AP1000 Updated Containment Calculations
Part I: MSLB Analysis

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Prepared By
Jack Tills, JTA, Inc.
Sandia Park, NM

For
Organization 6415
Sandia National Laboratories
Albuquerque, NM

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1 Introduction

ISL's AP1000 CONTAIN input deck used to perform a MSLB accident scoping calculation[1] during the NRC's pre-application review stage for the AP1000 was reviewed and modified to be consistent with the current AP1000 design described in WCAP-15846, Revision 0. In addition, the input model was revised to include the biases used in WGOTHIC analyses that support plant certification. Those biases not included in the scoping calculations are as follows:

- Exclusion of floor surfaces as heat sinks
- Air gap (20 mils) between all steel lined concrete heat sinks
- No heat transfer to below operation deck dead-ended compartments after blowdown injection
- Reduced mass and heat transfer coefficients on inner containment shell surface, multiplied by factor of 0.73
- Reduced mass and heat transfer coefficients on outer containment shell surface, multiplied by factor of 0.84
- PCS air flow loss coefficients increased by 30% above the experimental determined coefficients

In addition to biases above, a recent revision to the MSLB injection source has been reported subsequent to the ISL calculations, and therefore this new injection source was also included in an updated CONTAIN input deck in order to compare results with the most recent WGOTHIC MSLB calculation.[2]

Section 2 of this report compares the most recent CONTAIN MSLB calculation that includes the above biases and the updated injection source for the worst case MSLB scenario (30% power, DER) to WGOTHIC results documented in the AP1000 DCD.

A number of sensitivities (16 cases) associated with the biases, injection source, stratification modeling, and PCS operation are discussed in Section 3. In Section 4, a summary of the CONTAIN updated AP1000 calculations is given. A listing of the reference CONTAIN input for the MSLB accident is presented in Appendix A.

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[1] B. J. Gitnick, "CONTAIN 2.0 Model for the Westinghouse AP1000: Advanced Passive Reactor Containment Analysis," ISL-NSAD-NRC-01-007, November, 2001.
[2] AP1000 Design Control Document, Tier 2 Material, Revision 0 and 1.

2 Reference Calculation

2.1 Biases

Exclusion of the floor surfaces was accomplished by setting each floor surface area to a small area ~ 1.0e-10 m^2. For structure connected surfaces (floor to roof), the outer boundary condition was converted from a structure connect to an adiabatic boundary.

A 20 mil air gap was added to each steel lined concrete structure by including an additional node of "air" material between the steel and concrete last and first node, respectively. The air properties (thermal conductivity, density, and specific heat) were obtained from the AP1000 DCD.

To simulate the termination of heat transfer to below operation deck, dead-ended compartments, a restart procedure was adopted wherein the calculation was restarted at the end of the blowdown with dead-ended heat transfer turned off using the HT-TRAN option input.

The reduced mass and heat transfer to containment shell surfaces (commented in the ISL deck) was included by changing the commented out "hmxmul = 0.73 or 0.84" input in STRUC blocks to active input.

The increased PCS duct loss coefficients were included by replacing the vcfc values for the PCS in the FLOWS block with coefficients multiplied by 1.3.

2.2 MSLB Injection

Shown in Figure 1 is a comparison between the old (ISL) steam injection and the new (AP1000 DCD) injection for the MSLB scenario that produces the maximum peak pressure in the containment. This injection is based on a 30% power, double-ended rupture of a main steam line located above the operation deck. In the configuration of the AP1000, the location of the break for the MSLB is in CONTAIN compartment # 7, as shown in Figure 2. The characteristics of the change in the new source compared to the old source are 1) the initially higher mass rate from 0-1 seconds, and 2) the extension of the source cut off from ~ 660 seconds to ~ 840 seconds. The new source total mass injection is approximately 10% greater than the old source, this being due mainly to the extension of the cut off time, see Figure 3.

2.3 Results

Shown in Figure 4 is a comparison of the MSLB containment pressure calculated with the updated CONTAIN input (w biases and new source) and the most recent WGOTHIC calculation report in the AP1000 DCD. As indicated the agreement is quite good. The maximum pressure calculated with CONTAIN is 57.8 psig, as compared to 57.3 psig with WGOTHIC. In Figure 5, the containment temperatures are plotted for all internal containment cells (see Figure 2 for cell locations). Cells numbering 7-9 and 20-23 are those cells in the above operation deck region. The below deck cells are numbered 1-6. As noted, there is a significant stratification calculated between the above and below deck compartments. The stratification can also be shown for the steam concentration, Figure 6. It should be noted that the degree of temperature stratification indicated in Figure 5 has been predicted also with CONTAIN for a benchmark MSLB experiment using the hybrid flow solver, as invoked here.[3] A maximum temperature of 374.9 F (463.7 K) occurs at ~ 100 seconds in cell #22, just below the injection cell #7. The injection of superheated steam from the break results in superheated gas temperatures in the vicinity of the break. The degree of superheating can be affected by the amount of steam condensation in a cell. In the case of cells #7 and #22, cell #22 has significantly more exposed miscellaneous steel, and the additional steam condensation in cell #22 increases the degree of superheating. The saturation temperature however in cell #22 remains below the saturation temperature in the injection cell, as expected (see Table 1). Also of interest is the stratification in the air density between above and below deck compartments. Shown in Figure 7 is the air density variation between cell #9 (dome) and cell #3 (CMT, CVS, accumulator cavities).

Shown in Figure 8 is the total energy absorbed by heat sinks in the various compartments below the operation deck. The largest amount of energy is absorbed in compartment #3, which is the CMT, CVS, accumulator cavity NE and SE volume.

3 Sensitivity Calculations

Sensitivity calculations have been performed to investigate variation in maximum containment pressure that could be associated with uncertainty in conservative modeling assumptions (biases), mass injection, stratification, and PCS operation. Since the reference calculation results in a maximum containment pressure that is ~ 98% of the design pressure, it is important to the confirmatory process that the degree of conservatism inherent in the design basis calculation be evaluated. The evaluation should be put into the context of the changes (creep) in peak pressures that have been reported by Westinghouse in their design basis analysis of AP1000, as indicated in Table 2.

3.1 Conservative Biases

The conservative biases listed in Section 1 have been removed from the CONTAIN input to generate a "nominal" input to investigate the degree of conservatism associated with the biases. Removal of the biases reduced the peak pressure by 1.2 psi, resulting in a peak pressure of 56.6 psig. Therefore, all of the discussed biases in Section 1 amount to slightly greater than 1 psi of conservative margin.

[3] See the CVTR test analysis in "An Assessment of CONTAIN 2.0: A Focus on Containment Thermal Hydraulics (Including Hydrogen Distributions)," SMSAB-02-02, July 2002.

3.2 Injection Mass

The reported peak pressure given in WCAP-15612 (ISL's WCAP reference document) was calculated by WGOTHIC with a total mass injection of 148.3e3 kg. In AP1000 DCD document (Rev 1) the mass injection increased by ~ 10% to 163.6e3 kg. That 10% increase in mass injection alone results in a 1.68 psi increase in the peak pressure (biases included). The potential for further increases in the peak pressure due to changes in the mass rates, as indicated in Figure 9, are shown in Figure 10. With biases included, an increase in the steam mass of ~ 3.9% over the reference MSLB injection results in a calculated peak pressure that is approximately equal to the containment design pressure. It is therefore quite important that the reference MSLB injection be known to be a conservative injection, with no unforeseen increases as noted in recent WCAPs.

3.3 Stratification

As indicated in Section 2, the CONTAIN calculation predicts a significant amount of stratification for the reference calculation. Overmixing in a lumped parameter code such as CONTAIN is controlled here by using the hybrid flow solver (default).[4] The ability of the hybrid flow solver to predict stratifications in geometries and conditions similar to the MSLB scenario is demonstrated with relatively good accuracy in the CVTR tests[5] and the Westinghouse LST[6]. The reference calculation therefore should be considered a best estimate calculation for stratification in AP1000 during the MSLB scenario. However, the case for overmixing (similar to what may be predicted in the case of WGOTHIC) can be simulated in CONTAIN by disabling the hybrid flow solver, reverting to the typical (or older) lumped parameter solution method. In CONTAIN, this is accomplished by the inclusion of the keyword MSTABLE in the FLOWS block. Shown in Figures 11 and 12 is the change in compartment #3 temperature and steam mole fraction, respectively, as a result of an addition of the MSTABLE keyword in the CONTAIN calculation. The decrease in the containment peak pressure due to the overmixing in the lower compartments is ~ 0.5 psi.

For the WGOTHIC calculations, the question regarding possible overmixing during injection (LOCA and MSLB) was addressed by the conservative biasing of below deck heat transfer during times subsequent to the blowndown. In the case of LOCA scenario, this was accomplished by turning heat and mass transfer off for dead-ended compartments below deck after the first 30 seconds of the accident. The first peak in the containment pressure due to lower compartment heat transfer, during the blowdown, was unaffected by the bias. The second containment peak pressure however that occurs during the post-blowdown was affected by the bias. For the MSLB, the blowdown is not followed with additional injection; therefore, a bias that cuts off heat transfer to lower

[4] K.K. Murata and D.W. Stamps, "Development and Assessment of the CONTAIN Hybrid Flow Solver," SAND96-2792, November, 1996.
[5] J. Tills, et. al., "An Assessment of CONTAIN 2.0: A Focus on Containment Thermal Hydraulics (Including Hydrogen Distributions), " SMSAB-02-02, July 2002.
[6] J. Tills, et. al., "User Guidance on the CONTAIN Code for Advanced Light Water Reactors," SAND96-0947, April 1996.

compartments is <u>not</u> a contributing factor for the MSLB peak pressure calculation. In concern for consistency in the reasoning behind the conservative biasing with respect to lower compartment heat transfer a series of sensitivity calculations were conducted. As indicated in Figure 1 the MSLB injection drops significantly after approximately 10 seconds. Beyond 100 seconds, the peak containment temperatures show a significant decline. A review of the mass injection rates for times greater than 100 seconds in the case of the MSLB and the post-blowdown injection for the LOCA indicate that the injection rates are similar in magnitude, ~ 100-200 kg/s. Therefore, it would appear to be appropriate to considered an earlier lower compartment cut-off time for the heat transfer than time for MSLB blowdown termination. Shown in Figure 13 are the effects that cut-off times for lower compartment heat transfer have on the containment peak pressure. Also shown is the sensitivity of including either the entire below deck compartments or only compartment #3 (CMT, CVS, and accumulator cavities) in the bias assumption. As indicated in the figure, cut off time of ~ 400-500 seconds, which may be argued is consistent with the LOCA biasing assumption, results in calculated peak pressures that are approximately equal to the design pressure.

3.4 PCS Parameters

The sensitivity calculations for the PCS parameters include variations in 1) PCS flow rate and 2) PCS stripping. For the case of flow rates, a calculation was made with 50% of the PCS flow rate used in the reference calculation. The reduced flow rate resulted in a containment peak pressure of 60 psig, ~ 1psi over the design pressure. For the stripping sensitivity study, the wetted region on the containment shell was reduce from 90% to 50%. The region effect included the lower portion of the dome and all of the cylindrical shell. The reduced stripping resulted in the calculated containment peak pressure increaseing from 57.8 to 59 psig, which at 59 psig is the containment design pressure.

4 Summary

An updated CONTAIN input has been generated for the AP1000 MSLB scenario using as a basis the ISL CONTAIN reference input deck. The updates included 1) a revised injection source (AP1000 DCD), and 2) changes to the input to reflect the containment conservative input biases used for the WGOTHIC calculations described in various WCAPs.

The CONTAIN reference calculation pressure profile shows good agreement with the most recently reported WGOTHIC profile. The CONTAIN peak pressure and temperature are calculated only slightly above the WGOTHIC values; pressure and temperature values are ~ 0.5 psi and < 1 degree above report values, respectively.

A series of calculations have been completed to investigate the sensitivity of containment peak pressure to 1) inclusion of biasing, 2) mass injection, 3) stratification effects, and 4) PCS operation. A summary of the results of the sensitivity calculations are presented in Table 3. It is noted that for Case 9, which excludes the hybrid flow solver, the containment peak pressure is essentially identical to the WGOTHIC calculation, with both calculations reporting a peak pressure of 57.3 psig. The general improvement in agreement with WGOTHIC in this instance compared with the reference case that used the hybrid flow solver to maintain stratification is believed to be reasonable (since WGOTHIC would be considered a overmixing model). However, it should be noted that other differences in the CONTAIN and WGOTHIC models still exist even for Case 9. The most notable of these is the use of the Uchida correlation for internal heat sinks in the case of the WGOTHIC model compared to the heat and mass transfer analogy method used in the CONTAIN model.

Table 1 Peak Temperatures (K) during a MSLB in AP1000 (CONTAIN time = 100 sec.)*			
Temperature type	Cell #7	Cell #22	WGOTHIC
Gas	452.5	463.7	463.1
Saturation	403.8	382.5	---

*30% power, DER

Table 2 Reported peak pressure for MSLB in AP1000 (WGOTHIC)		
Document	Peak Pressure, psig	Safety margin*, psi
WCAP-15612 (12/2000)	56	3.0
WCAP-15846 (4/2002)	56.5	2.5
AP1000 DCD (Rev 1)	57.3	1.7

* Design pressure – calculated max pressure (59 – calc. max pressure)

Table 3 Summary of the CONTAIN sensitivity calculations for containment peak pressure for the MSLB (30% power, DER) in AP1000				
Case #	Type	Description	Peak Pressure psig	Safety Margin* psi
---		WGOTHIC (AP1000 DCD)	57.3	1.7
1	Reference	Reference case (w biases, updated source	57.8	1.2
2	Biases	Case 1 w/o biases	56.6	2.4
3	Injection	Case 1 w "old" source	56.13	2.9
4		Case 1 w 3.9% total mass injected increase	59.3	-0.3
5		Case 1 w 7.2% total mass injected increase	60.33	-1.33
6		Case 2 w "old" source	54.6	4.4
7		Case 2 w 3.9% total mass injected increase	57.85	1.15
8		Case 2 w 7.2% total mass injected increase	58.84	0.16
9	Stratification	Case 1 w MSTABLE (overmixing)	57.3	1.7
10		Case 1 w HT cut off time = 100s for below deck compartments	61.8	-2.8
11		Case 1 w HT cut off time = 300s for below deck compartments	60.1	-1.1
12		Case 1 w HT cut off time = 500s for below deck compartments	59.1	-0.1
13		Case 1 w HT cut off time = 100s for compartment #3 only	60.3	-1.3
14		Case 1 w HT cut off time = 300s for compartment #3 only	59.4	-0.4
15		Case 1 w HT cut off time = 500s for compartment #3 only	58.7	0.3
16	PCS parameter	Case 1 w 50% PCS flow rate	60	-1.0
17		Case 1 w 50% stripping	59	0

* (59 – calc. max pressure)

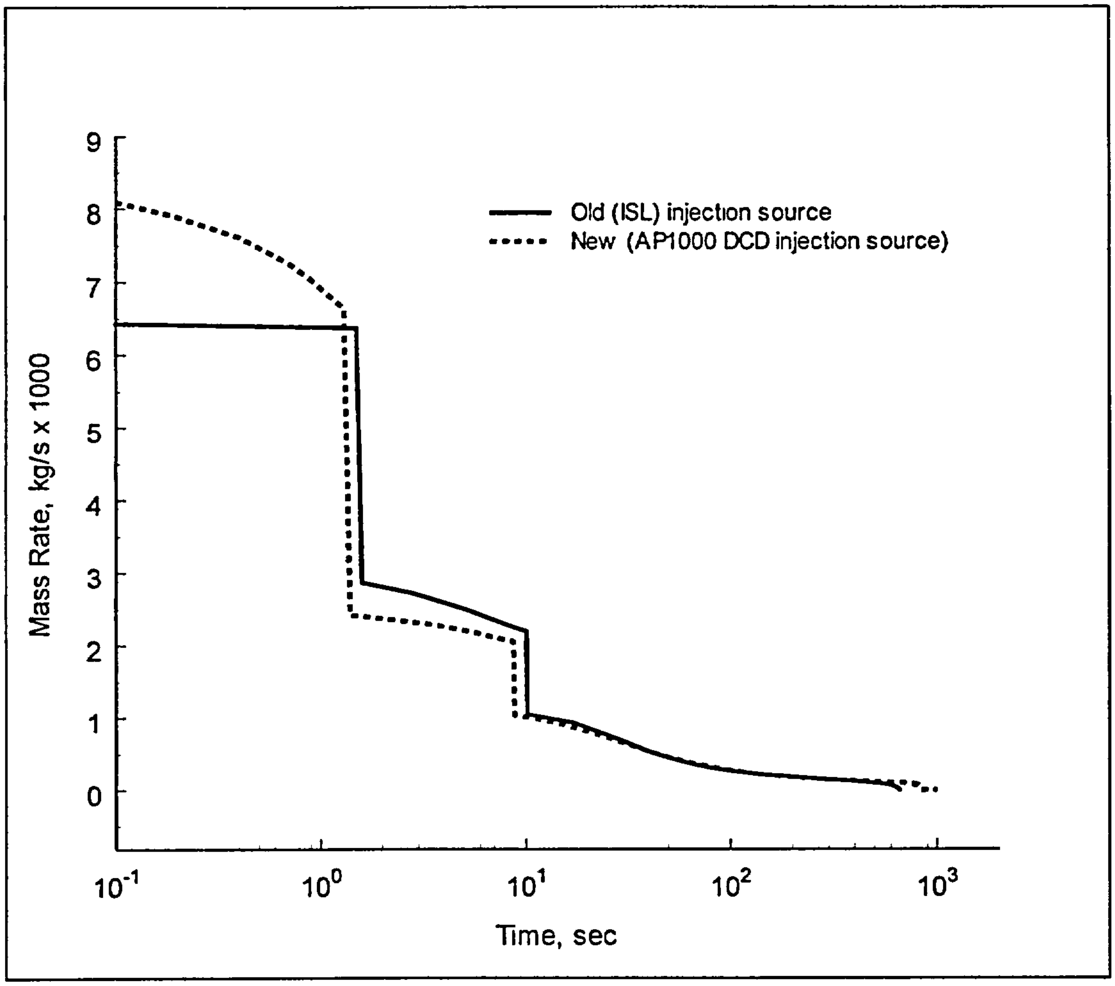

Figure 1. Comparison of "old" and "new" MSLB mass injection rate for AP1000.

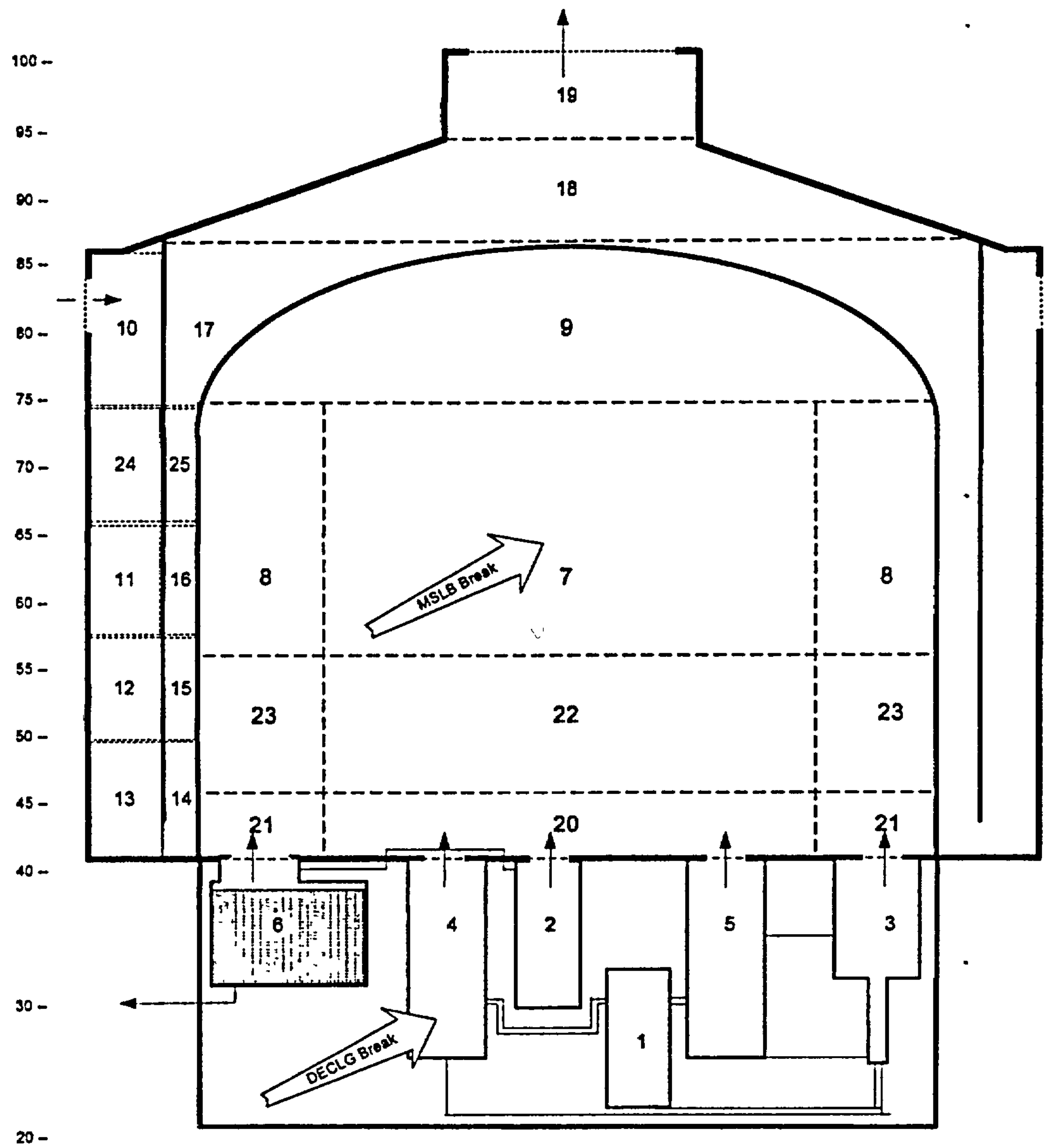

Figure 2. CONTAIN nodalization of the AP1000 (ISL-NSAD-NRC-01-007).

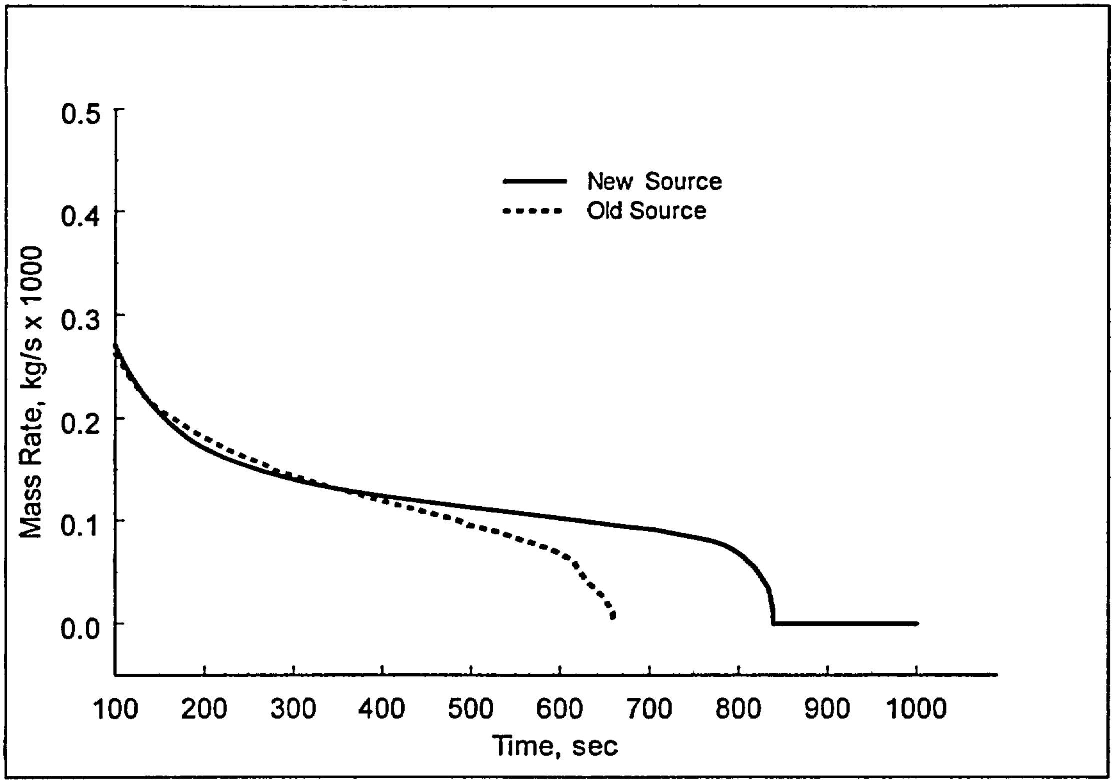

Figure 3. Comparison of late time MSLB mass injection rates for the "old" (ISL) and "new" (AP1000 DCD) sources, showing the extension of the cut-off time for the new source.

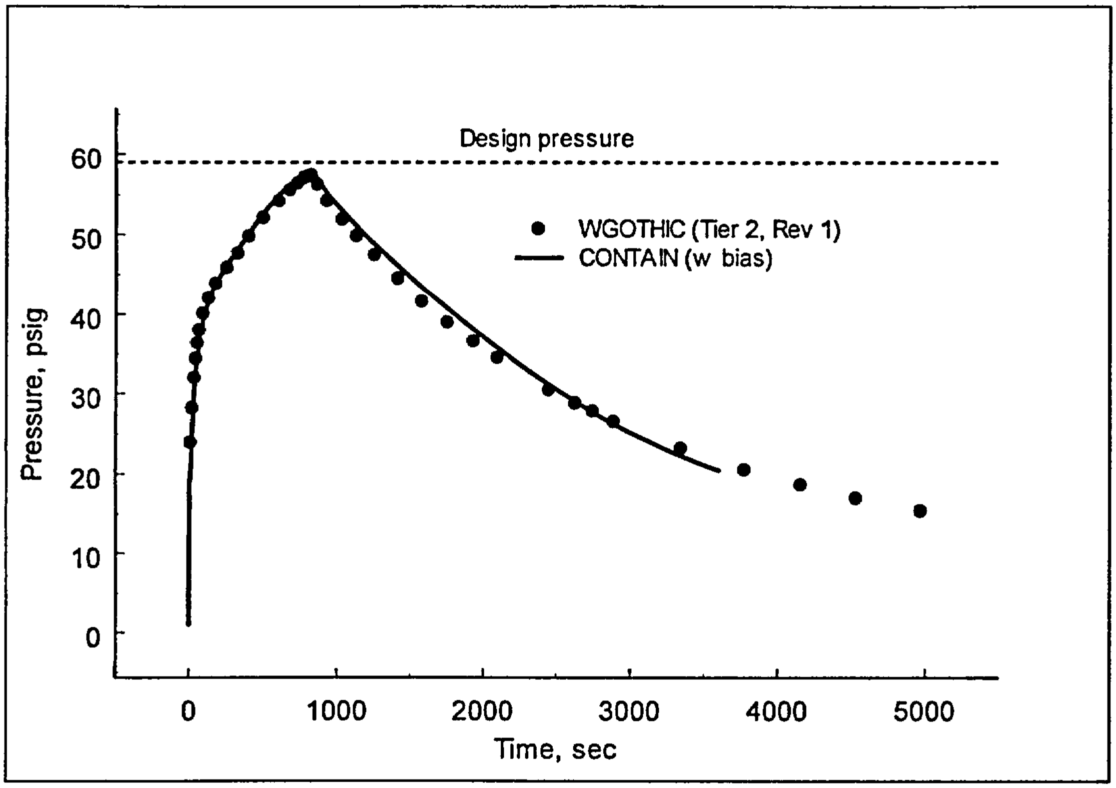

Figure 4. Comparison of CONTAIN and WGOTHIC containment pressure calculations for MSLB in AP1000 (30% power, DER).

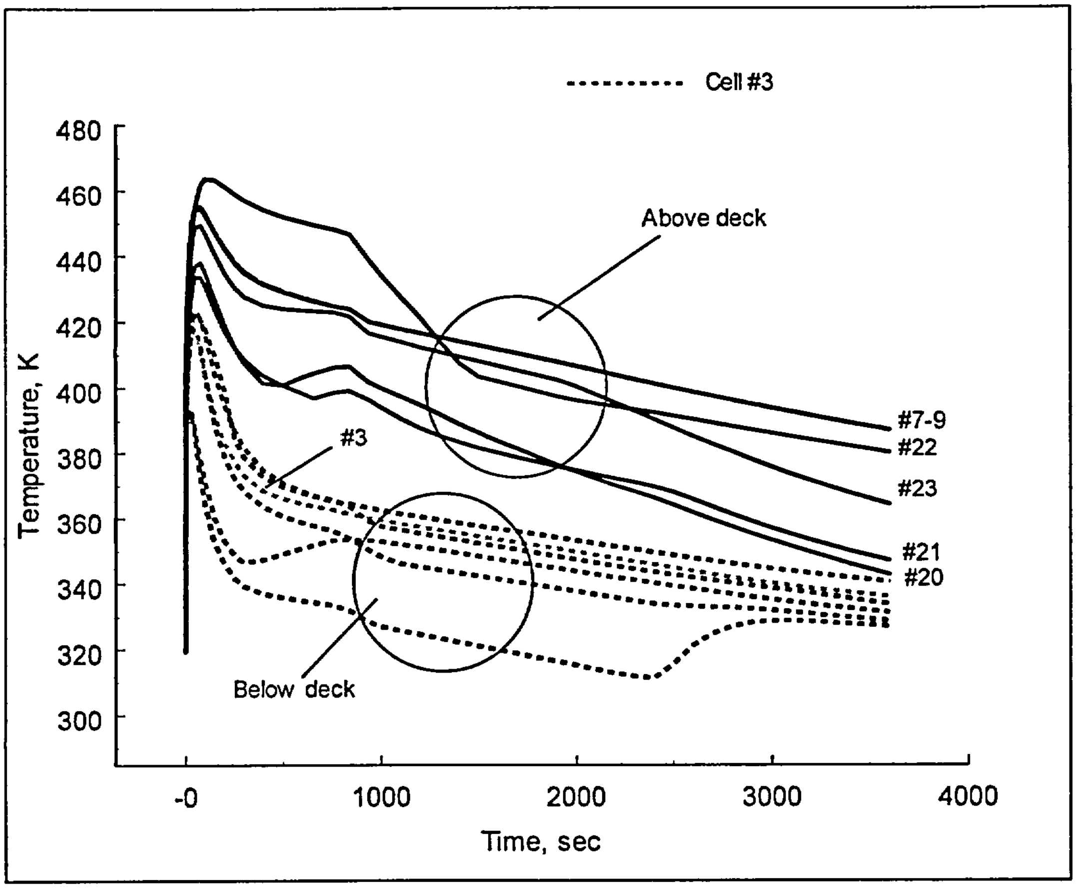

Figure 5. CONTAIN calculated gas temperatures for MSLB in AP1000 (30% power, DER).

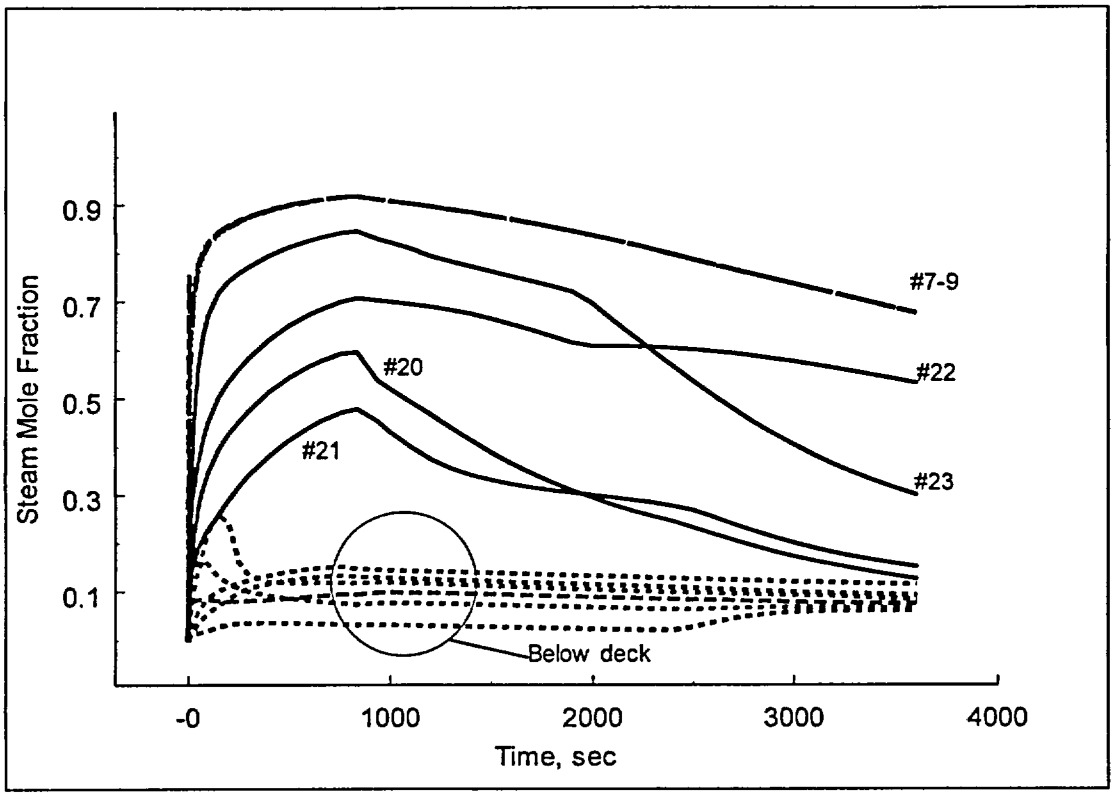

Figure 6. CONTAIN calculated steam mole fraction for MSLB in AP1000 (30%, DER).

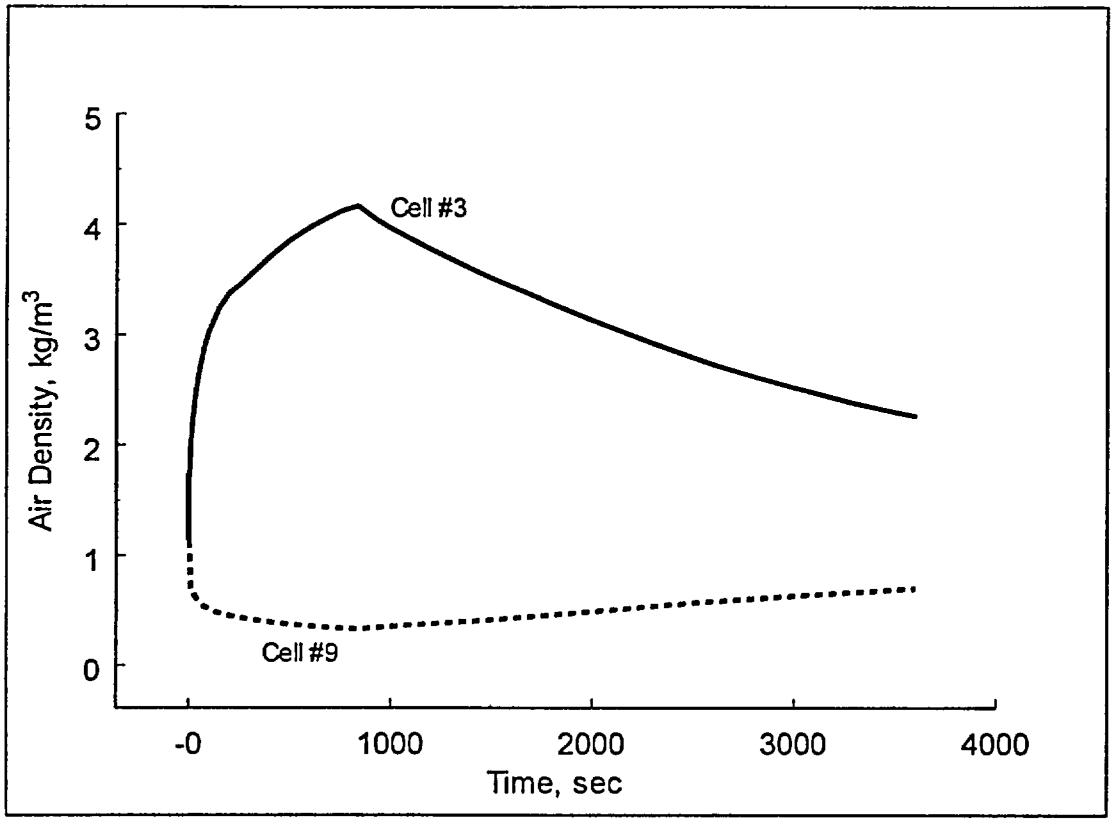

Figure 7. CONTAIN calculated air density stratification for MSLB in AP1000 (30% power, DER).

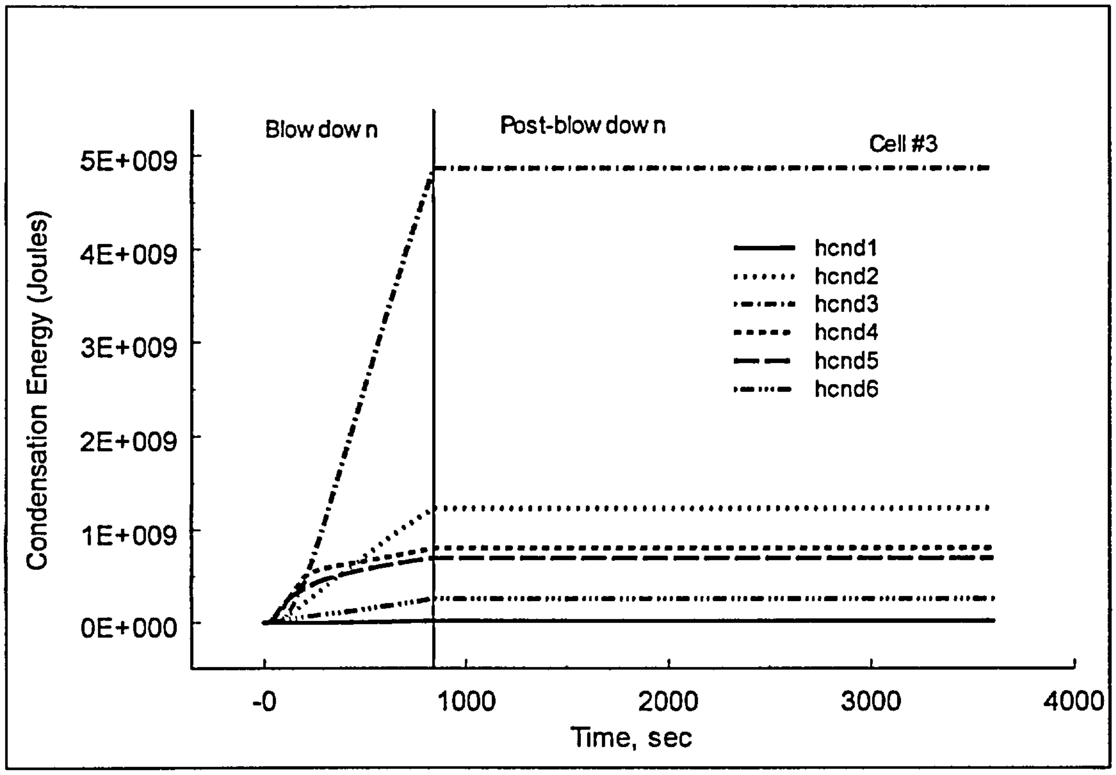

Figure 8. Cumulative condensation energy absorbed in below deck compartments for MSLB in AP1000 (30% power, DER).

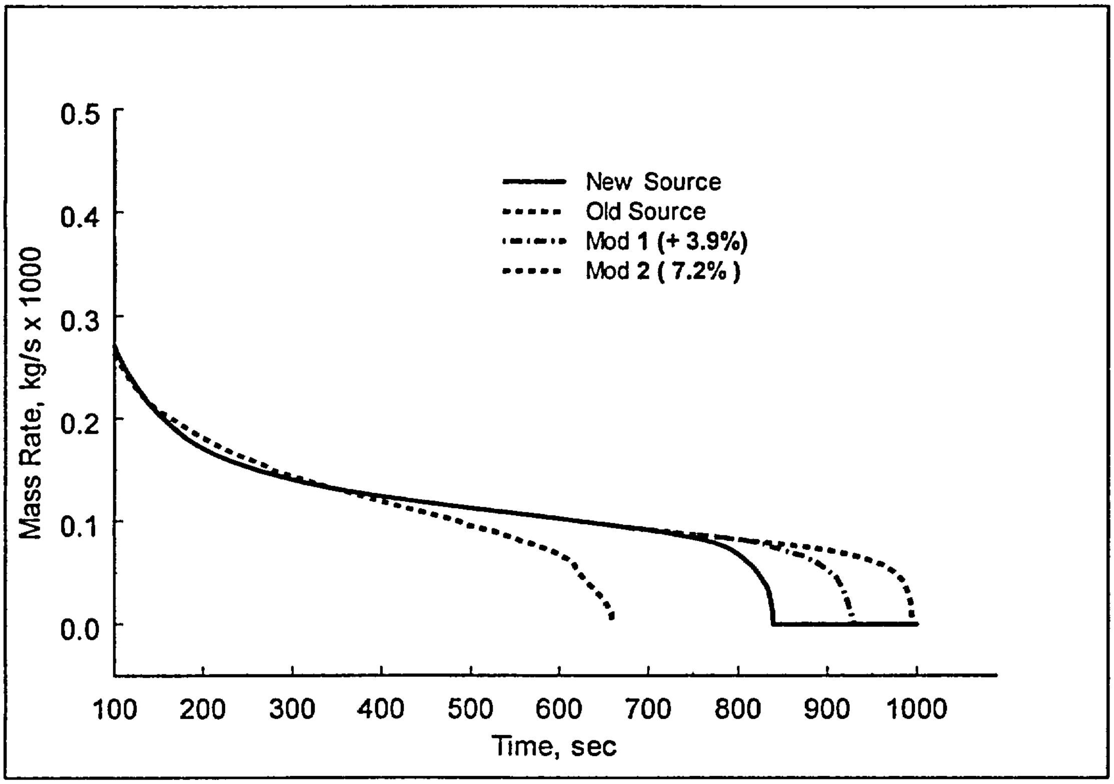

Figure 9. MSLB mass rate injection for AP1000 shown the "old" source used in the ISL report, the "new" source documented in the AP1000 DCD, and two modifications that increase the total mass injection by extending the cut-off time for the injection. The percentages refer to the increase in total mass injected compared to the mass injected with the "new" source.

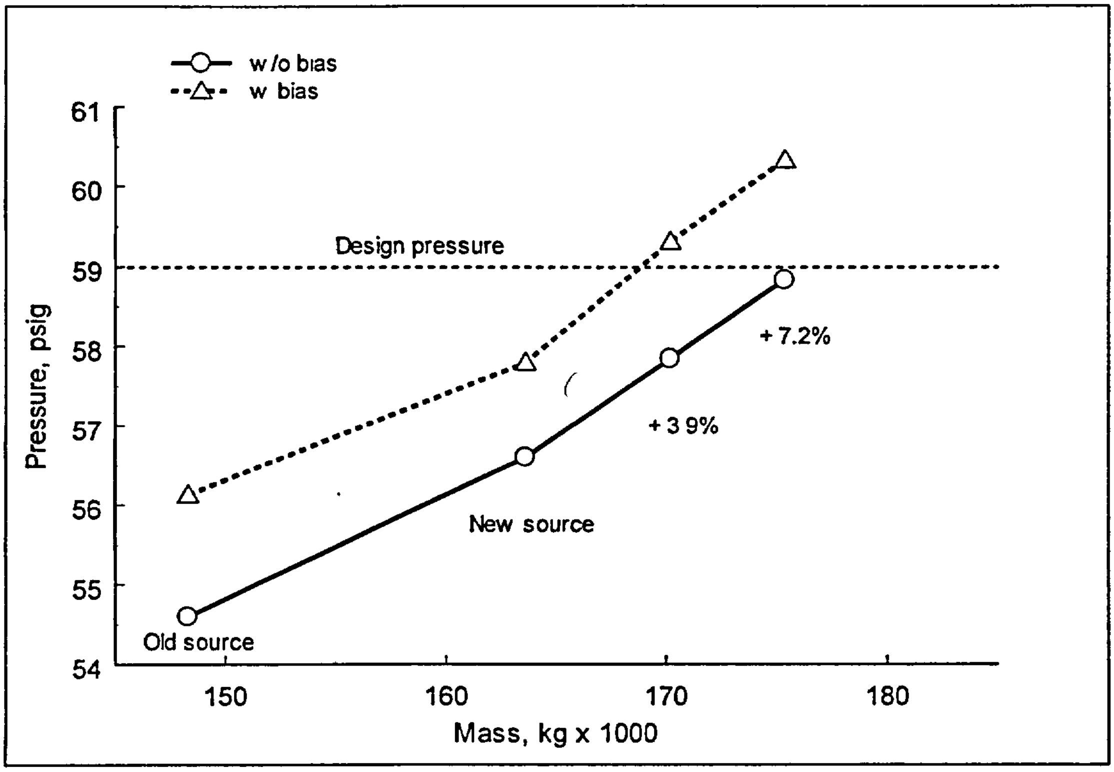

Figure 10. CONTAIN calculated peak pressure for various MSLB total steam injections.

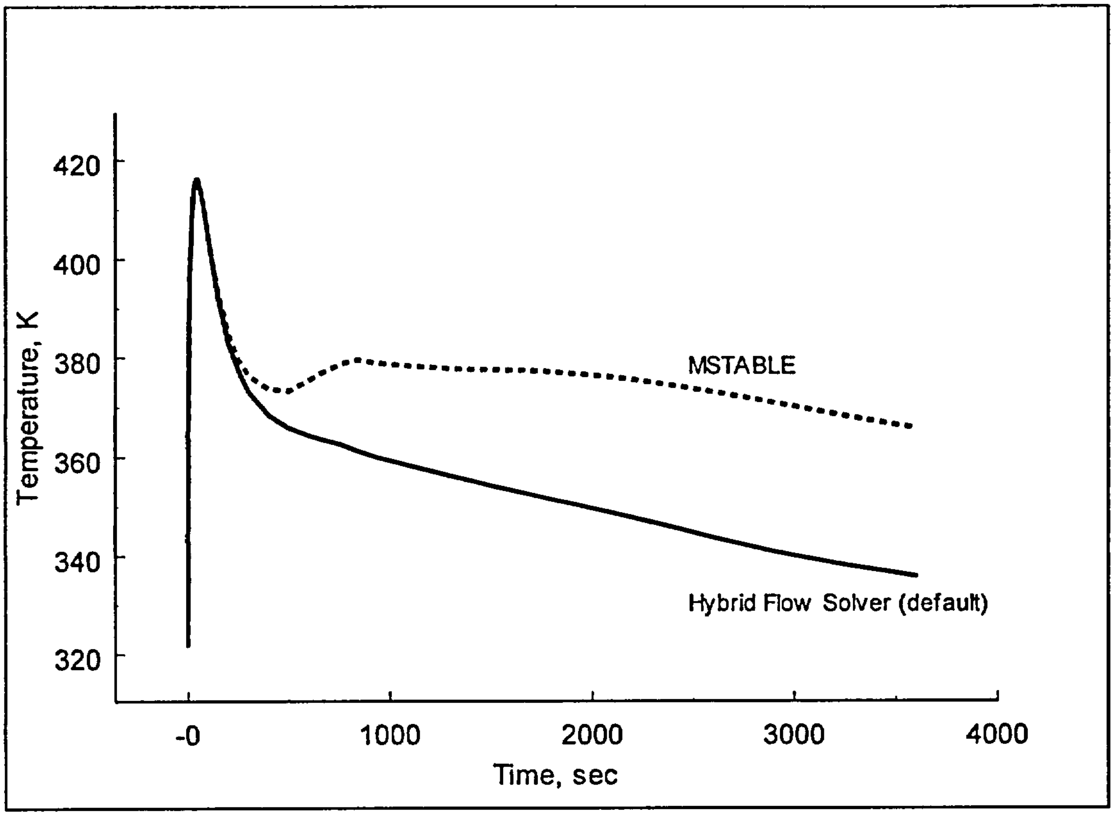

Figure 11. CONTAIN calculated temperatures in compartment #3 (CMT, CVS, accumulator cavities) for MSLB in AP1000 with overmixing and best estimate prediction of stratification.

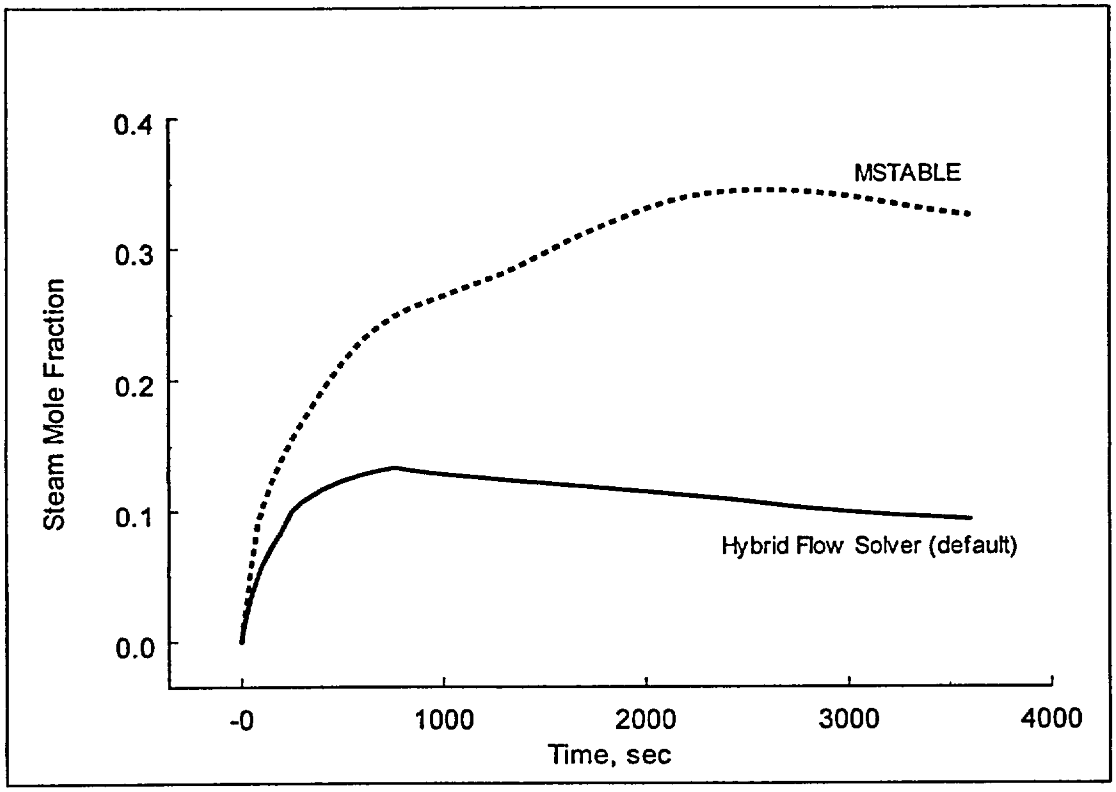

Figure 12. CONTAIN calculated steam concentration in compartment #3 (CMT, CVS, accumulator cavities) for MSLB in AP1000 with overmixing and best estimate prediction of stratification.

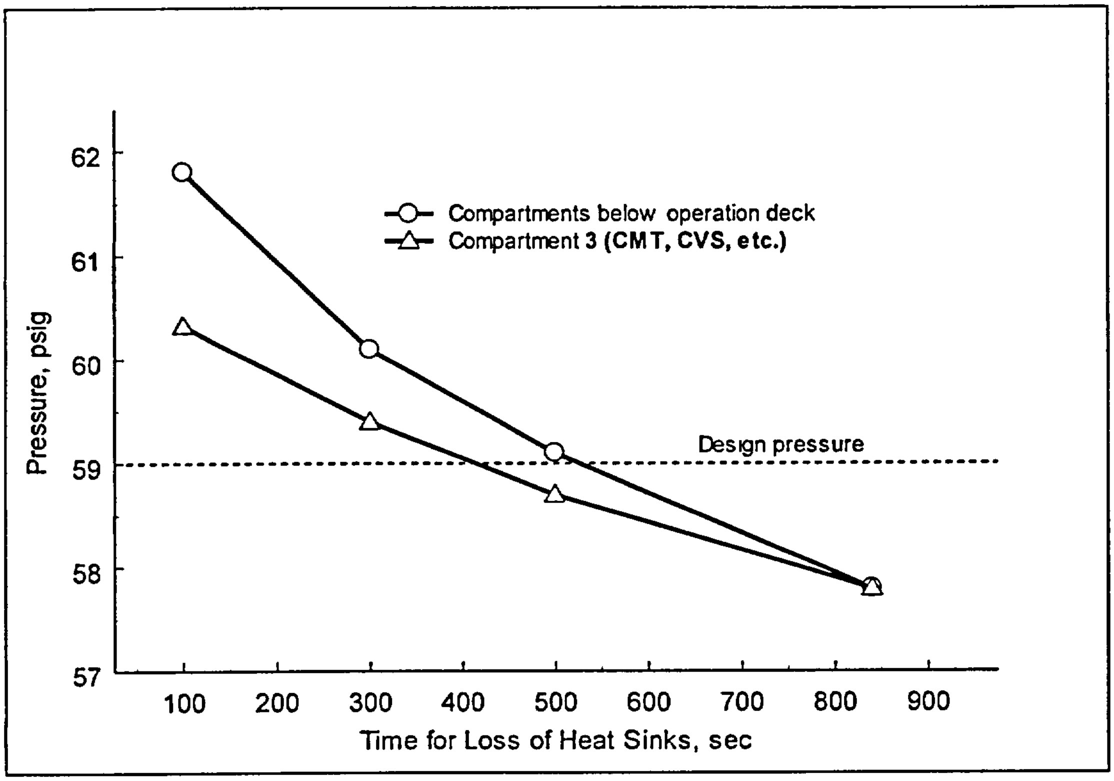

Figure 13. CONTAIN calculated peak pressure variation verses lower compartment heat transfer cut off times.