

**AP1000 Updated Containment Calculations
Part II: LOCA Analysis**

Final Letter Report
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AP1000 Updated Containment Calculations

Part II: LOCA Analysis

1 Introduction

ISL's AP1000 CONTAIN input deck used to perform a DECLG LOCA scoping calculation¹ 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 selected structures in dead-ended compartments after the blowdown injection²
- 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 DECLG LOCA injection source has been reported subsequent to the ISL calculations.³ The revised injection source has been included in the updated CONTAIN calculations report here. Also, in these updated calculations, the most recently reported PCS limited flow rate has been used to flood the external containment shell.⁴

Section 2 of this report compares the most recent CONTAIN LOCA calculation that includes biases, an updated injection source, and PCS flow rate to WGOthic results documented in the AP1000 DCD.

A number of sensitivities calculations associated with the WGOthic evaluation model biasing (steel structure and lower compartment heat transfer), two-phase injection modeling, and PCS operation are discussed in Section 3. In Section 4, a summary of the CONTAIN updated AP1000 LOCA calculations is given. A listing of the reference CONTAIN input for the LOCA accident is presented in Appendix A.

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 This bias is activated in Section 3 only

³ AP1000 Design Control Document, Tier 2 Material, Revision 0 and 1.

⁴ WCAP-15846, Revision 0.

2 Reference Calculation

2.1 Biases

Exclusion of the floor surfaces was accomplished by setting each floor surface area to a small area $\sim 1.0e-10 \text{ m}^2$. 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.

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 vcfv values for the PCS in the FLOWS block with coefficients multiplied by 1.3.

2.2 LOCA Single and Two-phase Injection

Shown in Figure 1 is the revised two-phase water injection to the east steam generator compartment (Cell 4) from the RCS vessel side of the cold leg break. The blowdown portion of the injection ends at 22.6 seconds. Once the two-phase blowdown is over, the steam generator compartment receives injections of liquid water from the vessel side of the break, Figure 1, and high temperature, post-blown steam from the steam generator side of the break, Figure 2. The liquid water is assumed to be diverted directly to the floor (pool) of the east steam generator compartment⁵, and the steam injection is sourced directly into the break compartment atmosphere. At approximately 1500 seconds, the water level in the core makeup tanks (CMTs) reaches the ADS-4 actuation setpoint. The ADS-4 relief valves are located in both the east (Cell 4) and west (Cell 5) steam generator compartments. For times after ~ 1500 seconds, the ADS-4 relief valves open and the ADS-4 portion of the steam injection is released; half to each steam generator compartment. The total steam injection for the east and west steam generator compartments is shown in Figure 3 and 4, respectively.⁶

2.3 Below Deck Nodalization

The ISL reference deck included a partial renodalization of the lower compartments in the original SNL AP600 containment model when they converted the deck to the AP1000 geometric description. The renoding, affecting the description of the cavity node (Cell 1), effectively removed the reactor coolant drain tank cavity (RCDT) from the problem.

⁵ Stated assumption for the WGOthic calculation

⁶ Note, the ISL reference deck did not include the ADS-4 stage injection into the west SG compartment, but instead included the entire ADS-4 stage (east and west) into the east SG compartment.

With the RCDT removed, a significant connecting pathway between the two steam generators was removed together with a relatively large draindown volume for liquid water overflowing from the floor of the east steam generator compartment. In addition, the flow path connection between the steam generator compartments and the CMT, CVS, accumulator rooms (Cell 3) was also eliminated in the ISL input. In the case of the cavity node (Cell 1), removal of the RCDT volume affected the cavity volume, but the RCDT structures were still included in the ISL deck. In the updated input deck used in this work, the RCDT volume has been replaced along with flow path connections in compliance with information provided in WCAP-15846. Liquid levels in the lower containment during the LOCA, as determined by CONTAIN, are now in general agreement with WGOthic levels reported in WCAP-15846.

Most importantly, it is noted that with the updated input there are gas flow pathways from the east steam generator compartment (break) to the CMT room; one pathway directly from the upper portion of the east steam generator compartment and one via the RCDT compartment.

2.4 PCS Film Flow and IRWST Draindown Modeling

The PCS flow rate used in the updated CONTAIN calculation is the PCS evaporation limited film flow rate obtained from Figure 13-93, WCAP-15846. The IRWST draindown rate is obtained from the same WCAP, in Figure 13-94.

2.5 Results

Shown in Figure 5 is the CONTAIN calculated containment pressure during the blowdown portion of the DECLG LOCA. The peak pressure calculated for this early period is 44.6 psig. A comparison of the CONTAIN and WGOthic (AP1000 DCD) calculated long-term containment pressure is shown in Figure 6. The CONTAIN calculated gas temperatures and steam mole fractions throughout the containment are shown in Figures 7 through 9. The peak temperature calculated above the operation deck after the blowdown period is ~282 F, which compares exactly with the WGOthic reported value in AP1000 DCD.

The calculated PCS annulus air flow rate is shown in Figure 10 and the external shell (cylinder) heat transfer rate is shown in Figure 11.

3 Sensitivity Calculations

3.1 Exposed Steel Structures

A number of exposed steel structures (platforms, stairs, etc.) below deck were excluded from the CONTAIN reference deck similar to the method of treating these structures in the WGOthic evaluation model. The impact on the pressure calculation whether or not these structures are modeled is small as can be seen in Figure 12.

3.2 Lower Compartment Heat Transfer After Blowdown

As indicated in the reference calculation, the low injection in the steam generator compartment produces good mixing within the above deck cells and also the cell that models the CMT, CVS, and accumulator rooms (Cell 3). For this reason, the reference calculation was not run with a bias that turns heat transfer off to selected structures in “dead-ended” rooms. Trying to simulate the WGOthic bias for turning heat transfer off for selected structures is problematical for the CONTAIN input since the structures modeled in the CONTAIN input do not represent a one-to-one correspondence to the WGOthic structures. However, for the purpose of performing pressure sensitivity to lower compartment structure heat transfer, a case was run with the Cell 3 heat transfer turned off after the blowdown period. The pressure history for that case is shown in Figure 13 in comparison to the reference case.

3.3 Two-phase Injection

To treat the two-phase water blowdown in the reference calculation, the injection is sourced into the containment using the SRV source model.⁷ This model performs a “pressure flash” expansion (constant enthalpy) for two-phase water, putting the vapor portion into the atmosphere and the liquid portion into the injection cell pool region. This method of treating the two-phase injection produces the highest containment pressure and is therefore considered a conservative method for DBA-type analyses. Another method, referred to as a temperature flash method sources the two-phase water directly into the containment atmosphere. The assumption here is that the injection turbulence carries and disperses all injected water into the atmosphere which then comes into temperature equilibrium with the gas phase. Shown in Figure 14 is the pressure sensitivity result for treating the injection by the temperature flash method.

3.4 PCS Operation Parameters

Two PCS operation parameters are included as boundary conditions to the CONTAIN API1000 model: they are the input PCS film flow rate and the external shell water film coverage. As discussed, the PCS flow rate for the reference calculation is the WGOthic

⁷ This capability for the SRV modeling was added to the CONTAIN code subsequent to original AP600 CONTAIN input model documented in SAND96-0947, which is the source document for the ISL input deck.

PCS limited film flow rate. The film coverage for the shell in the reference calculation is the coverage percentage used in the WGOthic evaluation model, 56% (wet) on top dome, and 90% (wet) for dome knuckle region and vertical cylinder. For the sensitivity analysis, the PCS flow rate is varied by +/- 20%, and in a separate case, the film coverage is reduced to 40%/70% (top dome/knuckle and cylinder). Shown in Figure 15 are the results for the PCS flow rate variation. Figure 16 shows the effect of varying the film coverage.

4 Summary

Previous WGOthic analyses of the AP1000 containment response to a DECLG LOCA has indicated significant variation in reported peak pressure, Table 1. In this letter report, the CONTAIN input deck used by ISL, in a previously reported effort, has been used as a starting point to generate input to perform updated containment calculations. The modifications made to the ISL input included 1) adding the WGOthic evaluation model biases (excluding the shut-off of lower dead-ended heat transfer after blowdown), 2) updating mass and energy sources, and 3) modifying lower compartment geometrical input (cavity volume and various pathway connections to be in compliance with AP1000 geometry description). CONTAIN calculation results using a reference case were reported showing good agreement between the calculated peak pressure (and temperature) and the most recent WGOthic reported values documented in the AP1000 DCD (see Table 1).

A series of sensitivity calculations were completed including an omitted bias in the reference case (dead-ended compartment heat transfer), addition of steel structures, two-phase injection, and PCS operation. The most sensitive parameter appeared to be associated with assumptions regarding limited dead-ended compartment heat transfer after the blowdown. An exact simulation of lower compartment heat transfer biasing used in the WGOthic evaluation model could not be incorporated into the CONTAIN input due to differences in the manner that structures are detailed between the CONTAIN and WGOthic inputs. The CONTAIN sensitivity case for this particular bias however was believed to represent an upper bound on the effect of excluding lower compartment (Cell 3) heat transfer subsequent to the blowdown. Inclusion of the bias was observed to increase the reference peak pressure from 55 to 59.3 psig (0.3 psi > design pressure). All other sensitivities calculations produced peak pressures that remained below the design pressure.

Table 1 Calculated peak pressure for DECLG in AP1000 (WGOTHIC)		
Document	Peak Pressure, psig	Safety margin*, psi
WCAP-15612 (12/2000)	46	13.0
WCAP-15846 (4/2002)	58.2	0.8
AP1000 DCD (Rev 1)	55.4	3.6
Updated CONTAIN/ w biases**	55	4
Update CONTAIN / w biases	59.2	-0.2

* design pressure – calculated pressure

** excluding biasing heat transfer in dead-ended lower compartments after blowdown

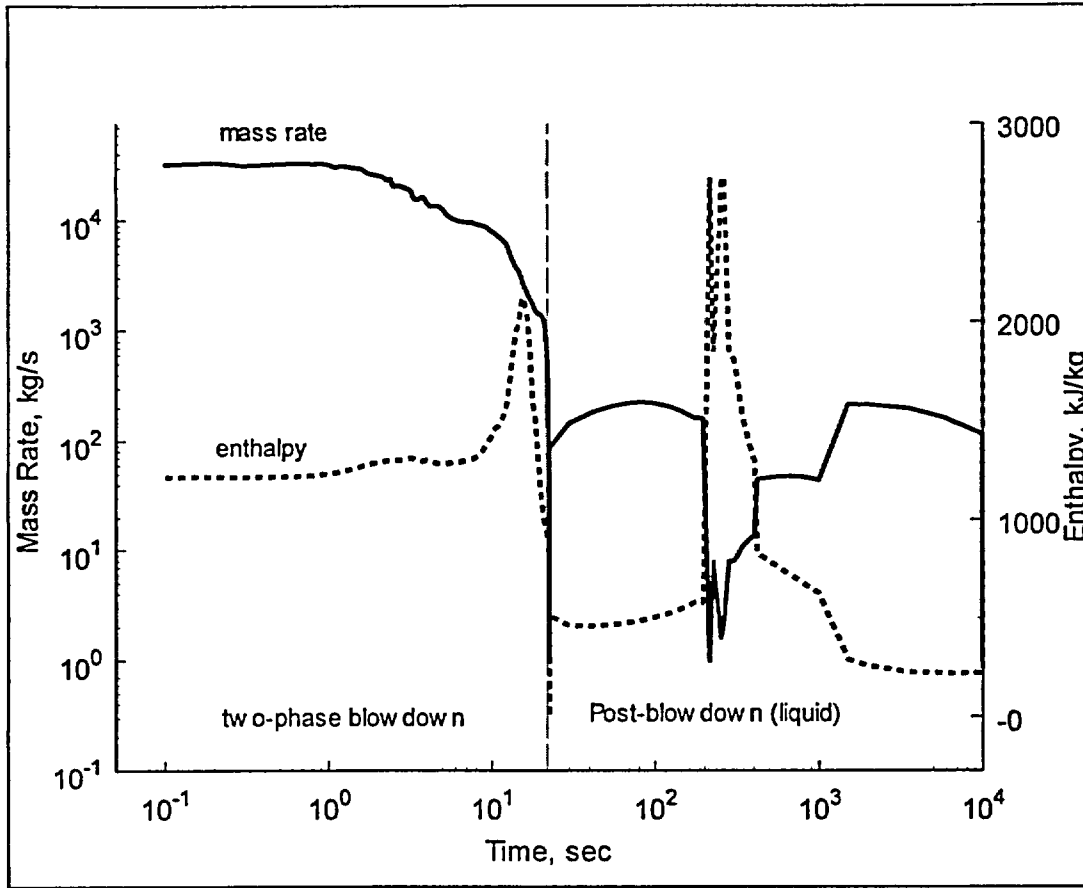


Figure 1 Two-phase water injection for DECLG LOCA (vessel side break flow).

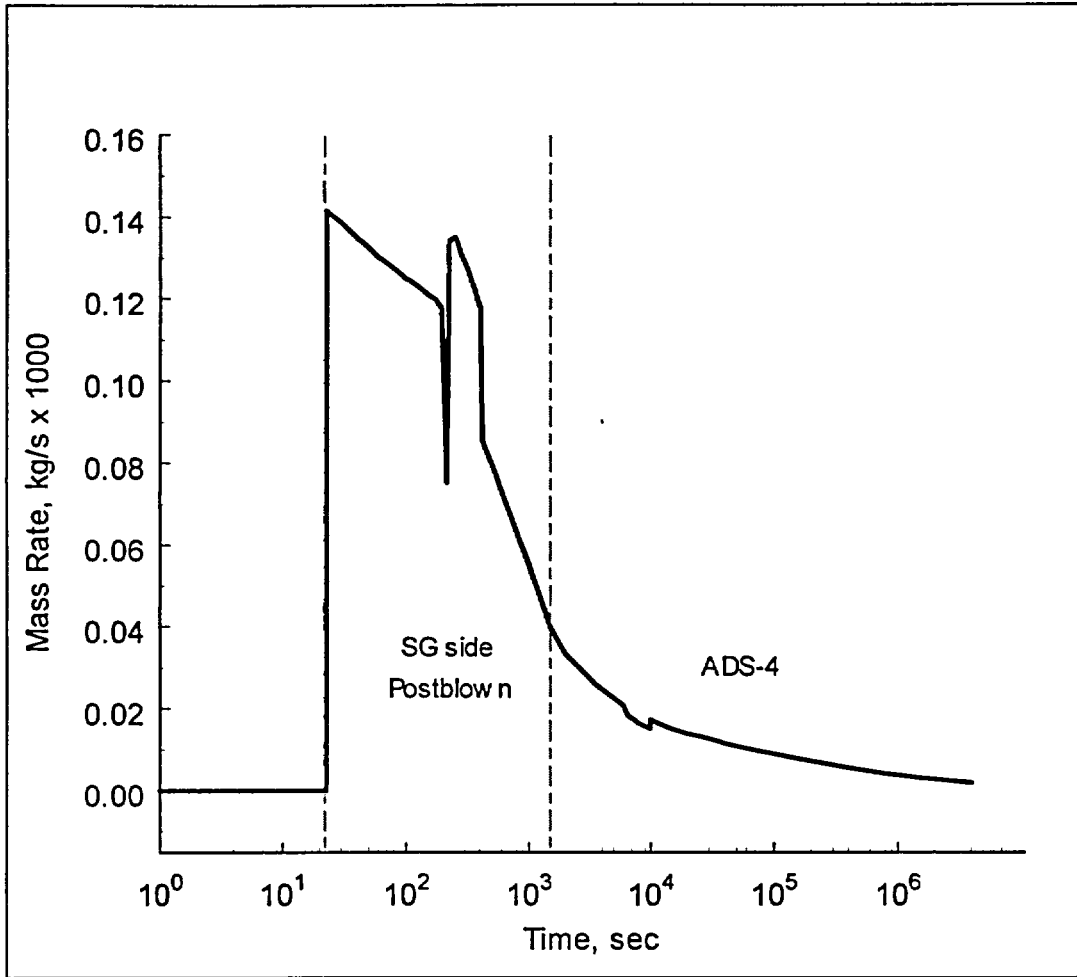


Figure 2 Steam injection into the AP1000 containment for DECLG LOCA.

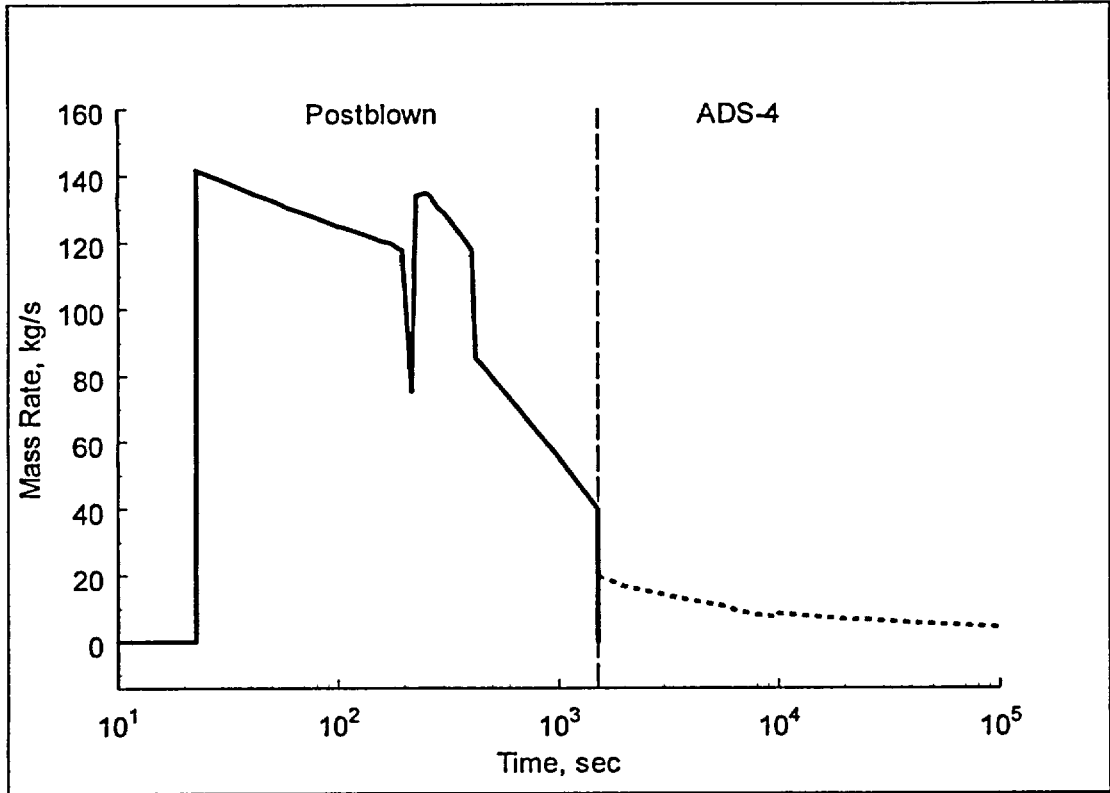


Figure 3 East steam generator (Cell 4) compartment steam injection.

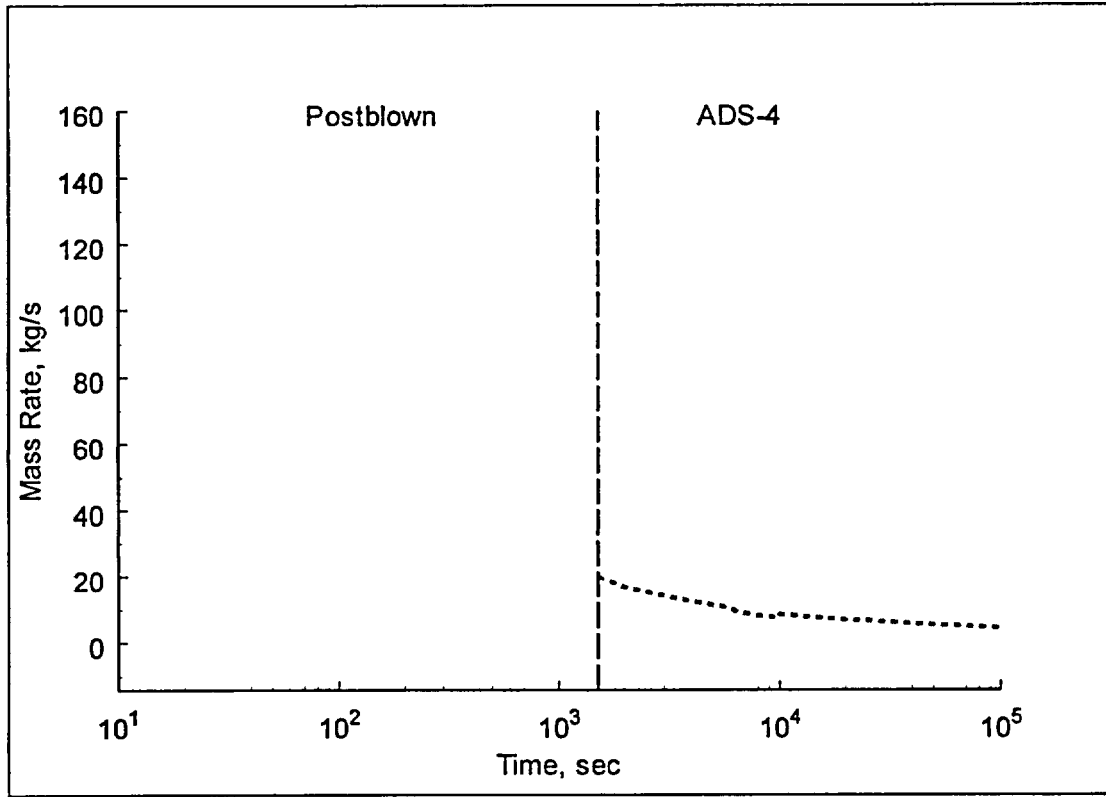


Figure 4 West steam generator (Cell 5) steam injection.

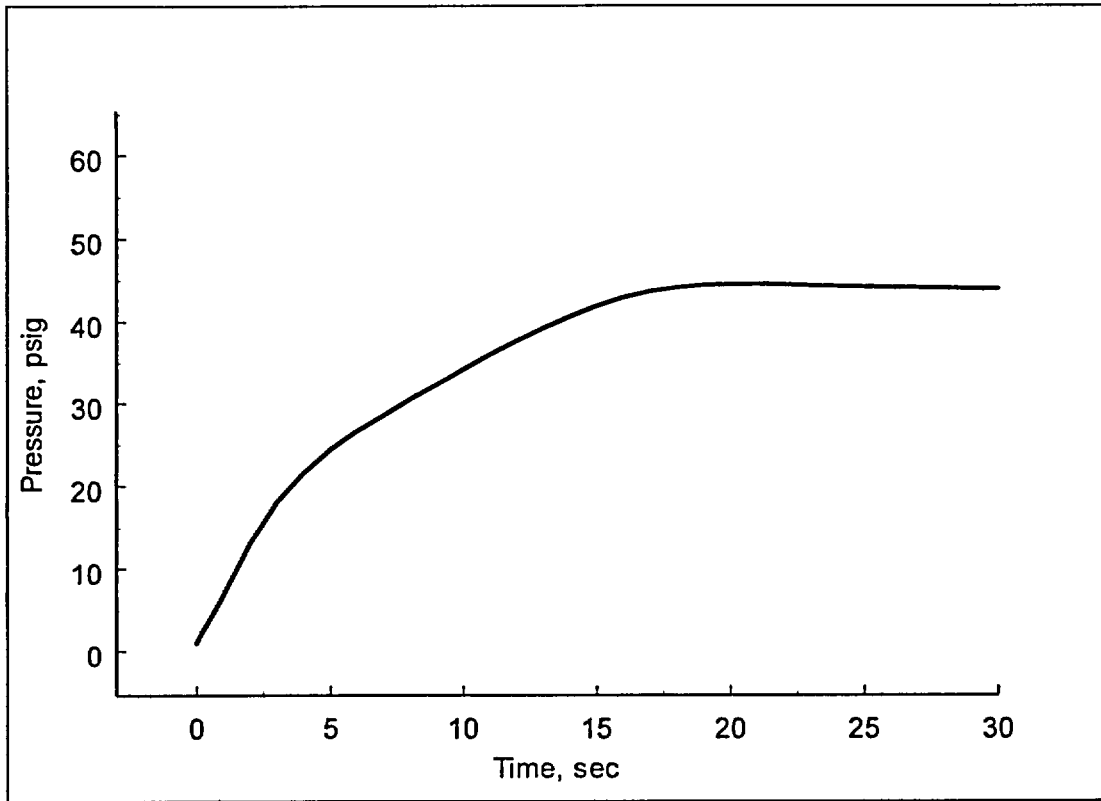


Figure 5 CONTAIN calculated containment pressure during the blowdown period of the DECLG LOCA.

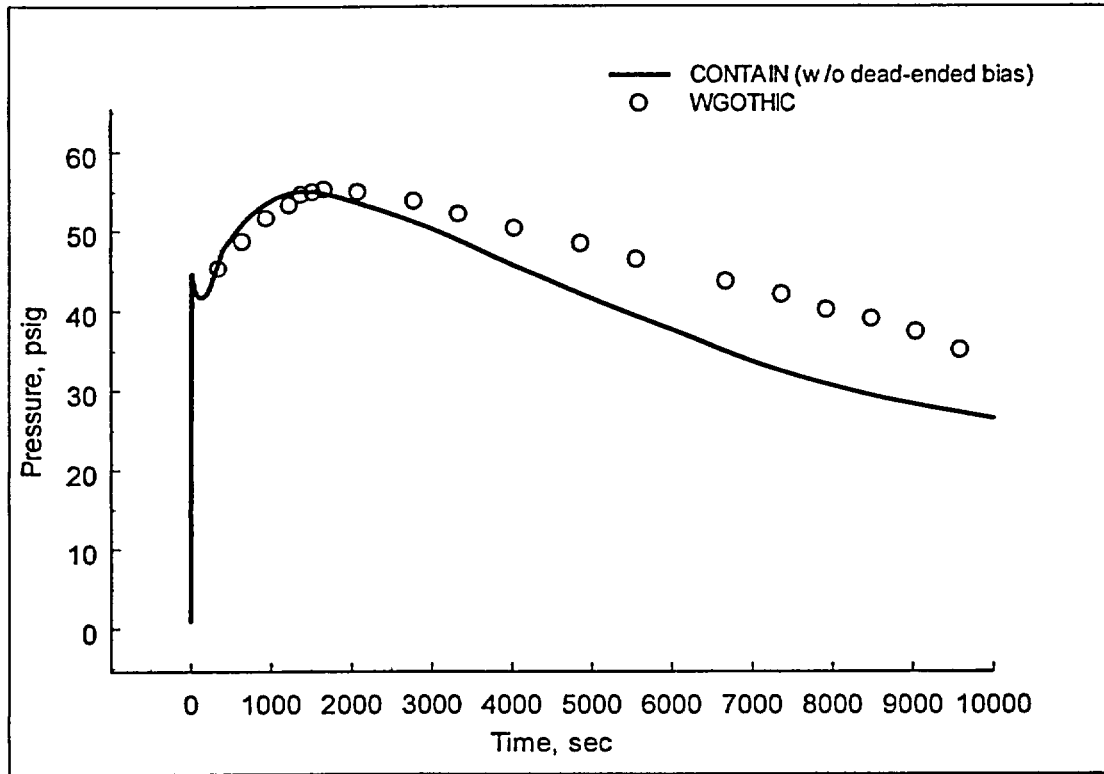


Figure 6 Comparison of CONTAIN and WGOthic calculated long term containment pressure for DECLG LOCA.

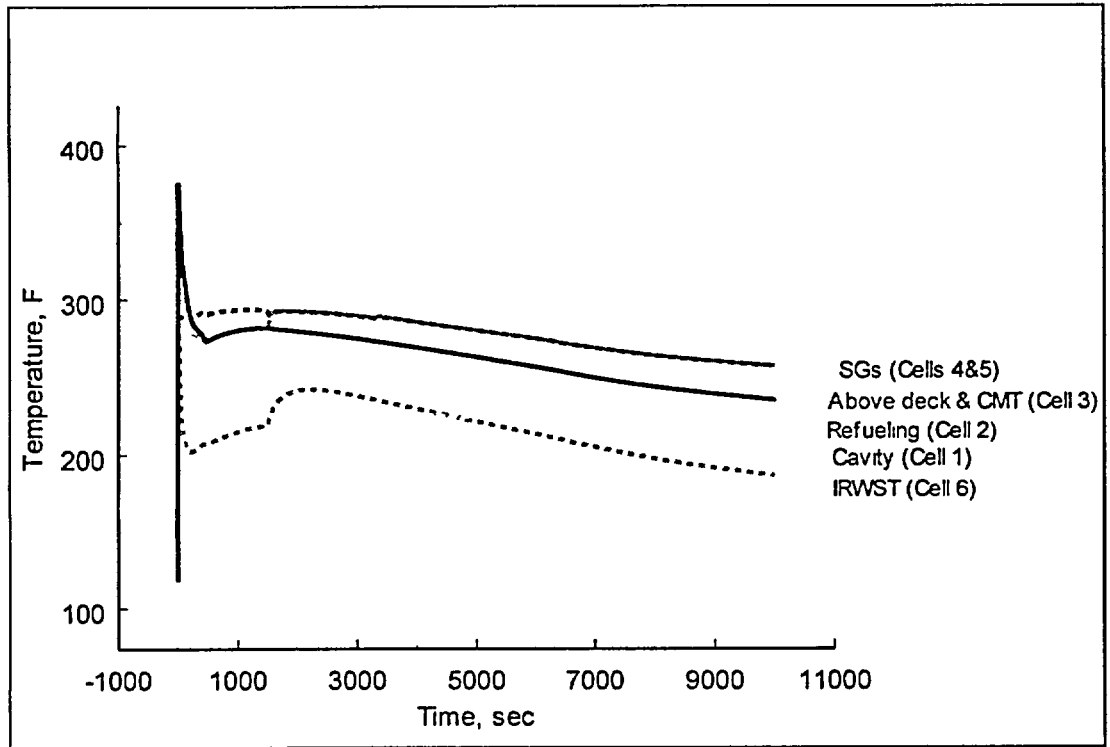


Figure 7 CONTAIN calculated containment gas temperatures for DECLG LOCA.

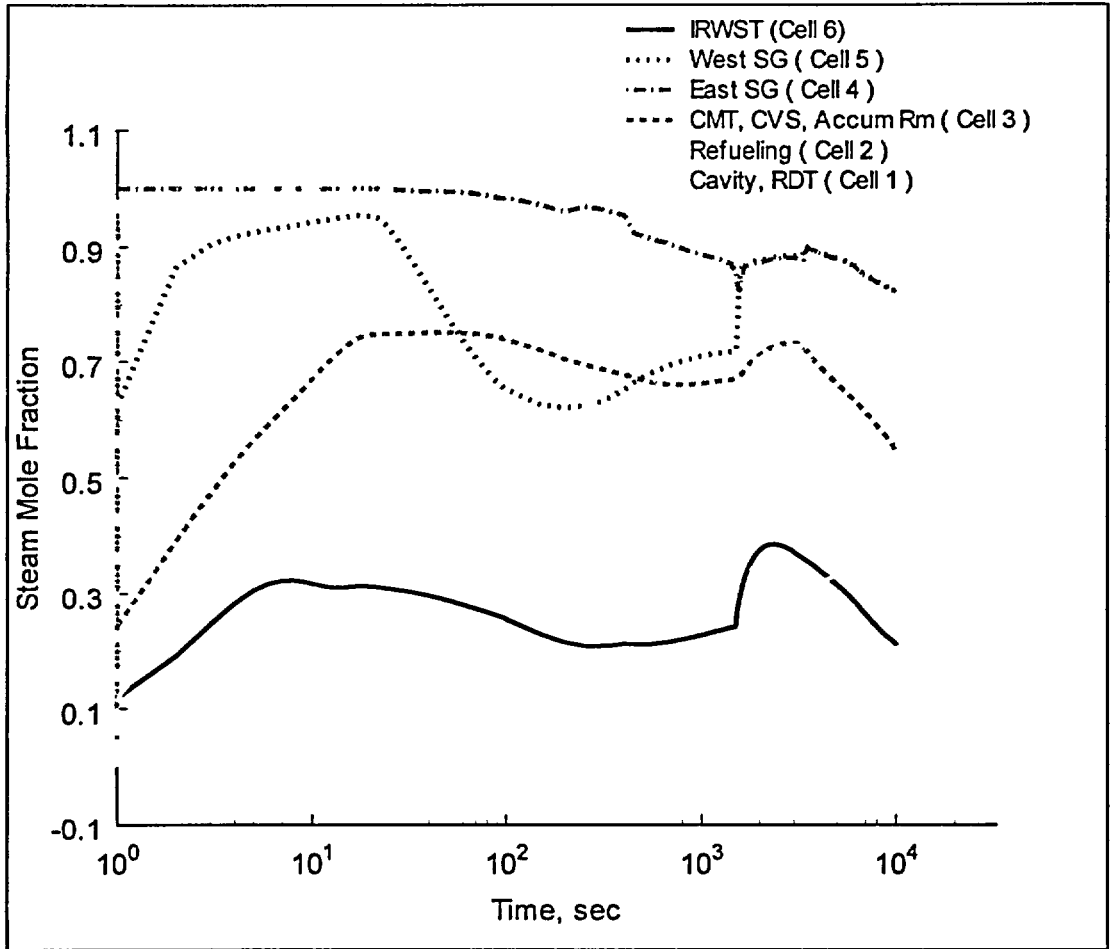


Figure 8 CONTAIN calculated below deck steam mole fractions for DECLG LOCA.

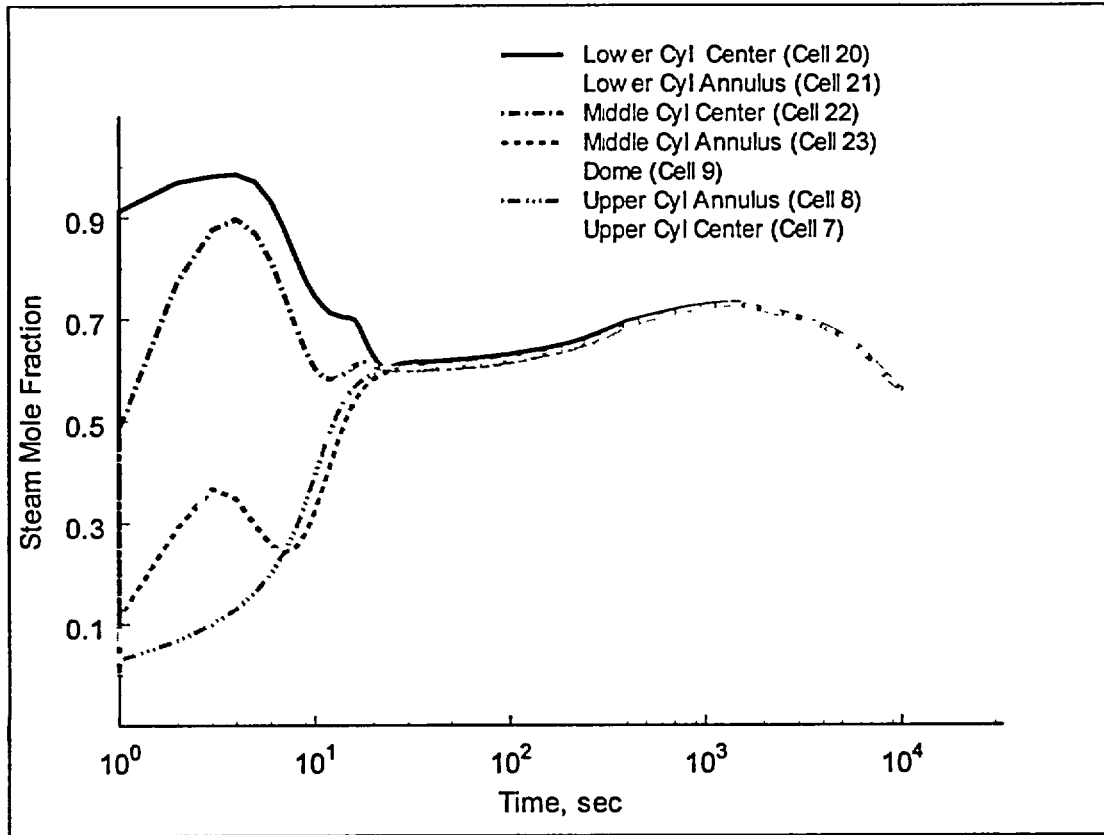


Figure 9 CONTAIN calculated above deck steam mole fraction for DECLG LOCA.

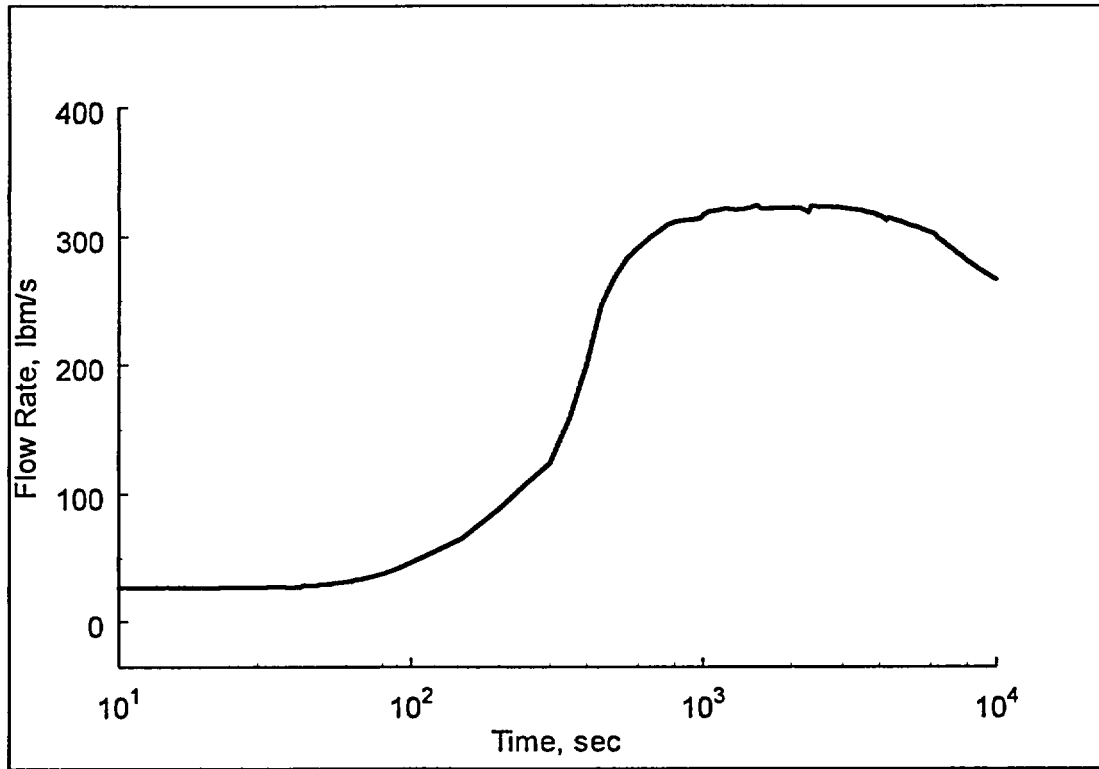


Figure 10 CONTAIN calculated PCS annulus air flow for DECLG LOCA.

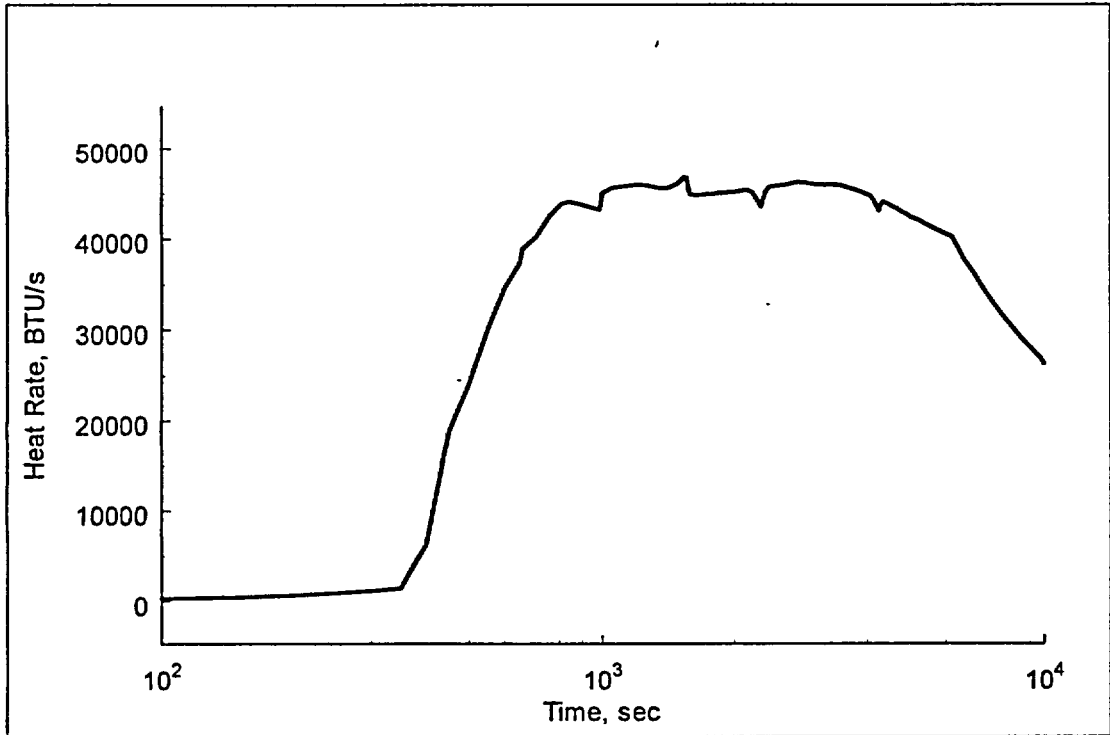


Figure 11 CONTAIN calculated external shell (Cylinder) heat transfer rate for DECLG LOCA.

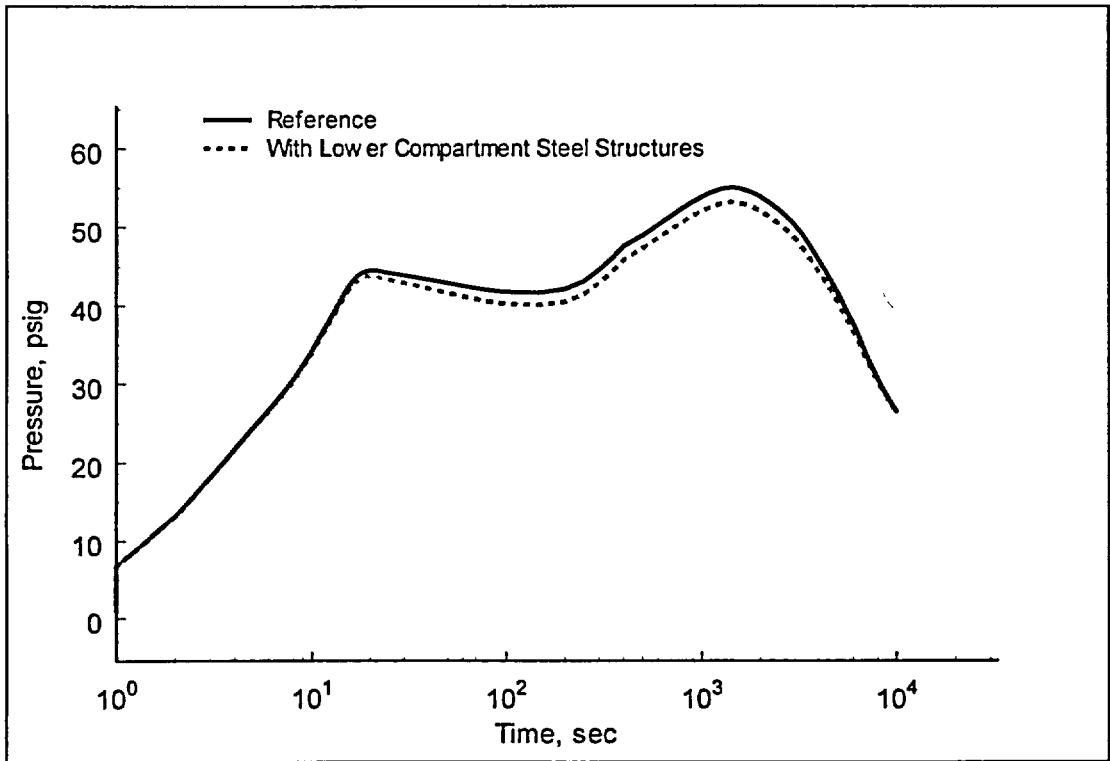


Figure 12 Pressure sensitivity to inclusion of lower compartment steel structures.

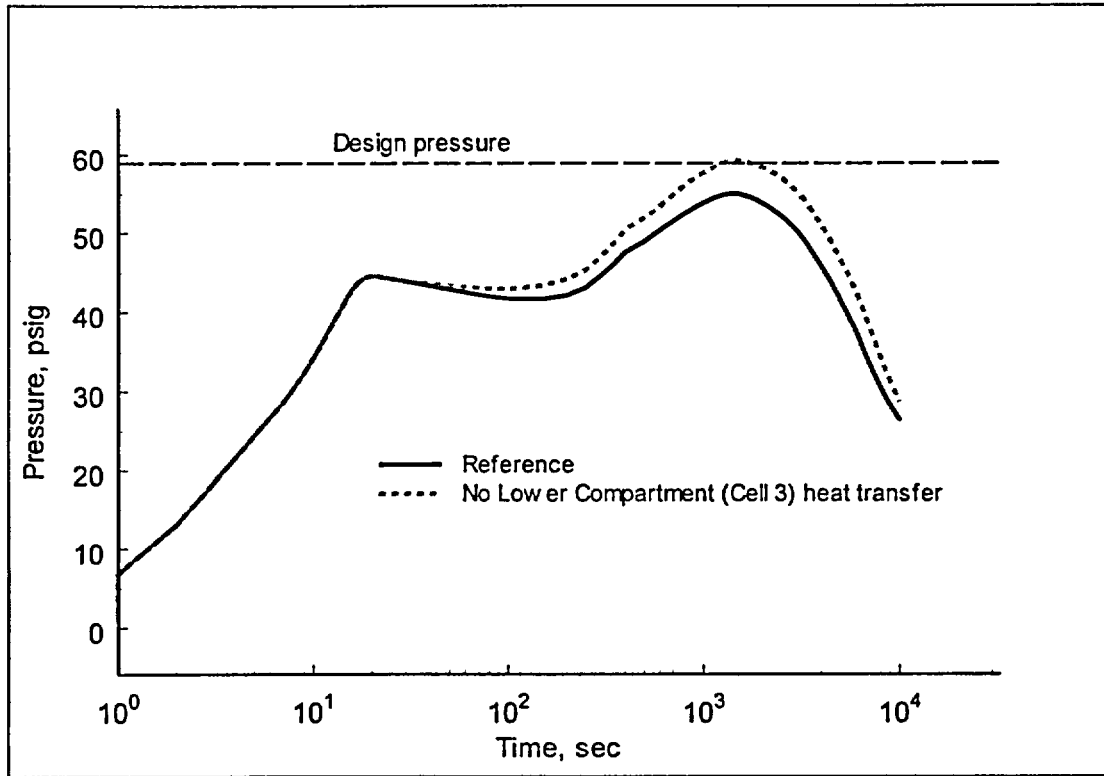


Figure 13 Pressure sensitivity to turning off heat transfer in Cell 3 (CMT ..) after the blowdown period.

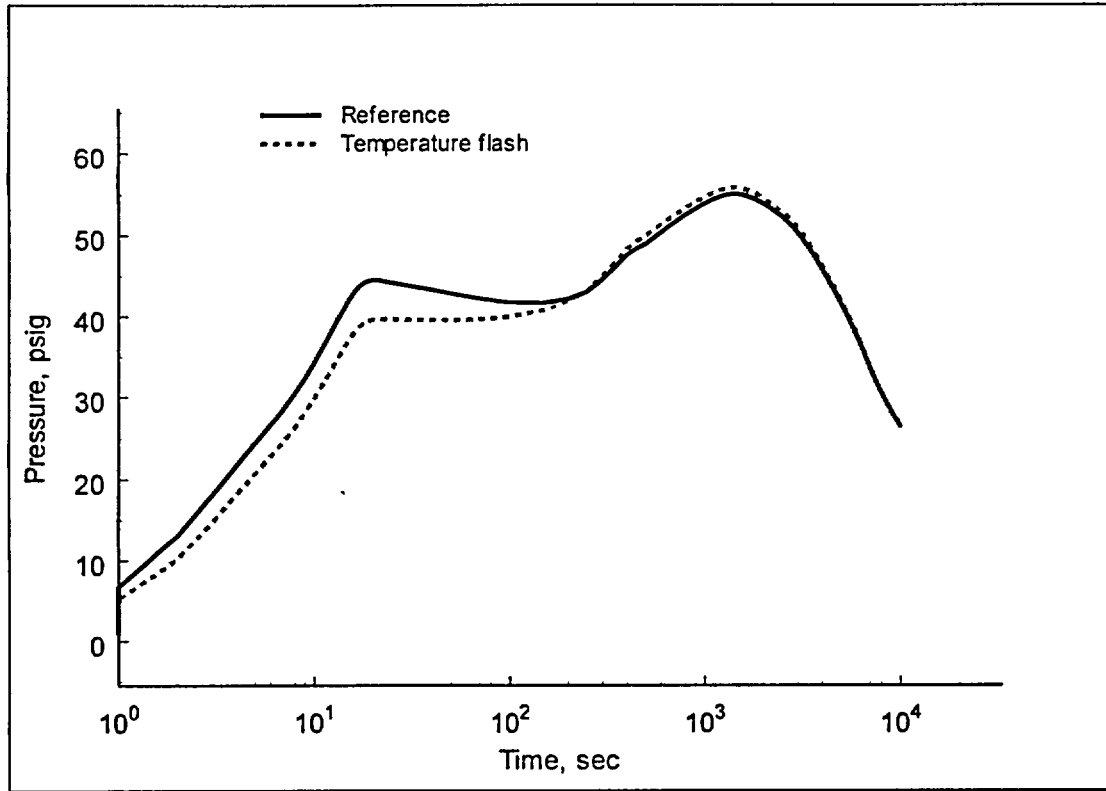


Figure 14 Pressure sensitivity to pressure (reference) and temperature flash methods for treating the two-phase blowdown injection.

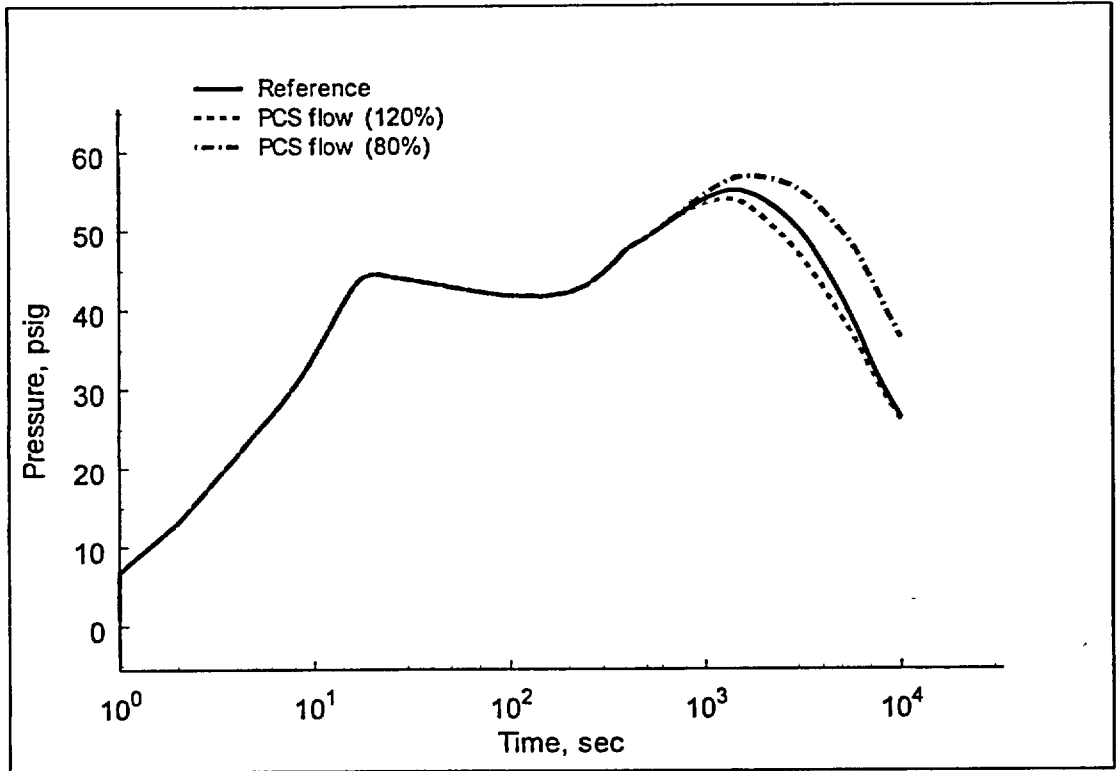


Figure 15 Pressure sensitivity to PCS file flow rate.

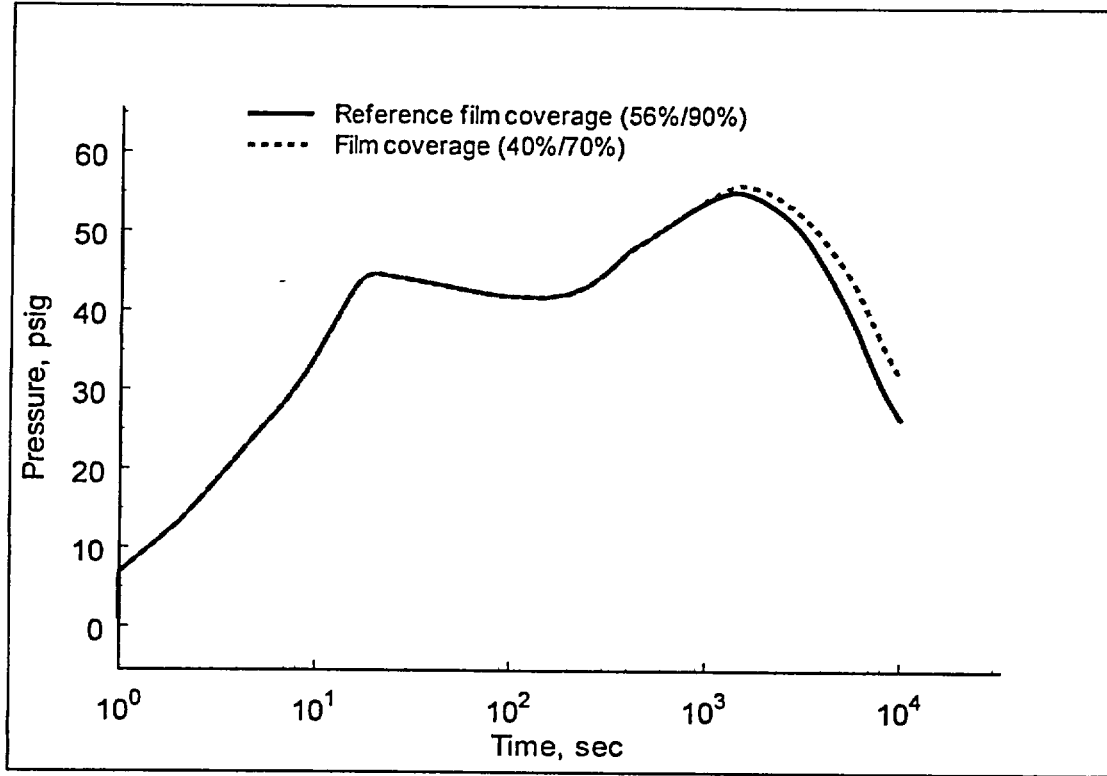


Figure 16 Pressure sensitivity to external shell film coverage.