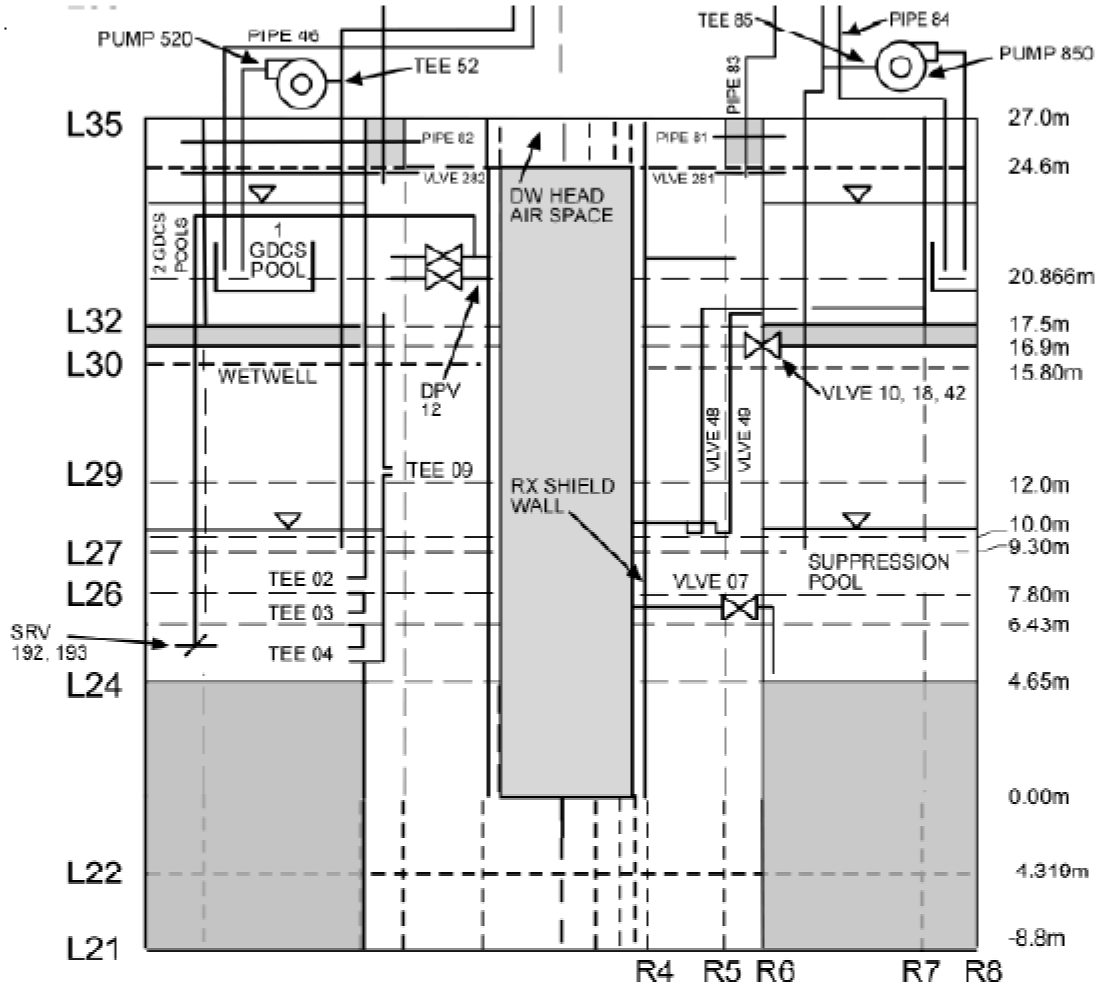

Figure C-3 TRACG 2-D containment nodalization layout, DCD Rev 6 Figure 6.2-7.

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Figure C-4 Translation of the ESBWR drywell regions into the TRACG nodalization scheme.

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Figure C-5 TRACG sensitivity calculation showing the post-3day pressure increase for the re-noded drywell model [[ ]]

Appendix D

GEH Re-calculation of the Post-3day Intervention Period [RAI 6.2-140S06]

During the review of the TRACG calculation for the MSLB event during the post-3day period presented in DCD Revision 6, modeling issues were raised concerning 1) refill of the PCC tanks not being modeled according to operational procedures, and 2) fan outlet submergence not modeled to maintain a submergence of 10 inches (design). In RAI 6.2-140S06 response, GEH reports on a re-calculation of the post-3day period with these concerns addressed. The re-calculation corrects the refill modeling to remove previous (RAI 6.2-140S05 response) level control during intervention. Treatment of fan outlet submergence maintained at 10 inches is addressed in the RAI response; however, the corrective measure does not simulate in a mechanistic manner the effect of GDCS drain pan inclusion on fan exit submergence. Rather, a minimum submergence depth is simulated by forcing discrete adjustments in the fan outlet height to maintain a minimum submergence depth at or greater than 10 inches. The outlet height adjustment method that periodically steps the submergence on restart to 16 inches (6 inch bump) of submergence introduces instability into the post-3day re-calculation such that the containment pressure prediction is suspect. Subsequently, discussion with GEH in joint teleconference (NRC staff/JTA/GEH) with follow-up documentation (MFN 09-023 Supplement 5, Enclosure 1; ML1028102280) has confirmed that smaller periodic adjustment in submergence depth on restarts significantly improves stability in fan head/flow (fan chatter), and the smaller periodic adjustments (1 inch bump) in submergence depth show an increase in fan flow which would indicate a reduced containment pressure over the reported profile documented in the RAI 6.2-140S06 response.

Shown in Figures D-1 and D-2 are the post-3day containment pressure calculations as documented in DCD Revsion 6 and Revision 7, respectively. The re-calculated pressure shows a late time increase in pressure of approximately 25 kPa compared to the DCD TRACG pressure calculation at 30 days. The re-calculation however also shows some significant stability problems for other dependent variables not otherwise indicated in the DCD report. For example, shown in Figures D-3 and D-4 are the RAI-6.2-140 TRACG calculated and re-calculated circulation flows through the fan vent line. Instabilities shown in the RAI response appear at the time that fan outlet height adjustments are made. The height adjustments (6 inches + submergence of 10 inches, referred to as a 6 inch bump) force the fan operation into a relatively high fan head region of the fan performance curve where the fan head vs. flow is essentially flat. Operation in this region can result in fan chatter as observed also in the MELCOR calculation when the intervention period is first initiated, Figure D-5.

As a consequence of the instabilities evident in the Revision 7 calculation, the GEH method for simulating the GDCS drain pan effect on fan flows and containment pressure was drawn into question. GEH therefore repeated a portion of the post-3day calculation reducing the submergence step at restart from 16 to 11 inches (6 to 1 inch bump). The reduction in the restart submergence step smoothed out the fan flow oscillations and produced a slightly greater average fan flow than indicated in the RAI 6.2-140S06 response. With this fan model adjustment, the DW pressure, Figure D-6, was observed to drop relative to the pressure documented in DCD Revision 7 at time of the first restart. Later, however, the adjusted pressure asymptotically approached the Revision 7 pressure curve.

Shown in Figure D-7 is the fan head curve for the Revision 7 and re-calculation using the smaller submergence stepping (bump). The fan chatter that the ad hoc fan exit submergence procedure initiates with the 6 inch bump appears to be directly the result of the fan head being maintained within the flat region (fan head vs. flow) of the fan performance curve [[ ]]. This operation region, due to the high sensitivity of flow rate to head change, could *physically* cause fan flow oscillations or chatter. The issue concerning possible inappropriate specification by GEH of PCCS vent fan performance (fan rated performance) was raised by NRC staff and ACRS consultant at the 17 November 2009 ACRS subcommittee meeting on ESBWR long-term cooling. However, at that meeting the oscillations were only momentary observed at the time when the fans were activated and the fan head was the highest – DCD Revision 6 calculation review. As time progressed, the TRACG fan model (without the drain pan effect) and the MELCOR model (with drain pan effect) showed that the calculated fan head trended out of the sensitive portion of the fan performance curve. Once the TRACG fan restart stepping procedure was introduced for the DCD Revision 7 calculation, a higher fan head was maintained with the stepping procedure and the period of prolonged fan chatter was observed. The somewhat uncertain fan flow behavior noted for the Revision 7 pressure profile therefore appeared as a consequence of fan rating specification coupled with the TRACG fan exit model that used a rather large restart stepping procedure to maintain fan exit submergence equal or greater than 10 inches. A smaller submergence stepping procedure that would provide a more realistic modeling of fan exit pipe (similar to the MELCOR modeling), was shown to eliminate the late-time fan chatter with minimal changes to containment pressure response.

The revised submergence stepping procedure corrected the fan chatter problem. However, the revised calculation was only taken out to 350 hours (i.e., a portion of the intervention period that in total goes out to 720 hours), and was not taken out further for use in replacing the calculation presented in DCD Revision 7. [[

]] Since the revised (1 inch bump) calculation appeared to provide a lower bound on the Revision 7 calculation, [[ ]] the Revision 7 calculation remained the calculation of record for the ESBWR certification application.

Finally, for comparison purposes (MELCOR vs. TRACG re-calculation), it should be pointed out that the MELCOR post-3day DW pressure calculation will remain higher than the GEH re-calculation for a number of reasons, some of which have been addressed in the audit report (e.g., the difference in pressure drop or cliff when the PCCS vent fans are initially activated). However, there are other more subtle reasons similar to the minor effect discussed for the GEH re-calculation above. For example, the following observations all tend to place the MELCOR post-3day pressure profile higher than the profile presented GEH response to RAI 6.2-140S06: 1) the MELCOR scenario remains as the 1DPV failure case (case #1, DCD table 6.2-5a) , while the TRACG intervention re-calculation uses the MSLB scenario with 1SRV failure with offsite power (case #5, DCD table 6.2-5a) that has a slightly lower 3 day containment pressure than the 1DPV failure case, 2) the 3 day containment condition with respect to pressure is calculated higher with MELCOR since there is no DW hold-up of NC gases (see DCD Tier 2 Revision 6, Table 6.2-5); 3) the MELCOR upper containment, DW upper head, and GDCS volume nodalization in MELCOR follows the document ESBWR design; whereas, the current TRACG model does not (Appendix C); and, 4) the MELCOR mechanistic modeling of PCCS efficiency for low steam flow appears to be slightly more conservative in the MELCOR modeling than the TRACG empirical model. As a result, we observe that the MELCOR DW pressure calculation for the post-3day period, while lower than the 72 hour peak, is not reducing at late time but trending flat to 30 days, which indicates a more conservative representation of the pressure profile than obtained with the TRACG model. In conclusion, the MELCOR DW pressure at 30 days results in a 24% margin to containment design pressure, which is ~ 50 kPa higher than the most recent TRACG re-calculation reported in RAI 6.2-140 S06, and documented in DCD Revision 7.

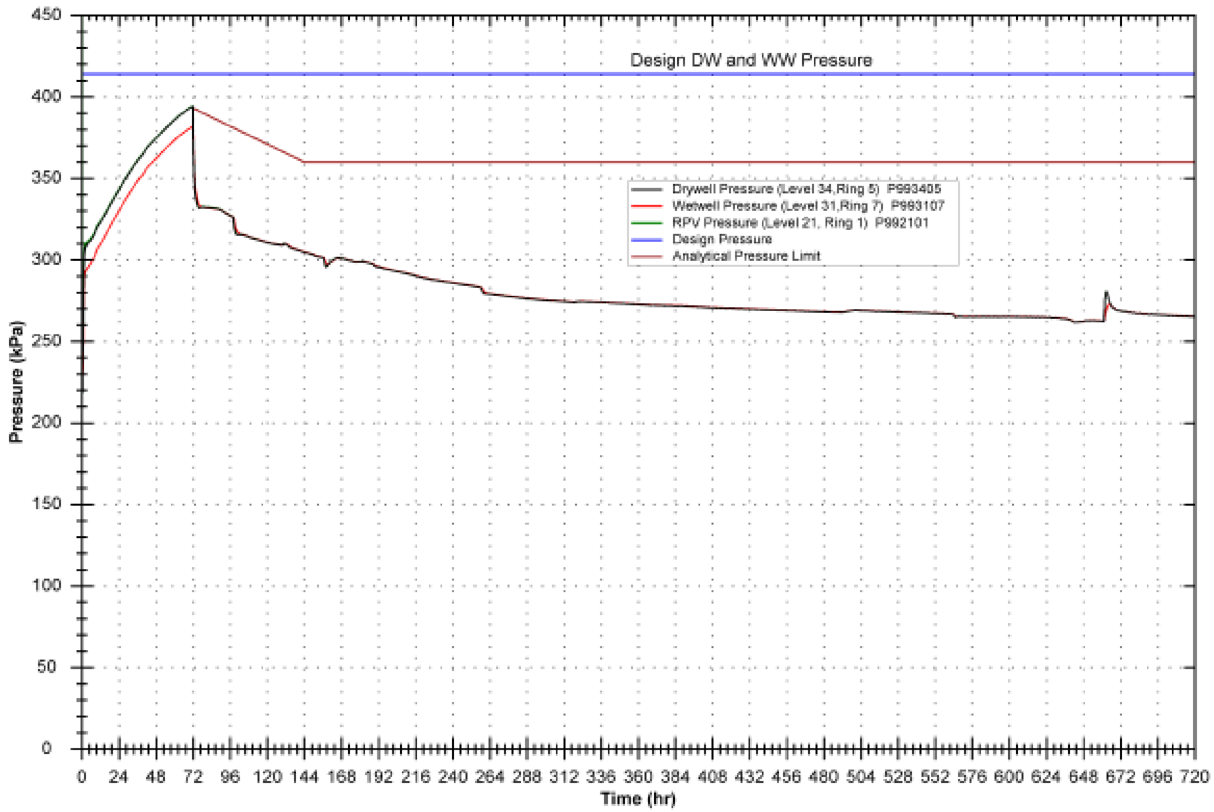

Figure D-1. TRACG post-3day pressure response as documented in the DCD Rev6 submittal (DCD Figure 6.2-14e1).

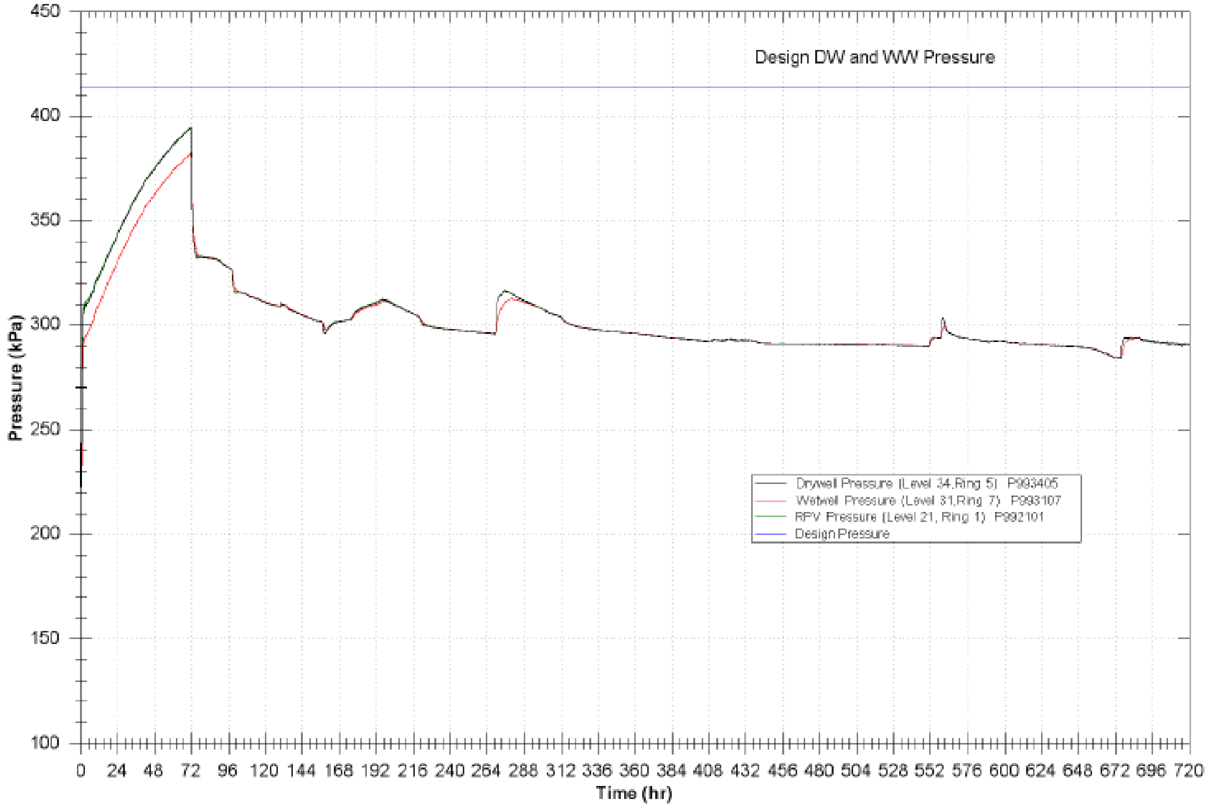

Figure D-2. TRACG post-3day pressure response as documented in the GEH response to RAI 6.2-140S06.

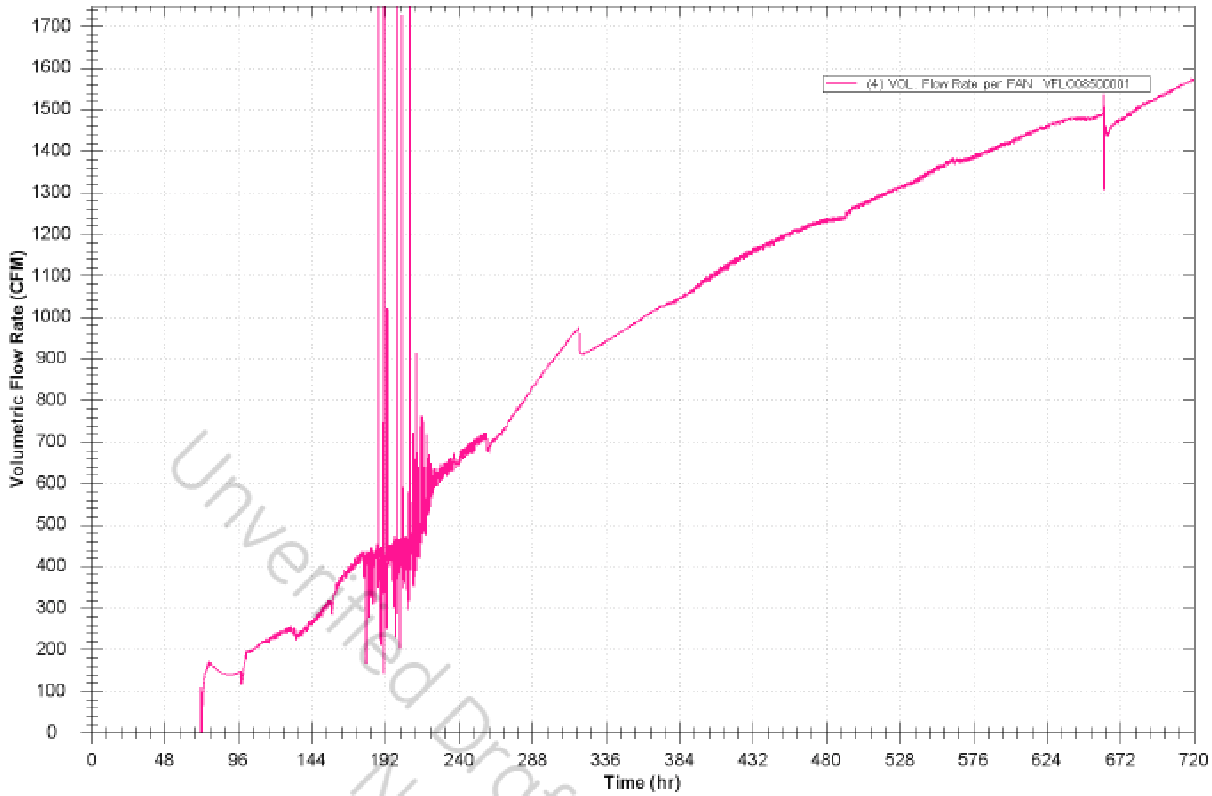

Figure D-3. Re-circulation flows for the DCD Rev 6 post-3day period.

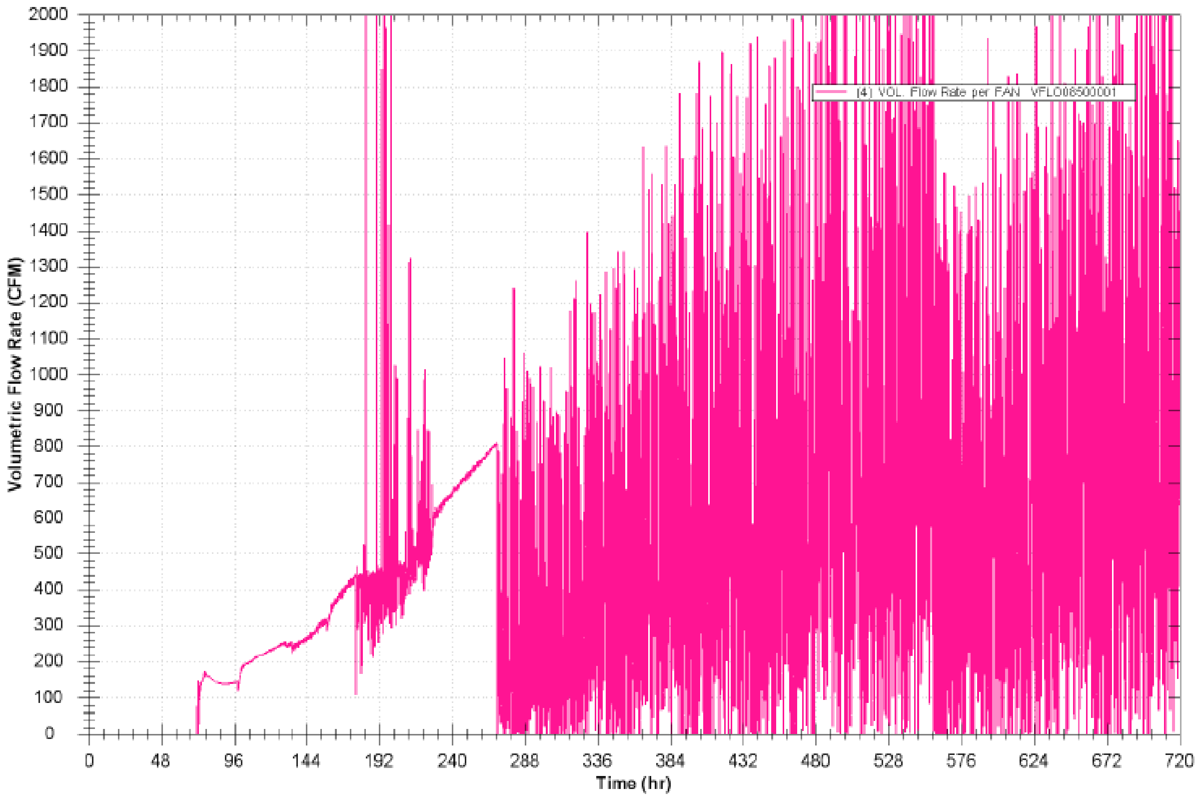

Figure D-4. Re-calculation of the re-circulation flow as documented in GEH response RAI 6.2-140S06.

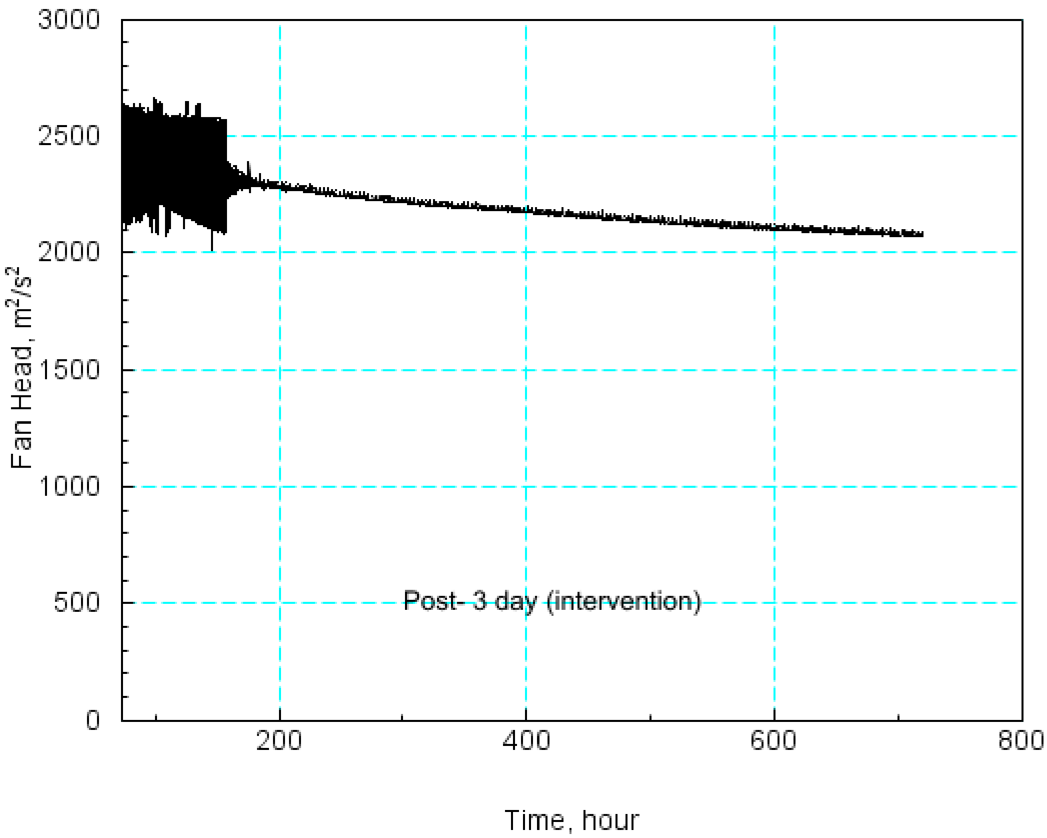

Figure D-5. Fan head time history calculated with the MELCOR post-3day intervention model, showing the initial instability period as a result of operation in a highly sensitive region of fan performance (head vs. flow), experienced during the fan start-up period.

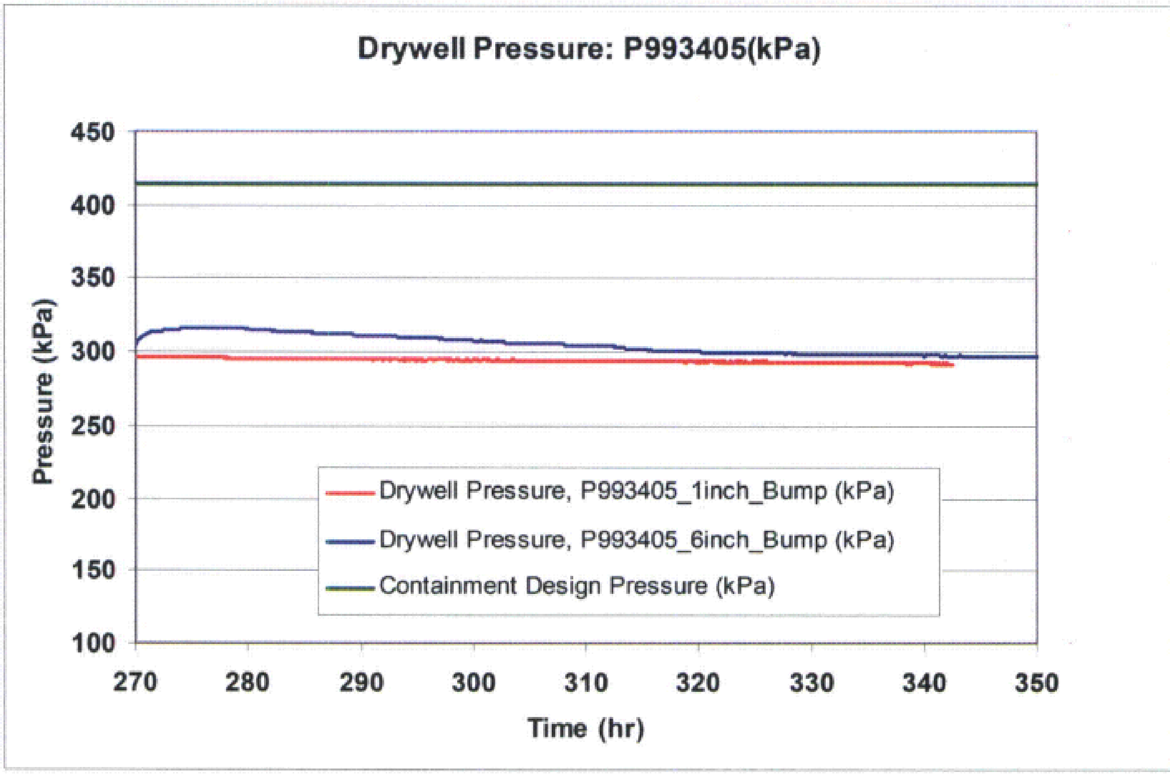

Figure 3 Main Steam Line Break (Bounding Case) Containment Pressure

Figure D-6. Revised TRACG post-3day pressure profile (1 inch bump) that bounds the DCD Revision 7 pressure trace (6 inch bump) [ML102810228].

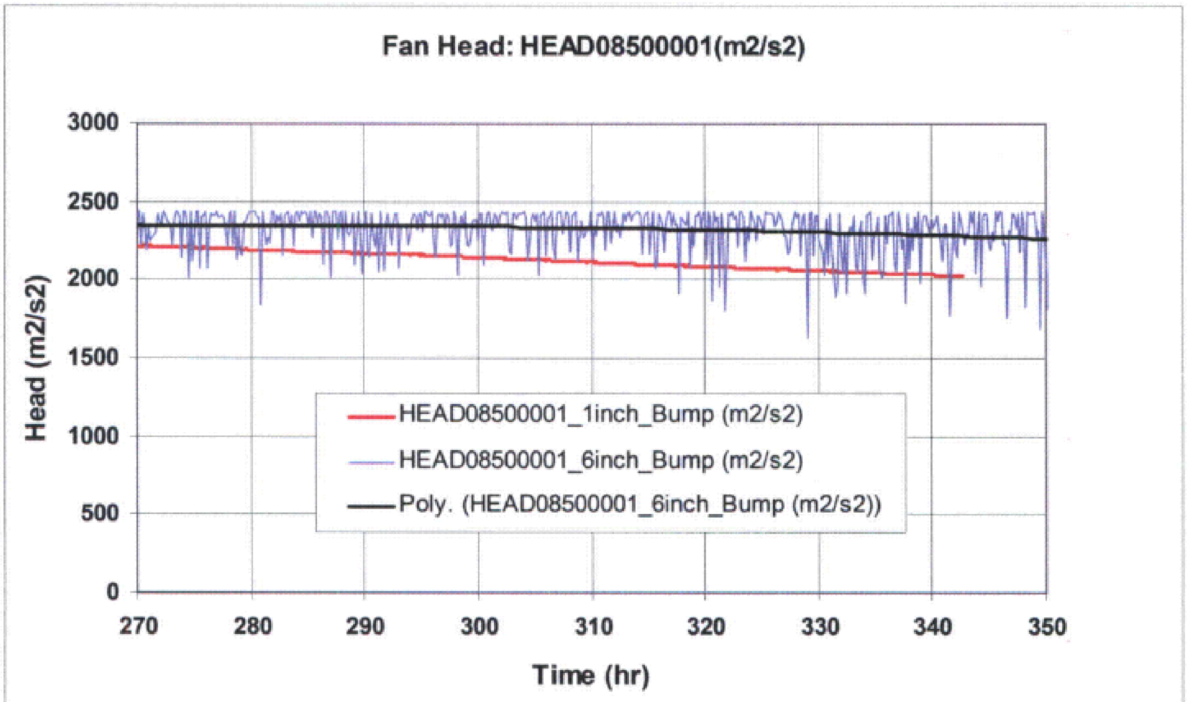

Figure 2 Main Steam Line Break (Bounding Case) PCC Vent Fan Head

Figure D-7. Revised TRACG post-3day fan head (1 inch bump) that bounds the smoothed DCD Revision 7 head trace (6 inch bump), while producing a stable head profile [ML102810228].

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