LTR-NRC-09-43 NP-Enclosure

"NRC Containment Audit – Hydrodynamic Loads – Pool Swell STP 3&4 COLA"

August 2009

Westinghouse Electric Company LLC
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NRC Containment Audit
Hydrodynamic Loads – Pool Swell
STP 3&4 COLA

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August 18, 2009

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Westinghouse

Introduction

Agenda

- Introduction
- Attendees
- Desired Outcomes
- GOTHIC vs. DCD Model - Comparison
- Pool Swell Test Data
- Comparison with Test Data and DCD Results
- ABWR Analysis and Sensitivity Studies
- Pool Swell Load Application
- Topical Report
- Response to Informal Questions

Introduction

STP Team Attendees

• Scott Head	STPNOC
• Jim Tomkins	STPNOC
• Aaron Heinrich	STPNOC
• Brad Maurer	Westinghouse
• Nirmal Jain	Westinghouse
• Rick Ofstun	Westinghouse
• Jason Douglass	Westinghouse
• Tom George	NAI
• Hirohide Oikawa	Toshiba
• Koichi Kondo	TANE

Introduction

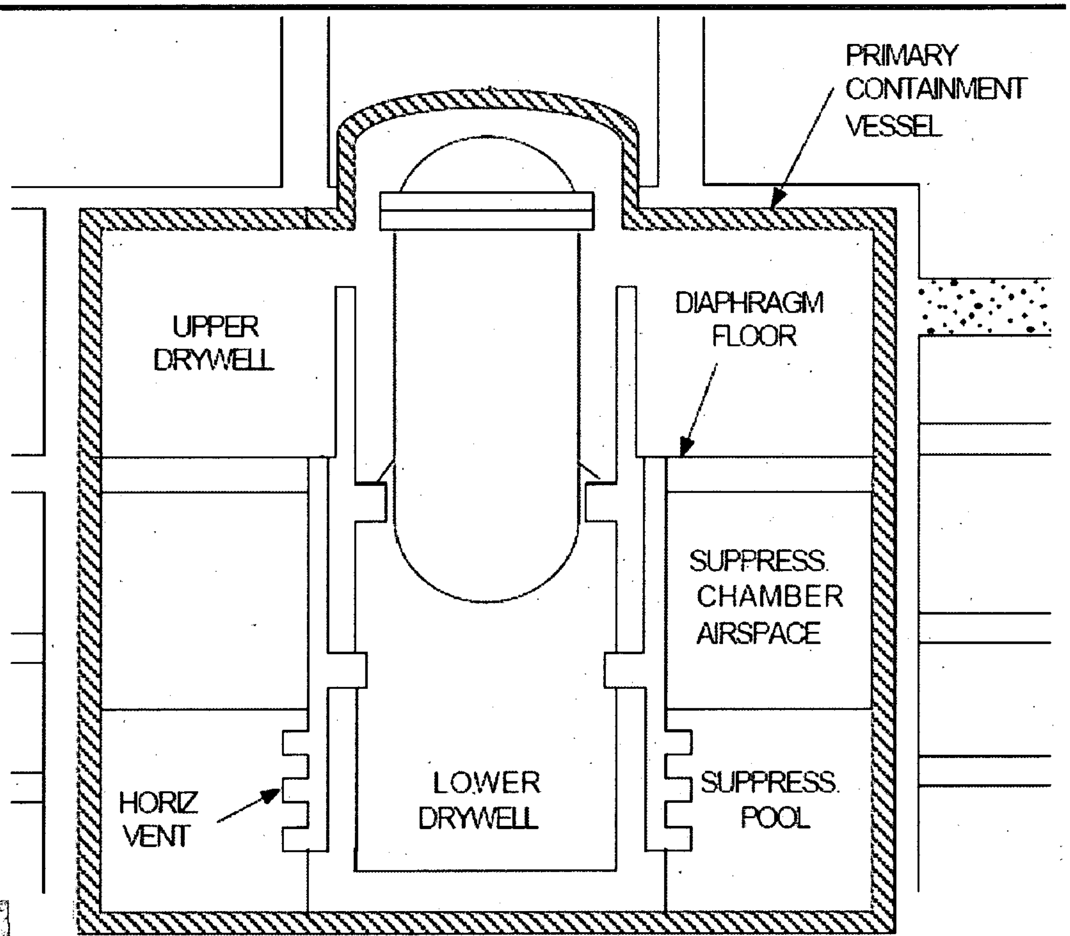
Desired Outcomes

- Provide better understanding of related test (PSTF)
- Provide an update of comparisons with tests and DCD, and ABWR analysis
- Address the items raised by NRC at July 7 P/T Audit
  - Drawing showing equipment in wetwell airspace
  - Methodology for calculating equipment loads
  - Uncertainty in pool swell results
  - Table comparing Input differences for P/T and Pool Swell
- Provide information on the load application procedure and the scope content of the pool swell topical report
- Receive feedback from NRC

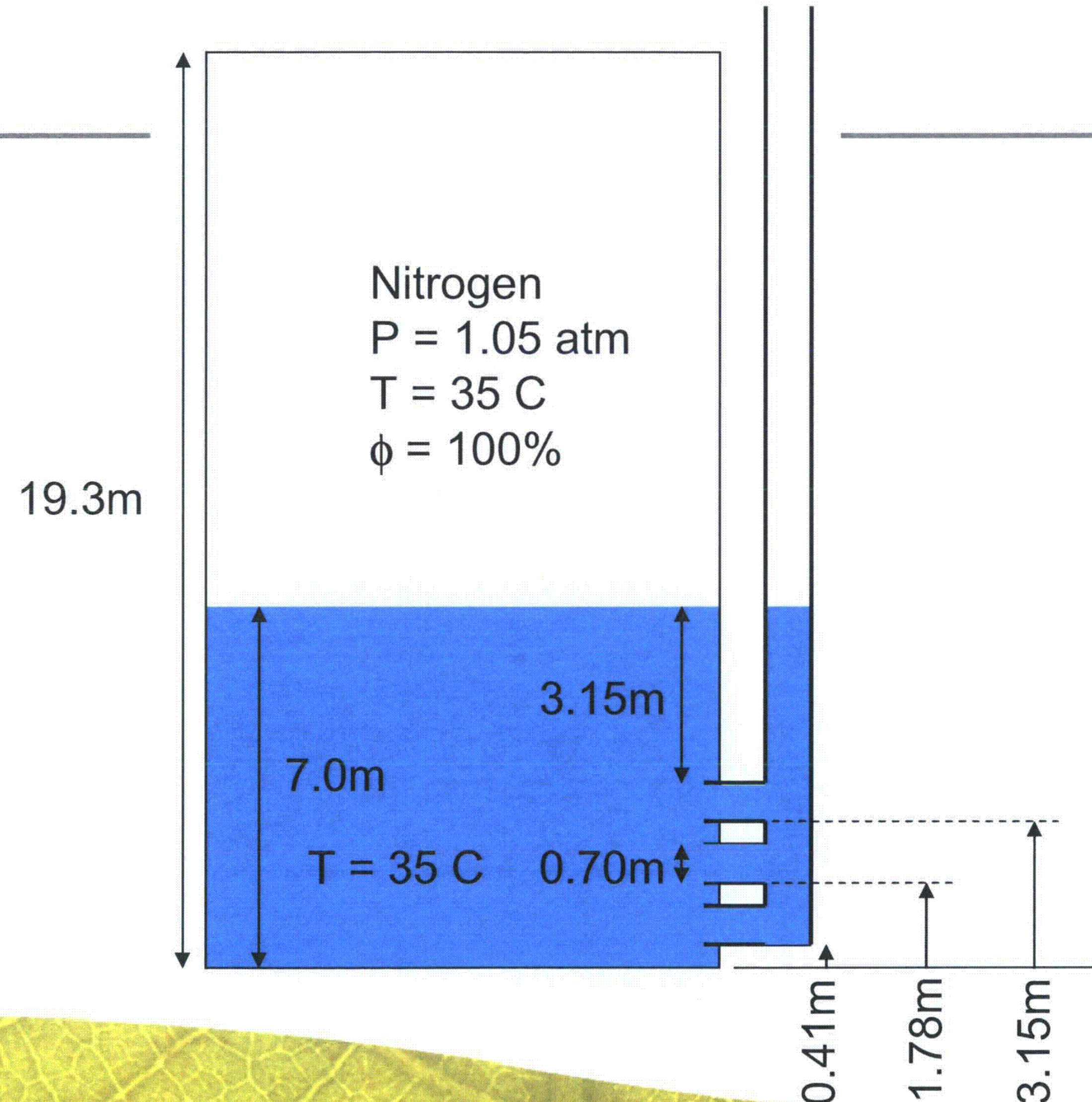
Analysis Approach

- Develop GOTHIC modeling approach for conservative estimates of
  - Maximum swell height
  - Maximum pool velocity
  - Peak gas space pressure during swell
  - Peak bubble pressure during swell
- Results comparison with
  - PSTF 1/3 Scale Test
  - ABWR DCD
  - NEDO-33372
- Results for ABWR design
- Application of Pool Swell Results for Structural Loads Analysis

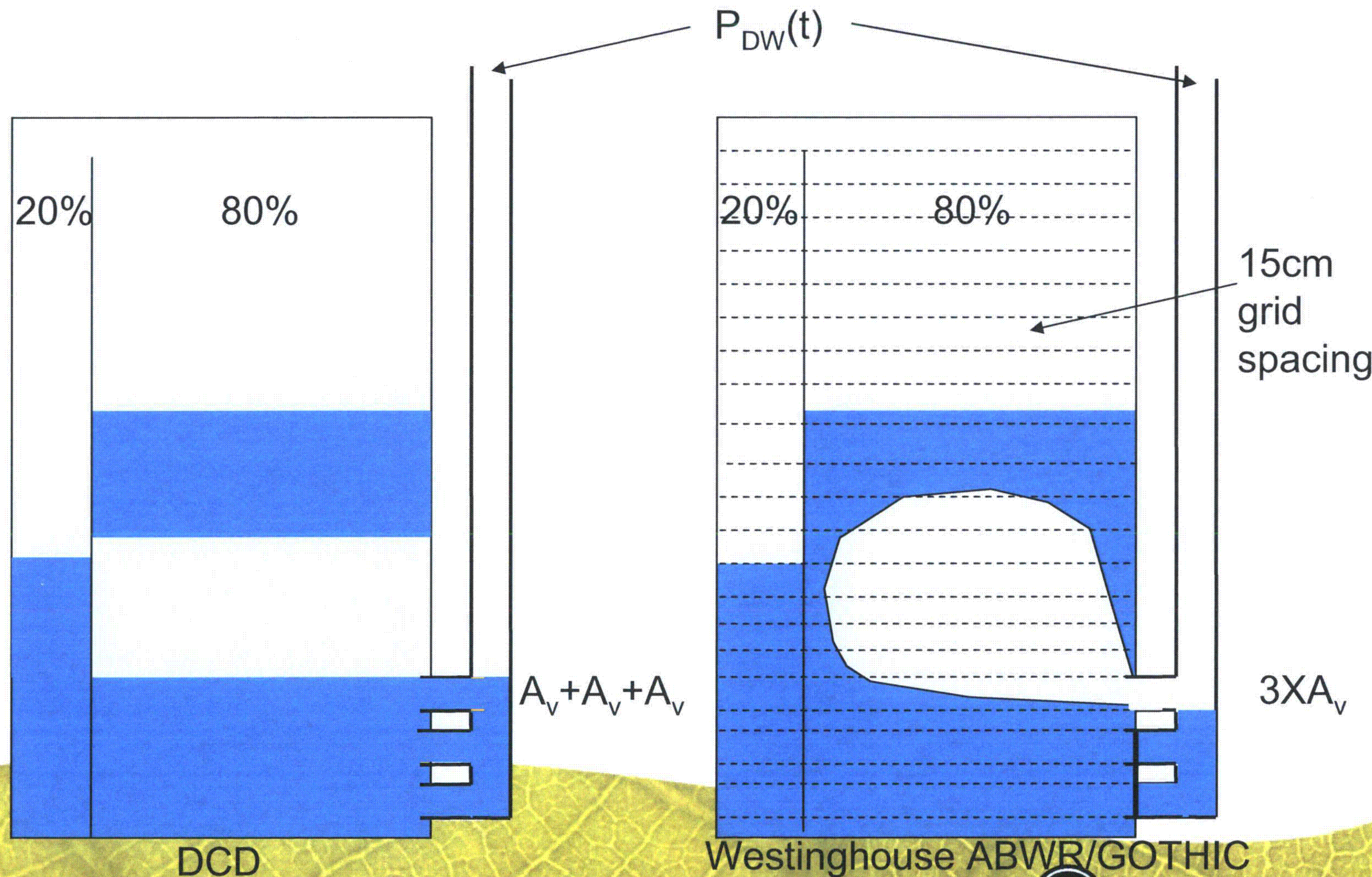
ABWR Containment



ABWR Wetwell Geometry



Approach Comparison



Approach Comparison

	DCD	ABWR/GOTHIC
Initial water in vertical and horizontal vent pipes	Ignored	Included. Vent clearing modeled.
Vent location	Gas injected at elevation of top of top vent	Gas injected at actual elevation of top vent
Vent area	Sequential addition of vents	All vents located at the top vent
Injection Pressure	Drywell pressure transient	Drywell pressure transient

Approach Comparison

	DCD	ABWR/GOTHIC
Injection Composition	100% N_2 – perfect gas	100% N_2 – perfect gas
Injection Temperature	$T_{Drywell}$ from isentropic compression	GOTHIC calculated DW temperature transient
Vent Path Pressure Loss	Friction	Ignored
Vent Choking	Unclear	Included

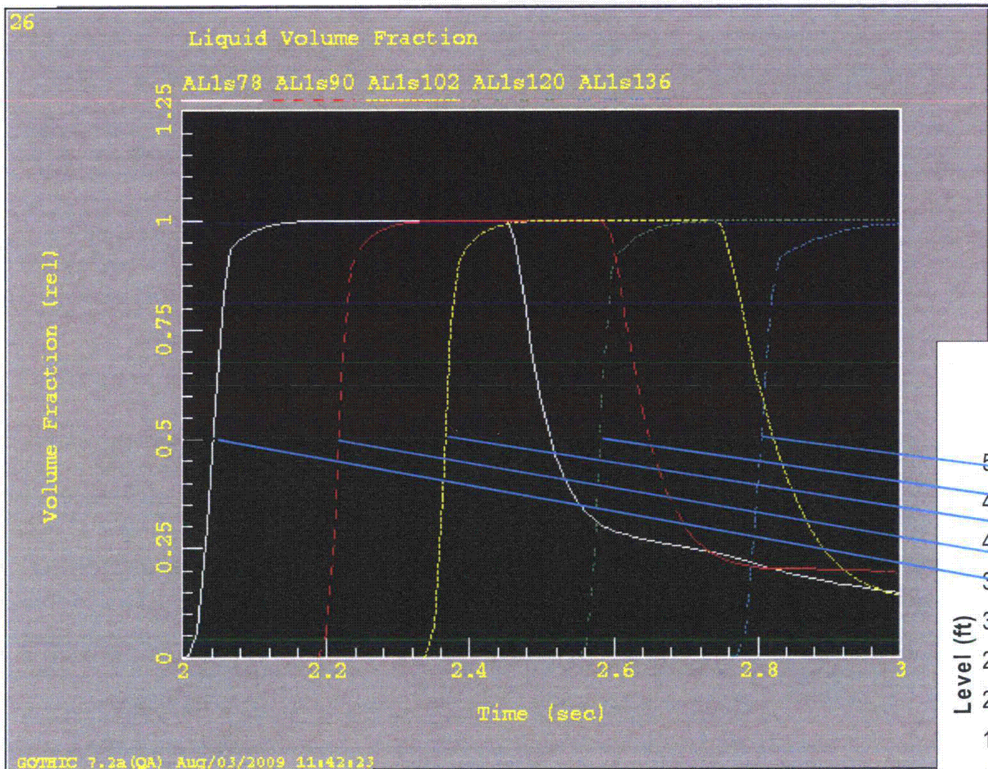
Approach Comparison

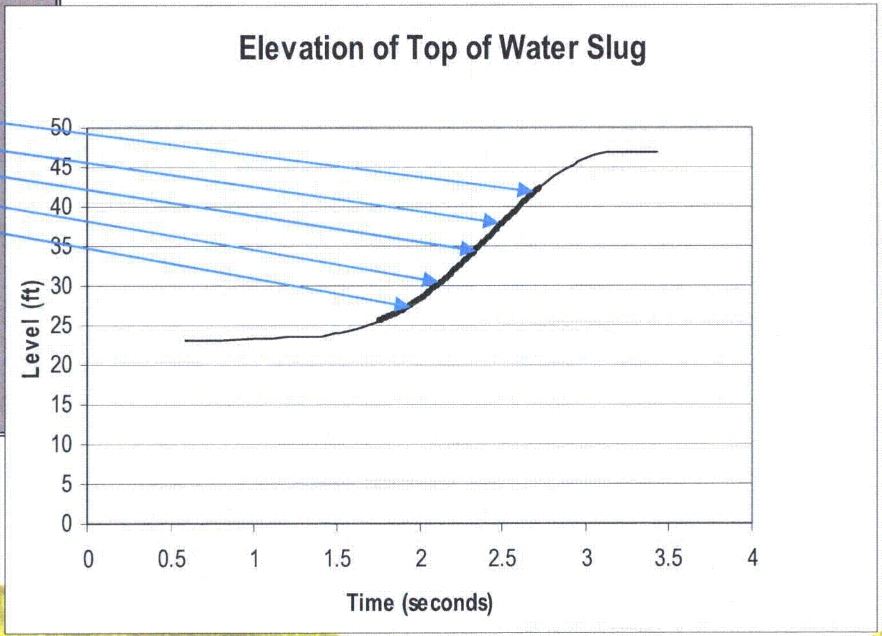
	DCD	ABWR/GOTHIC
Gas Temperature in Bubble	Drywell temperature	Near pool temperature
Pool swell drag	Ignored	Ignored
Gas Temperature above Pool – Maximum Swell	Polytropic compression - PV^k=const (k=1.2)	Near isothermal compression
Gas Temperature above Pool – Maximum Pressure	Isentropic compression - PV^k=const (k=1.4)	Near isentropic compression

Approach Comparison

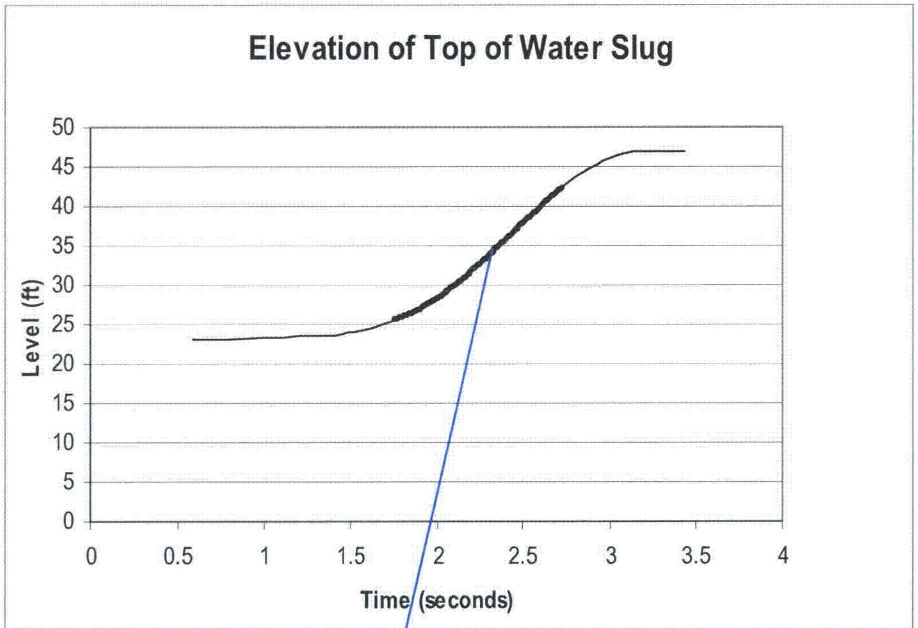
	DCD	ABWR/GOTHIC
Pool swell region	80% of wetwell	80% of wetwell (a,c)
Rising water slug	Constant thickness	[ ]
Conservative multiplier on maximum swell velocity	1.1	1.1

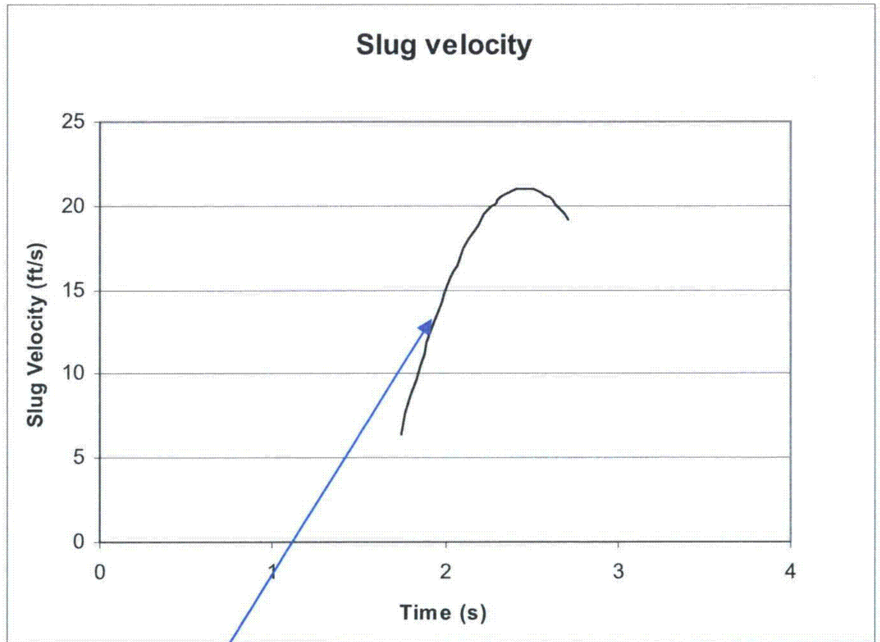
GOTHIC Pool Surface Detection





Pool Surface Velocity





$$Z = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

$$u = \frac{dZ}{dt}$$

Class 1

NRC Containment Audit for STP 3&4 COLA

Pool Swell Test Data

August 18, 2009

Outline

Class 1

- Pressure suppression test facility (PSTF) description
- Test matrix
- Test case used for GOTHIC benchmark

PSTF Test

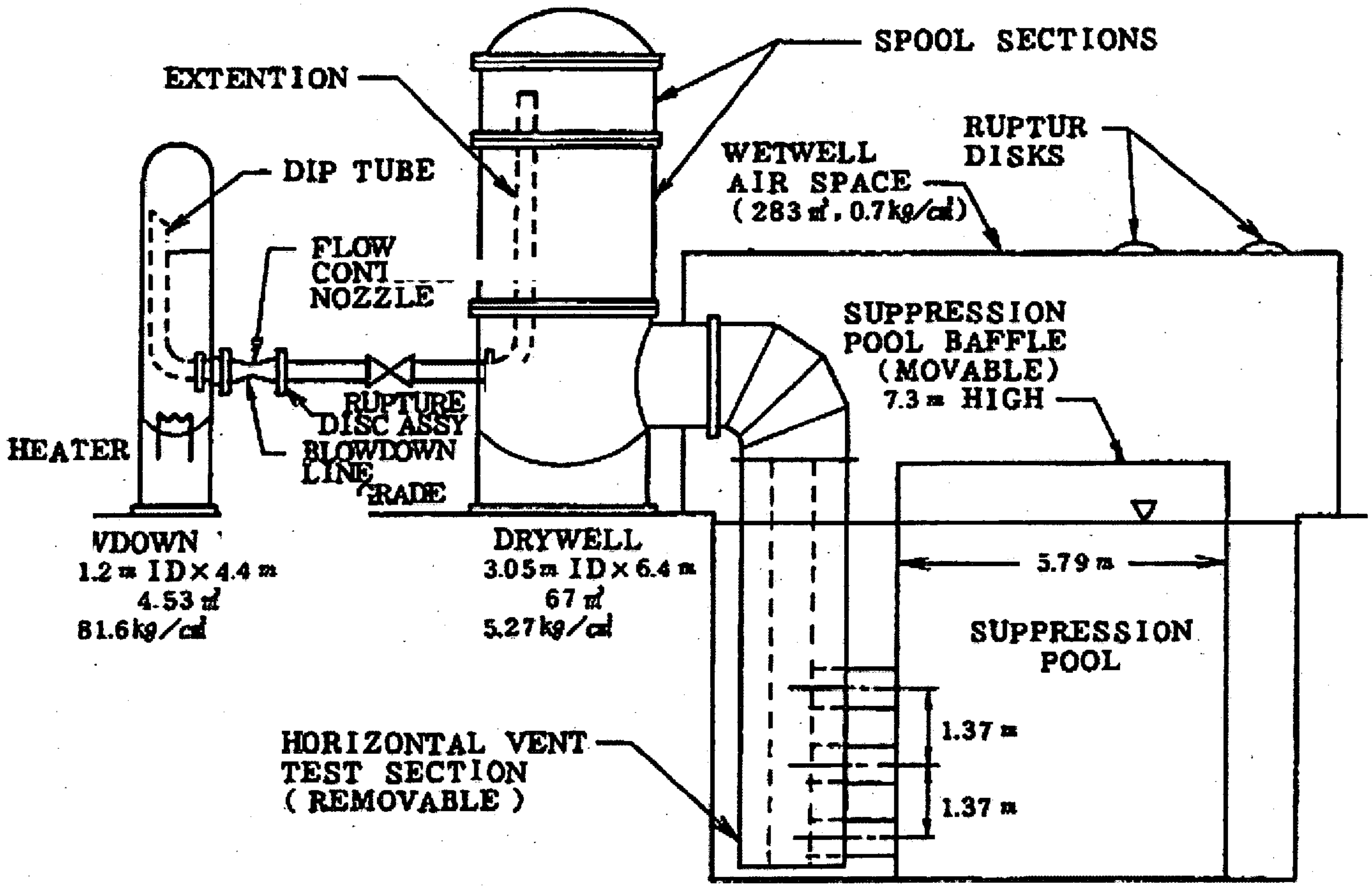
Class 1

- Pressure suppression test facility (PSTF)
  - Confirmatory test by GE (San Jose, CA)
  - Simulates Mark-III containment with horizontal vent configuration
  - LOCA related hydrodynamic loads (pool swell, CO and chugging)
- Configuration
  - 1/135 (vol.) of BWR/6 Mark-III containment
  - Test section scale : Full, 1/3, 1/9 (area)
- Test results
  - Drywell and wetwell pressurization
  - Vent clearing
  - Pool swell
  - Condensation oscillation
  - Chugging

Pressure Suppression Test Facility (PSTF)

Class 1

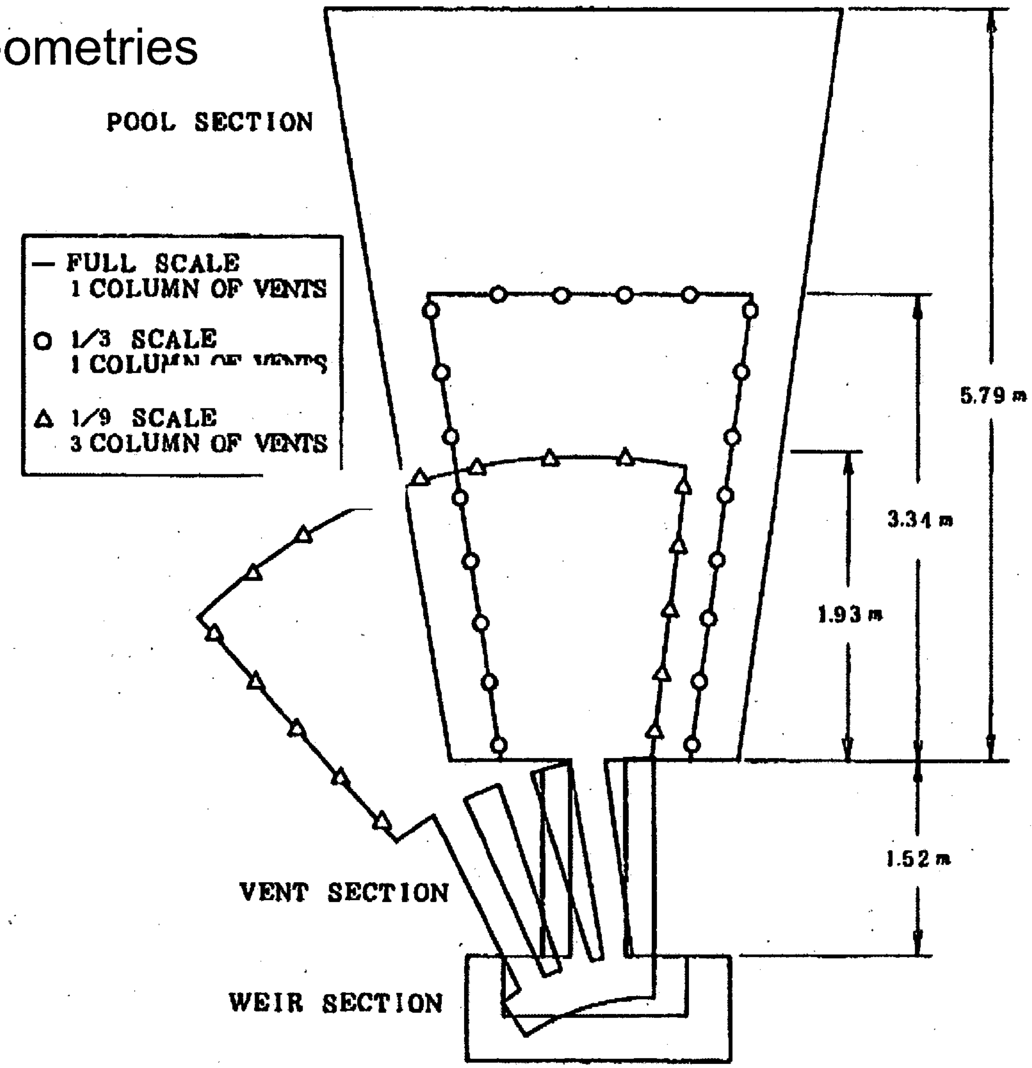
Pool Swell Test Facility



Pressure Suppression Test Facility (PSTF)

Class 1

Wetwell Geometries



PSTF (Instrumentation)

Class 1

PSTF Scaling

Class 1

	Mk-III	Full Scale (Run 5700)	1/3 (Run 5800)	1/9 (Run 6000)
Boiler	1	1 / 132	1 / 132	1 / 132
Break Area	1	1 / 130	1 / 130	1 / 130
DW Volume	1	1 / 128	1 / 128	1 / 128
Vent Area	1	1 / 45	1 / 135	1 / 138
Pool Area	1	1 / 46	1 / 134	1 / 135
WW Volume	1	1 / 112	1 / 112	1 / 112

PSTF Test Matrix

Class 1

Scale	Test Series	Test Cases	Venturi Size (in)	Blowdown	Vent Row	Submergence (ft @CL)	Objectives
Full	5701	21	2' 1/8" ~ 3' 5/8"	Sat. Steam	1	2 ~ 15.5	Vent Clearing Demonstration Drywell Pressure
	5702	17	2' 1/8" ~ 3' 5/8"	Sat. Steam	2	1.93 ~ 11.97	Vent Clearing
	5703	3	2' 1/2" ~ 3' 5/8"	Sat. Steam	3	6.77 ~ 11.05	Vent Clearing
	5705	4	1 ~ 4' 1/4"	Air	2	6 ~ 8	Pool Swell (Scoping)
	5706	7	4' 1/4"	Air	2	6 ~ 10	Pool Swell Impact Load
	5707	22	2' 1/8" ~ 3	Sat. Steam	3	7.5	Chugging
1/3	5801	19	2' 1/8" ~ 3	Sat. Steam	3	5 ~ 10	Demonstration Pool Swell Roof dP
	5802	3	2' 1/8" ~ 3	Sat. Steam	3	6	Pool Swell
	5803	2	2' 1/8" ~ 3	Sat. Liquid	3	5 ~ 7.5	Demonstration Liquid Blowdown
	5804	5	2' 1/8" ~ 3	Sat. Steam	3	5	Roof dP (repeat)
	5805	52	1 ~ 3	Sat. Steam	3	5 ~ 10	Pool Swell (Impact)
	5806	12	2' 1/2" ~ 4' 1/4"	Air	3	5 ~ 7.5	Pool Swell
	5807	20	1 ~ 3	Sat. Steam and Liquid	3	7.5	Steam Condensation
1/9	6002	14	2' 1/8" ~ 3	Steam	9	5 ~ 10	Pool Swell (Multi Vent)
	6003	12	2' 1/2"	Steam	9	7.5	Steam Condensation (Multi Vent)

Case Selection for Benchmark

Class 1

- Series 5800 (1/3 area scale) is "best balanced"
  - Consistent scale (RPV / DW / vent / WW)
  - Smaller configuration (1/9 scale) behaves more 1D like
- Runs 5806 provide representative pool swell data
  - Large steam line break
  - (Pool width / submergence) ratio is close to ABWR
- Data availability
  - Various measurements (swell velocity, slug thickness etc.)
  - 3D information (bubble and pool surface shape)
- NRC adopted 5800 series for pool swell evaluation basis

Bubble and Pool Surface Shape

Class 1

Pool Swell Level and Velocity

Class 1

Summary

Class 1

■ PSTF test outline

- The only test of pool swell in horizontal vent configuration
- Test facility configuration and test matrix were summarized

■ Test case selected for GOTHIC benchmark

- 1/3 scale series (pool swell runs)
- Scaling balance (vol.-area scale, pool aspect ratio)
- Data availability

Comparison with Test Data and DCD Results

- PSTF (Pressure Suppression Test Facility)
  - 1/3 Scale Test
- DCD

PSTF Comparison

- Test Run 5806
  - 1/3 Scale
  - 3 Vents
  - Compressed Air Injection
  - Primary Objective – Pool Swell
  - 5.0 – 7.5 feet top vent submergence
    - Selected Case – 5.0 feet submergence
- 1/3 Scale tests have closest overall scaling to prototypic conditions
  - Pool and vent aspect ratios better matched in full scale tests.

GOTHIC Results for PSTF 5806-1 Pool Swell

(a,b,c)

[ ]

GOTHIC Results for PSTF 5806-1 Pool Surface Velocity

(a,b,c)

GOTHIC Results for PSTF 5806-1 Slug Thickness

(a,b,c)

[ ]

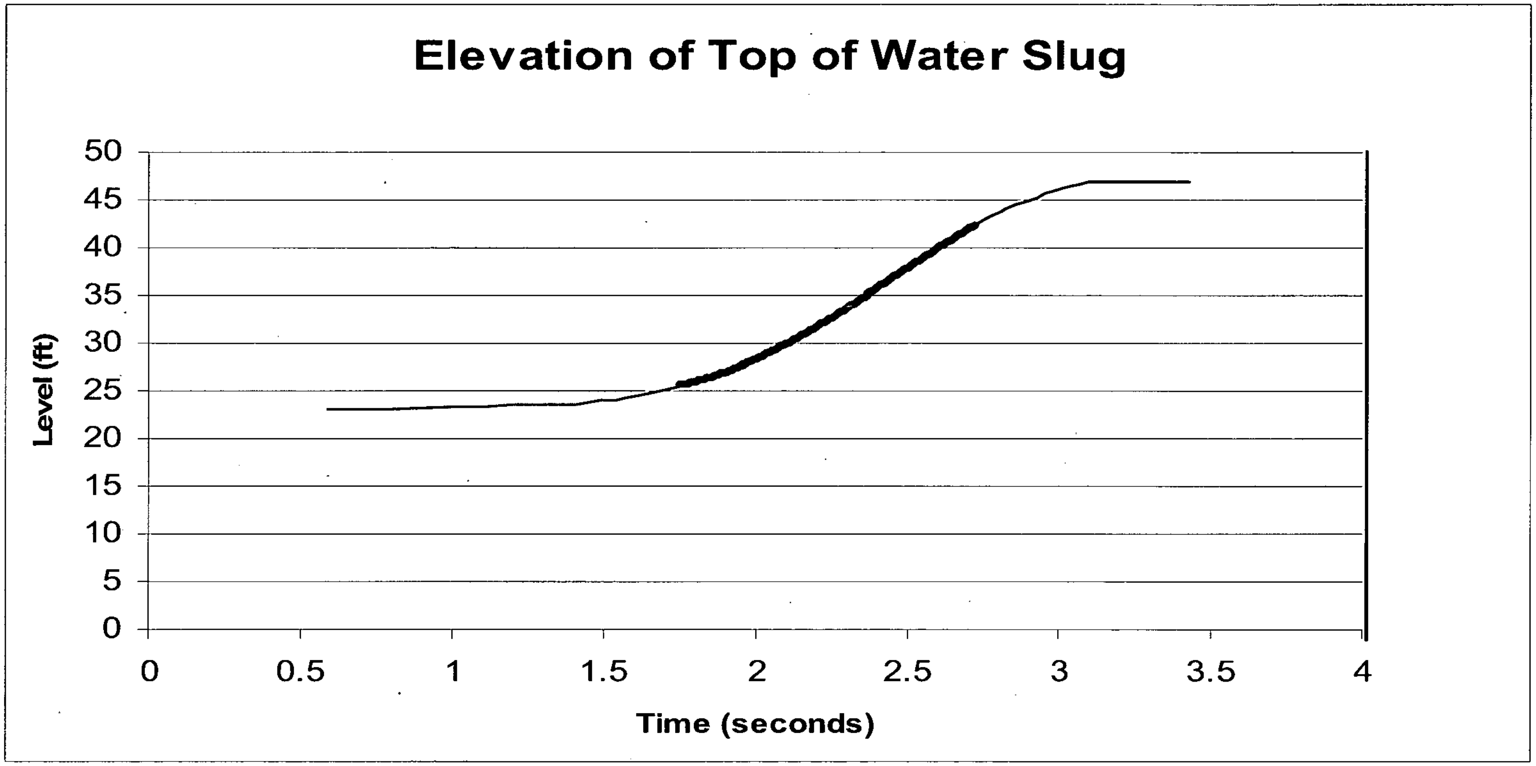
GOTHIC Results for PSTF 5806-1

- GOTHIC modeling approach bounds surface elevation transient and surface velocity transient.
- Model allows some thinning of rising slug but less than indicated by test.
- Due to open gas space, 80% pool area has minimal impact on results.
- Vent Clearing Time
  - Measured 0.8 seconds
  - Simulation 0.7 seconds

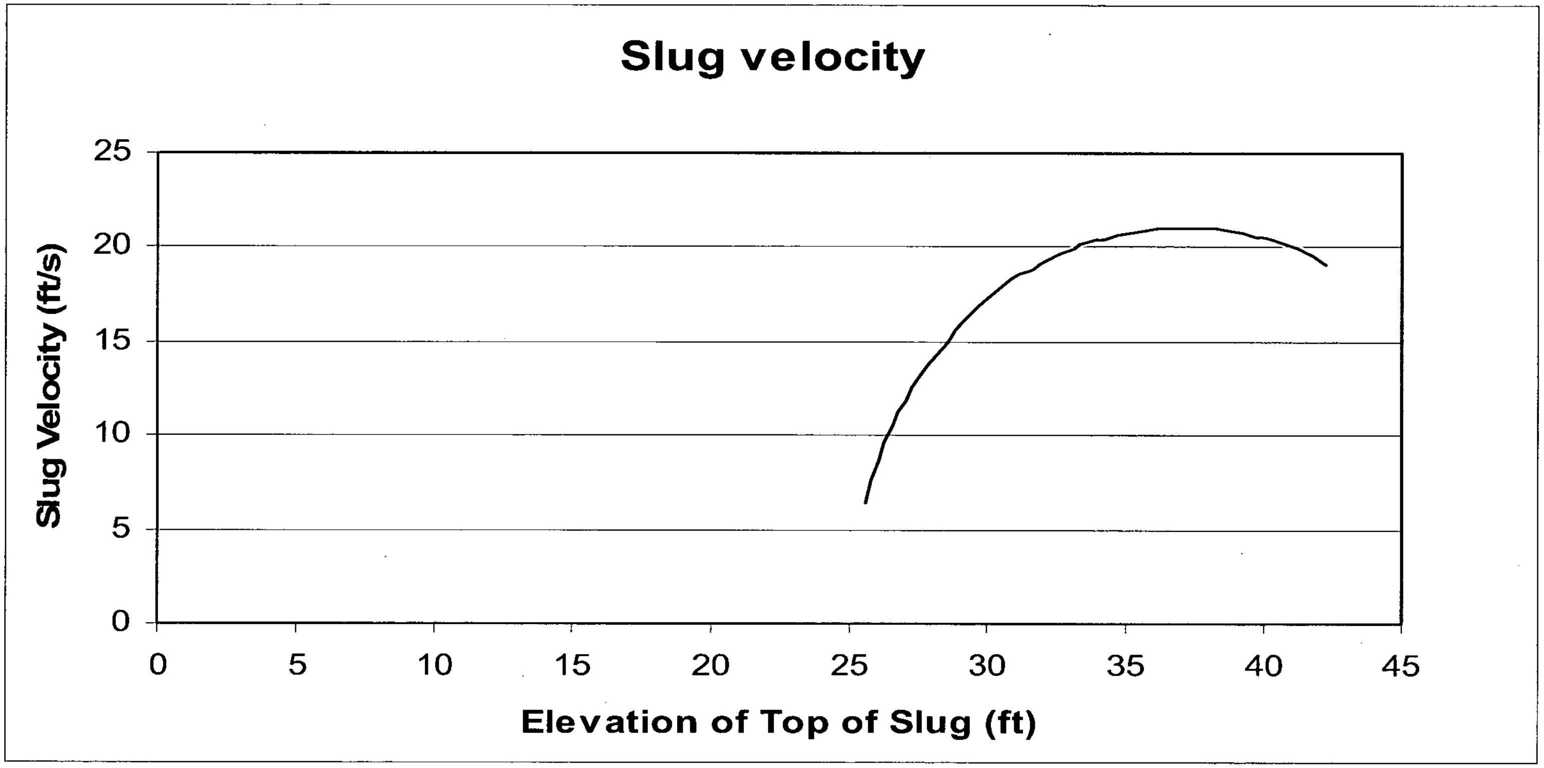
DCD Comparison

- Specified drywell pressure transient from FWLB in DCD.
- GOTHIC modeling approach is same as for PSTF comparison except that gas space is a closed volume.

DCD Comparison
GOTHIC Results for DCD Conditions



DCD Comparison
GOTHIC Results for DCD Conditions



Comparison of Results

	DCD	ABWR/ GOTHIC 80% Pool
Max Swell Height (m)	7.0	7.4
Max Slug Velocity (m/s) with 1.1 multiplier	6.0	7.0
Max Gas Space Pressure (kPag)	108	106
Max Bubble Pressure (kPag)	133	141

GOTHIC Results for DCD Comparison

- GOTHIC modeling approach bounds DCD results for peak swell elevation, peak surface velocity and peak bubble pressure.
- Gas space peak pressure is slightly lower.
  - Uncertainty in DCD peak pressure definition.
  - Small heat and mass transfer at pool surface.

ABWR Design Case

- Applied drywell pressure transient is the upper envelope curve for all MSLB and FWLB transients considered for peak short term containment pressure and temperature.
- MSLB gives faster pressure rise in the drywell and is therefore bounding for pool swell analysis.
- Drywell pressure response includes vent inertia
  - Increases very short term drywell pressure rise rate and peak for MSLB cases.

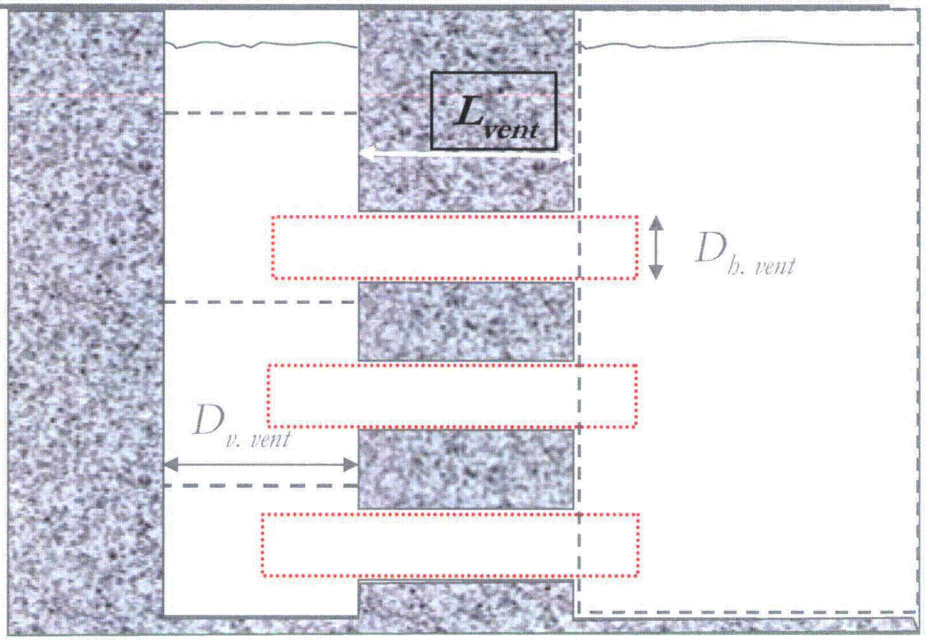
Horizontal Vent Inertia

- Horizontal vent inertia is ignored in short term PT analysis (maximized peak pressure value).

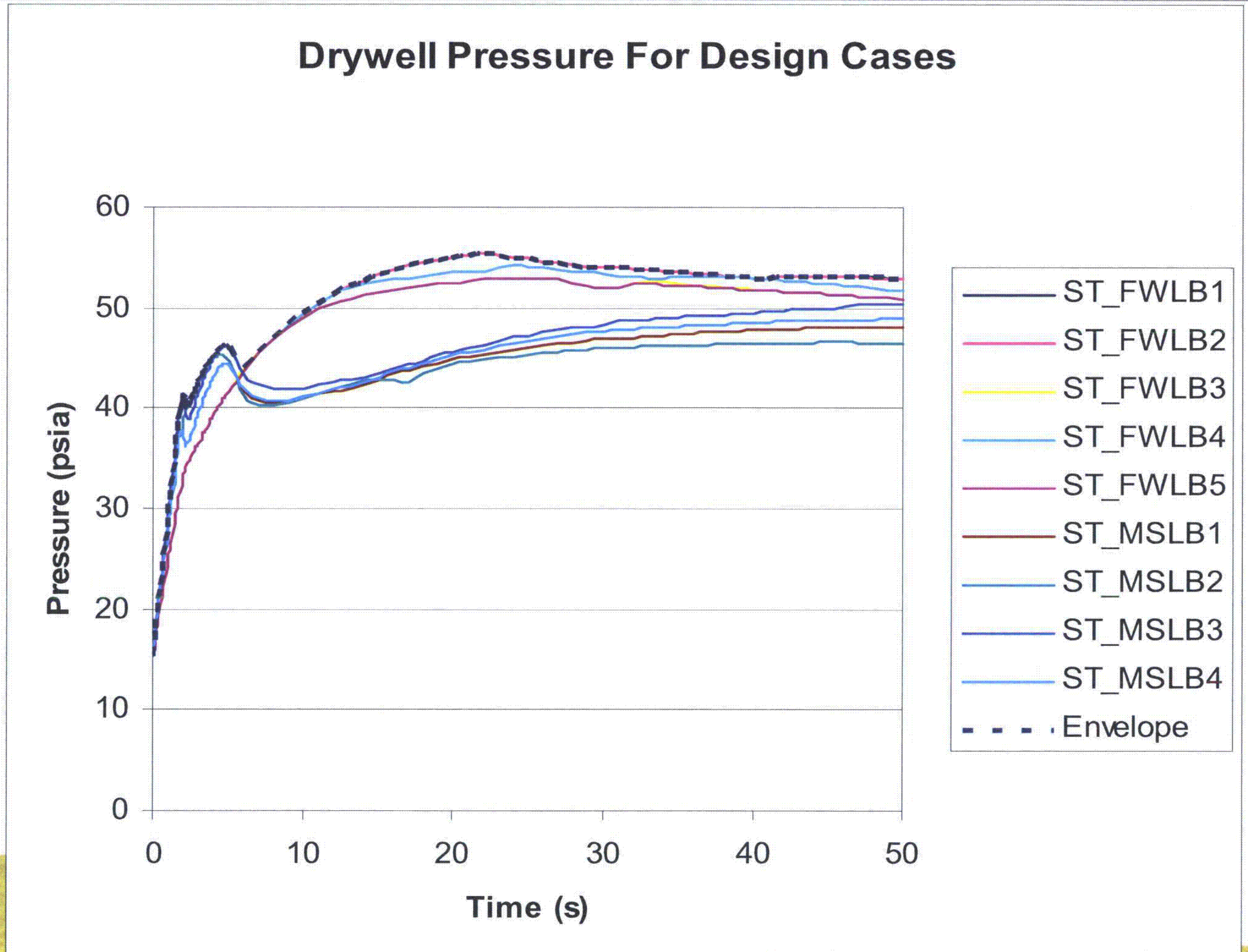
(a,c)

[ ]

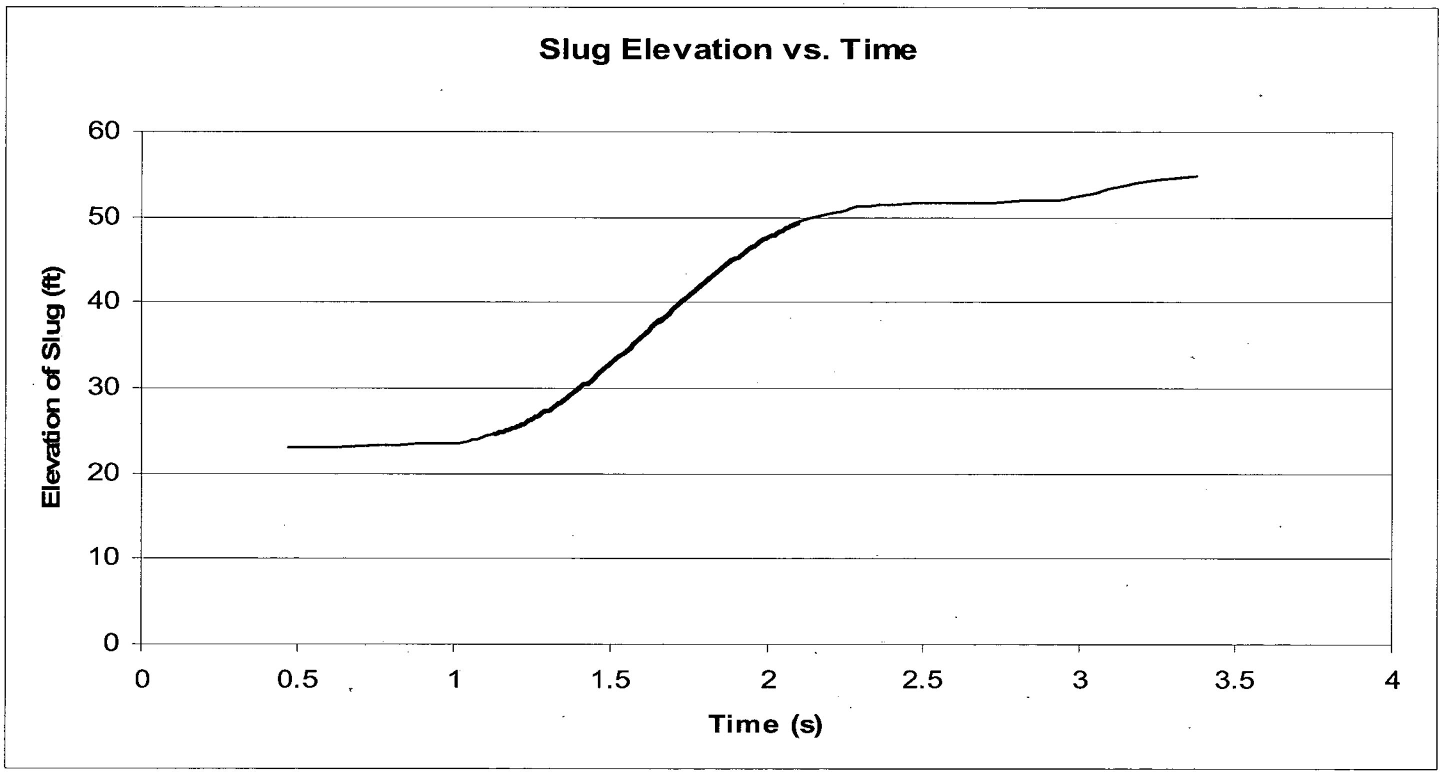
- Based on numerical experiments



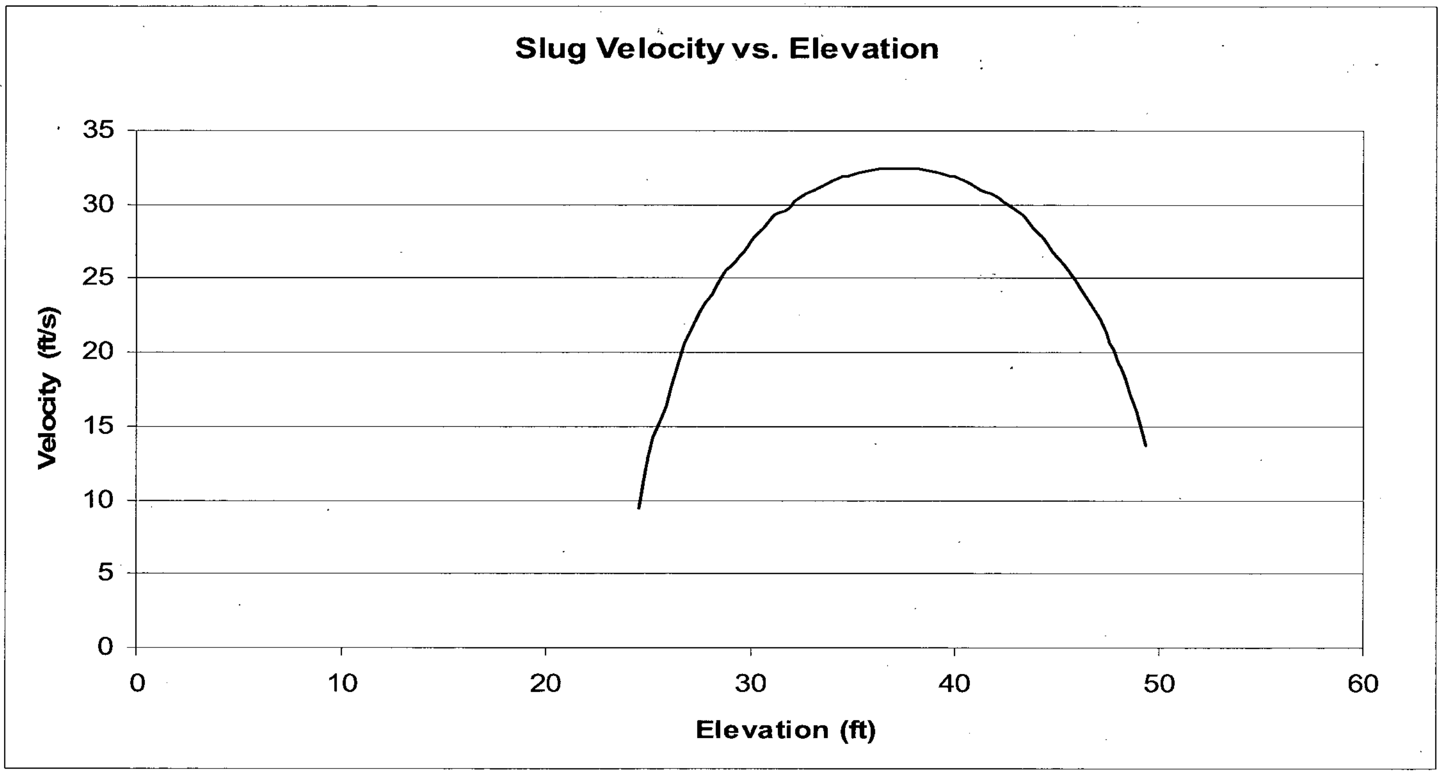
Design Case Drywell Pressure



Design Case Pool Swell



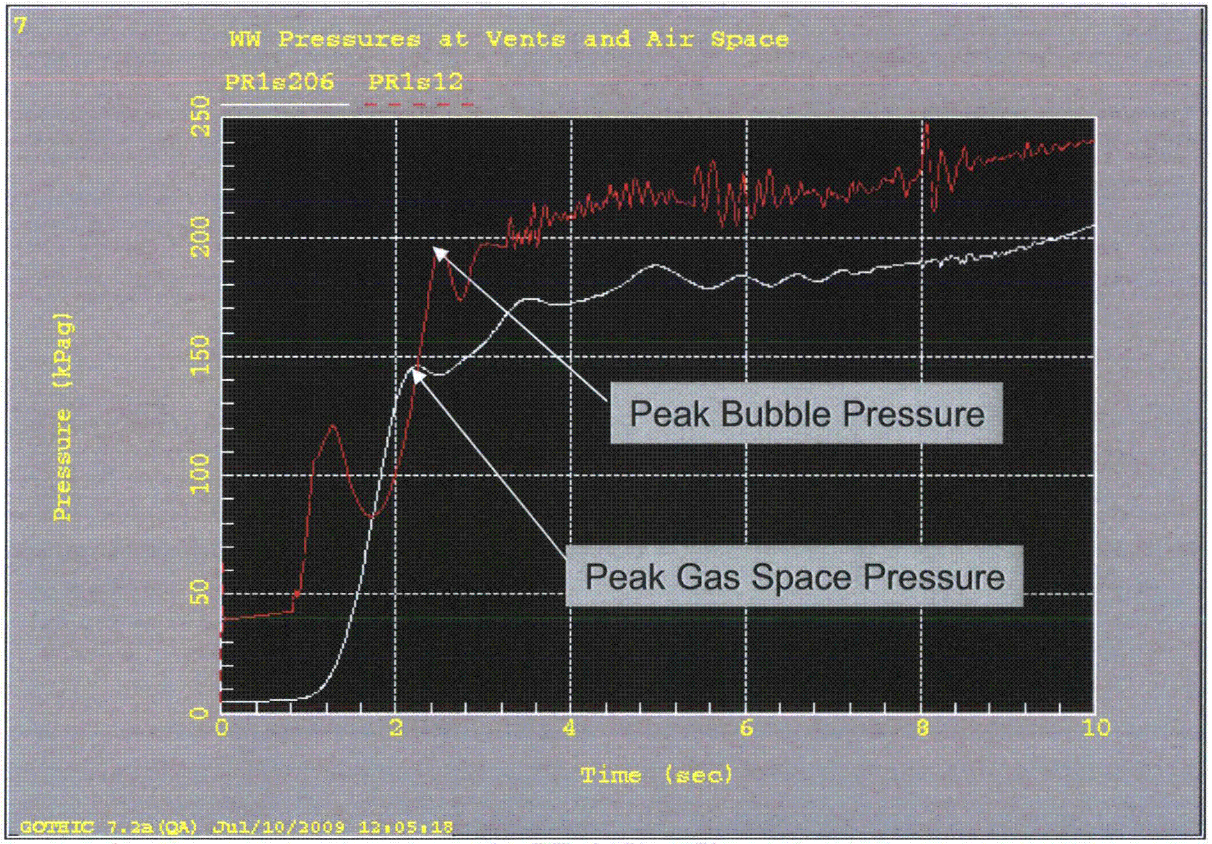
Design Case Pool Surface Velocity



Design Case Froth Level

- Assumed maximum froth level extends to 3.3 m above the maximum pool swell height.
- Consistent with NUREG-0978 for Mark III
- ABWR froth height is expected to be less.
  - Back pressure on the pool slug results in lower water inertia when the bubble breaks through the surface.
  - Reduced water momentum will result in lower froth height.
  - Higher gas space pressure results in reduced gas expansion and reduced water carry-up.

Design Case Bubble and Gas Space Pressure



- Peaks registered just before or at breakthrough

Design Case Results

	DCD	NEDO 33372	Westinghouse ABWR
Max Swell Height (m)	7.0	8.3	8.8
Max Slug Velocity (m/s) with 1.1 multiplier	6.0	6.0	10.9
Max Gas Space Pressure (kPag)	108	154	146
Max Bubble Pressure (kPag)	133	185	195

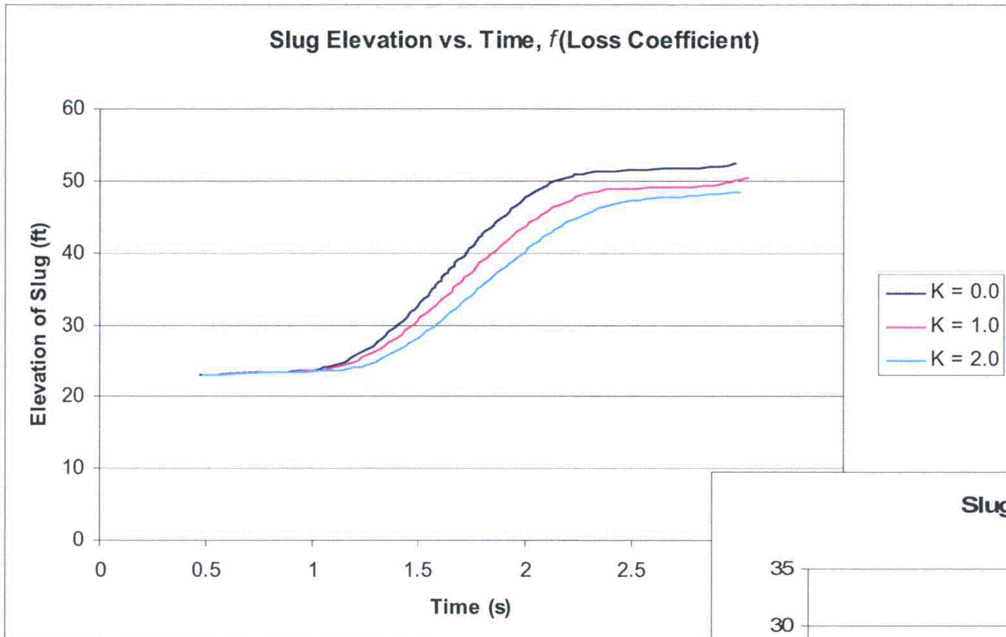
GOTHIC Results for ABWR Design

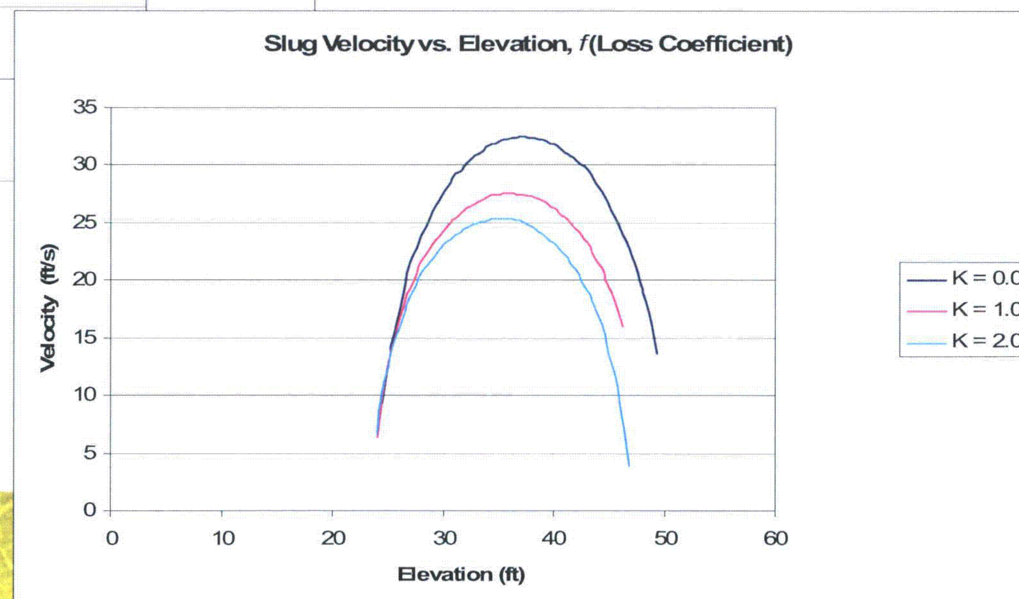
- GOTHIC modeling approach bounds NEDO-33372 results for peak swell elevation, peak surface velocity and peak bubble pressure.
- Gas space peak pressure is slightly lower.
  - Uncertainty in DCD peak pressure definition.
  - Small heat and mass transfer at pool surface.

Sensitivity Studies

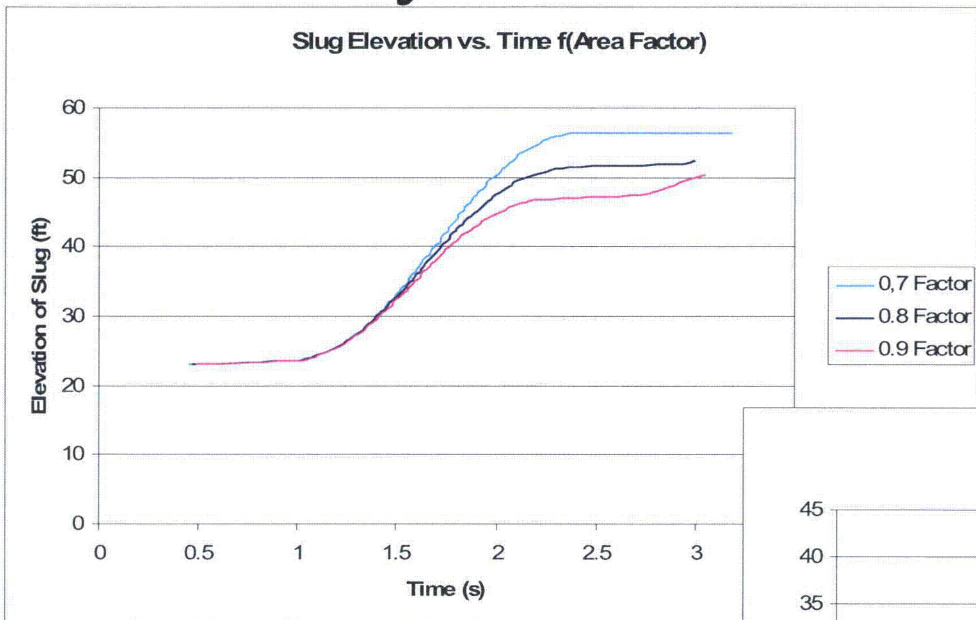
- Variations on Design Case
  - Vent loss factor
  - Pool area factor
  - Vent inertia length
  - Gas space thermal behavior

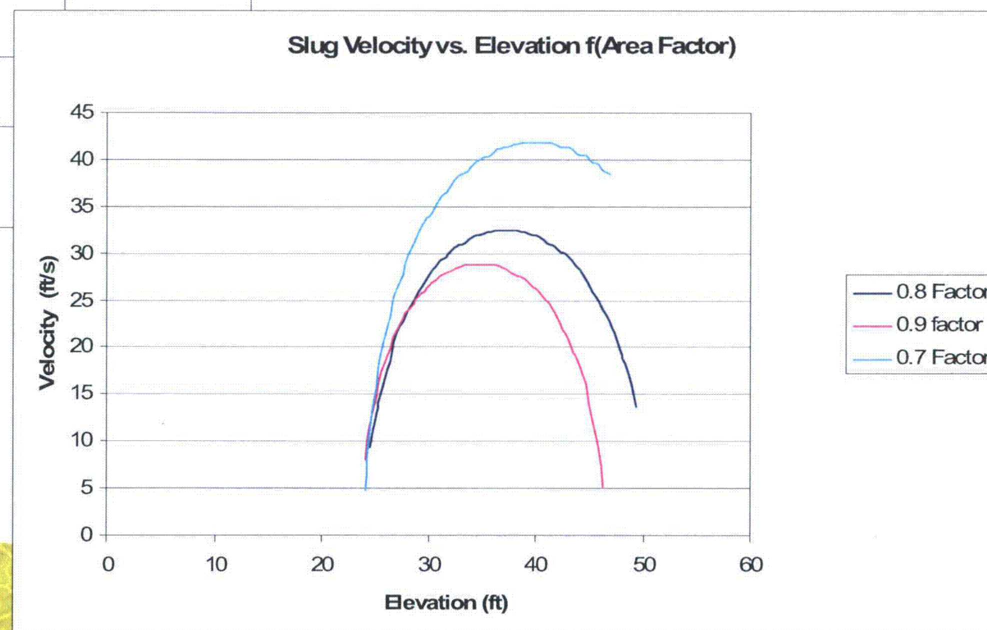
Sensitivity to Vent Loss Factor



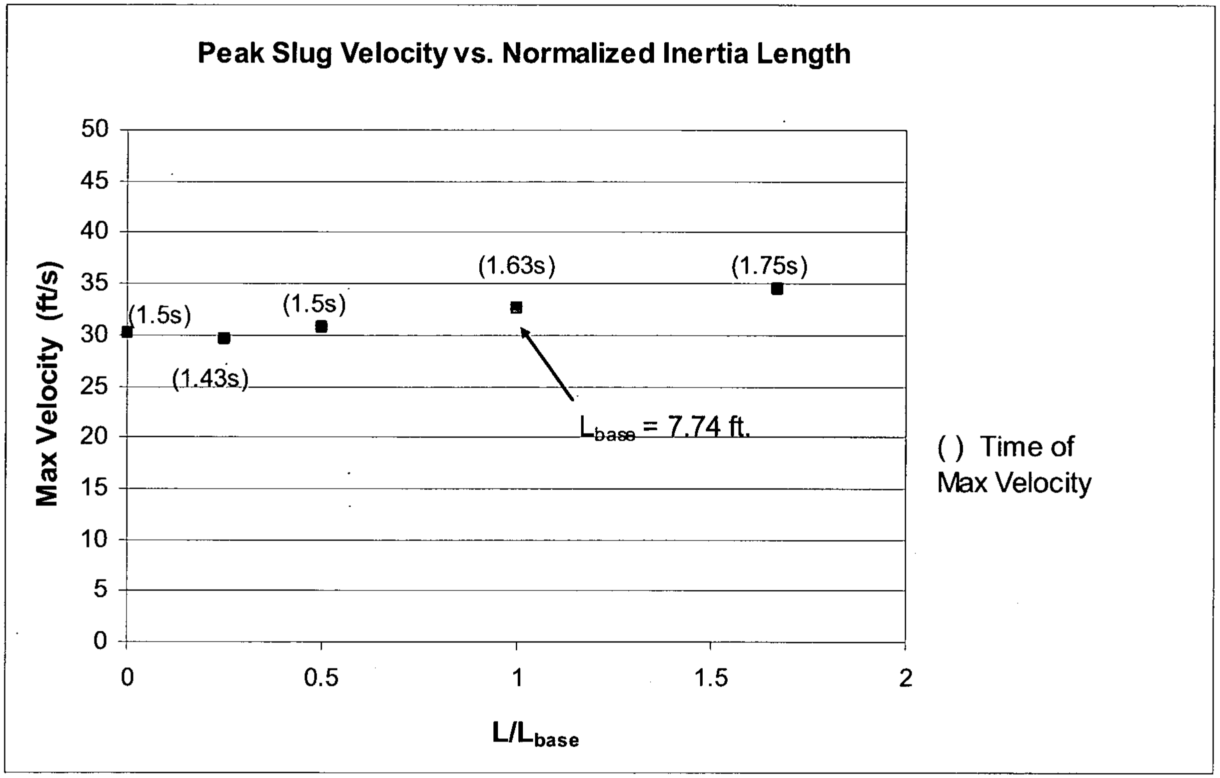


Sensitivity to Pool Area Factor

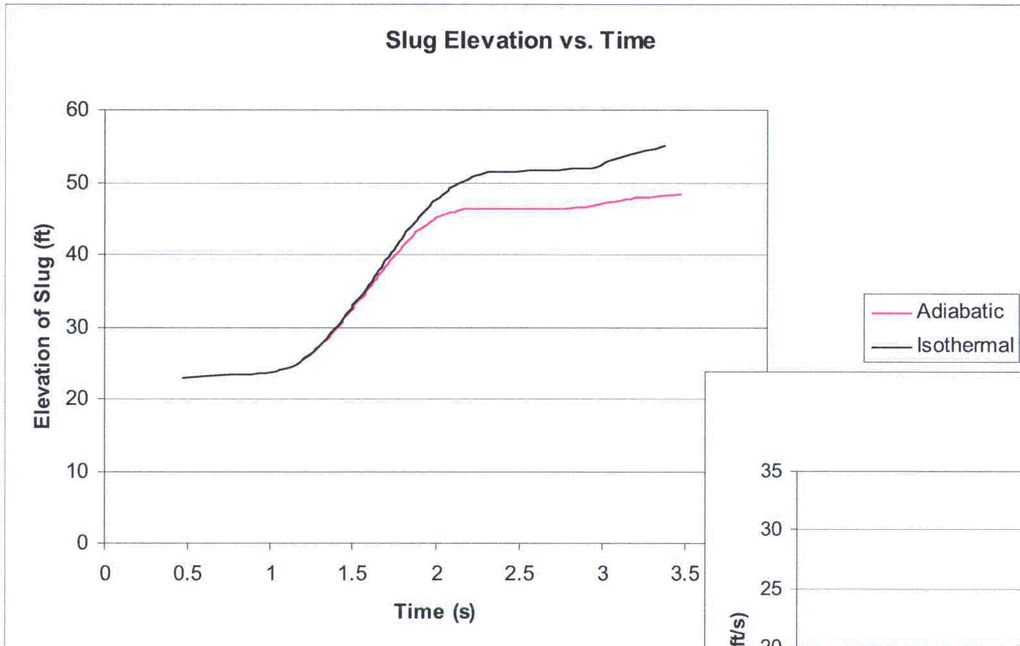




Sensitivity to Vent Inertia Length



Sensitivity to Gas Space Thermal Behavior



Sensitivity Conclusions

- Relative response to selected sensitivity parameters is as expected.
- Results are most sensitivity to pool area factor.
- Small sensitvity to inertia length.
- Overall modeling approach is considered conservative.

Conservatisms in Modeling Approach

- High estimate of drywell pressure transient
  - High vent losses
  - Vent inertia effects included
  - Maximum pool level
- Vent losses ignored in pool swell calculations
- Isothermal gas space minimizes back pressure on rising slug
- Minimum initial slug thickness
- Nitrogen injection
  - 20-30% higher peak swell velocity compared to tests with steam blowdown in the drywell

Summary

- GOTHIC modeling approach bounds peak swell height, peak surface velocity and peak bubble pressure from
  - PSTF Test 5806-1
  - DCD
  - NEDO 33372
- GOTHIC results for peak gas space pressure are close to DCD and NEDO 33372 values
- Significant conservatisms are built into the GOTHIC modeling approach.

Class 1

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Pool Swell Load Application

August 18, 2009

Outline

Class 1

- Pool swell load application methodology
  - Wetwell (WW) boundary
  - Structures in WW airspace (NUREG-0487 / 0978)
  - Submerged structures

- Information of relevant equipment location (typ.)

Pool Boundary Load

Class 1

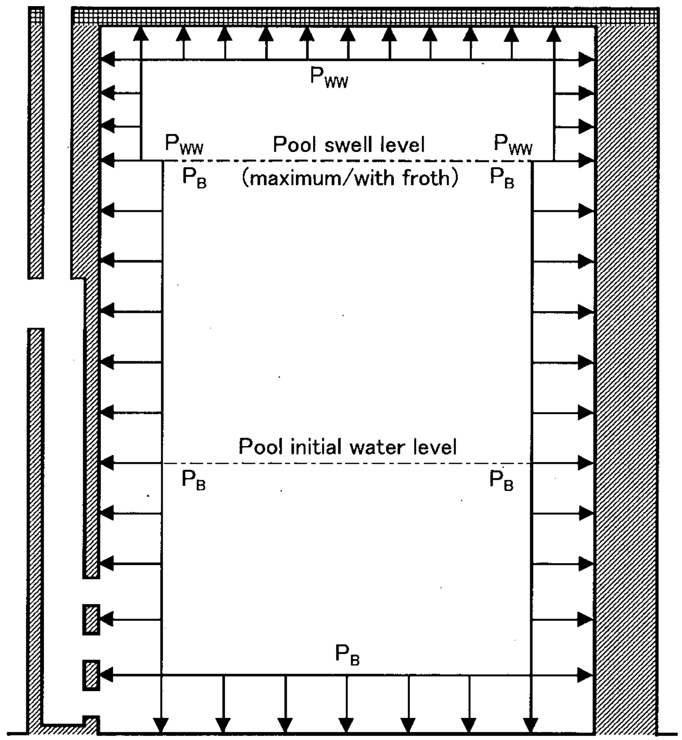
■ Methodology

The pressure loads calculated by GOTHIC are applied to pressure boundary.

- Wetwell air space boundary
- Suppression pool boundary

  Bubble pressure +

  Hydrostatic head



Structures in WW

Class 1

Structures in WW (SRVDL)

Class 1

Load on Structure in WW

Class 1

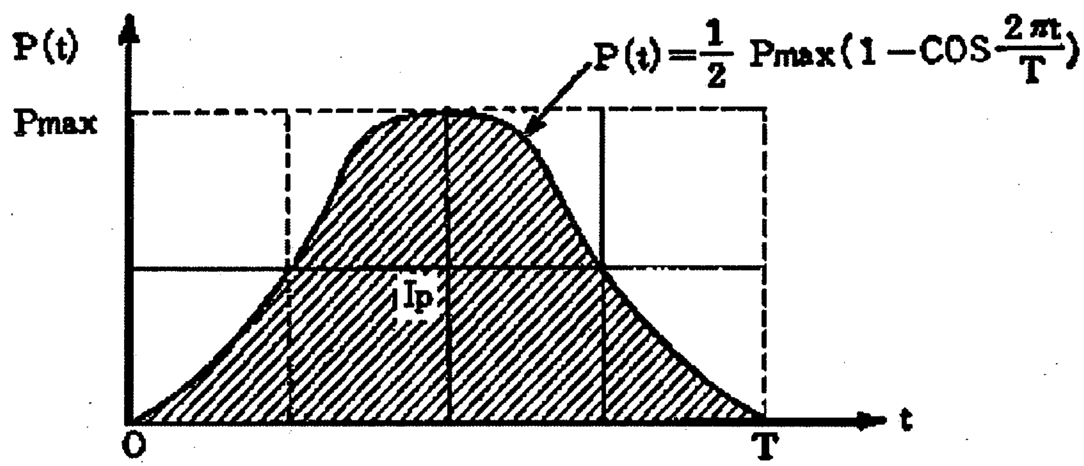
Methodology

The methodology is the same as that used for DCD.

- Impact load (for small structure): NUREG-0487

$$P(t) = P_{max}\,(1 - \cos(2\pi\, t / T)\,) / 2$$

$$P_{max} = 2I_P / T, \quad I_P = (M_H / A)\ V / g_C$$



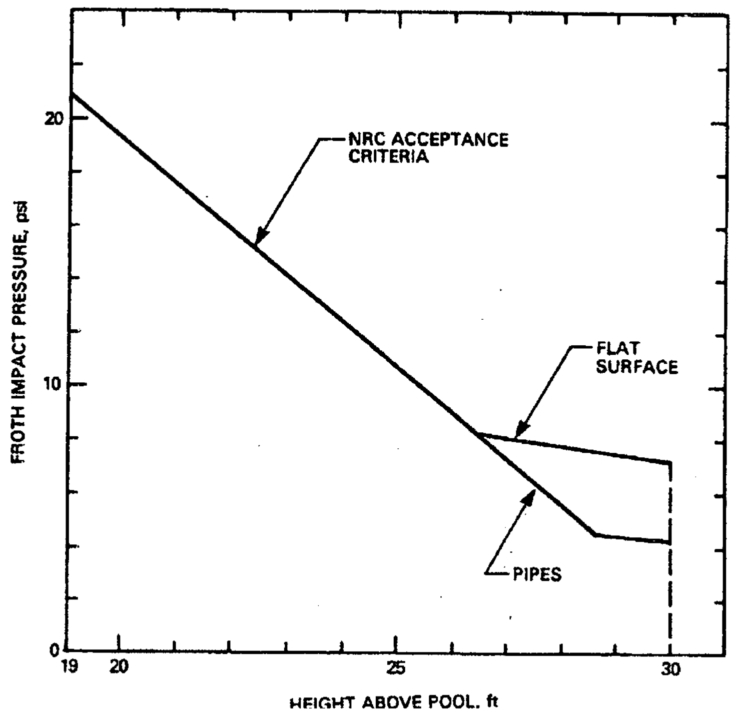
Load on Structure in WW (cont.)

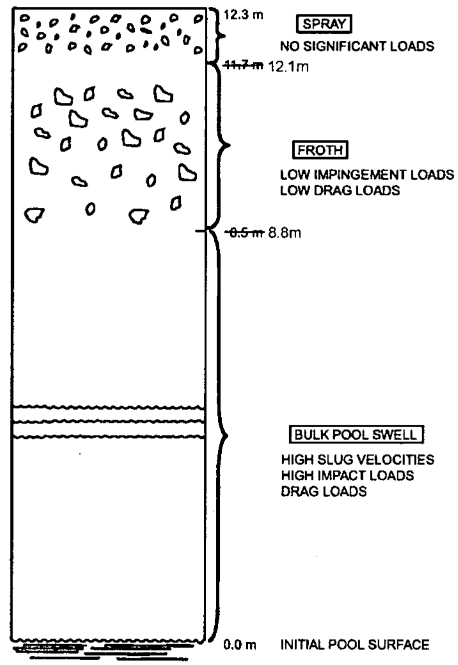
Class 1

- Drag load: the sum of standard and acceleration drags

$$P_d = 1/2\, C_D\, \rho\, (V^2/g_C) + V_A\, \rho\, (\dot{V}/g_C)$$

- Treatment of froth region: NUREG-0978





Load on Submerged Structure

Class 1

■ Methodology

The methodology is based on the analytical model for LOCA charging bubble-induced load (Dr. Moody, NEDE-21471, 1977).

- Spherical, adiabatic ideal gas bubble dynamics equations with the flow field being described by a point source

$$R \ddot{R} + 3/2 \dot{R}^2 = g_c (P_{bubble} - P_{\infty}) / \rho$$

- The total drag is the sum of standard and acceleration drags
- The boundaries (including the free surface) are incorporated by using the method of images.

Submerged Structures

Class 1

Summary

Class 1

- Pool swell load application adopts existing and accepted methodology
  - Described in NUREGs and their references
  - GOTHIC results (P, V, H) are used in formulation
- Specific design calculation will be performed in detail design stage

Contents of Topical Report (Preliminary)

1. Introduction and Background
2. Purpose
3. Pool Swell Phenomena and Related Hydrodynamic Loads
4. GOTHIC Capabilities for Pool Swell Phenomena
5. GOTHIC Model Description for ABWR Pool Swell
6. Comparison of GOTHIC Methodology with the ABWR DCD Methodology
7. Comparison of GOTHIC Results with the ABWR DCD Results
8. PSTF Comparison
9. Results for ABWR
10. Sensitivity Studies
11. Application of Pool Swell Results for Structural Loads Analysis
12. Conclusions
13. References

Appendix A – Key GOTHIC ABWR Suppression Pool Model Input Parameters
Appendix B – Comparison of GOTHIC Pool Swell Methodology with PSTF Test Data
Appendix C – Drywell Pressure Transient for DCD Benchmark
Appendix D – Drywell Pressure and Temperature Transients for Design Analysis
Appendix E – Sensitivity Studies

Response to Questions

- Scale drawings of equipment in wetwell air space
  - Discussed in presentation on design analysis
- Discussion of approach for calculating pool swell induced loads on equipment
  - Discussed in presentation on design analysis
- Effects of uncertainties in calculation of pool swell level surge
  - Discussed in presentation on design analysis
- Comparison of input differences for Short Term P/T, Long Term P/T, and Pool Swell Analyses
- Vent clearing times

Model Input Comparison

Modeling Element	Short Term PT	Short Term for PS Input	Long Term PT

(a,c)

Vent Clearing Times

Test or Analysis	Vent Clearing Time (seconds)

(a,b,c)

Questions?