# PWROG-15060 Review Status

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# Presentation Purpose

- Provide a forum for discussion of gas accumulation in pump suction piping for all meeting participants
- Identify background and regulatory requirements
- Discuss gas accumulation pump suction modeling including tests, NRC staff review of PWROG-15060, and initial requests for additional information (RAIs)

# Background

- 11/13/2015: Fee exemption request
- 12/30/2015: Draft PWROG-15060-P provided to NRC staff to support NRC inspections - review started at that time
- 05/05/2016: PWROG-15060-NP submitted to NRC for review and endorsement
- 05/09/2016: PWROG-15060-P submitted
- 06/13/2016: Formal NRC staff review of PWROG-15060 initiated (TAC. No. MF7789)
- 07/01/2016: Fee exemption granted
- 07/05/2016: New TAC No. MF8075 established

# Applicable Regulatory Requirements

- Plant-specific GDCs or Appendix A GDCs 1, 34, 35, 36, 37, 38, 39, and 40
- Appendix B Criteria III, V, XI, XVI, and XVII
- 10 CFR 50.46
- TS criteria such as 10 CFR 50.36(c)
- Current Design Basis

# Proposed Schedule

- 09/30/2016 Complete Farley inspection
- 10/31/2016 Complete PWROG-15060 draft SE
- 07/30/2017 Complete draft guidance document (Document type to be determined. May be a RG.)
- 12/16/2017 Complete gas management action plan
- Currently considering RIS, RG, IMC Revision, and SRP update

# Technical and Other Considerations

- The principal concern, and the focus of the present NRC staff review, is the effect of gas accumulation on pump operability due to gas entering a pump.
- In-depth use of computer programs that have proven capabilities, such as GOTHIC, is not included in the present review.
- Pump discharge piping and such phenomena as water hammer are of less concern and are not included in the present review.

# NEI / NRC Pump Void Fraction Criteria

An end point of a void investigation is establishing that voids reaching a pump will not cause a loss of operability. The following table provides acceptable pump suction void criteria:

| | **Q/Q(BEP)** | **BWR Typical Pumps** | PWR Typical Pumps | | |
|---|---|---|---|---|---|
| | | | Single Stage (WDF) | Multi-Stage Stiff Shaft (CA) | Multi-Stage Flexible Shaft (RLU, JHF) |
| Steady State Operation > 20 seconds | 40%-120% | 2% | 2% | 2% | 2% |
| Steady State Operation > 20 seconds | <40% or >120% | 1% | 1% | 1% | 1% |
| Transient Operation | 70%-120% | 10% For ≤5 sec | 5% For ≤20 sec | 20% For ≤20 sec | 10% For ≤5 sec |
| Transient Operation | <70% or >120% | 5% For ≤5 sec | 5% For ≤20 sec | 5% For ≤20 sec | 5% For ≤5 sec |

# Pump Void Criteria Observations

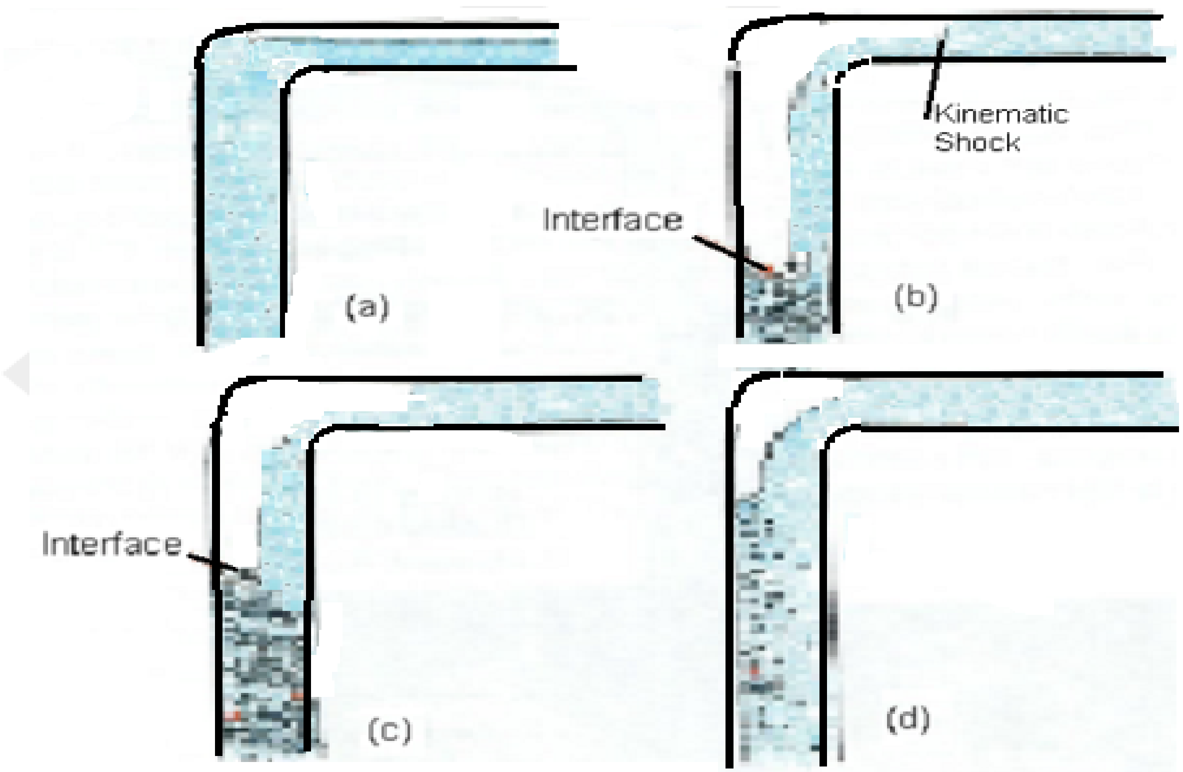
- Above criteria are conservative and may not need additional safety factors.
- The Electric Power Research Institute (EPRI) Pump Roadmap Report provides pump-specific criteria that some pumps may be acceptable with steady state 8% void and 25% transient void.
- The Pump Roadmap criteria are based on an extensive in-depth industry investigation of many pump types.
- The criteria may be acceptable if safety factors are used.

# Methodology Development

- Tests conducted at Purdue University using 4, 6, 8, and 12 inch pipe diameters provided data for development of the gas transport correlations reported in PWROG-15060.
- Tests conducted at the Westinghouse (W) Thermal Hydraulic Laboratory, for a Millstone 3 gas transport issue, reported by W and others for RHR suction piping from PWR hot legs, and at Alden Laboratories for draining tanks, provide information.
- The PWROG-15060 correlations are summarized on the following slides followed by test information.

# The PWROG-15060 Correlations

The initial behavior modeled by the PWROG-15060 correlations is summarized by the following sketch. The NRC staff confirmed that the equations were identical to the equations provided in WCAP-17271 with the exception of nomenclature changes.



# The PWROG-15060 Correlations, Continued

- $L_S =$ (4-2)

where: $L_S$ = ideal shock length = initial distance water falls through the void as a waterfall, ft

$V_i$ = initial gas volume, $ft^3$

$P_{t,I}$ = top header initial pressure

$P_t$ = top header average pressure over flow initialization time.

- $N_{FR} = \frac{u_{mix}}{\sqrt{g_c\, d\, /12}}$ (4-7)

where: $N_{FR}$ = Froude number

$u_{mix}$ = mixture velocity, ft/sec

$g_c$ = gravitational constant, $ft/sec^2$

d = pipe inside diameter, inch

# The PWROG-15060 Correlations, Continued

- Time to completely remove the initial gas volume, the flow initialization time, is given by:

- $\Delta t_{init} =$ (4-1)

- Weber number is given by:

$$W_e = \frac{\rho_\ell \, u_{mix}^2 \, L_{S,id}}{g_c \, \sigma} \qquad (4\text{-}4)$$

where:

| | | |
|---|---|---|
| | $\rho_\ell$ | = liquid density, lbs/ft$^3$ |
| | $g_c$ | = gravitation constant, ft/sec |
| | $\sigma$ | = surface tension, lbs/ft |
| | $u_{mix}$ | = mixture velocity, ft/sec |

# The PWROG-15060 Correlations, Continued

- The average gas volumetric flux at the kinematic shock exit at the bottom of the void in the downcomer where homogeneous bubbly flow is obtained is given by:

$\beta =$ (4-3)

- The gas volumetric flux at the entrance to an elbow below a downcomer is described by:

$\beta_{el,in} =$ (4-8)

where:

$\beta_{S,\,out}$ = volumetric flux ratio exiting a downcomer shock ( given by Equation 4-3)

$P_{S,\,out}$ = pressure at exit from DC shock

$P_{el,\,in}$ = pressure at entrance to elbow at bottom of the downcomer

# The PWROG-15060 Correlations, Continued

- β exiting an elbow is obtained from:

$$\beta_{el,out} = \qquad (4\text{-}6)$$

where: $\Delta t_{el,\ in}$ = time fluid is entering the elbow (Equation 4-1), sec

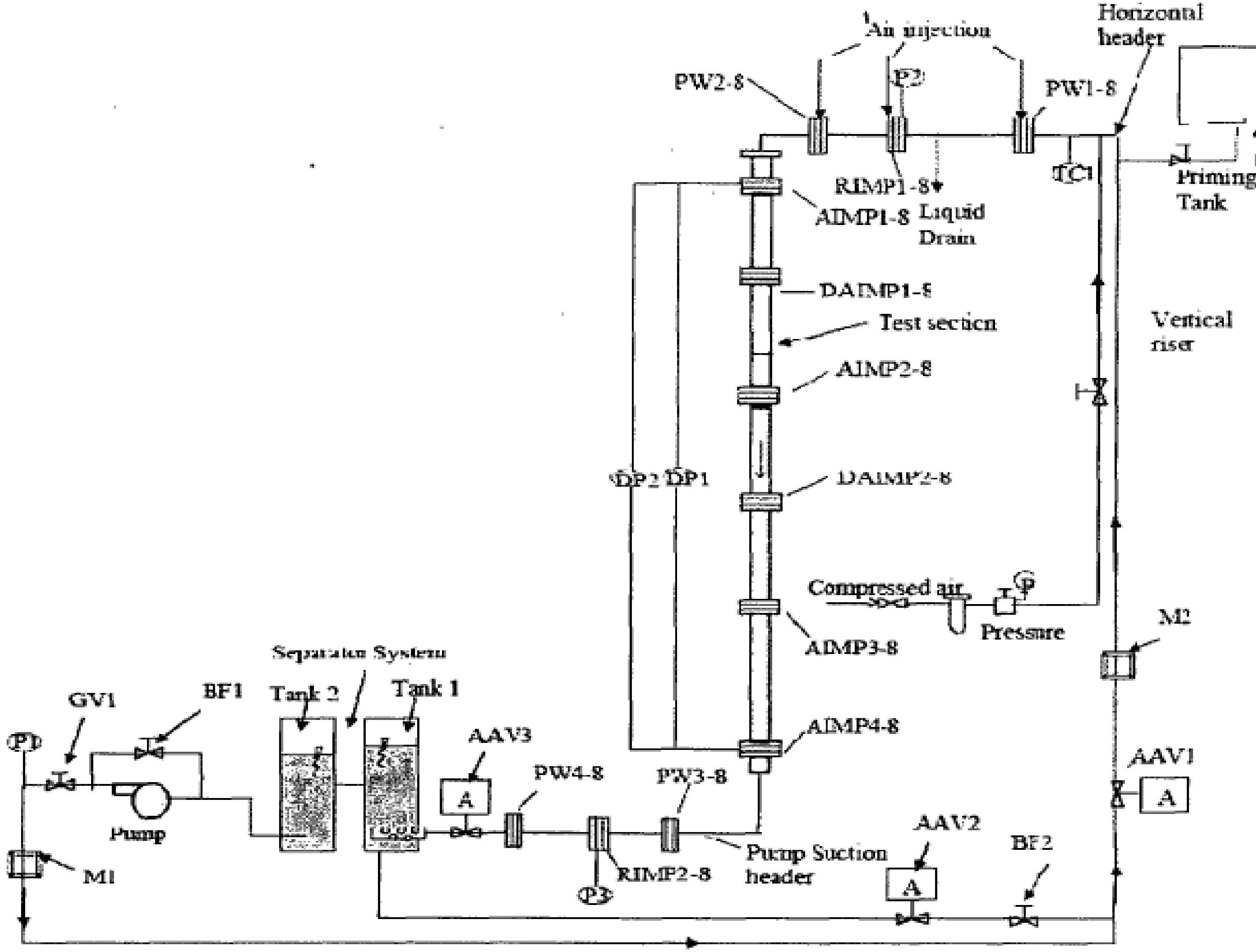
The time over which gas leaves the elbow is:

$$\Delta t_{el,out} = \qquad (4\text{-}9)$$

The downcomer length required to achieve homogeneous bubbly flow is given by:

$$L_S = \qquad (5\text{-}6)$$

# 8 Inch Purdue University Test



# Experiments – Purdue University

# Correlation Comparison to Purdue Data

The following slides compare the volumetric flux ratio (β) values estimated from graphs from WCAP-17271 Vol 3 to the solid lines that were generated by using Excel with the WCAP-17271 and PWROG-15060 correlations.

β at downcomer (DC) bottom "data" correspond to about 4 to 5 ft above the bottom of DC. $\beta_{out}$ "data" are about 12 ft from the DC bottom in the lower horizontal pipe. Both are assumed to be downstream of the kinetic shock effects.

# Correlation comparison to Purdue Data
# 5% Initial Void Volume, 8 Inch Pipe, Bottom of DC

# Correlation comparison to Purdue Data
# 5% Initial Void Volume, 8 Inch Pipe, Exit From Elbow Following Kinematic Shock in Lower Horizontal Pipe

# Correlation comparison to Purdue Data
## 5% Initial Void Volume, 8 Inch Pipe, Δβ Across Elbow

# Correlation comparison to Purdue Data
# 20% Initial Void Volume, 8 inch Bottom of DC

# Correlation comparison to Purdue Data
# 20% Initial Void Volume, 8 inch Pipe, DC Exit

# Correlation comparison to Purdue Data
# 20% Initial Void Volume, 8 Inch Pipe, Δβ

# Correlation comparison to Purdue Data
# 20% Initial Void Volume, 6 Inch Pipe, Bottom of DC

# Correlation comparison to Purdue Data
# 20% Initial Void Volume, 6 Inch Pipe, DC Exit

Correlation comparison to Purdue Data

20% Initial Void Volume, 6 Inch Pipe, Δβ

# Downcomer Length to Achieve Homogeneous Bubbly Flow Based on Purdue Eight Inch Tests

| Φ | Approximate length from Equation 5-6, ft | Estimated Length from Purdue Data, ft | Factor of four length with $N_{FR}$ = 1.27, ft |
|---|---|---|---|
| 0.05 | | | |
| 0.10 | | | |

Equation 5-6 predicts that a greater DC length is required to bound the kinematic shock than is required by the data. This is a conservative result.

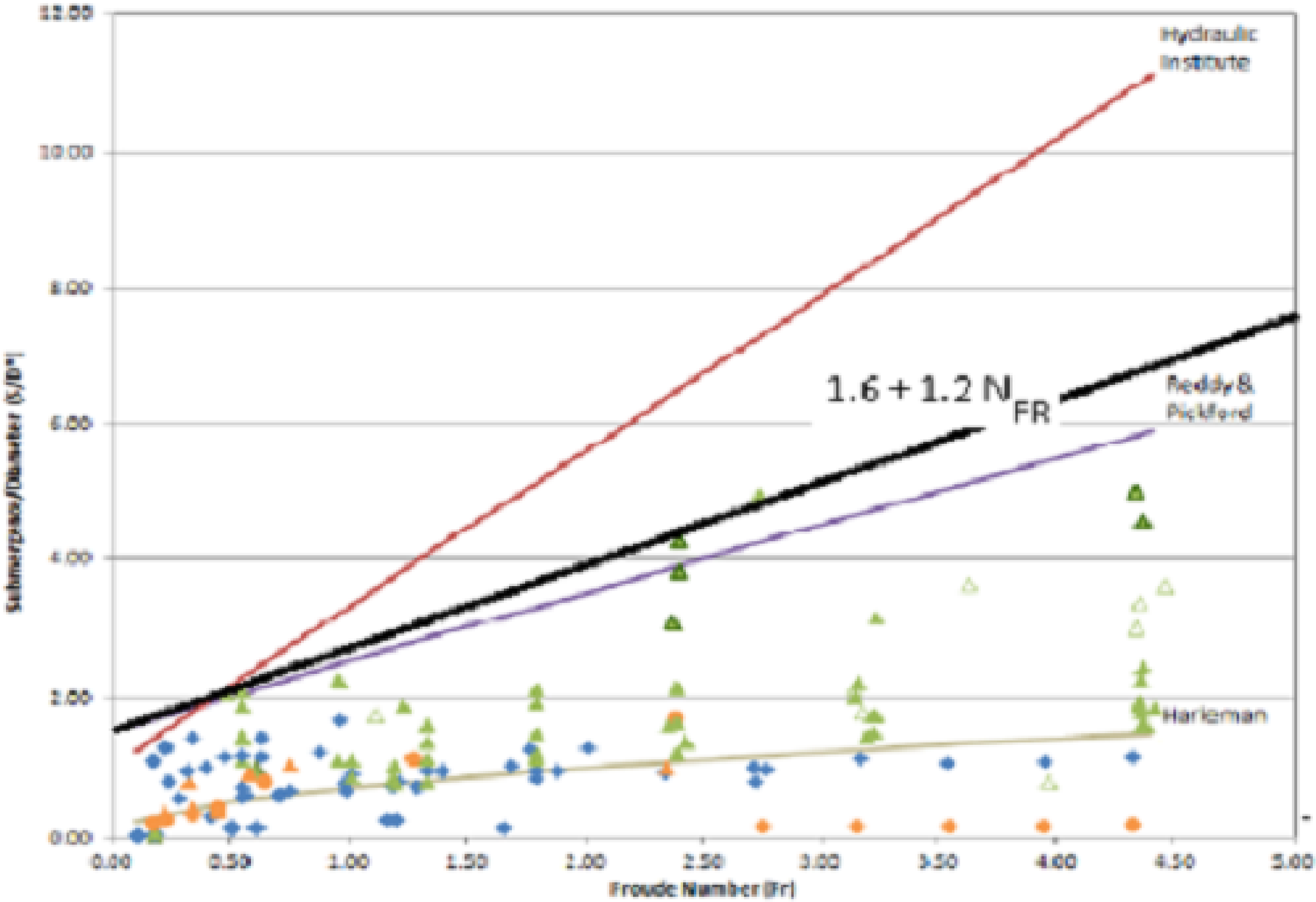
# Comparison Conclusions

- Comparison of the PWROG-15060 correlations to Purdue data does not substantiate the predicted β values or trends. Review is not complete.
- Comparison of predicted downcomer length required to achieve homogeneous bubbly flow using Equation 5-6 is conservative when compared to Purdue data and is substantially less than required by the factor of four criterion.

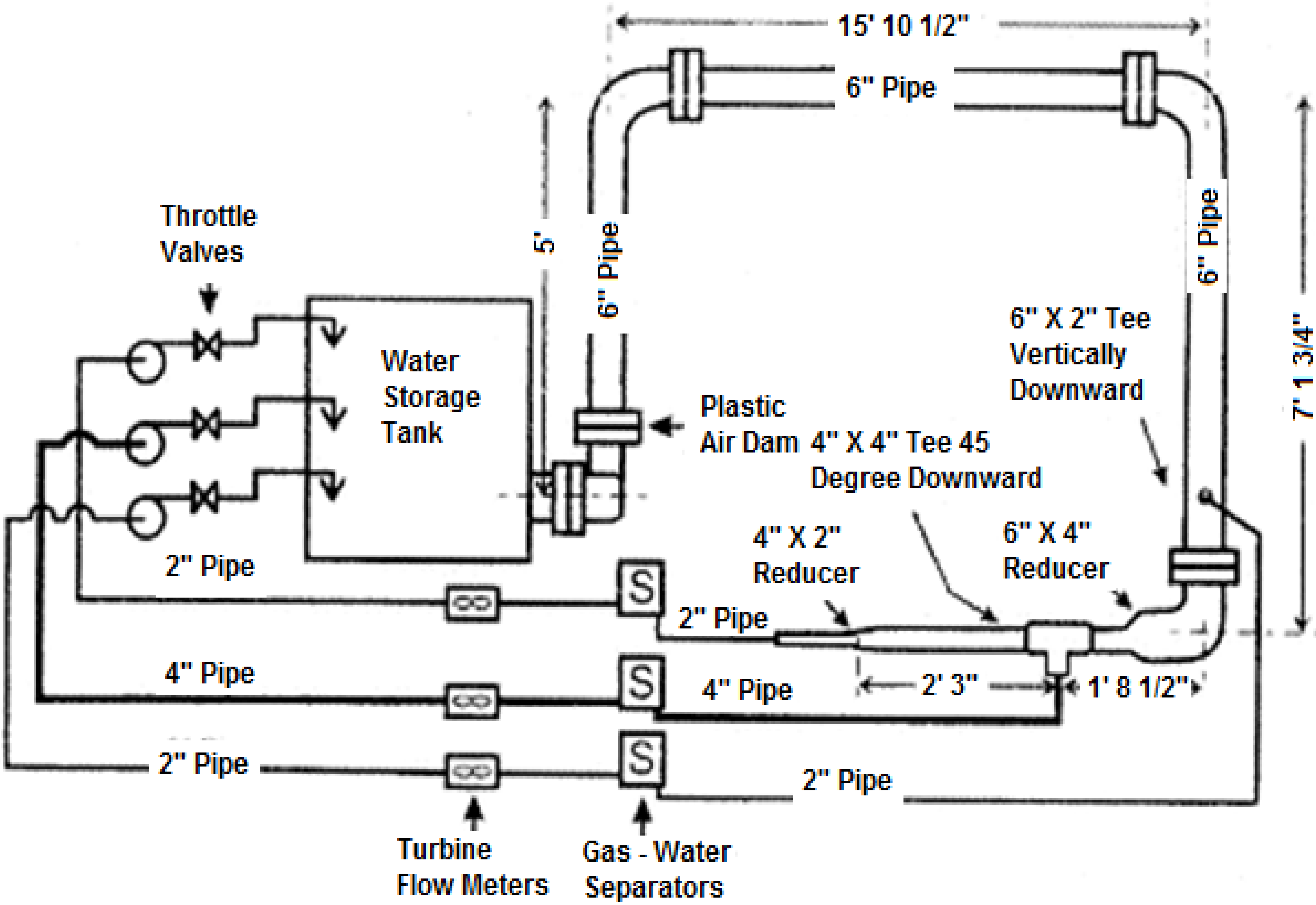
# Experiments – Westinghouse Thermal Hydraulic Laboratory

# PWROG-15060 Correlation Comparison to W data in Lower Horizontal Pipe

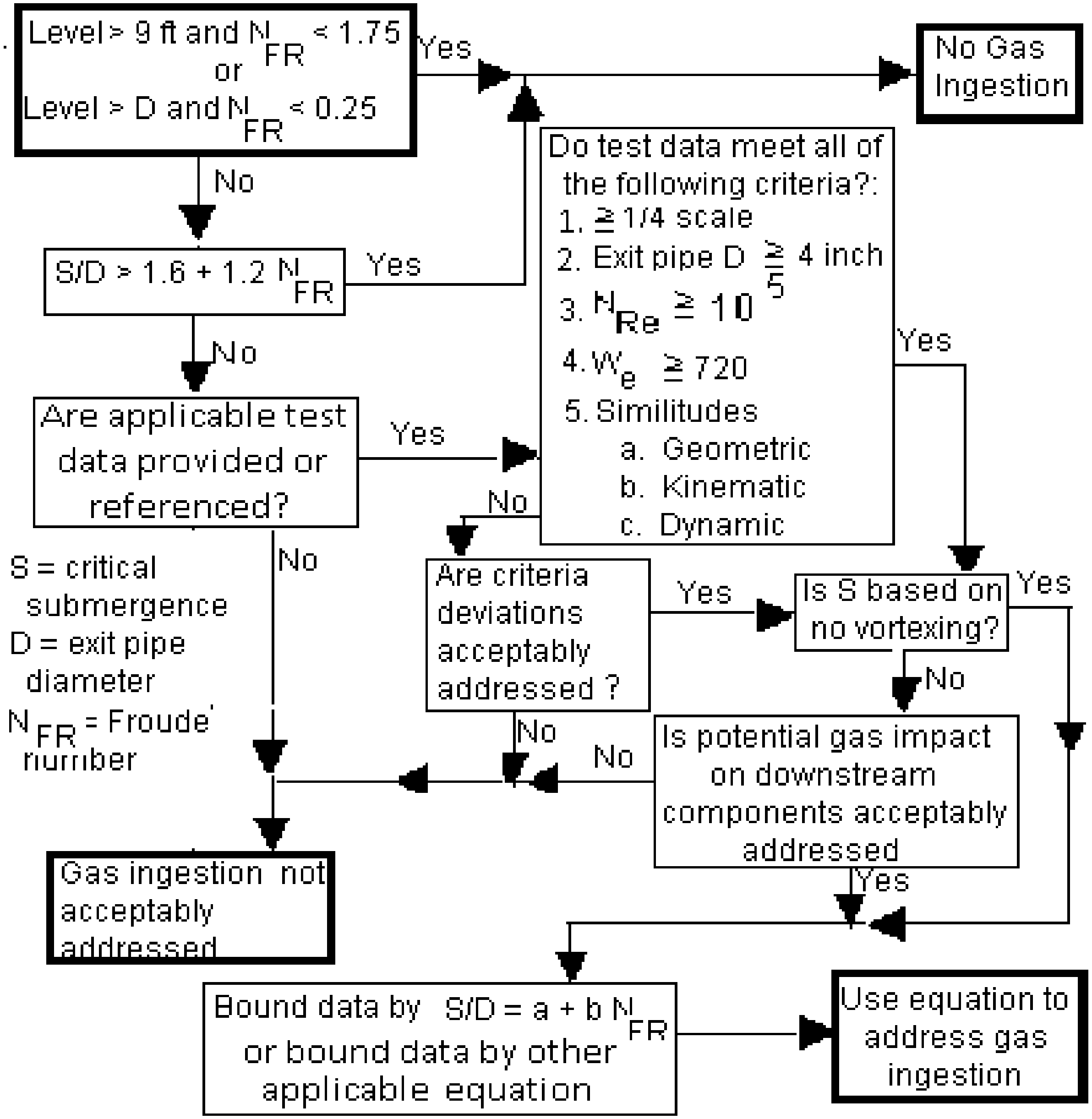
Alden Laboratory Minimum Tank Level Test Results



# Experiments –Millstone 3 Tests



# Minimum Tank Level and PWR RHR Hot Leg Operation



RAI 1. We understand that some of the Froude numbers attained in the Purdue tests differ from the planned numbers. Please explain. What values of Froude numbers should be used when analyzing the Purdue data?

This understanding resulted from information obtained during support of an inspection. The next slide shows the variation.

# Planned Versus Actual Froude Numbers

RAI 2. Please provide tables of transport times that were determined by the process discussed in Section 8.2.2 of WCAP-17271-P Volume 1.

We need this information to evaluate the calculation of volumetric flux ratio ($\beta$) as discussed in RAI 3.

- RAI 3. Please provide calculations of a representative selection of the volumetric flux ratio, β, provided in the graphs contained in WCAP-17271-P Volume 3 using the transport times identified in RAI 2 and the following PWROG-15060-NP equation:

- $$\beta = \frac{Q_g}{Q_{mix}} = 448.8\,\frac{V_i\left(\frac{P_{t,i}}{P_M}\right)}{Q_{mix}\,\Delta t} \qquad (4\text{-}5)$$

or, if a different process was used to calculate β, describe that process and provide the requested calculation using the different process. See also RAI 4.

RAI 4. In assessing flow characteristics discussed in WCAP-17271-P, is it correct to obtain the liquid velocity from the published Froude Number? If not, how is liquid velocity obtained? Equations 8-7 and 8-8 can be combined to obtain the mixture flow rate, $Q_{mix}$, as a function of Froude Number. Is it correct to obtain $Q_{mix}$ from that equation and to use the resulting $Q_{mix}$ to obtain $\beta$ from Equation 4-5?

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# RAI 5.

β exiting an elbow is obtained from:

$$\beta_{el,out} = \qquad (4\text{-}6)$$

where

$$\beta_{el,in} = \qquad (4\text{-}8)$$

$$\Delta t_{init} = \qquad (4\text{-}1)$$

$$L_S = \qquad (4\text{-}2)$$

Provide justification for using Equation 4-6 for the following:

# RAI 5, Continued

- The upstream downcomer length is less than required to accommodate the ideal gas length that is calculated by PWROG-15060-P Equation 4-2.
- The upstream downcomer length is less than required to ensure that homogeneous bubbly flow occurs at the downcomer exit.
- The downcomer is located downstream of another downcomer and the connecting pipe is a short horizontal pipe where a kinematic shock does not occur.
- The downcomer is located downstream of another downcomer and the connecting pipe is a long horizontal pipe where a kinematic shock has occurred.
- The downcomer is located downstream of another downcomer and the connecting pipe provides homogeneous bubbly flow at the entrance of the downstream downcomer.

RAI 6. Please address how the data in PWROG-15060-P Figures 9-1 through 9-3 are related to the System Test points in Figure 9-4.

Figure 9-1 System Test: 2 Percent Initial Gas Volume Fraction, 500 gpm

Figure 9-2 System Test: 23 Percent Initial Gas Volume Fraction, 500 gpm

Figure 9-3 System Test: 50 Percent Initial Gas Volume Fraction, 500 gpm

Figure 9-4 W Facility Test Results

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- RAI 7. Please provide the information necessary to independently reconstruct the points (including the x and y coordinates and the corresponding values) in PWROG-15060-P Figure 9-4. For example, what are the test conditions that resulted in the x coordinate values?

- RAI 8. Please provide a calculation using the WCAP-17271 correlations to obtain the WCAP-17271points in PWROG-15060-P Figure 9-4.