ATTACHMENT 4

GE Hitachi Nuclear Energy Report 0000-0163-8881-R0,
"Exelon Nuclear LaSalle County Generating Station Units 1 & 2 Pool Swell Response,"
October 2016

(Non-Proprietary)

LASALLE COUNTY STATION
UNITS 1 AND 2

Docket Nos. 50-373 and 50-374

Facility Operating License Nos. NPF-11 and NPF-18

42 pages follow

HITACHI

GE Hitachi Nuclear Energy

003N9278-R0-NP
Revision 0
October 2016

Non-Proprietary Information – Class I (Public)

EXELON NUCLEAR
LASALLE COUNTY GENERATING STATION
UNITS 1 & 2
POOL SWELL RESPONSE

INFORMATION NOTICE

This is a non-proprietary version of the document 003N9278-R0-P, Revision 0, which has the proprietary information removed. Portions of the document that have been removed are indicated by an open and closed bracket as shown here [[ ]].

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

PLEASE READ CAREFULLY

The design, engineering, and other information contained in this document is furnished for the purposes of supporting an evaluation for LaSalle County Generating Station pool swell in proceedings before the U.S. Nuclear Regulatory Commission (NRC). The only undertakings of GEH with respect to information in this document are contained in the contracts between GEH and its customers or participating utilities, and nothing contained in this document shall be construed as changing that contract. The use of this information by anyone for any purpose other than that for which it is intended, is not authorized; and with respect to any unauthorized use, GEH makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

REVISION SUMMARY

Revision	Required Changes to Achieve Revision
0	Initial issuance of the version containing marked GEH proprietary information. This report is based on 0000-0163-8881-R0 dated February 2014.

ACRONYMS AND ABBREVIATIONS

Short Form	Description
BWR	Boiling Water Reactor
CF	Core Flow
CLTP	Current Thermal Power
DBA	Design Basis Accident
DEGB	Doubled Ended Guillotine Break
DW	Drywell
°F	Degrees Fahrenheit
ft	Feet
GEH	GE Hitachi Nuclear Energy
HWL	High Water Level
LAMB	Loss-of-Coolant Analysis Model for Boiling Water Reactors, GEH Computer Code for Break Mass and Energy Calculation
LCGS	LaSalle County Generating Station
LOCA	Loss-of-Coolant Accident
M3CPT	Mark III Containment Pressure and Temperature; GEH Computer Code for Short-term DBA-LOCA Containment Response Analysis.
MSIV	Main Steam Isolation Valve
MWt	Megawatts thermal
N/A	Not Applicable
NFWT	Normal Feedwater Temperature
NRC	National Regulatory Commission
NSSS	Nuclear Steam Supply System
PICSM	GEH Pool Swell Response Code
psia	Pounds Per Square Inch Absolute
psid	Pounds per square inch differential
PSTF	Partial Scale Test Facility
RFWT	Reduced Feedwater Temperature
RPV	Reactor Pressure Vessel
RSL	Recirculation Suction Line
RSLB	Recirculation Suction Line Break
sec	Second
SRV	Safety Relief Valve
TPO	Thermal Power Optimization
TRACG	GEH Proprietary Version of the Transient Reactor Analysis Code (TRAC), GEH Computer Code for Best Estimate BWR Transient and Accident Analysis Calculations.

Short Form	Description
WW	Wetwell

TABLE OF CONTENTS

1.0 TASK SCOPE AND PURPOSE

This report discusses and presents the results of analyses performed to generate pool swell response profiles for the LaSalle County Generating Station (LCGS) plant in support of an Exelon assessment of the pool swell loads for LCGS.

Analyses are performed to generate Recirculation Suction Line Break (RSLB) Design Basis Accident – Loss-of-Coolant Accident (DBA-LOCA) mass and energy release using the GEH TRACG method. Drywell (DW) pressure history is calculated using the GEH M3CPT method. Pool surface level, velocity and acceleration histories are subsequently generated with the GEH PICSM method.

The analysis in this report is applicable to the Current Licensed Thermal Power (CLTP) with Thermal Power Optimization (TPO) of 3,546 MWt and lower. The maximum power used in the analysis is 3,559 MWt, which is 102% of the stretch power uprate licensed thermal power (3,489 MWt) or 100.36% of the TPO CLTP of 3,546 MWt. This analysis covers the entire power/flow map including the effect of reduced feedwater temperature operation.

Other plant performance improvement and equipment out-of-service options identified in Reference 1 have no effect on the RSLB mass and energy release analyses. The current analysis, therefore, continues to support all flexibility and equipment out of service options.

2.0 BACKGROUND

The RSLB DBA-LOCA is the limiting event with respect to the initial mass and energy break flow to the DW, and therefore limiting for DW pressurization and associated pool swell response. Pool swell loads occur following a postulated DBA LOCA event during which the expulsion of water within the vent system and subsequent transfer of steam and non-condensable mass from the DW through the containment venting system produces loads on initially submerged structures and suppression pool boundaries as well as on structures above the initial suppression pool surface. The pool swell response is driven by the initial DW pressurization during the first couple of seconds which is controlled by the blowdown mass and energy release rate to the DW during this period. This analysis provides a prediction of the RSLB DBA-LOCA DW pressure response for this initial time period and a prediction of the associated pool swell response.

3.0 INPUTS AND ASSUMPTIONS

The analysis in this report is applicable to the CLTP with TPO of 3,546 MWt and lower. The maximum power used in the analysis is 3,559 MWt, which is 102% of the stretch power uprate licensed thermal power (3,489 MWt) or 100.36% of the TPO CLTP of 3,546 MWt.

The mass and energy release from a recirculation suction line double-ended guillotine break was calculated using the TRACG code and the DW pressure response was calculated using the approved M3CPT code. The M3CPT methodology is the same as that used in the current analysis of record for the short term containment analysis for LCGS Units 1 and 2. The use of the M3CPT model (References 2 and 3) for prediction of the driving DW pressure response and the Mark II pool swell response methodology (PICSM, Reference 4) was approved by the NRC in References 5 and 6.

A more detailed description of inputs and assumptions are discussed in Section 4 for the TRACG break mass and energy calculation, in Section 5 for the M3CPT DW pressure calculation and in Section 6 for the PICSM pool swell response analysis.

4.0 BLOWDOWN MASS AND ENERGY

4.1 Methodology (TRACG)

The TRACG mass and energy release analysis models the entire reactor system producing accurate pressure and enthalpy conditions for the break and also accounts for the flow inertia in the piping that provides a more realistic evaluation of transient dynamics for downstream containment analysis. Details of the methods used to perform LCGS RSLB mass and energy release analysis are provided below.

The ability of the TRACG code to accurately model critical flow and the mechanisms that control flashing within the ruptured pipe are demonstrated by critical flow model test comparisons documented in Section 3.4 of NEDE-32177P (Reference 7). Section 3.4.1 of NEDE-32177P presents comparisons to Marviken Critical Flow Tests. Section 3.4.2 of NEDE-32177P presents comparisons to Partial Scale Test Facility (PSTF) critical flow tests. Section 3.4.3 of NEDE-32177P presents comparisons to the Edwards pipe blowdown tests. The comparisons to the Marviken and PSTF tests show that TRACG is capable of accurate modeling of critical flow for a range of initial conditions ranging from subcooled water to saturated steam for pressures consistent with Boiling Water Reactor (BWR) vessel pressures. When taken in total, the comparisons documented in Section 3.4 of NEDE-32177P support the conclusion that the TRACG code can be used to generate more realistic mass and energy release rates than that from other codes, such as LAMB (Reference 8).

4.1.1 RSLB Mass and Energy Release Methodology Details

4.1.1.1 TRACG Model for Recirculation Suction Line Break

The TRACG model is based on a full reactor system model that has been modified to model breaks at the nozzle safe end to pipe weld for the recirculation suction nozzle. Figure 4-1 presents a diagram of the recirculation loop model used in the standard TRACG reactor system model. The recirculation suction line portion is modeled as [[ ]] component in TRACG (PIPE0050).

[[

]]

Figure 4- 1: Standard TRACG Transient Analysis Model Recirculation System Model

For the LCGS pool swell mass and energy release analysis, a double ended guillotine rupture of the Recirculation Suction Line (RSL) is modeled with [[ ]]. The break modeled in this report is an instantaneous Double Ended Guillotine Break (DEGB). The break area is equal to the sum of the cross-sectional areas of the reactor vessel nozzle and the pump-side pipe area.

[[

]]

[[

]]

Figure 4-2: Instantaneous Double-Ended Guillotine Break Model

[[

]]

[[

]]

Flow from both sides of the break remains choked at the break location throughout the duration of this event.

Due to the symmetrical design of the reactor pressure vessel and the recirculation loops, the model is applicable to breaks at either RS nozzle safe end. In addition, the model is applicable to either unit, as the key inputs to the RSLB model are identical for LCGS Units 1 and 2.

The TRACG break flow model and qualification basis are described in NEDE-32176P (Reference 9) and NEDE-32177P (Reference 7) respectively.

4.1.1.2 Operating Conditions Considered for Recirculation Suction Line Break

Break flow is affected by the enthalpy in in the RSL. The enthalpy of the fluid in the RSL depends on the reactor thermal power, core flow and dome pressure. A lower initial RSL enthalpy results in higher mass flux at the break.

Initial operating conditions listed in Table 4-1 were selected to envelope all licensed operating conditions that may affect this analysis. The following conditions listed in Table 4-1 were selected for the RSLB mass and energy release analysis.

Table 4-1: Power/Flow Conditions Analyzed for RSLB

Case	Power (% TPO)	Flow (% Rated Flow)	Dome Pressure (psia)	Feedwater Temperature [3]
[[			1,040	RFWT
			1,040	RFWT
			1,040	RFWT
			1,040	RFWT
			1,040	RFWT
			1,040	NFWT
		]]	1,040	NFWT

Notes:

1. 2% uncertainty in power is included.
2. This is percentage of TPO power of 3,546 MWt. The absolute thermal power is 3,559 MWt for those cases.
3. Feedwater temperature reduction of 100°F is considered. The normal feedwater temperature at CLTP is 428.5°F.

4.2 Input and Assumptions

4.2.1 Key Inputs (TRACG)

Item	Parameter	Value	Units	Reference / Basis
1	Reactor Dome Pressure	1,040	psia	--
2	Power/Flow Map	Power/Flow Map	N/A	Reference 1
3	Length of Recirculation Suction Nozzle from the Vessel	[[ ]]	inch	--
4	Loss Coefficient for Flow from the Vessel into the Recirculation Suction Nozzle	[[ ]]	N/A	[[ ]] Sheet 4 of 4, K Factor Table, Appendix A, Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings and Pipe," 25th Printing, 1991.
5	Safety Relief Valve (SRV) Numbers and Setpoints	Same as Reference 10	N/A	[[ ]]
6	Main Steam Isolation Valve (MSIV) Closure Time	[[ ]]	sec	[[ ]]
7	Feedwater Flow Coast Down Time	[[ ]]	sec	--

4.3 Results

4.3.1 TRACG Mass and Energy Release

Figures 4-3 and 4-4 show the break mass flow rate and break flow enthalpy, respectively for the cases shown in Table 4-1 at Reduced Feedwater Temperature (RFWT). [[

]]

For comparison, the break mass flow rate and break flow enthalpy for the cases shown in Table 4-1 at NFWT are shown in Figures 4-5 and 4-6, respectively.

This analysis covers the entire power/flow map including the effect of reduced feedwater temperature operation.

Other plant performance improvement and equipment out of service options identified in Reference 1 have no effect on the RSLB mass and energy release analyses. The current analysis, therefore, continues to support all flexibility and equipment out of service options.

[[

]]

Figure 4-3: RSLB Mass Release Rates (RFWT)

[[

]]

Figure 4-4: RSLB Fluid Enthalpy (RFWT)

[[

]]

Figure 4-5: RSLB Mass Release Rates (NFWT)

[[

]]

Figure 4-6: RSLB Fluid Enthalpy (NFWT)

5.0 DRYWELL PRESSURE

5.1 Methodology (M3CPT)

The DW pressure response is calculated with the M3CPT code. The M3CPT code was used for the short-term DBA-LOCA analysis of record and was also applied to the Reference 10 analysis. The use of the M3CPT containment response models as an input to the PICSM calculation has been approved by the NRC in References 5 and 6. The M3CPT models include a containment model and a vessel model which is used for calculating internally generated blowdown mass and energy. For this calculation only the containment models of M3CPT are applied, with blowdown mass and energy externally generated (TRACG) and entered as an input to M3CPT.

5.1.1 Inputs and Assumptions

Inputs

Key inputs for the M3CPT analyses are summarized in Appendix A.

Assumptions

1. Initial containment conditions are assumed to maximize the DW pressure response and maximum initial DW non-condensable gas.
2. Suppression pool is at the maximum level allowed for normal plant operation (High Water Level (HWL)).
3. WW airspace is saturated with an initial relative humidity of 100%
4. DW airspace relative initial humidity is at the minimum value (20%)
5. The vent flow consists of a homogeneous mixture of the fluid in the DW.
6. No heat loss from fluids in the DW to the structure (heat sinks)
7. The effect of vent back pressure on vent flow is not simulated. The M3CPT model has the capability to simulate the effects of vent backpressure produced by the LOCA bubble on the vent flow calculation and on the DW pressure response. As discussed by the NRC in Reference 5, the DW pressure response obtained with the M3CPT models, with the effects of vent inertia ignored (vent back pressure), are adequate for use with the References 2 and 3 M3CPT models for prediction of the pool swell response.

5.2 Results

5.2.1 Drywell Pressure

Figure 5-1 provides a comparison of the DW pressure response for the different TRACG cases identified in Table 4-1. Figure 5-1 also contains a comparison to the prediction based on a blowdown generated with the LAMB (Reference 8) code at 100.36% TPO CLTP/100% Core Flow (CF) and a comparison to the DW pressure used as input to define the LCGS pool swell design basis load.

Based on the comparison shown in Figure 5-1 the limiting case with TRACG break flow is RFWT Case A. As indicated by the results in Figure 5-1, the DW pressure response for the limiting TRACG-based case is comparable to the LAMB-based prediction. However, it is significantly higher than the DW pressure response shown in the LCGS design basis pool swell calculation during the post vent clearing period which controls the pool swell response.

[[

]]

Figure 5-1: Drywell Pressure Comparison

6.0 POOL SWELL RESPONSE

6.1 Methodology

The Mark II pool swell response is calculated using the GEH pool swell analytical code (PICSM). This calculates the Mark II pool swell elevation, velocity and acceleration as a function of time. The vent LOCA bubble pressure and WW pressurization due to compression effects is also predicted by the model and included in the output. The PICSM models, as described in Reference 4, were accepted by the NRC for use in predicting the Mark II pool swell response in References 5 and 6.

6.1.1 Inputs and Assumptions

Inputs

Geometry related inputs were developed based on the data shown in Appendix A. DW pressure data input to the PICSM calculations were selected from the M3CPT analysis of the limiting case (RFWT Case A) as discussed Section 5.0.

Assumptions

The following assumptions are associated with the PICSM models (Reference 4).

1. The air is assumed to behave as an ideal gas.
2. Following vent clearing, two assumptions for the vent flow feeding the air bubble beneath the pool are available:
   i) Air only flows into the suppression pool, rather than a mixture of air and steam. This maximizes the mass flow rate of non-condensables and therefore maximizes the resultant pool swell. This assumption is referred to as all-air carryover. This assumption is identified for use in design calculations per Reference 4 as approved by the NRC in References 5 and 6.
   ii) A flow of air only until a specified amount of air (established by the air mass contained within the non-submerged portion of the vent downcomer) has been purged from the DW and vent systems, followed by a flow of an air-vapor mixture for the remainder of the transient. Complete condensation of the vapor is assumed so that the resultant driving flow of non-condensables to the bubble is reduced. This assumption is called mix and purge. This assumption, which applies for Cases 3 and 4, assumes that only air flows through the downcomers until all air initially within the non-submerged portion of the downcomers is purged into the suppression pool. For the remainder of the transient, the steam/air ratio for the vent flow is held constant at a value established by the steam/air content in DW at the time all initial air in the downcomer is purged.

   The assumption of a constant steam/air mixture is conservative relative to a dynamic steam/air ratio because the amount of air in the mixture gets progressively smaller with time into the transient.

   The results with both options are presented in this report.

3. The mass flow rate of non-condensables into the bubble is calculated assuming adiabatic flow through a duct with friction.
4. The air in the DW is isentropically compressed and heat transfer to the walls is conservatively neglected. For this compression process it is assumed that no mixing occurs, but mix and purge is allowed for in the vent mass flow model.
5. A variable bubble temperature equal to the current DW temperature throughout the transient.
6. Following vent clearing, the water above the exit of the vent (equal to the initial vent submergence plus the pool displacement due to vent clearing) accelerates as a slug of constant thickness.
7. Frictional losses between the water and the confining walls are negligible.
8. Viscous forces are negligible compared to the inertial and pressure forces.
9. The suppression pool air space is isentropically compressed by the upward moving water slug. Heat transfer to the walls is neglected. (Note that for this calculation a polytropic coefficient of 1.2 is used for air compression pressurization when establishing peak pool swell elevation and for calculation of pool swell velocity and acceleration).
10. The air velocity in the DW is sufficiently small so that static and stagnation conditions are equivalent.
11. The entire pool surface rises as a uniform ligament of constant thickness.

Four PICSM cases are performed.

Case 1 – All Air Vent Flow, Polytropic Coefficient (k) of 1.2 for WW Airspace Compression

Case 2 – All Air Vent Flow, Isentropic Coefficient (k) of 1.4 for WW Airspace Compression

Case 3 – Mixed Air/Steam Vent Flow, Polytropic Coefficient (k) of 1.2 for WW Airspace Compression

Case 4 – Mixed Air/Steam Vent Flow, Isentropic Coefficient (k) of 1.4 for WW Airspace Compression

Case 1 assumptions are in accordance with the approved methodology in References 5 and 6 for design calculations.

Cases 1 and 2 use the standard assumption of all air vent flow for the analysis duration which is the more conservative assumption and identified in References 4, 5 and 6 for use in design applications. Cases 3 and 4 use the more realistic air/steam mixture (mix and purge option) which was identified in Reference 4 for application in best estimate calculations.

A polytropic coefficient of 1.2 is used to calculate the WW pressurization due to airspace compression for Cases 1 and 3. This value maximizes pool swell elevation and velocity. The results with the polytropic coefficient of 1.2 should be used to establish maximum elevation, velocity and acceleration profiles for design application. The results based on the polytropic coefficient of 1.2 should also be used for assessments of WW airspace pressurization loads due to

pool swell induced WW airspace compression. This is consistent with direction given in Appendix C of NUREG-0808 (Reference 6) which specifies that the WW air compression should be calculated consistent with the analyses for determination of the peak pool swell elevation.

The isentropic coefficient of 1.4 for air (Cases 2 and 4) is used to obtain results which maximize pressurization of the WW airspace due to compression effects. The results based on the isentropic coefficient of 1.4 are presented as a sensitivity study for information purposes and not for design application.

All cases use the isentropic coefficient of 1.4 for air in calculating vent flow rates. The use of 1.4 versus a lower coefficient value (such as 1.3 for steam) results in higher vent flow rates and is therefore used to conservatively calculate vent flow for all cases.

6.2 Results

6.2.1 Maximum Pool Swell Elevation

The maximum pool swell height is not directly calculated with PICSM.

Per Reference 6, the maximum pool swell elevation is defined as the higher of 1.5 times the initial submergence (= 1.5* 12.33 ft = 18.5 ft), or the elevation corresponding to the time at which there is a 2.5 psid compressed WW airspace to DW pressure difference (uplift differential pressure). Per Reference 6, the maximum elevation should be determined based on the WW pressurization response calculated with a 1.2 polytropic coefficient for WW airspace compression.

The results of the PICSM calculation for all cases shows that the WW-to-DW differential pressure (uplift differential pressure) never reaches + 2.5 psid. Therefore, the maximum pool swell elevation as defined per the Reference 6 criteria, is established by 1.5 times the initial vent submergence (12.33 ft) = 18.5 ft.

6.2.2 Pool Swell Response Data

Figures 6-1 through 6-4A show the predicted pool swell response for the four PICSM cases described above. Tables 6-1 through 6-4 provide the tabular data used to generate the pool swell response plots shown in the figures. These tables also provide the LOCA bubble pressure and compressed WW airspace pressure.

Figure 6-1 shows the PICSM predicted pool swell elevation versus time. The elevations in Figure 6-1 include a 1.1 multiplier adjustment on the PICSM elevation prediction to be consistent with the 1.1 multiplier on the predicted velocity as required by References 5 and 6. The elevations also include a 0.7 ft adder to the PICSM prediction to account for the difference between initial pre-LOCA elevation and initial PICSM elevation which corresponds to the elevation after vent clearing. The elevations shown in this and subsequent figures correspond to elevation relative to the pre-LOCA initial pool surface elevation.

Figure 6-2 shows the PICSM predicted pool swell velocity versus time. The velocities in Figure 6-2 include a 1.1 multiplier adjustment on the PICSM velocity prediction as required by References 5 and 6. Velocities corresponding to adjusted elevations greater than the maximum pool swell elevation of 18.5 ft are not included.

Figure 6-3 shows the PICSM adjusted pool swell velocity vs adjusted elevation up to a maximum adjusted elevation of 18.5 ft. Velocities and elevation used to generate Figure 6-3 include a 1.1 multiplier adjustment.

Figure 6-3A shows the PICSM adjusted pool swell velocity vs. adjusted elevation up to a maximum adjusted elevation of 18.5 ft. However, in Figure 6-3A, the maximum velocity is held constant for elevations above the elevation at which the maximum velocity occurs. This uses the Mark II Owners Group load description for pool swell velocity included in Appendix C of Reference 6. Velocities and elevations used to generate Figure 6-3A include a 1.1 multiplier.

Figure 6-4 shows the PICSM adjusted pool swell acceleration vs. adjusted elevation up to a maximum adjusted elevation of 18.5 ft. Velocities and elevations used to generate the acceleration profiles in Figure 6-4 include a 1.1 multiplier.

Figure 6-4A shows the PICSM adjusted pool swell acceleration vs. adjusted elevation up to a maximum adjusted elevation of 18.5 ft. However, in Figure 6-4A, the acceleration is set to zero for elevations above the elevation at which the maximum velocity occurs. This provides consistency with the velocity assumption used for Figure 6-3A. Velocities and elevations used to generate the acceleration profiles in Figure 6-4A include a 1.1 multiplier.

Table 6-1: Case 1: PICSM Pool Swell Response – All Air Vent Flow, Polytropic Gas Coefficient of 1.2 for Wetwell Airspace Compression – 1.1 Multiplier on Elevation and Velocity

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec²)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec²)
0.744	34.7	15.9	0.78	6.237	0	6.237	0
0.769	33.76	15.997	0.961	8.151	76.56	8.151	76.56
0.794	33.46	16.122	1.192	10.021	74.8	10.021	74.8
0.819	33.08	16.274	1.467	11.803	71.28	11.803	71.28
0.844	32.74	16.454	1.786	13.508	68.2	13.508	68.2
0.869	32.4	16.662	2.138	15.125	64.68	15.125	64.68
0.894	31.99	16.898	2.534	16.654	61.16	16.654	61.16
0.919	31.6	17.164	2.974	18.084	57.2	18.084	57.2
0.944	31.24	17.459	3.436	19.404	52.8	19.404	52.8
0.969	30.93	17.785	3.942	20.625	48.84	20.625	48.84
0.994	30.64	18.142	4.47	21.747	44.88	21.747	44.88
1.019	30.35	18.531	5.031	22.759	40.48	22.759	40.48
1.044	30.08	18.954	5.603	23.672	36.52	23.672	36.52
1.069	29.83	19.412	6.208	24.475	32.12	24.475	32.12
1.094	29.61	19.905	6.835	25.157	27.28	25.157	27.28
1.119	29.43	20.436	7.462	25.74	23.32	25.74	23.32
1.144	29.27	21.004	8.122	26.202	18.48	26.202	18.48
1.169	29.15	21.612	8.782	26.554	14.08	26.554	14.08
1.194	29.05	22.26	9.442	26.785	9.24	26.785	9.24
1.219	28.99	22.95	10.113	26.906	4.84	26.906	4.84
1.244	28.95	23.681	10.784	26.906	0	26.906	0
1.269	28.94	24.455	11.455	26.785	-4.84	26.906	0
1.294	28.97	25.27	12.126	26.543	-9.68	26.906	0
1.319	29.02	26.127	12.786	26.169	-14.96	26.906	0
1.344	29.1	27.022	13.435	25.674	-19.8	26.906	0
1.369	29.21	27.955	14.073	25.047	-25.08	26.906	0
1.394	29.36	28.92	14.689	24.299	-29.92	26.906	0
1.419	29.53	29.913	15.283	23.419	-35.2	26.906	0
1.444	29.74	30.927	15.855	22.407	-40.48	26.906	0
1.469	29.99	31.954	16.405	21.274	-45.32	26.906	0
1.494	30.27	32.985	16.922	20.02	-50.16	26.906	0
1.519	30.59	34.006	17.406	18.656	-54.56	26.906	0
1.544	30.94	35.006	17.846	17.182	-58.96	26.906	0

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec^2)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec^2)
1.569	31.34	35.969	18.264	15.62	-62.48	26.906	0
1.585	31.63	36.562	18.5	14.47371	-64.1283	26.906	0

Notes:

1- Pool Surface elevation, velocity and acceleration account for a 1.1 multiplier to the PICSM output on elevation and velocity.

2- Per Appendix C of Reference 6 velocity held constant at maximum velocity and acceleration held at zero for times after maximum velocity reached.

Table 6-2: Case 2 PICSM Pool Swell Response – All Air Vent Flow, Isentropic Gas Coefficient of 1.4 for Wetwell Airspace Compression – 1.1 Multiplier on Elevation and Velocity

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec^2)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec^2)
0.744	34.7	15.975	0.78	6.237	0	6.237	0
0.769	33.77	16.089	0.961	8.14	76.12	8.14	76.12
0.794	33.47	16.235	1.192	9.988	73.92	9.988	73.92
0.819	33.1	16.413	1.467	11.759	70.84	11.759	70.84
0.844	32.76	16.624	1.775	13.442	67.32	13.442	67.32
0.869	32.43	16.868	2.138	15.037	63.8	15.037	63.8
0.894	32.03	17.146	2.534	16.533	59.84	16.533	59.84
0.919	31.65	17.458	2.963	17.919	55.44	17.919	55.44
0.944	31.31	17.805	3.425	19.206	51.48	19.206	51.48
0.969	31	18.189	3.92	20.383	47.08	20.383	47.08
0.994	30.73	18.61	4.448	21.439	42.24	21.439	42.24
1.019	30.47	19.069	4.987	22.396	38.28	22.396	38.28
1.044	30.22	19.568	5.559	23.243	33.88	23.243	33.88
1.069	29.99	20.109	6.153	23.958	28.6	23.958	28.6
1.094	29.8	20.691	6.758	24.563	24.2	24.563	24.2
1.119	29.64	21.317	7.374	25.036	18.92	25.036	18.92
1.144	29.51	21.988	8.012	25.388	14.08	25.388	14.08
1.169	29.42	22.704	8.65	25.619	9.24	25.619	9.24
1.194	29.35	23.467	9.288	25.718	3.96	25.718	3.96
1.219	29.32	24.275	9.937	25.696	-0.88	25.718	0
1.244	29.33	25.129	10.575	25.531	-6.6	25.718	0
1.269	29.36	26.027	11.213	25.234	-11.88	25.718	0
1.294	29.44	26.968	11.829	24.805	-17.16	25.718	0
1.319	29.54	27.948	12.445	24.233	-22.88	25.718	0
1.344	29.68	28.963	13.039	23.529	-28.16	25.718	0
1.369	29.85	30.007	13.622	22.693	-33.44	25.718	0
1.394	30.07	31.071	14.183	21.714	-39.16	25.718	0
1.419	30.32	32.148	14.711	20.603	-44.44	25.718	0
1.444	30.61	33.225	15.206	19.371	-49.28	25.718	0
1.469	30.94	34.29	15.679	18.018	-54.12	25.718	0
1.494	31.31	35.328	16.108	16.555	-58.52	25.718	0
1.519	31.73	36.323	16.504	14.993	-62.48	25.718	0
1.544	32.19	37.258	16.856	13.354	-65.56	25.718	0

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec^2)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec^2)
1.569	32.7	38.118	17.164	11.649	-68.2	25.718	0
1.594	33.26	38.887	17.439	9.889	-70.4	25.718	0
1.619	33.87	39.55	17.659	8.118	-70.84	25.718	0
1.644	34.52	40.097	17.846	6.347	-70.84	25.718	0
1.669	35.21	40.519	17.978	4.609	-69.52	25.718	0
1.694	35.93	40.814	18.077	2.926	-67.32	25.718	0
1.719	36.69	40.982	18.132	1.32	-64.24	25.718	0
1.744	37.47	41.027	18.143	0	-52.8	25.718	0
Extended			18.5[3]			25.718	0

Notes:

1. Pool Surface elevation, velocity and acceleration account for a 1.1 multiplier to the PICSM output on elevation and velocity.
2. Per Appendix C of Reference 6 velocity held constant at maximum velocity and acceleration held at zero for times after maximum velocity reached.
3. Velocity and acceleration for design per Reference 6 extended to 18.5 ft.

Table 6-3: Case 3: PICSM Pool Swell Response – Mix and Purge Option for Vent Flow, Polytropic Gas Coefficient of 1.2 for Wetwell Airspace Compression – 1.1 Multiplier on Elevation and Velocity

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec^2)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec^2)
0.744	34.7	15.9	0.78	6.237	0	6.237	0
0.769	33.76	15.997	0.961	8.151	76.56	8.151	76.56
0.794	33.46	16.122	1.192	10.021	74.8	10.021	74.8
0.819	33.08	16.274	1.467	11.803	71.28	11.803	71.28
0.844	32.74	16.454	1.786	13.508	68.2	13.508	68.2
0.869	32.4	16.662	2.138	15.125	64.68	15.125	64.68
0.894	30.2	16.898	2.534	16.522	55.88	16.522	55.88
0.919	28.76	17.158	2.963	17.578	42.24	17.578	42.24
0.944	27.84	17.442	3.414	18.403	33	18.403	33
0.969	27.2	17.746	3.887	19.074	26.84	19.074	26.84
0.994	26.74	18.07	4.371	19.602	21.12	19.602	21.12
1.019	26.37	18.413	4.866	20.02	16.72	20.02	16.72
1.044	26.08	18.776	5.361	20.328	12.32	20.328	12.32
1.069	25.85	19.156	5.878	20.537	8.36	20.537	8.36
1.094	25.68	19.554	6.395	20.658	4.84	20.658	4.84
1.119	25.55	19.969	6.912	20.68	0.88	20.68	0.88
1.144	25.47	20.4	7.429	20.636	-1.76	20.68	0
1.169	25.42	20.846	7.935	20.504	-5.28	20.68	0
1.194	25.41	21.307	8.452	20.295	-8.36	20.68	0
1.219	25.43	21.781	8.958	20.009	-11.44	20.68	0
1.244	25.48	22.267	9.453	19.668	-13.64	20.68	0
1.269	25.56	22.763	9.937	19.25	-16.72	20.68	0
1.294	25.67	23.267	10.41	18.766	-19.36	20.68	0
1.319	25.81	23.778	10.872	18.227	-21.56	20.68	0
1.344	25.97	24.294	11.323	17.633	-23.76	20.68	0
1.369	26.16	24.811	11.752	16.984	-25.96	20.68	0
1.394	26.38	25.328	12.17	16.291	-27.72	20.68	0
1.419	26.63	25.841	12.566	15.543	-29.92	20.68	0
1.444	26.9	26.347	12.951	14.762	-31.24	20.68	0
1.469	27.2	26.844	13.303	13.948	-32.56	20.68	0
1.494	27.52	27.328	13.644	13.112	-33.44	20.68	0
1.519	27.87	27.796	13.963	12.243	-34.76	20.68	0
1.544	28.25	28.245	14.26	11.363	-35.2	20.68	0

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec^2)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec^2)
1.569	28.66	28.673	14.535	10.472	-35.64	20.68	0
1.594	29.09	29.076	14.777	9.592	-35.2	20.68	0
1.619	29.55	29.454	15.008	8.712	-35.2	20.68	0
1.644	30.03	29.803	15.217	7.854	-34.32	20.68	0
1.669	30.53	30.123	15.404	7.018	-33.44	20.68	0
1.694	31.06	30.412	15.569	6.215	-32.12	20.68	0
1.719	31.59	30.672	15.712	5.445	-30.8	20.68	0
1.744	32.15	30.902	15.844	4.73	-28.6	20.68	0
1.769	32.72	31.103	15.954	4.07	-26.4	20.68	0
1.794	33.3	31.278	16.042	3.465	-24.2	20.68	0
1.819	33.89	31.427	16.13	2.926	-21.56	20.68	0
1.844	34.48	31.554	16.196	2.464	-18.48	20.68	0
1.869	35.08	31.662	16.251	2.079	-15.4	20.68	0
1.894	35.68	31.753	16.295	1.771	-12.32	20.68	0
1.919	36.26	31.832	16.339	1.529	-9.68	20.68	0
1.944	36.83	31.902	16.372	1.386	-5.72	20.68	0
1.969	37.38	31.967	16.405	1.309	-3.08	20.68	0
1.994	37.91	32.03	16.438	1.298	-0.44	20.68	0
Extended			18.5[3]			20.68[3]	0

Notes:

1. Pool Surface elevation, velocity and acceleration account for a 1.1 multiplier to the PICSM output on elevation and velocity.
2. Per Appendix C of Reference 6 velocity held constant at maximum velocity and acceleration held at zero for times after maximum velocity reached.
3. Velocity and Acceleration for design per Reference 6 extended to 18.5 ft.

Table 6-4: Case 4: PICSM Pool Swell Response – Mix and Purge Vent Flow Option, Isentropic Gas Coefficient of 1.4 for Wetwell Airspace Compression – 1.1 Multiplier on Elevation and Velocity

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec^2)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec^2)
0.744	34.7	15.975	0.78	6.237	0	6.237	0
0.769	33.77	16.089	0.961	8.14	76.12	8.14	76.12
0.794	33.47	16.235	1.192	9.988	73.92	9.988	73.92
0.819	33.1	16.413	1.467	11.759	70.84	11.759	70.84
0.844	32.76	16.624	1.775	13.442	67.32	13.442	67.32
0.869	32.43	16.868	2.138	15.037	63.8	15.037	63.8
0.894	30.24	17.145	2.534	16.401	54.56	16.401	54.56
0.919	28.82	17.452	2.952	17.424	40.92	17.424	40.92
0.944	27.92	17.785	3.403	18.216	31.68	18.216	31.68
0.969	27.3	18.143	3.865	18.832	24.64	18.832	24.64
0.994	26.85	18.524	4.338	19.316	19.36	19.316	19.36
1.019	26.51	18.929	4.822	19.668	14.08	19.668	14.08
1.044	26.25	19.355	5.317	19.921	10.12	19.921	10.12
1.069	26.04	19.802	5.823	20.064	5.72	20.064	5.72
1.094	25.9	20.27	6.329	20.108	1.76	20.108	1.76
1.119	25.8	20.757	6.824	20.053	-2.2	20.108	0
1.144	25.75	21.262	7.33	19.91	-5.72	20.108	0
1.169	25.74	21.783	7.825	19.69	-8.8	20.108	0
1.194	25.76	22.319	8.309	19.382	-12.32	20.108	0
1.219	25.82	22.868	8.793	18.997	-15.4	20.108	0
1.244	25.92	23.428	9.255	18.535	-18.48	20.108	0
1.269	26.04	23.996	9.717	18.007	-21.12	20.108	0
1.294	26.2	24.569	10.157	17.402	-24.2	20.108	0
1.319	26.4	25.145	10.586	16.742	-26.4	20.108	0
1.344	26.62	25.719	10.993	16.027	-28.6	20.108	0
1.369	26.88	26.289	11.389	15.257	-30.8	20.108	0
1.394	27.16	26.85	11.752	14.443	-32.56	20.108	0
1.419	27.48	27.398	12.104	13.585	-34.32	20.108	0
1.444	27.83	27.93	12.434	12.705	-35.2	20.108	0
1.469	28.21	28.442	12.742	11.792	-36.52	20.108	0
1.494	28.62	28.93	13.028	10.857	-37.4	20.108	0
1.519	29.06	29.39	13.281	9.922	-37.4	20.108	0
1.544	29.54	29.82	13.523	8.987	-37.4	20.108	0

TIME-S	Vent Bubble Pressure (psia)	Wetwell Airspace Pressure (psia)	Pool Surface Elevation Above initial Elevation[1] (ft)	Pool Surface Velocity[1] (ft/sec)	Pool Surface Acceleration[1] (ft/sec^2)	Pool Surface Velocity Per Reference 6[2] (ft/sec)	Pool Surface Acceleration Per Reference 6[2] (ft/sec^2)
1.569	30.04	30.217	13.732	8.063	-36.96	20.108	0
1.594	30.56	30.58	13.93	7.161	-36.08	20.108	0
1.619	31.1	30.906	14.095	6.292	-34.76	20.108	0
1.644	31.67	31.196	14.238	5.456	-33.44	20.108	0
1.669	32.26	31.449	14.37	4.675	-31.24	20.108	0
1.694	32.87	31.667	14.469	3.949	-29.04	20.108	0
1.719	33.48	31.852	14.568	3.278	-26.84	20.108	0
1.744	34.12	32.007	14.634	2.684	-23.76	20.108	0
1.769	34.76	32.133	14.7	2.167	-20.68	20.108	0
1.794	35.4	32.235	14.744	1.738	-17.16	20.108	0
1.819	36.03	32.317	14.788	1.397	-13.64	20.108	0
1.844	36.65	32.384	14.821	1.133	-10.56	20.108	0
1.869	37.26	32.439	14.843	0.957	-7.04	20.108	0
1.894	37.84	32.487	14.865	0.869	-3.52	20.108	0
1.919	38.4	32.533	14.887	0.858	-0.44	20.108	0
Extended			18.5[3]			20.108[3]	0

Notes:

1. Pool Surface elevation, velocity and acceleration account for a 1.1 multiplier to the PICSM output on elevation and velocity.
2. Per Appendix C of Reference 6 velocity held constant at maximum velocity and acceleration held at zero for times after maximum velocity reached.
3. Velocity and Acceleration for design per Reference 6 extended to 18.5 ft.

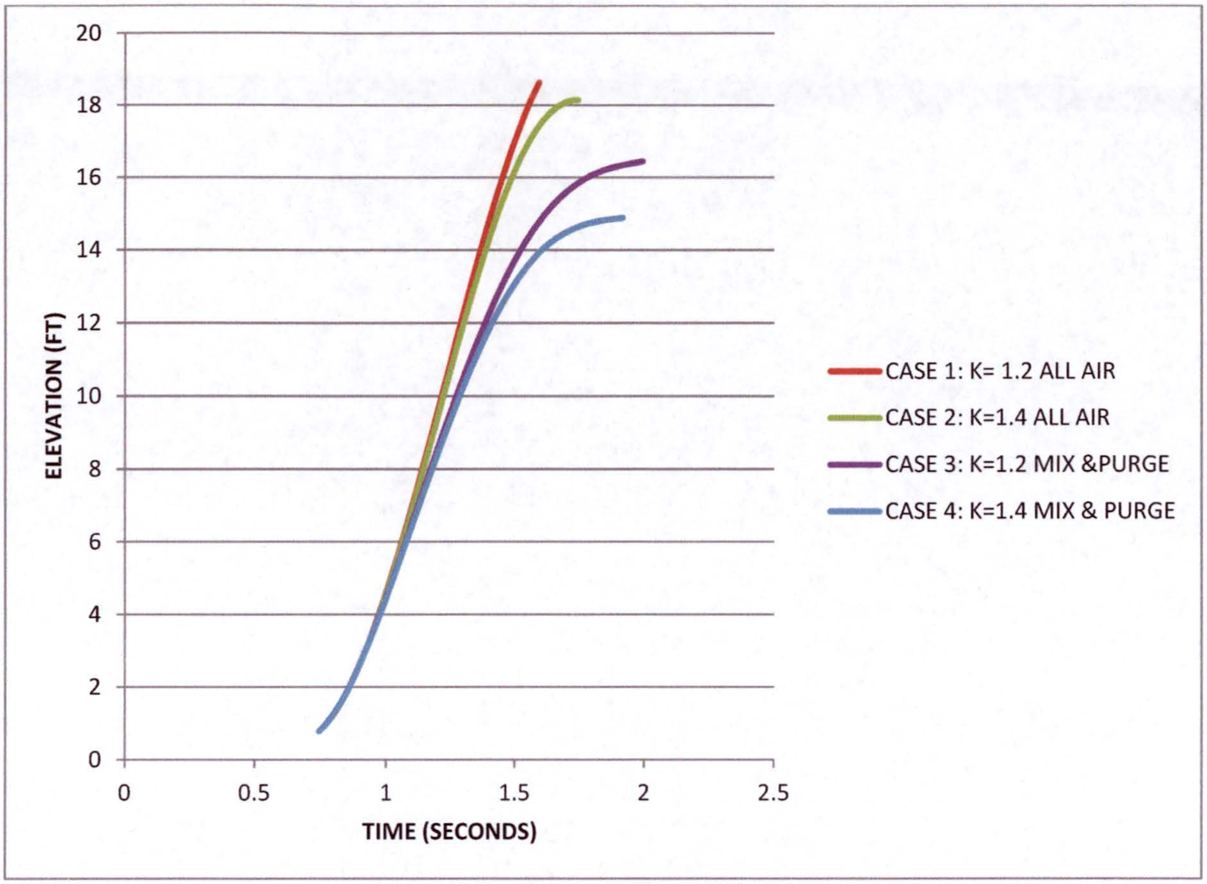

Figure 6-1: Pool Swell Elevation versus Time

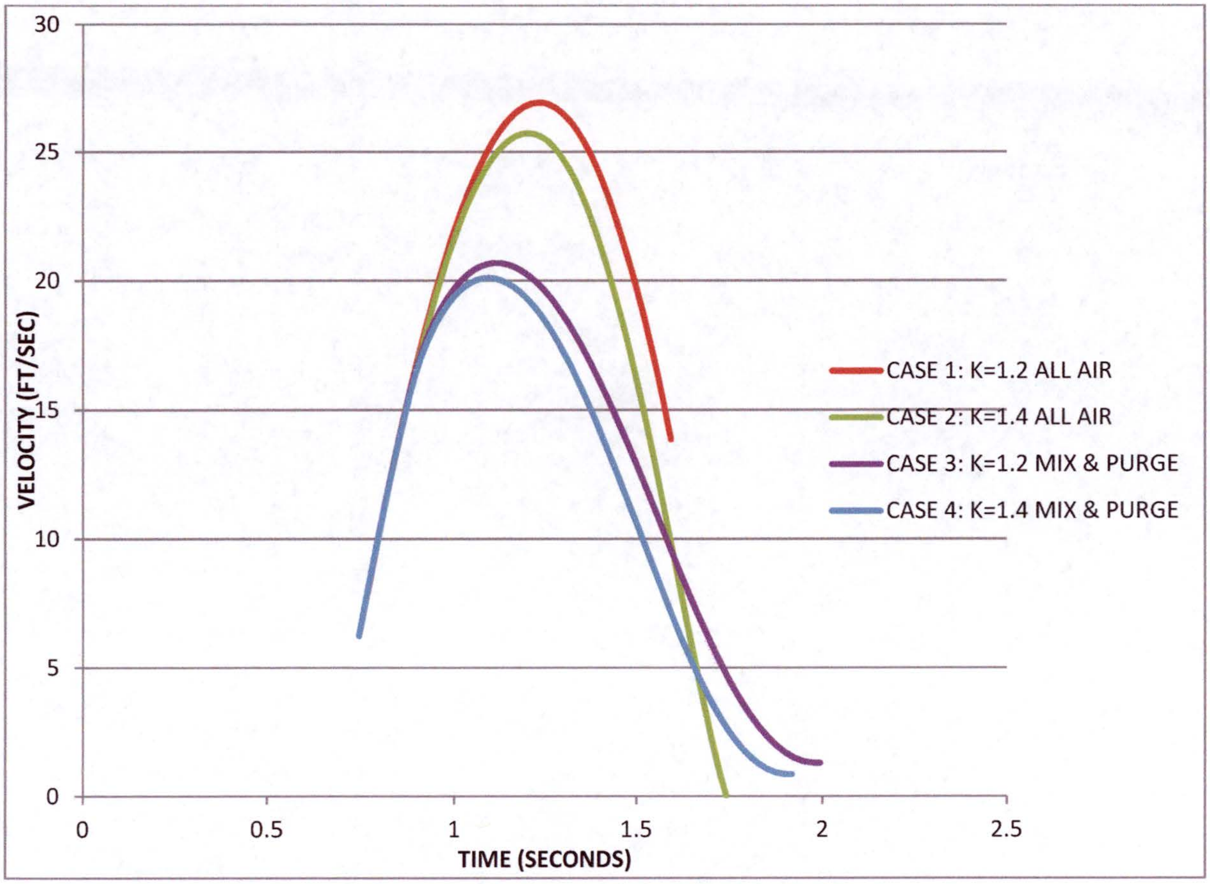

Figure 6-2: Pool Swell Velocity versus Time

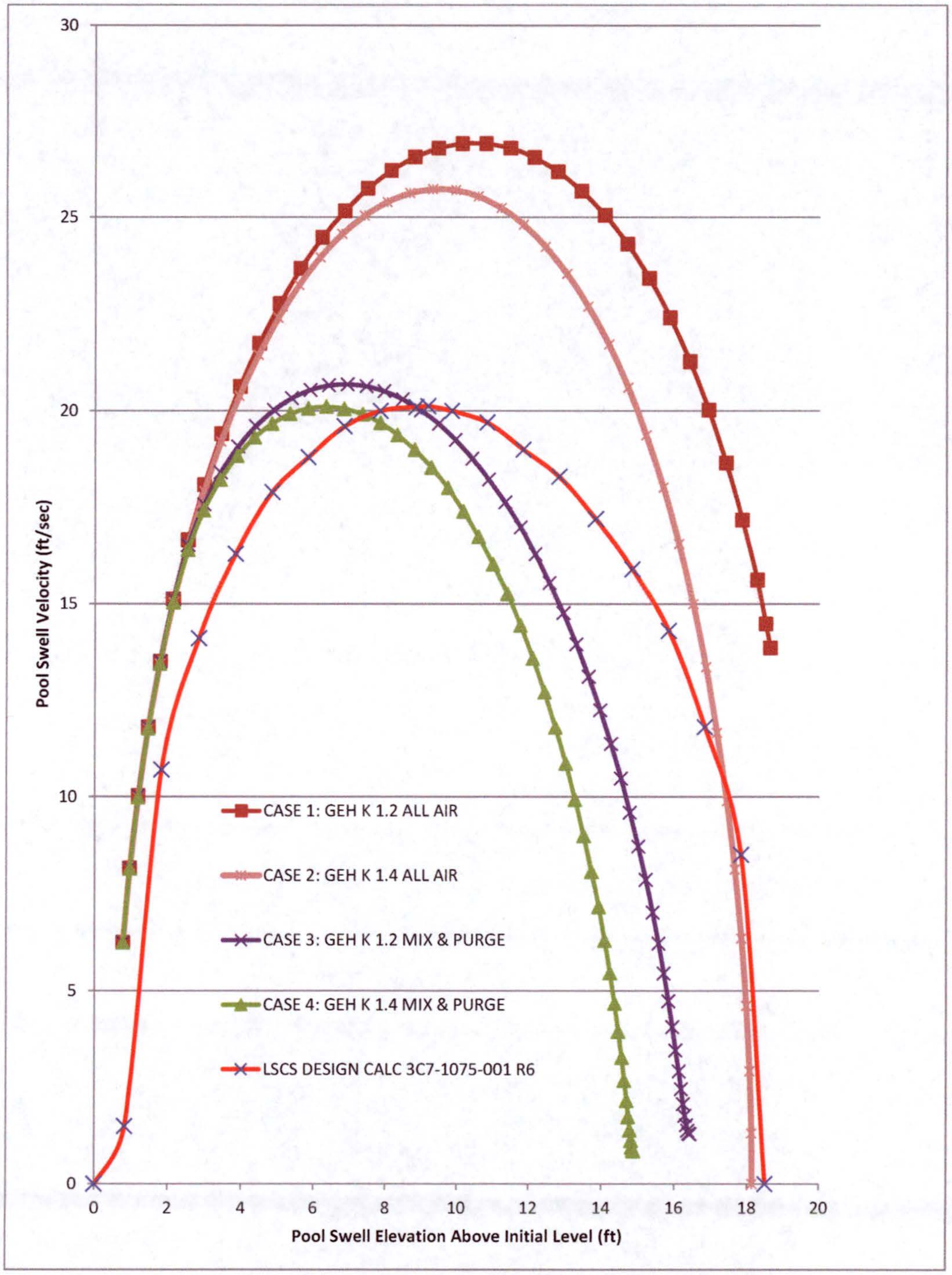

Figure 6-3: Pool Swell Velocity versus Elevation

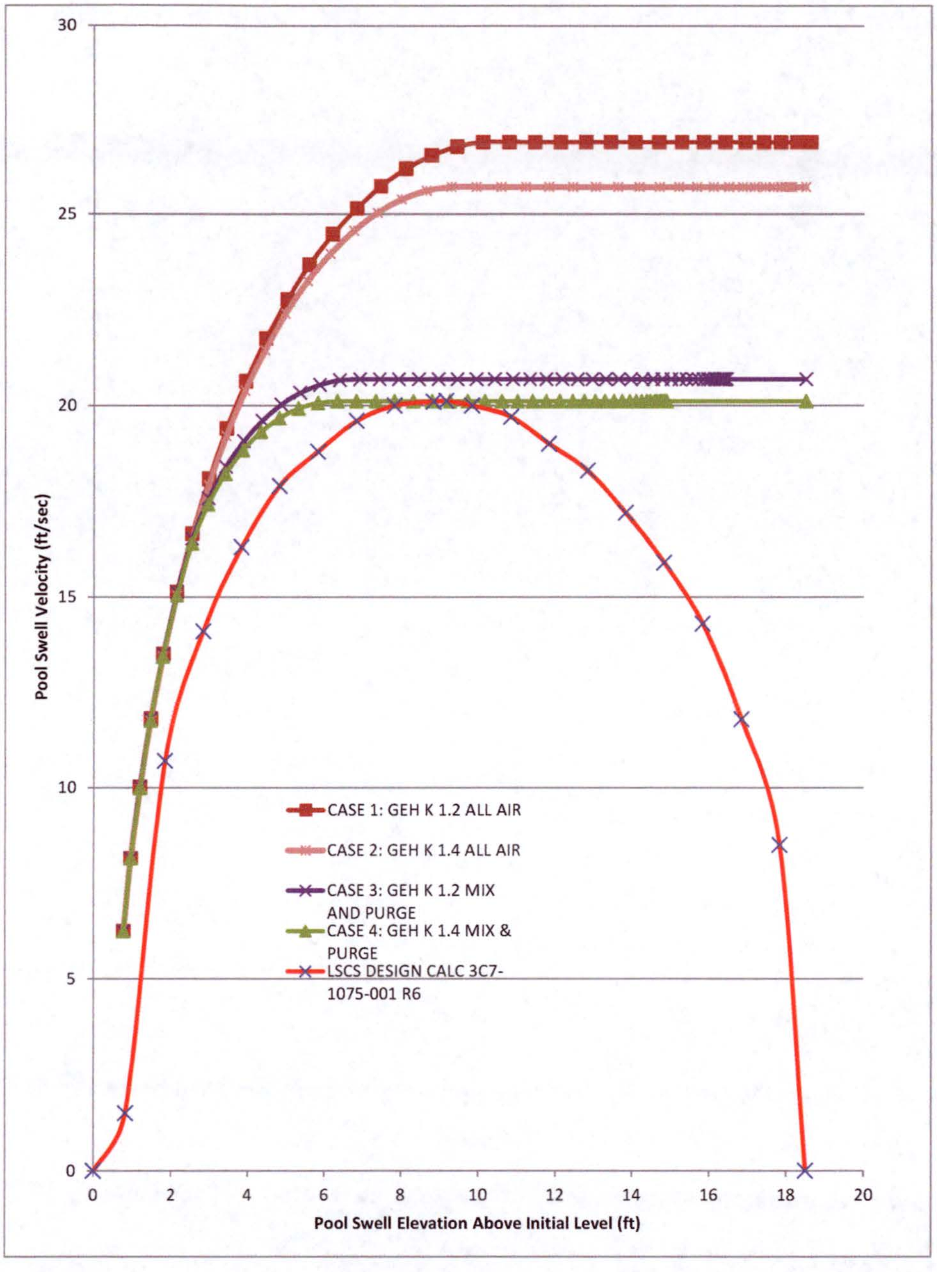

Figure 6-3A: Pool Swell Velocity versus Elevation (Velocity Held Constant at Maximum Velocity for Elevations Above Elevation of Maximum Calculated Velocity per NUREG-0808 Appendix C)

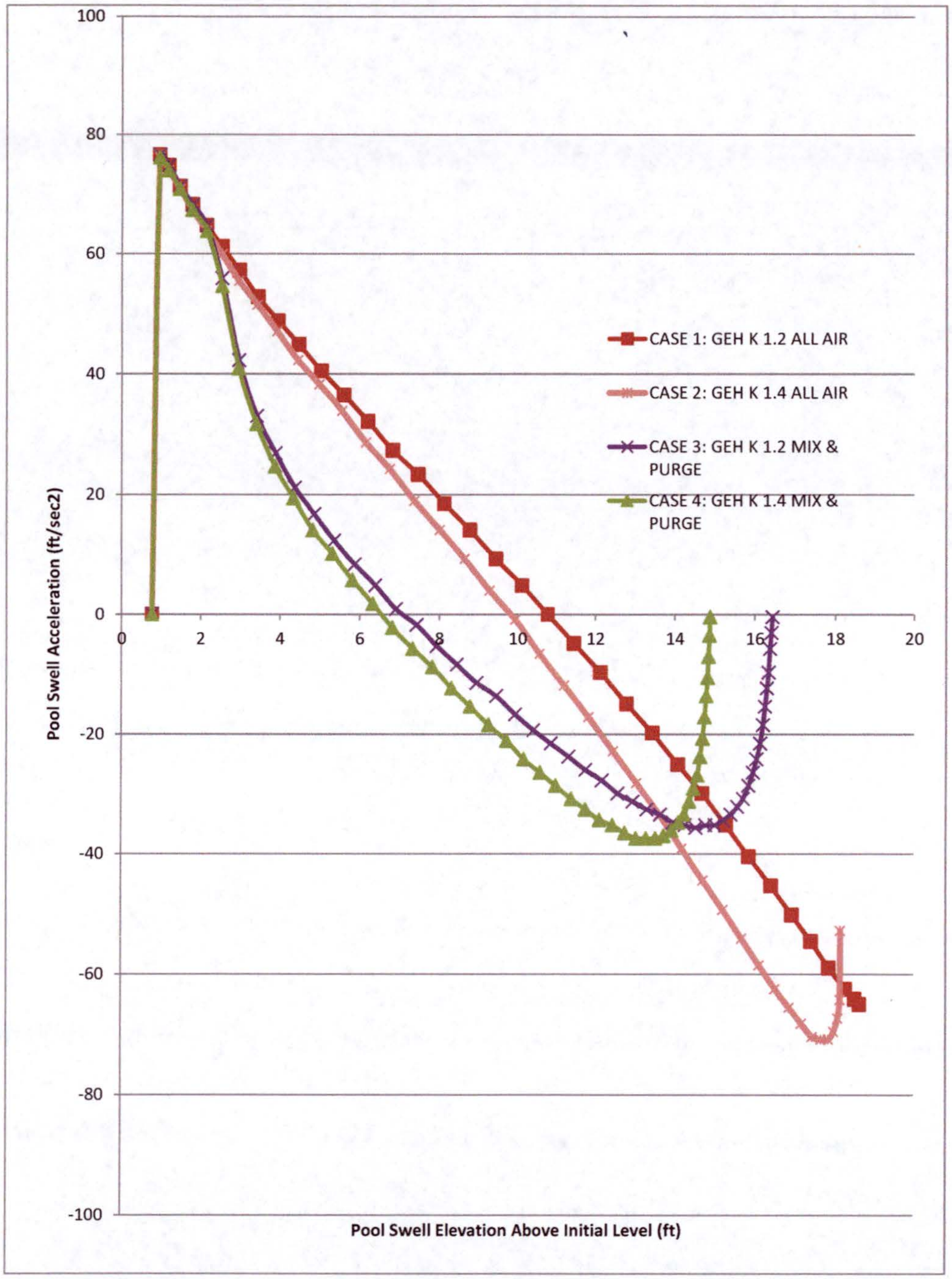

Figure 6-4: Pool Swell Acceleration versus Elevation

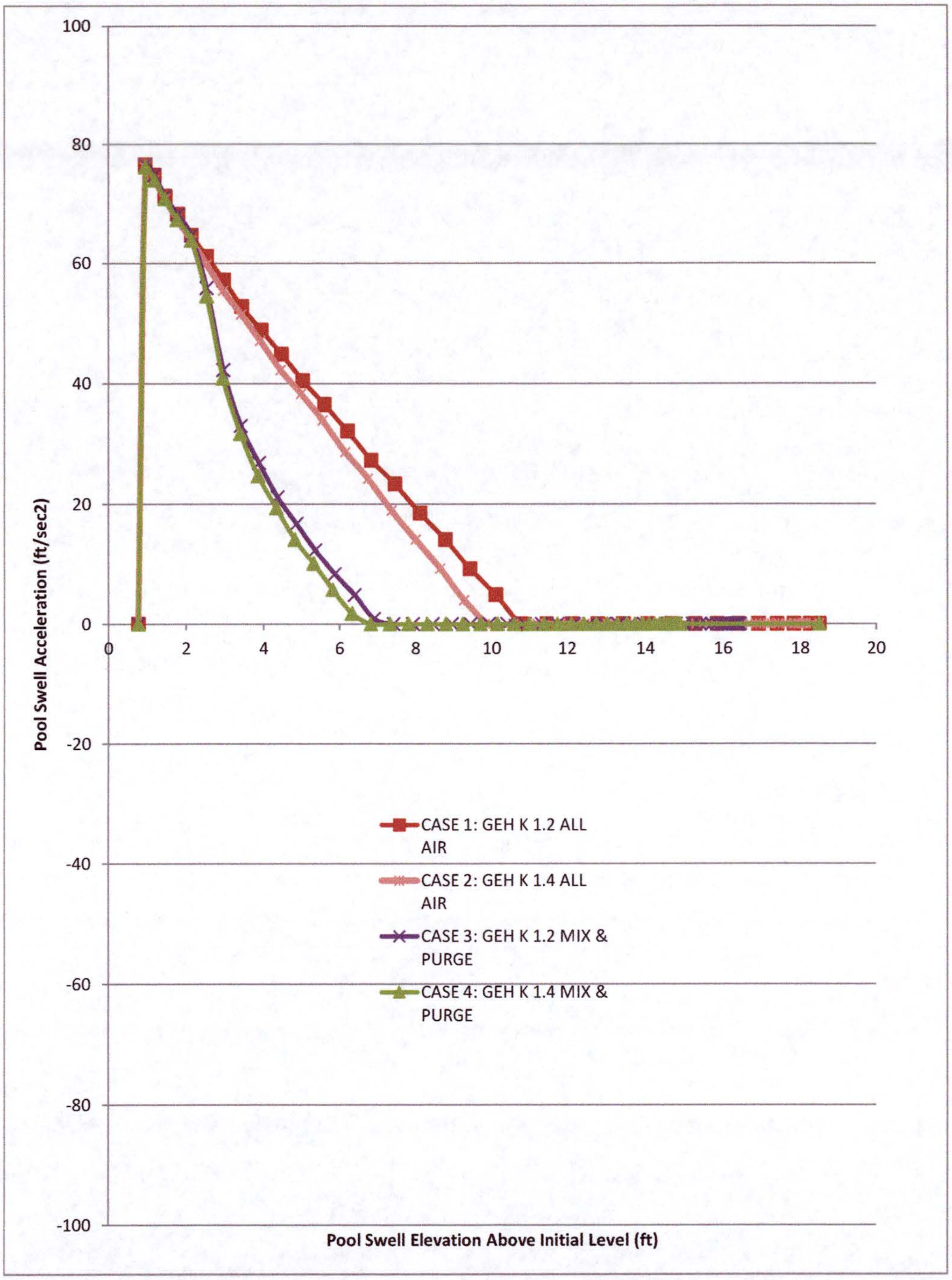

Figure 6-4A: Pool Swell Acceleration versus Elevation (Zero Acceleration for Elevations Above Elevation of Maximum Calculated Velocity, Consistent with Velocity Profile per NUREG-0808 Appendix C)

7.0 OBSERVATIONS

It is noted that the predicted RSLB DBA-LOCA DW pressure response prior to vent clearing, as shown on Figure 5-1, appears to be higher than the DW pressure history reportedly applied for the LCGS design basis pool swell analyses. The DW pressure history prior to vent clearing was not used for the pool swell response calculation. However, the DW pressure history prior to vent clearing can affect the loads defined for vent clearing (e.g., submerged structure drag loads due to expulsion of the liquid slug initially within the vent downcomer). Therefore, it is recommended that Exelon review the LCGS design basis for vent clearing loads to determine if the limiting DW pressure response prior to vent clearing, presented in Figure 5-1, is bounded by the DW pressure used to define the LCGS vent clearing loads.

The use of the mix and purge modeling (air/steam mixture) is considered a best estimate option as is identified in Reference 4. However, even with the use of this option there remains conservatism in the overall pool swell prediction results presented in this report. The TRACG calculations assume an instantaneous double ended guillotine break which maximizes the break flow during the critical initial period for pool swell. Additionally, the analysis reactor dome pressure of 1,040 psia is higher than the normal operating pressure of 1,020 psia and LCO of 1,035 psia and is being applied for the limiting TRACG case (Case A with RFWT) even though this case corresponds to an off-rated condition. The inherent conservatisms in the M3CPT model are retained for the calculation of the DW pressure response which is used in PICSM. Surface condensation of vapor on initially cold DW and vent downcomer surfaces is neglected. The constituents of the fluid flowing through the vents are based on a homogeneous mixture of the fluid in the DW. This assumption yields increased vent system flow density resulting in higher flow losses and therefore higher DW pressure. The mix and purge option as applied for the PICSM calculation uses a constant value for air fraction (= 0.61) for the transient analysis duration which corresponds to the air fraction in the DW at the time the air initially contained within the downcomer vents have been purged to the suppression pool (approximately 0.9 seconds). As shown in Figure 7-1, the DW air fraction after this time fall to values during the pool swell transient analysis period (to approximately 2 seconds) which are significantly lower than the constant value of 0.61 used for the PICSM calculation. The PICSM calculations use a polytropic coefficient of 1.2 which minimizes the WW airspace compression pressurization and thereby maximizes the predicted pool swell elevation and velocity. The drag effects of downcomer bracing on the bulk pool swell response is neglected in the PICSM pool swell response prediction. The inherent conservatism in the PICSM prediction, along with the use of the 1.1 multiplier, produces a conservative pool swell response prediction. When the 1.1 multiplier is applied to the PICSM predicted data shown in Figure 6.42 of Reference 4 (which is based on best estimate predictions of the Mark I 4T tests using the mix and purge option), persistent over prediction of the test data is demonstrated (see Figure 7-2). Similar trends in PICSM predicted results versus test data have been shown for predictions of the 1/13 scale Mark II multi-vent tests (Reference 11) cited in NUREG-0487 and the JAERI full scale multi-vent Mark II tests cited in NUREG-0808.

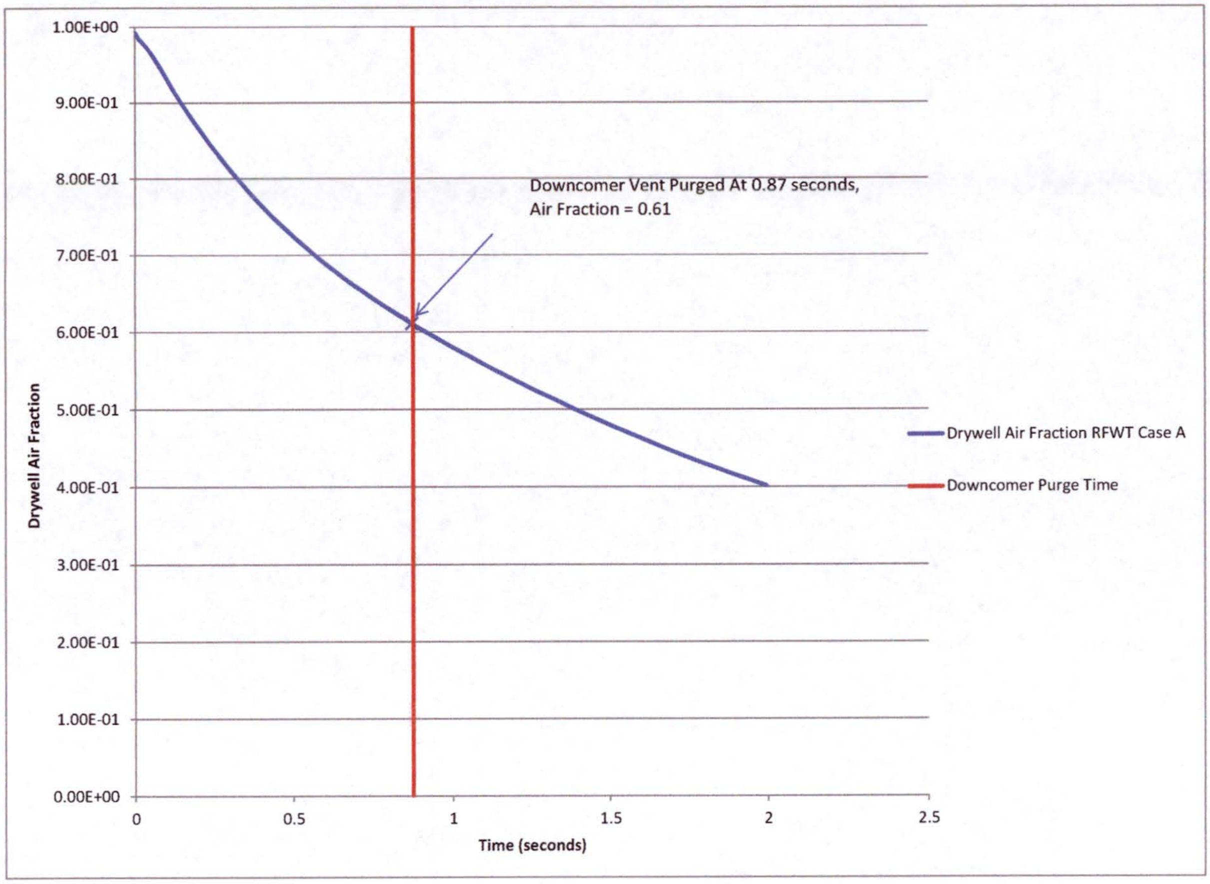

Figure 7-1: Drywell Air Fraction (Air Mass/(Air Mass + Steam Mass))

[[

]]

Figure 7-2: Comparison of Measured versus Predicted Maximum Pool Swell Velocity Based on Best Estimate of Mark II 4T Test Boundary Conditions

8.0 REFERENCES

1. GE Hitachi Nuclear Energy, "Safety Analysis Report for LaSalle County Station Units 1 and 2 Thermal Power Optimization," NEDC-33485P, Revision 0, January 2010.

2. General Electric Company, "The GE Pressure Suppression Containment Analytical Model," NEDM-10320, March 1971.

3. GE Nuclear Energy, "The General Electric Mark III Pressure Suppression Containment System Analytical Model," NEDO-20533, June 1974.

4. GE Nuclear Energy, "Mark II Pressure Suppression Containment Systems: An Analytical Model of the Pool Swell Phenomenon," NEDE-21544-P, December 1976.

5. NUREG-0487, Supplement 1, "Mark II Containment Lead Plant Program Load Evaluation and Acceptance Criteria," September 1980 and NUREG-0487, "Mark II Containment Lead Plant Program Load Evaluation and Acceptance Criteria," October 1978,

6. NUREG-0808, "Mark II Containment Program Load Evaluation and Acceptance Criteria," August 1981

7. GE Hitachi Nuclear Energy, "TRACG Qualification," NEDE-32177P, Revision 3, August 2007.

8. General Electric Company, "General Electric Company Analytical Model for Loss-of-Coolant Analysis in Accordance with 10CFR50 Appendix K," NEDE-20566-P-A, September 1986.

9. GE Hitachi Nuclear Energy, "TRACG Model Description," NEDE-32176P, Revision 4, January 2008.

10. GE Hitachi Nuclear Energy, "Exelon Nuclear, LaSalle County Generating Station Units 1 & 2 Short-Term Containment Bounding Pa Assessment," 0000-0149-2311-R0, August 2012.

11. General Electric Company, "Comparison of the 1/13 Scale Mark II Containment Multi-Vent Pool Swell Data with Analytical Methods," NEDO-21667, August 1977.

APPENDIX A - KEY INPUT PARAMETERS FOR DRYWELL PRESSURE AND POOL SWELL RESPONSE ANALYSIS

Item No.	Parameter	Value
1.0	**CONTAINMENT GEOMETRY PARAMETERS**	
1.a.	DW Volume (ft^3)	229,538
1.b.	WW Airspace Volume at Suppression Pool HWL (ft^3)	164,800
1.c.	Initial Suppression Pool Volume at HWL (ft^3)	131,900
1.d.	Suppression Pool Surface in Contact with WW Airspace (ft^2)	4,999
1.e.	Suppression Pool Depth at HWL (ft)	26.813
1.f.	Vent Submergence at Suppression Pool HWL (ft)	12.333
1.g.	Number of Downcomers	98
1.h.	Downcomer Inner Diameter (ft)	1.958
1.i.	Vent Loss Coefficient	5.2
1.j.	Total Vent Downcomer Length from Entrance Above DW Floor to Submerged Vent Dowcomer Exit in Suppression Pool (ft)	49.29
2.0	**INITIAL CONDITIONS**	
2.a.	Initial DW Temperature (°F)	98
2.b.	Initial DW Pressure (psia)	15.45
2.c.	Initial DW Relative Humidity (%)	20
2.d.	Initial WW Airspace Temperature (°F)	105
2.e.	Initial Suppression Pool (SP) Temperature (°F)	105
2.f.	Initial WW Pressure (psia)	15.45
2.g.	Initial WW Relative Humidity (%)	100
3.0	**LOCA BUBBLE VENT BACK PRESSURE**	
3.a.	LOCA Bubble Vent Back Pressure Effect Modeled	No (See discussion in Section 5)
4.0	**ADDITIONAL PICSM SPECIFIC MODELING PARAMETERS**	

Item No.	Parameter	Value
4.a.	Vent Flow Air Fraction	Results are Presented with All Air and Mix and Purge Option. (See discussion in Section 6)
4.b.	Specific Heat Ratio (Polytropic Coefficient) for PICSM WWAirspace Compression Calculation	Results are Presented with Isentropic Coefficient of 1.4 (air) and Polytropic Coefficient of 1.2. (See discussion in Section 6)
4.c.	Bubble Temperature Specification Option	Set Equal to Current Calculated DW Temperature.
4.d.	Specific Heat Ratio for Compressible Vent Flow Calculation	Isentropic Coefficient of 1.4 for Air Used. (See discussion in Section 6)
4.e.	Vent Loss Coefficient	5.2
4.f.	Multiplier on Pool Swell Velocity	1.1 (See discussion in Section 6)