June 22, 2015

MEMORANDUM TO: Christopher P. Jackson, Chief
Reactor Systems Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Warren C. Lyon ***/RA/***
Reactor Systems Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: SUMMARY OF JANUARY 15, 2015 NEI MEETING TO ADDRESS ISSUES INVOLVING POTENTIAL GAS ACCUMULATION IN SYSTEMS THAT ARE IMPORTANT TO SAFETY

The subject closed meeting to discuss proprietary information was held at the Westinghouse offices at 12300 Twinbrook Pkwy, Rockville, MD 208521606. Attendance is provided in Attachment 1. A non-proprietary copy of the U.S. Nuclear Regulatory Commission (NRC) Reactor Systems Branch (SRXB) slides is provided in Attachment 2. Westinghouse also presented proprietary slides that addressed the proprietary Purdue correlation that is described in the SRXB slides. Westinghouse generally confirmed that the NRC staff calculations using the Purdue correlation were correct with the exception that the NRC used Purdue void data at the closest measurement locations to the bottom of the downcomer and Westinghouse stated that lower horizontal pipe measurements further from the downcomer should be used. This was based on the conclusion that further measurement location data should be used because they are more representative of downstream flow void characteristics.

Industry follow-up actions included (1) a comprehensive gas closure plan will be provided and (2) Regulatory Information Conference (RIC) Session W17 (Wednesday, March 11, 2015) industry participants will be identified. SRXB follow-up actions included (1) provide an updated Action Plan, (2) assess the Westinghouse use of lower horizontal pipe void measurements, and

Contact: Warren C. Lyon, DSS/SRXB
(301) 415-2897

Enclsoures:
1. 01/15/2015 NEI Meeting Attendance
2. SRXB SLIDES

(3) provide in-depth support for an ongoing NRC inspection that addresses use of the Purdue correlations. NRC Item 3 will be combined with applicable generic information when received from industry.

cc: Christine Lipa
Joe Holonich
Shaun Anderson
Jonathan Bartley

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cc: Christine Lipa
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Jonathan Bartley

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OFFICE	NRR/DSS	NRR/DSS			
NAME	WLyon	CJackson			
DATE	6/16/2015	6/22 /2015			

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Enclosure 1

O1/15/2015 NEI Meeting Attendance

Dated June 22, 2015

01/15/2015 NEI Meeting Attendance

Warren Lyon	NRC	warren.lyon@nrc.gov
Jack Stringfellow	PWROG	njstring@southernco.com
Bridget Curran	NRC	briget.curran@nrc.gov
Chris Jackson	NRD	christopherjackson@nrc.gov
Rob Slough	PWROG	Robert.slough@luminant.com
Henry Hegrat	FENCC/PWROG	hihegrat@exeloncorp.com
Jim Riley	NEI	jhr@nei.org
Jay Boardman	PWROG	boardmjd@pwrog.com
Anderson Lin	PG&E	axle@pge.com
John Freeman	Exelon/BWROG	john.freeman@exeloncorp.com
Mark Bergman	GE-H	mark.bergman@ge.com
Phil Grissom	PWROG	pdgrisso@southernco.com
Chris Brennan	Exelon/BWROG	Christopher.brennan@exeloncorp.com
Steve Swantner	Westinghouse	swantnsr@westinghouse.com
Matt Swartz	Westinghouse	swartzmm@westinghouse.com
Jim Andrachek	Westinghouse	andracjd@westinghouse.com
Matthew Hamm	NRC (via telephone)	matthew.hamm@nrc.gov
Nestor Feliz-Adorno	NRC (via telephone)	nestor.feliz-adorno@nrc.gov
Geoffrey Ottenberg	NRC (via telephone)	Geoffrey.ottenberg@nrc.com

ENCLOSURE 1

Enclosure 2

SRXB Slides

Dated June 22, 2015

SRXB SLIDES

OFFICE OF NUCLEAR REACOT REGULATION
Reactor Systems Branch (SRXB)
Status of Systems Gas Issues and Resolution Plans

ENCLOSURE 2

Presentation Purpose

- Identify and address gas issues that may impact operation of systems that are important to safety.
- Address selected outstanding issues related to SRXB's assessment of gas behavior in systems designed to be water-solid (Slides 3 – 30).
- Summarize topics that have been previously addressed (Slides 31 – 77).
- Provide insights that will be addressed in planned documentation

Topics

Optional Presentation and Discussion

The Design Basis

- The design basis for systems that are important to safety and are designed to be water solid generally requires no gas to be present.
- When gas is found, its must be removed as soon as is practical and the cause corrected when practical.
- Analysis methodologies must be experimentally verified or must be clearly conservative.
- Judgment cannot be a key part of a Design Basis methodology.

The Design Basis, Operability, and NEI 09-10

- NRC Safety Evaluation of NEI 09-10: "The stated approach is to 'ensure that the fluid systems susceptible to gas accumulation are operated and maintained within their design bases and remain ready to perform their intended design basis function when required. It is expected that systems will be designed, operated, and maintained in a manner to prevent accumulation of gas. Where accumulated gas cannot be reasonably prevented, engineering technical evaluations must account for the presence of such gas and its impact on system performance.'"

The Design Basis, Operability, and NEI 09-10, continued

- “In cases where the existence of voids is determined to be acceptable in the long term, a design change should be completed and evaluated”
- “In general the design limit for gas accumulation in a fluid system may be documented in the design basis. If there is no specified design limit then the design limit is no gas present.”
- Design basis changes require a 10 CFR 50.59 evaluation and may require NRC approval.

The Design Basis, Operability, and NEI 09-10, continued

- “Trivial volumes of gas, such as occasional bubbles in a horizontal pipe that cannot be reasonably removed, do not require documentation.”
- “the discovery of all gas accumulation that exceeds the design limit should be entered into the station’s corrective action program.“
- “An immediate operability determination or functionality assessment is required if discovered gas volume is greater than the monitoring procedure design limit. “

The Design Basis, Operability, and NEI 09-10, continued

- “Gas that exceeds the design limit should be removed immediately using methods described in this document. Gas that cannot be removed immediately due to plant configuration or conditions should be removed at the next available opportunity, consistent with the station corrective action process as long as appropriate operability evaluations are documented and operability is reasonably assured.”

The Design Basis, Operability, and NEI 09-10, continued

- “Gas that exceeds the design limit should be removed immediately using methods described in this document. Gas that cannot be removed immediately due to plant configuration or conditions should be removed at the next available opportunity, consistent with the station corrective action process as long as appropriate operability evaluations are documented and operability is reasonably assured.”

Operability

- Inadvertent gas accumulation must not cause a loss of operability.
- When a gas condition is not immediately eliminated, correction may be addressed by the Corrective Action Program (CAP) with the objective of achieving correction at the earliest practical time.
- Analysis methods and acceptance criteria must be experimentally supported or otherwise justified.
- Judgment is allowed when used in conjunction with acceptable analysis methods and criteria.

Operability, continued

- Realistic pump suction criteria are provided in Huffman, K., “Report of the Expert Panel on the Effect of Gas Accumulation on Pumps," EPRI Report Number 1026498, August, 2012.
- These criteria may be applied as part of operability determinations.
- The difference between the EPRI and NEI 09-10 criteria may be credited as a conservatism when performing an operability determination if the NEI 09-10 pump suction criteria are satisfied.
- The Purdue correlation has been proposed to assess downcomer behavior as part of operability determinations.

A left bar delineates where proprietary information has been deleted.

The Purdue Correlation from WCAP-17271

L_S = the length occupied by the original void assuming all void has been displaced into the top of the downcomer

V_i = injected volume

P_{ti} = initial pressure

P_t = pressure that exists when void in located in top of downcomer

A = pipe cross sectional flow area

W_e = Weber number

ρ = liquid density

g_c = gravitational constant

σ = liquid surface tension

u_m = mixture velocity

β = volumetric flux fraction exiting shock

β_{in} = gas volumetric flux entering the elbow at the bottom of the downcomer

= β decreased by pressure change from β location to downcomer bottom

β_{out} = gas volumetric flux exiting the elbow at the bottom of the downcomer

N_{FR} = Froude number

Δt_{in} = time when gas is entering elbow at the bottom of the downcomer

The Purdue Correlation - Restrictions

- Homogeneous bubbly flow must exist at the downcomer exit.
- Complex geometries such as offtakes and tees do not exist.
- $N_{FR} > 1.0$ and no gas is held up in the vicinity of the bottom of a downcomer by another mechanism.

The first item must be established before the correlation can be applied to predict void behavior in a downcomer.

WCAP Volume 3 provided data for determination of downcomer length to achieve homogeneous bubbly flow at the downcomer exit. For 8 inch diameter pipes:

General behavior based on available Purdue data is consistent with the 8 inch correlation for . Much of the data scatter is due to inaccurate determination of the necessary downcomer length.

Consider the following Eight Inch Initial $\Phi = 0.05$, $N_{FR} = 1.24$ Data with respect to the Purdue Correlation

Comparison of Data and Correlation

- Above data show β decreased from 0.057 to ≈ 0.02, a factor of three decrease in this test.
- Taking into account that measurements are not at the elbow, β decreased from about 0.055 to 0.03, a factor of two change.
- The Purdue correlation predicts β decreases from 0.0332 to 0.00836, a factor of four change.
- Correlation is non-conservative for this example.
- Comprehensive comparisons are provided on the next slides.

Comparison of Purdue Data and Correlation for 4, 6, 8, and 12 inch pipe diameters

Comparison of Purdue Data and Correlation for 4, 6, 8, and 12 inch pipe diameters

Comparison of Purdue Data and Correlation for 4, 6, 8, and 12 inch pipe diameters

Purdue Correlation Conclusions

- Slides 18 and 19: The correlation is non-conservative by a factor of two to three for this sample.
- Slide 22: Correlation is non-conservative since much of $\beta_{\text{out data}} > \beta_{\text{out calc}}$
- Slide 21: Scattered results for β_{in} with more points on the non-conservative side. Note this is not a downcomer exit characteristic.

Purdue Correlation Conclusions, continued

- Slide 18: This is consistent with Slide 16 since it shows most $\beta_{\text{out data}} > \beta_{\text{out calc}}$, a non-conservative result.
- The non-conservative correlation can be used for operability evaluations in conjunction with estimated conservatisms provided the estimated conservatisms are acceptably large.
- Amount of conservatism should be assessed with respect to pipe-specific Purdue data.

TSTF 523 Status

- 32 Units have submitted LARs to adopt the TSTF
- 8 Units have extended the LAR submittal date
- 1 Unit has decided not to adopt the TSTF

Plans, NUREG (Tentative dates)

Initial Draft	10/05/2014
To NRC offices for concurrence	01/30/2015
To NEI for proprietary review	02/16/2015
Receive NEI response	03/13/2015
Submit to FRN for publishing	04/13/2015
Publish in FRN	N (date)
Receive comments	N + 60 days
Address comments	N + 100 days
Submit final for publishing	N + 125 days

Plans, Other Activities

• Regulatory Information Conf.	03/11/2015
• Regional Inspection Tools	04/06/2015
• Future Publications Decision	N + 90 days
• Complete Gas Action Plan	07/31/2016

Conclusions

An item that is acceptable for Design Basis determinations is also acceptable for Operability determinations.

- NEI 09-10 pump void acceptance criteria are acceptable for design basis determinations.
- Pump roadmap pump void acceptance criteria are acceptable for operability determinations.
- ARL vortex test data conducted consistent with past tests are acceptable for design basis determinations. See Slide 36 for more info.

Conclusions, continued

- The Purdue correlation and the Simplified Equation Methodologies are acceptable for operability determinations provided the qualifications are met.
- All other aspects of gas analyses must be traceable to acceptable experimental data. Correction factors may be applied where analyses do not provide adequate coverage.
- All computer code applications are currently plant-specific and subject to inspection.

Conclusions, continued

- Use of N_{FR} is acceptable for determining gas transport behavior in design basis determinations.
- The factor of four criterion is acceptable for determination of the downcomer length necessary to achieve homogeneous bubbly flow at the downcomer exit in design basis determinations.
- is acceptable for operability determinations provided (L = ft; V = initial void volume upstream of downcomer, ft^3). See also Slides 16 and 17.

Assessment Approach

- Theoretical understanding of gas behavior in such systems is often inadequate.
- Stochastic behavior complicates assessment.
- Gas movement methodologies must be confirmed by applicable test data.
- Primary concern is loss of pump function.

Vortices

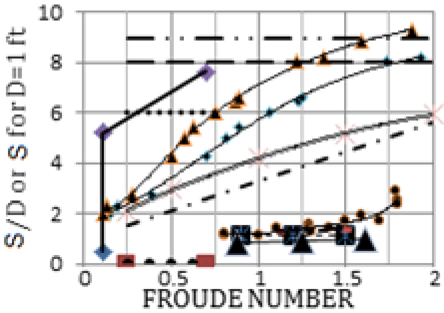
- Vortexing is a mechanism for gas to enter systems while taking fluid from a water source.
- Vortexing is a precursor to loss of RHR during mid-loop operation.
- Vortexing has caused loss of operability, pump damage, and has jeopardized core cooling.
- A key to avoiding vortex issues is prediction.
- Accurate prediction is difficult due to sporadic behavior and the effect of the environment.
- Vortexing should be avoided where practical.

Vortices, continued

- Tests are necessary.
- Test time is important due to stochastic behavior.
- Dynamic similarity for N_{FR} to be identical in test and actual hardware requires $N_{RE} > 10^5$, $N_{We} > 720$, test scale ≥ ¼.
- Gas handling pipes must be ≥ 4 inch diameter.
- Tests must accurately simulate operation or differences must be justified.

Vortices, continued

Test results vary widely:



S = critical submergence, D = exit pipe diameter

Therefore, test configuration and operation must accurately represent plant hardware.

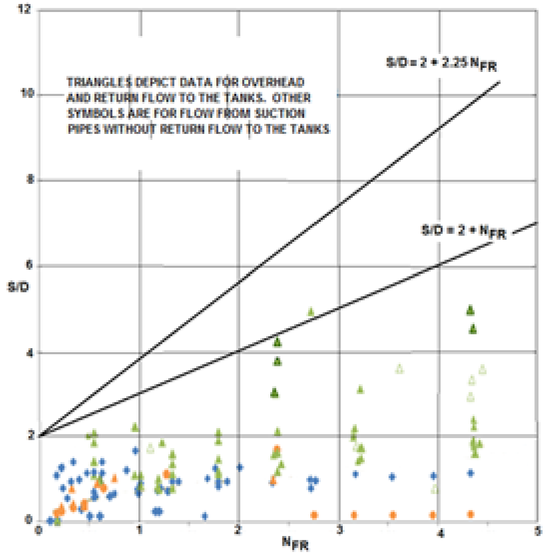
Vortices, continued

- Alden Research Laboratory (ARL) has conducted about 20 separate tests with 15 tanks that represented different applications.
- Vertically scaled cylindrical tanks ranged from 30 ft to 57 ft in diameter.
- Two 12 ft diameter horizontal tanks were tested.
- Test model scales ranged from ½ to 1/6.
- Suction nozzle diameters ranged from 6 to 24 inches.

Vortices, continued

- ARL usually meets acceptable test criteria.
- Test are conducted using draindown conditions that simulate the plant transients.
- A small amount of gas may be ingested near the end of draindown. Duration is short and the gas quantity is typically small. This is not judged to be a concern.
- ARL test results are typically acceptable to support design basis determinations.

Vortices, continued – ARL Test Results



Vortices, continued

- Other test data that are based on tests that acceptably simulate the applicable plant hardware and are of a quality consistent with the ARL tests may be used for design basis determinations.
- Vortex correlations, such as Lubin-Springer, Jain, and Harleman, may be used for determinations provided they have been established to bound acceptable test data.

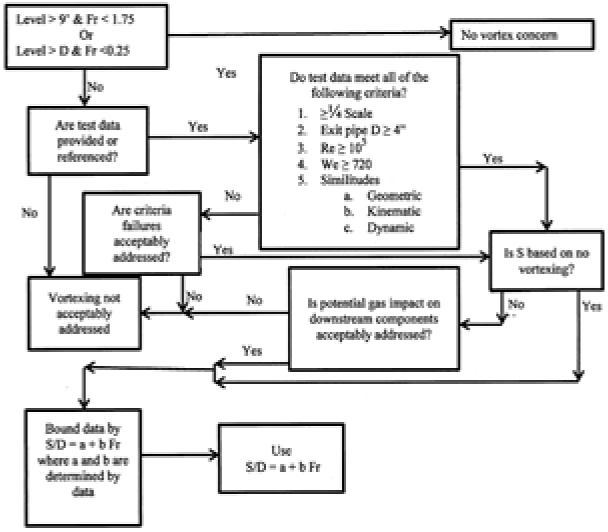
Vortices During Midloop Operation

- It is desirable to not have vortexing or air ingestion during midloop operation.
- In existing plants prevention of incipient vortexing may be unnecessarily conservative and may not be achieved without impractical hardware modifications that are unnecessary to achieve safe operation.
- Vortexing or air ingestion should not occur in advanced design plants.

Vortices During Midloop Operation, continued

- A small continuous air ingestion rate due to vortexing may be proposed to support an operability determination but it must be justified with respect to potential downstream accumulation and subsequent movement of accumulated air with an increased void fraction, potential operator response concerns, vortex instability, and pump acceptance criteria.
- Operating experience may be used as a justification.

Vortex Assessment Chart



Vortex Suppressors

- A broad range of configurations are available that have been established as effective by testing.
- Adding a suppressor may be detrimental – such as decreasing downstream pressure that jeopardizes pump operation.
- No analysis methodologies have been found acceptable.
- Hydraulic model data are necessary to confirm operation.

Froude Number

N_{FR} is defined by:

$$N_{FR} = \frac{V}{\sqrt{\frac{Dg_c(\rho_L - \rho_g)}{\rho_L}}}$$

where:

- D = pipe diameter
- V = liquid velocity based on total pipe area
- g_c = gravitational constant
- ρ = density
- subscript L indicates liquid, g indicates gas

Froude Number, continued

- ≤ 0.31: No significant gas movement in horizontal pipe if Φ ≤ 0.20
- 0.31 < N_{FR} ≤ 0.65: Some gas may transport depending on pipe geometry
- > 0.54: Gas moves toward downstream end of horizontal pipe with no local high points. Bubbles may move down in a vertical pipe.
- < 0.8: Dynamic venting not effective.

Froude Number, continued

- $0.8 < N_{FR} < 2.0$: Time to clear gas is a function of flow rate and piping geometry.
- ≥ 1: Gas gradually removed from inverted "U" tube heat exchanger. Not applicable at bottom of downcomer connected to horizontal pipe.
- > 1.2: Open end horizontal pipe will run full.
- > 2.0: Gas removed from pipe. Gas likely moves as slug.

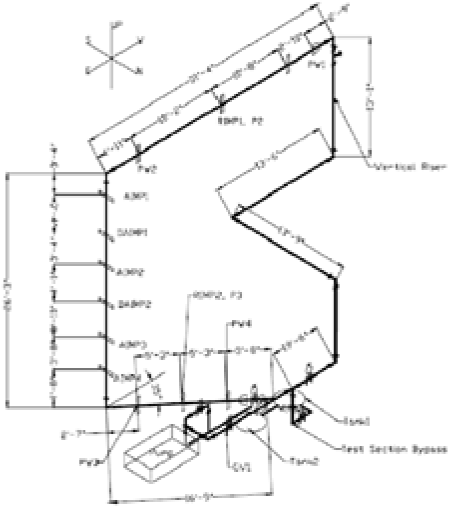
Conservative Method for Operability Assessment

- Multiply pump acceptable void fraction by total volumetric flow rate by 0.5 seconds.
- Provides upstream void volume that will not jeopardize Operability.
- Often too conservative to be useful
- Identified in ML13136A129, p. 28

The Purdue Tests

- Transient tests were conducted at Purdue University using 4, 6, 8, and 12 inch diameter pipes.
- An initial gas void was established in an upper horizontal pipe.
- Then flow was initiated that moved the void to the downstream end of the pipe where it was connected to a downcomer.
- Void behavior was then observed as the void moved through the test facility.

The Purdue Test Configuration



Typical Test Initiation Timing

A typical test initiated at about 10 seconds.

Pressure Implications

- A typical test would initiate with an upper horizontal pipe pressure, P2, of 14.7 psia,
- This would decrease upon test initiation, thus increasing the starting void volume. This would affect most calculated characteristics.
- Pressure in the lower horizontal pipe would decrease upon test initiation. This would affect calculation of β_{in} from β.

Typical Upper Horizontal Pipe Pressure, P2

Variation makes it difficult to select a representative pressure
for the time of interest in the transient.

Typical Lower Horizontal Pipe Pressure, P3

In contrast to P2, P3 is constant over the transient time.

Eight inch P2 and P3 data from WCAP correlated by straight lines for 8 inch calculations:

Other pipe diameter tests generally did not exhibit straight line behavior and experimental pressures were used.

Calculation Methodology

- Excel was used to facilitate calculation of Purdue correlation.

- The following slides illustrate the input data for a Purdue Test with $N_{FR} = 1.24$ and $\Phi = 0.05$ and describe the Excel program.

Excel – Input data

Parameter	Definition	Spread-sheet Location	Description	Value
A	Input	B4	flow area of 8 inch diameter pipe, ft^2	0.3474
P_{ti}	Input	B5	monitoring pressure at initial void location, psia	14.7
P_t	Input	B6	operating pressure at initial void location, psia	7.25
ρ_l	Input	B9	liquid density, lbs/ft^3	62.4
σ	Input	B10	surface tension, lbs force/ft	0.005
N_{FR}	Input	B12	Froude number	1.24
V_i	Input	B11	volume at monitoring pressure, ft^3	0.55
PW2	Input	B7	pressure at top of downcomer, psia	7.25
PW3	Input	B8	pressure at bottom of downcomer, psia	17.84

Excel Calculation

Factor of Four Downcomer Criterion

- Fauske & Associates established that homogeneous bubbly flow would exit from a downcomer if downcomer volume ≥ 4 X initial void volume in a connected upper horizontal pipe for $1 < N_{FR} < 2$ (ML110480456).
- This is conservative when compared to Purdue transient test results.

Downcomer Correlation

- The correlation is an acceptable representation of downcomer length necessary to obtain homogeneous bubbly flow in eight inch diameter Schedule 40 pipes. (L = necessary downcomer length, ft; V = initial void volume upstream of downcomer, ft^3)
- See also Slides 16 and 17.

The Simplified Equation (*FAI/09-130-P; WCAP-17276-P, Rev. 1)*

$$V_{\text{allowable}} = \alpha_{\text{pump}}\, \Delta t_{\text{pump}}\, Q_{\text{pump}} \left(\frac{P_{\text{pump}}}{P_{\text{High-Point}}}\right)_{\text{Post-Accident}}$$

= allowable void volume upstream of the pump

- α_{pump} = allowable void fraction at the pump entrance
- Δt_{pump} = time period when allowable void fraction enters the pump
- Q_{pump} = pump flow rate
- P_{pump} = absolute static pressure at pump suction
- $P_{high\text{-}point}$ = absolute static pressure at high point location

Simplified Equation Application

- Obtain α_{pump} and Δt_{pump} from pump void acceptance criteria tables.
- Calculate $V_{allowable}$.
- Calculate maximum kinematic shock depth in downcomer, by:

$$y_1 = \frac{1}{A}\left\{V_{GAS} + \frac{Q_0\,U_0}{g}\left[\frac{\sqrt{2\,g\,y_1}}{U_0} - \ln\left(1 + \frac{\sqrt{2\,g\,y_1}}{U_0}\right)\right]\right\}$$

A = flow area, V_{GAS} = $V_{allowable}$, Q_0 = liquid flow rate

U_0 = liquid velocity based on pipe inside flow area

g = gravitational constant

Simplified Equation Application, continued

- Calculate $\Delta t_{TRANSPORT}$ using proprietary WCAP (Westinghouse, January 2011) Equation 23:

- If $\Delta t_{TRANSPORT} < \Delta t_{pump}$, multiply $V_{allowable}$ by $\Delta t_{TRANSPORT} / \Delta t_{pump}$ to obtain the allowable void volume.

Simplified Equation Application, continued

In ML13136A129, NRC reported the simplified equation was acceptable for operability evaluation provided:

- $N_{FR} \leq 2.5$ or flow rate $\leq 10\ D^{2.5}$ gpm (D in inches
- 4 inches $\leq D \leq 30$ inches.
- No slug flow.
- Any downcomer configuration change must be below the 4 X criterion elevation.
- Flow downstream of the last horizontal pipe that follows a downcomer must be homogeneous immediately upstream of the pump entrance or, if stratified flow exists, pump operability must be justified.

Computer Codes

“any computer code used to develop a system specific model should be verified to be applicable to solve problems involving gas transport in piping systems via comparisons with laboratory test data or other appropriate methods. Further, a suitable safety factor should be added to predicted results to reasonably ensure the predictions encompass actual behavior.” NEI/NRC (ML13136A129)

Computer Codes, continued

- A quantitative safety factor is not always necessary. For example, the conservatism in pump void acceptance criteria can be credited for operability evaluations.
- Expert understanding of the code and the application is necessary.

Computer Codes, continued

- SRXB is not aware of any generic code approval for prediction of gas movement.
- Specific applications of GOTHIC and RELAP5 have been found acceptable.
- Licensees often use other codes, such as PIPER, SYSFLO, and AIRDIST. SRXB has no experience with other codes for the gas transport analyses of interest here.

Computer Codes, GOTHIC

- Solves conservation equations for mass, momentum, and energy for multi-component, multi-phase flow.
- Addresses non-condensing gases, steam, liquid drops, or liquid water.
- Uses orthogonal coordinates (x, y, z).
- Flow regimes from bubbly flow to film/drop flow as well as single phase flows.
- Includes heat transfer to structures.

Computer Codes, GOTHIC, continued

- Approved for containment analyses.
- Not otherwise approved but has been reviewed in depth (ML13270A176).
- Numerical Applications, Inc. (NAI) is well qualified to apply GOTHIC to gas analyses.
- GOTHIC predictions range from essentially overlay of data or analytic calculation results to about a factor of two difference.

Computer Codes, GOTHIC, continued

- Difficult to correctly model elbows, tees, sloped pipes, and vortexes.
- Weaknesses must be addressed but, in general, GOTHIC is useful for analysis of void behavior.
- More than 50 comparisons to applicable tests and analytical evaluations.
- Comparisons include Purdue tests, a Millstone test, water hammer, and Edwards rapid blowdown experiment.

Computer Codes, RELAP5

- Provides two phase two component model based on longitudinal nodes.
- Cannot predict void distribution with respect to radial and angular position.
- Cannot accurately address tees, elbows, or formation of a kinematic shock in a vertical downcomer immediately upstream of the pump suction when multi-dimensional representation of the void behavior is necessary.

Computer Codes, RELAP5, continued

- SRXB assessed application of RELAP5 to a scaled Millstone 3 test.
- With limitations, RELAP5 was found to be a useful contributor to understanding gas transport behavior.
- RELAP5 slightly over-predicted void fractions in pipes leading to some pumps.
- No other RELAP5 applications to transient gas issues have been reviewed by SRXB.

Computer Codes, Status

- No generic approvals for gas transport codes.
- All code applications to gas issues are currently being individually evaluated.
- Evaluations are labor-intensive and require an in-depth reviewer understanding.
- Many codes are used where NRC staff has no knowledge of code modeling or applicability.
- Most SRXB review activity has been in response to Region requests for inspection support.

Water Hammer

- Typical water hammers occur when a pump is started as a system is placed in service.
- To our knowledge, water hammers due to gas have not caused pipe ruptures but conditions have been identified where this could occur.
- Gas water hammers have caused relief valves to open and remain open.
- Gas water hammers have caused support structures to be damaged.

Water Hammer, continued

- Gas water hammers are less challenging that those caused by vapor collapse.
- Often the worst case is due to check valve closure.
- Axial force is strongly affected by system design and supports.
- Peak pressure is often determined by pump shutoff head, flow run-up transient, and initial gas pressure, volume, and location(s).

Water Hammer, continued

- Peak force is determined by peak pressure , pressurization rate, and configuration such as presence of a check valve.
- No generic analysis submittals.
- Review generally confined to regional inspections.
- GOTHIC has demonstrated water hammer capability.

Injection Delay

- NRC concluded that PWROG established "that an initial gas void of 5 ft^3 in high pressure system piping at 400 psia and 68 °F or low pressure system piping at 100 psia and 68 °F is not of concern with respect to most aspects of injection into a PWR RCS." ML13136A129
- "Further, it is assumed in the report that there is no delay or reduction in ECCS flow rate beyond the point assumed in the safety analyses of record."
- "Licensees referencing the information provided in this report must consequently establish that these assumptions are correct."

Net Positive Suction Head (NPSH)

- Actual NPSH criteria are typically applicable to steady state conditions and are not applicable to the short transients associated with many gas concerns.
- Required NPSH is the suction pressure that prevents vaporization within a pump.
- Inadequate NPSH may cause cavitation where vapor forms in the low pressure impeller region and collapses in the higher pressure region thus causing long-term damage.

NPSH, continued

- Non-condensible gas is typically not a cause of cavitation.
- Small amounts of gas have little effect on pump operation.
- Inadequate NPSH may cause unbalanced forces within a pump that results in pump damage.
- It is not usually necessary to address NPSH as part of transient gas investigations because it is addressed elsewhere.