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# Subscale Brine Injection Test

## Overview for NRC

Date: February 26, 2015

# Agenda

- Opening Remarks
- Background
- Experimental Objectives
- Scenario Description
- Previous Brine Testing
- Selection of Working Fluid
- Facility Overview
- Test Plan
- Test Results
- Feedback / Discussion

# Background

- Separate effects testing to support cold leg break GSI-191 concerns by demonstrating that communication between the core and the lower plenum will continue in the presence of a forming debris bed with a certain fiber load.
- Extend the use of the subscale test facility to inform the BAP program as to the influence of in-vessel debris on BAPC.
- Completion of this work will negate any need to separate BAP from GSI-191 since BAP concerns related to in-vessel fiber will be addressed.

# Experimental Objectives

- Determine fibrous debris limit that does not stop mass transport between the core and lower plenum driven by density gradients that develop due to boron solute buildup in the core during a large CLB.
  - Design an adiabatic separate effects test that takes advantage of the existing test apparatus constructed for GSI-191 closure.
  - Simulate the post-LOCA density gradient that exists between the core and lower plenum by injecting a high density salt solution that simulates boron solute buildup in the core post-LOCA.
  - Investigate how this density driven transport mechanism is influenced by the presence of debris collection at the core inlet.
  - Use instrumentation to measure the solution concentration and confirm the transport of mass through the core inlet geometry.

# Prototypic Scenario

- Limiting scenario for BAPC is a large cold leg break.
  - Excluding 2-Loop UPI plants
    - UPI plants are large hot leg break limited.
    - UPI plants will not accumulate fiber at the core inlet like plants with cold side injection.
  - Boric acid (BA) accumulates in the core region due to boil-off.
  - Multiple processes promote mixing of boric acid in core region with other regions of the reactor vessel.
- Buoyancy-driven convection occurs between the core and lower plenum.
  - Rate of mass transport is dependent on interface geometry, density gradient and steaming rate.
  - Effective mixing volume increases and build-up of BA slows.
  - The effects of debris collection at the core inlet are not well understood.

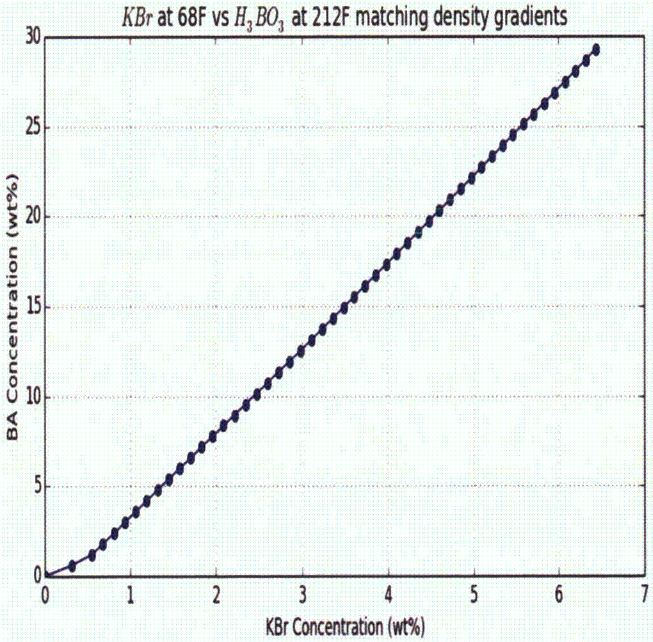
# Previous Brine Testing

# Previous Test Results

- Concentration gradient across core inlet independent of lower plenum geometry.
- Lower plenum mixing influenced by lower plenum geometry.

# Selection of Working Fluid

- Replicate the properties of varying concentrations of boric acid at 212°F and 14.7 psia.
- Examined four different salt solutions: Sodium Chloride (NaCl); Potassium Bromide (KBr); Potassium Chloride (KCl); Sodium Bromide (NaBr).
- KBr is chosen as the working fluid.



# Scaling Considerations

- Differences in absolute viscosity can be put into perspective through dimensional analysis. When the Grashof number (Gr) is large, viscous forces are negligible compared to the buoyancy and inertial forces.

$$Gr = \frac{g \cdot \beta \cdot (C_1 - C_0) \cdot L^3}{\nu^2}$$

- While the viscosity of the salt solution may be ~2-5x greater than BA, it is still relatively small.
- Even for a small concentration gradient, Gr is large, causing vigorous convection currents to arise.

# Scaling Considerations

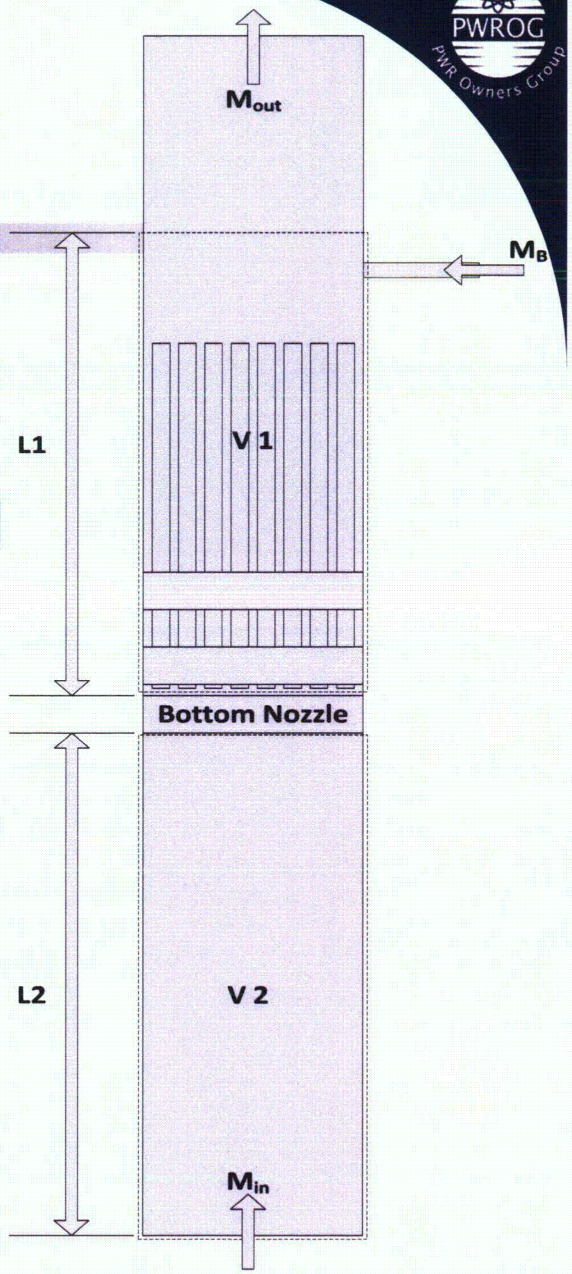
- Froude number (Fr) can be used to predict onset of density driven flow by providing the relative importance of inertia to buoyancy forces.

$$Fr = \sqrt{\frac{\rho_0 \cdot U^2}{g \cdot L^2 \cdot \frac{d\rho_0}{dz}}}$$

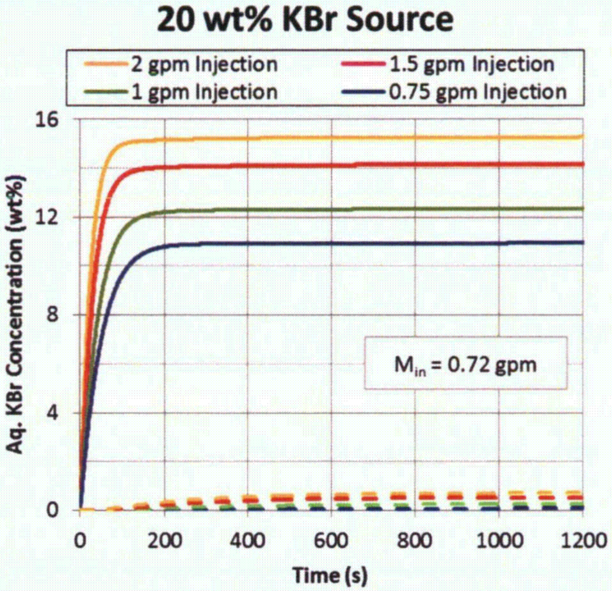
- The formulation of the Froude number reinforces the fact that so long as the density gradient is equivalent between the salt solution and the boric acid solution being simulated, the fluid behavior will be similar as well.

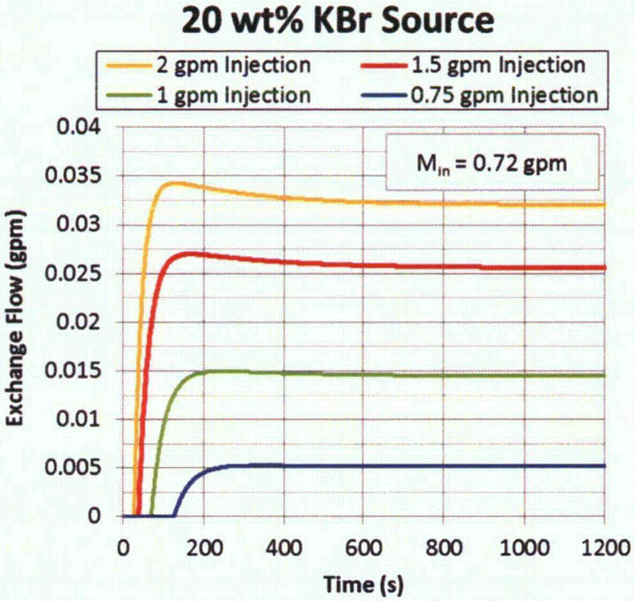
# Subscale Simulation

- Create series of steady-state conditions in which buoyancy-driven exchange flow will occur in the subscale facility.
- Brine will be injected into Control Volume 1 several inches above the test geometry.
- When the density gradient overcomes the upward flow, buoyancy-driven mass transport will begin between V1 and V2.
- Two-region transport model described in OG-13-205 used for simulation.
  - No temperature gradient between regions
  - Constant inlet flow
  - Solution exits flow column (NOT a "boiling pot")



# Simulation Results

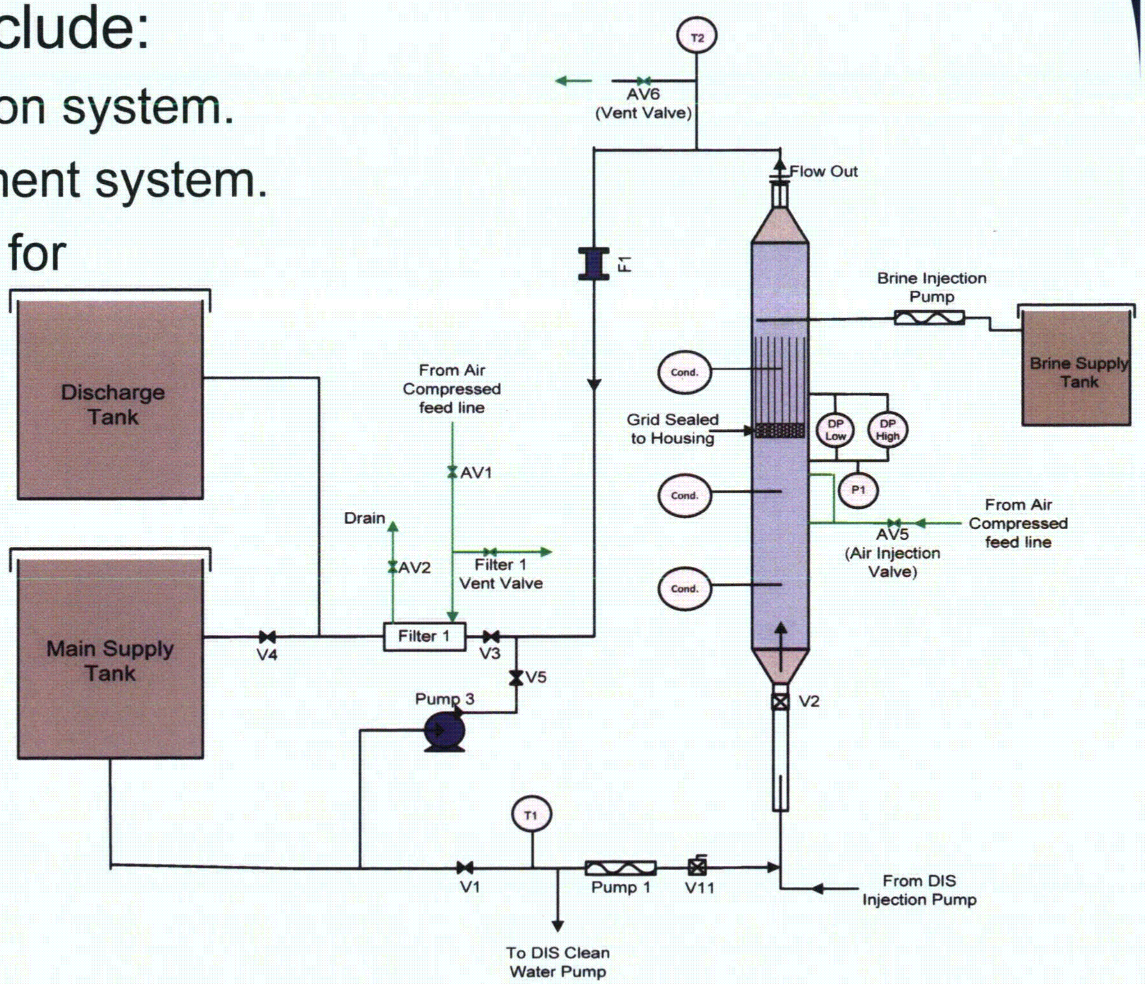



- Simulation Conclusions
  - Since the time scale associated with the onset of mass transport cannot be preserved, the time at which brine is injected relative to debris should be varied within the test matrix.
  - Injection flow rate or source concentration should be varied within the test matrix to create a range of exchange flow rates consistent with varying plant conditions.
  - The density gradient at the onset of mass transport can be preserved.

# Subscale Facility Modifications

- Major modifications include:
  - Addition of brine injection system.
  - Conductivity measurement system.
  - A second 300 gal. tank for once-through flow.

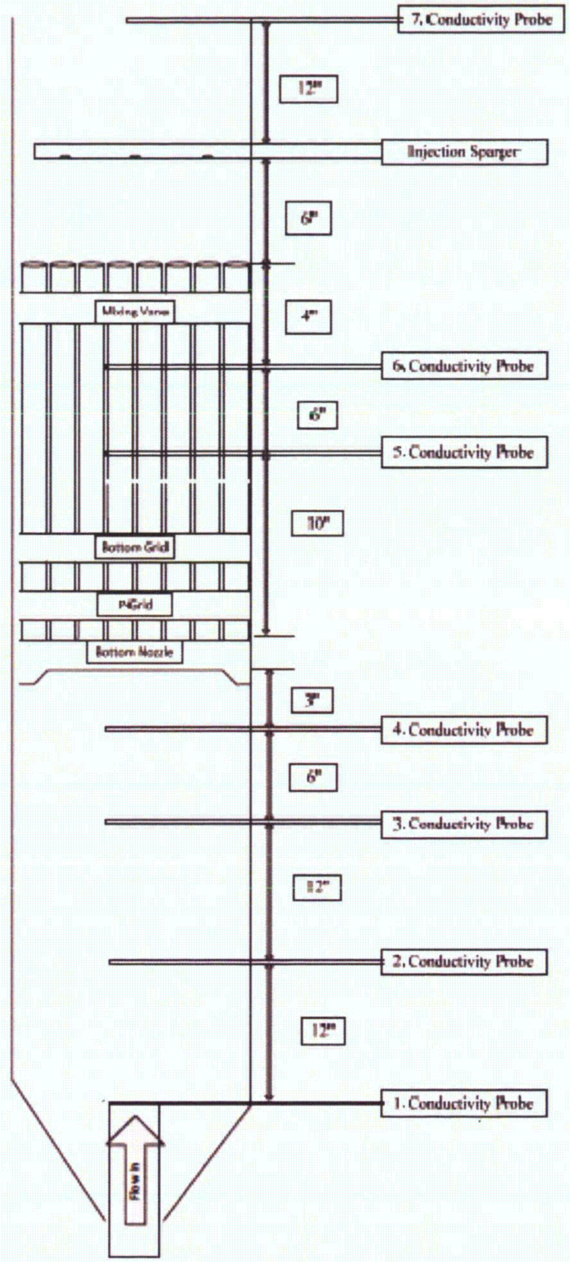


# Debris Constituents and Test Geometry

- Utilize fibrous and particulate debris.
  - Same material used in the PA-SEE-1090 test program.
- Chemical debris will not be considered.
- One round of tests will be completed using particulate debris.
  - Same debris size distribution and p:f ratio used in the PA-SEE-1090 test program.
  - Limit visual observations
- Test geometry will be the core inlet geometry used for the PA-SEE-1090 final limits testing.
- Consists of bottom nozzle, p-grid, and bottom spacer grid from a Westinghouse 17x17 RFA fuel assembly.

# Conductivity Probe

- Fast response micro-conductivity probe
  - Meets the functional requirements and has a 1/8” body diameter that can easily be installed in the subscale flow column.
- Will be calibrated using KBr solutions
  - Initial calibration using dip technique
  - Effect of flow field to be investigated



# Test Plan

- Separated into shakedown and final test phases.
  - Shakedown phase is to confirm that the new systems function as expected/required.
    - Finalize operating procedures that will be used for final testing.
    - Determine the baseline debris only conditions.
    - Characterize brine injection
  - Final Test Matrix defined using shakedown results.
    - Range of conditions for debris loads
    - Brine injection characteristics
    - Three parameters will be varied: timing of brine injection, debris load, and brine source concentration.

# Shakedown Testing (debris only)

| Test ID (Data File Name) | Units | 1188-TP001-01 | 1188-TP001-02 | 1188-TP001-03 | 1188-TP001-04 | 1188-TP001-05 | 1188-TP001-06 | 1188-TP001-07 |
|---|---|---|---|---|---|---|---|---|
| Repetition # | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Grid Type | | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN |
| Temperature | °F | 68 | 68 | 68 | 68 | 68 | 68 | 68 |
| Pressure (for fluid properties) | psia | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 |
| Density | lbm/ft3 | 62.3 | 62.3 | 62.3 | 62.3 | 62.3 | 62.3 | 62.3 |
| Volumetric Flow Rate | gpm | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Flow Rate (Scaled to single FA) | gpm/FA | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Fiber Type | | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON |
| Fiber Mass | g | 3.5 | 3.5 | 5.25 | 5.25 | 1.75 | 1.75 | 3.5 |
| Fiber Mass (Scaled to FA) | g | 15 | 15 | 22.5 | 22.5 | 7.5 | 7.5 | 15 |
| Particulate Type | | SiC | SiC | SiC | SiC | SiC | SiC | SiC |
| Particulate Size Distribution | | Dist. 1 | Dist. 1 | Dist. 1 | Dist. 1 | Dist. 1 | Dist. 1 | Dist. 1 |
| Particulate Mass | g | 0 | 42 | 0 | 63 | 0 | 7 | 21 |
| Particle to Fiber Ratio | | 0 | 12 | 0 | 12 | 0 | 4 | 6 |
| Debris Injection Duration | min | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Peak Fiber Injection Rate | g/min | 0.38 | 0.38 | 0.57 | 0.57 | 0.19 | 0.19 | 0.38 |
| Peak Particulate Injection Rate | g/min | 0 | 4.56 | 0 | 6.84 | 0 | 0.76 | 2.28 |

# Debris Only Results

- Pressure drop across debris bed is very small.
  - Less than 0.1 psid.
  - On the order of instrument accuracy.
- Fiber beds cannot support large particulate loadings and remain stable.
  - 12:1 injected p:f ratio results in break-through.
  - Particulate capture efficiency <10%.

# Shakedown Testing (brine injection)

| ID | Brine Injection (gpm) | Source Concentration (wt%) | Initial Column Flow (gpm) |
|---|---|---|---|
| SD 1 | 0.5 | 20 | 0 |
| SD 2 | 0.5 | 20 | 0.75 |
| SD 3 | 0.5 | 20 | 0.5 |
| SD 4 | 1 | 20 | 0 |
| SD 5 | 0.5 | 16 | 0.75 |
| SD 6 | 0.5 | 11 | 0.75 |

# Brine Injection Results

# Brine Injection Results

# Shakedown Testing (brine injection)

# Testing Plan (Phase 1)

| Test ID (Data File Name) | Units | 1188-TP001-08 | 1188-TP001-09 | 1188-TP001-10 | 1188-TP001-11 | 1188-TP001-12 | 1188-TP001-13 | 1188-TP001-14 | 1188-TP001-15 | 1188-TP001-16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Repetition # | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Grid Type | | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN | W-RFA-BN |
| Temperature | °F | 68 | 68 | 68 | 68 | 68 | 68 | 68 | 68 | 68 |
| Pressure (for fluid properties) | psia | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 |
| Initial Upward Flow Rate | gpm | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Initial Upward Flow Rate (Scaled to single FA) | gpm/FA | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |
| Brine Injection Flow Rate | gpm | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Brine Injection Concentration | wt% | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Start of Brine Injection Relative to Fiber Add. | min | -- | Concurrent | 20 | Concurrent | 20 | Concurrent | 20 | Concurrent | 20 |
| Fiber Type | | -- | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON | Blended NUKON |
| Fiber Mass | g | 0 | 1.17 | 1.17 | 1.75 | 1.75 | 2.33 | 2.33 | TBD | TBD |
| Fiber Mass (Scaled to FA) | g | 0 | 5 | 5 | 7.5 | 7.5 | 10 | 10 | TBD | TBD |
| Particulate Type | | -- | -- | -- | -- | -- | -- | -- | SiC | SiC |
| Particulate Size Distribution | | -- | -- | -- | -- | -- | -- | -- | Dist. 1 | Dist. 1 |
| Particulate Mass | g | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TBD | TBD |
| Particle to Fiber Ratio | | -- | 0 | 0 | 0 | 0 | 0 | 0 | TBD | TBD |
| Debris Injection Duration | min | -- | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Peak Fiber Injection Rate | g/min | -- | 0.13 | 0.13 | 0.19 | 0.19 | 0.25 | 0.25 | TBD | TBD |
| Peak Particulate Injection Rate | g/min | -- | 0 | 0 | 0 | 0 | 0 | 0 | TBD | TBD |

# Results: Concurrent Injection

# Results: Delayed Injection

# Results: Delayed Injection

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