AGENDA
PUBLIC MEETING
NOVEMBER 2, 2005
GSI-191 CHEMICAL EFFECTS

| TOPIC - PUBLIC MEETING | PRESENTER | TIME |
|---|---|---|
| Opening Remarks, Introductions | NRC/NEI | 9:00 A.M. |
| Chemical Effects Head Loss<br>Industry Test Plans | NEI/Industry | 9:20 A.M. |
| Break | | 10:30 A.M. |
| Discussion of Industry Test Plans | NRC/Industry | 10:50 A.M. |
| Lunch | | 12 Noon |
| Continue Discussion | NRC/Industry | 1:00 P.M. |
| NRC Update - Head Loss Tests | NRC | 1:45 P.M. |
| Adjourn Business Portion of Public Meeting | | 2:00 P.M. |
| NRC will address public questions/comments | | 2:00 P.M. |
| Adjourn Public Meeting | | 2:30 P.M. |

# Method for Evaluating Post-Accident Chemical Effects in Containment Sump Fluids

Prepared by: Tim Andreychek
Westinghouse Electric Company
412-374-6246

Presented by: Art Byers
Westinghouse Electric Company
Phone: 412-256-1678

November 2, 2005



## Summary of Results from ICET Testing

Integrated Chemistry Effects Test (ICET)

- Three (3) buffering agents used:
  - Sodium Hydroxide (NaOH)
  - Tri-sodium Phosphate (TSP)
  - Sodium Tetraborate
- Two (2) types of insulation used:
  - Fiberglass
  - Calcium Silicate (cal-sil)
- Some chemical products produced from reacting buffering agents and insulation types that are known to result in high head loss
- This was demonstrated in Argonne National Laboratory (ANL) vertical loop test
  - ANL test may be excessively conservative with respect to amount of chemical reactants
  - No attempt made to quantify amount of conservatism
- NRC is concerned
  - Issued Information Notice 2005-26
  - Held a public meeting on September 30, 2005

## Summary of ICET Insulation/Buffering Agent Reactions

| | | Type of Buffering Agent | | |
|---|---|---|---|---|
| | | Sodium Hydroxide | Tri-Sodium Phosphate | Sodium Tetraborate |
| Type of Insulation | 100% Fiberglass | Large quantity of aluminum salts formed; expect high head loss in vertical loop head loss test | Expect a limited amount of calcium phosphate formed from concrete | Limited chemical reactions observed |
| | 80% Calcium Silicate / 20% Fiberglass | Calcium seems to inhibit aluminum corrosion; may not see high head loss in vertical loop tests | Large quantity of calcium phosphate formed; high head loss in ANL vertical loop head loss test | |



## Use of ICET Results to meet Requirements of NRC GL 2004-02

ICET Tests Provided:

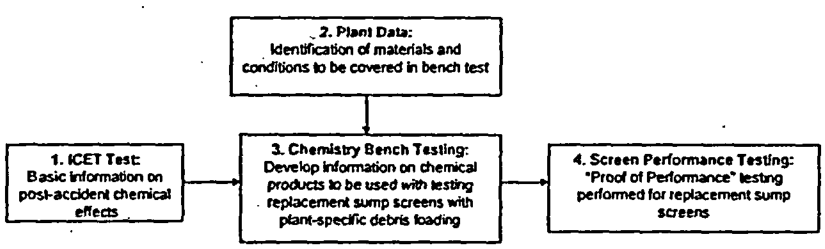
- The main chemical precipitants of interest for phosphate, sodium hydroxide, and sodium tetraborate buffer systems
  - AlOOH
  - Calcium phosphate
  - Upper limits for generation of precipitates during long term recirculation
- The ICET Results may be used to provide input for empirical verification tests for new screen designs

# Limitations on Use of ICET Tests

- Use ICET results have several short comings noted by the NRC
  - Temperature of 140°F selected for long term conditions; does not simulate first day of LOCA with temperature up to maximum containment pool temperatures.
  - ICET material containment mix designed to be representative, some materials of minor quantities were omitted from the simulated containment mix.
  - Calcium phosphate precipitate quantity may have been overestimated because of non-typical time/pH exposure of Cal-Sil insulation
  - Little characterization of particulate size and composition.
- Bench tests will be needed to generate additional information.



# Overview of Path Forward




1. The ICET tests provide basic information on post-accident sump chemical effects.
2. Using plant-specific input, specific materials and amounts of materials are selected for the bench testing.
3. Bench testing is conducted for the purpose of characterizing the type and amount of chemical products that are produced.
4. Chemical product information generated from bench testing is used as an input to performance testing of replacement sump screens.

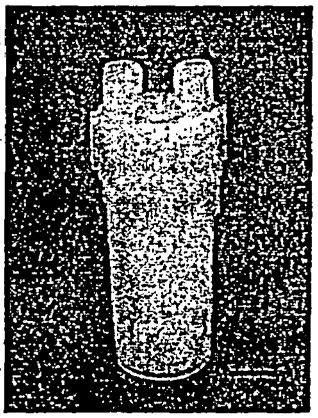
## Purpose of this Test Program

- The purpose of this test plan is to develop information to supplement and augment the information obtained from the ICET program.
- Specifically, more representative values of parameters will be used:
  - Types of insulation
    - Micro-therm, min-k, and other lesser-used insulations will be evaluated for post-accident chemical effects.
  - Amount of insulation
    - Debris generation calculations, not available when the ICET test plan was generated, will be used to guide selection of appropriate quantities of debris for use in testing.
  - Temperature effects
    - Evaluate chemical effects at sump water conditions representative of early (within 30 minutes of the postulated break) in the transient (using conservative licensing-basis assumptions, sump liquid temperatures are calculated to reach up to about 260 °F during time period.
- Technical basis for not including certain materials (i.e., known reactions, minute quantities, etc.) will be prepared for those materials.



## General Program Approach

- Tests will be done at the "bench level" scale.
  - This will allow testing to be completed in a time and cost effective manner.
- The dissolution rate and possibly the solubility limit for each of the containment materials of interest will be measured.
  - This will be done as a function of pH and temperature.
- Measurements will include:
  - Interactions between dissolved matter from various containment materials.
  - Precipitate formation upon cooling.
- Data will be used to construct a model to predict amounts and character of precipitates that will form from plant-specific containment material mixes for a LOCA.
- Design requirements for equipment that can then produce the type and quantity of precipitates needed for such tests will be generated.



Reaction Vessel

# Overall Test Approach

Produce reasonable but conservative estimates for precipitate formation.

- Measure dissolution rates for each containment material individually.
  - Rates are expected to be higher than that obtained from containment material mixtures.
  - Dissolution of one material will have either no effect or an inhibiting effect on the dissolution of other materials.
    - Cal-Sil inhibits the dissolution of aluminum (ICET Test 4), but the region of influence for some LOCAs will not include Cal-Sil, even at a plant with a large volume of Cal-Sil.
    - *Trisodium phosphate will inhibit the dissolution of Cal-Sil, but trisodium phosphate will take a finite period of time to dissolve, during which the Cal-Sil will dissolve at a high rate.*
- Test at temperatures up to a maximum value determined from industry survey of containment pool temperatures after large break LOCA and before recirculation.
  - Allows reactions during the first hours of a LOCA to be considered.
- Consideration of dissolution and precipitation reactions in separate bench tests:
  - Simplifies the interpretation of results and enables the use of the precipitation in chemical modeling.
  - Integrated testing with complex mixtures of materials may result in dissolution and precipitation occur simultaneously, making weight loss and gain information minimally useful.



# Dissolution Testing

- Dissolution of materials
  - Will be measured at temperatures determined from industry surveys with a range of pH values expected in the post LOCA environment.
  - All pH solutions will be contain 2800 ppm boric acid and HCl.
    - Maximum pH will be 12 (depending upon survey results) and will be generated with sodium hydroxide. This is the maximum pH expected for the containment spray solution in a plant using NaOH pH buffering.
    - An intermediate pH of 8 will be tested. This is a typical containment pool pH after complete addition of the pH buffering agent.
    - The minimum pH will be 4 (depending upon survey results). This is the lowest pH expected before complete dissolution of TSP or addition of sodium hydroxide.
  - pH values listed are starting values. The pH will vary as the containment materials dissolve.

# Dissolution Testing

- *The following materials are planned for testing:*
  - Aluminum sheet
  - Calcium silicate insulation
  - NuKon™ fiberglass
  - Previously untested fiberglass (Temp Mat)
  - Powdered concrete
  - Mineral Wool (e.g. K-Wool)
  - Microporous Insulation (e.g. Kool-phen)
  - Fire Retardant Material (e.g. FiberFax)
- Materials to be tested will be reviewed against plant input currently being collected.
- The total amount of material dissolving after at least two different periods of time will be measured.
  - Short time = 30 minutes. This is representative of the time before initiation of realigning the ECCS to the containment sump with all trains of ECCS operating.
  - Long time = 60 minutes. This is representative of the time before initiation of realigning the ECCS to the containment sump with only one train of ECCS operating.
  - *An intermediate time = 45 minutes may also used to evaluate rate of change of dissolution of the test material.*
- The tests will be repeated at 190 °F so that the effect of temperature can be modeled.



# Dissolution Testing

- Trisodium Phosphate Dissolution Rate
  - The exact timing of measurements will depend in part on the dissolution rate expected for trisodium phosphate.
  - Information will be collected on the dissolution rate anticipated for trisodium phosphate after a LOCA, and if necessary, additional dissolution rate tests will be performed with and without the presence of calcium in solution.
- Nickel and Iron from the RCS
  - Nickel and iron dissolution from the RCS will not be included in this testing.
  - Normal PWR shutdown chemistry evolutions have shown the iron will be released at insignificantly low levels.
  - Nickel concentrations as high as 12 ppm may be expected, but nickel is quite soluble in all of the postulated post-LOCA chemical environments and does not need to be included in studies related to head loss.

# Sample of Dissolution Test Matrix

- For Aluminum – repeats for other materials.
- Temperatures in the table may change based on plant surveys.

| Run | Test Conditions | | | Measurements | | | |
|---|---|---|---|---|---|---|---|
| | Material | Solution | T (°F) | 0.5 hr | 0.75 hr? | 1 hr | 1 hr |
| 1 | 1. Aluminum sheet | 2800 ppm B H3B03 + HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 2 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 3 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 4 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 5 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 6 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |

Sol. ICP = analysis of dissolved elements by ICP.
Coup. Mass = Mass loss of the starting material.



# Precipitation Testing

- Dissolved material produced at a maximum temperatures as determined from plant survey responses will be cooled to test for chemical precipitate formation.
  - The pH of the boric acid solutions will also be adjusted to pH 8 in separate tests using sodium tetraborate and trisodium phosphate.
- The following characteristics of the precipitate will be measured:
  - Precipitate mass
  - Precipitate settling rate
  - Settled precipitate volume
  - Precipitate filterability.
- Potential for interaction between different containment materials to produce precipitation beyond that produced from a single material will be investigated.
  - Use screening tests that measure the mass of precipitates only.
  - Up to 10 combinations of material dissolution products will be made before cooling and pH adjustment.
  - The selection of the combinations will be made on the basis on the most likely reactions.
  - The results of the dissolution tests will guide the selection of solutions to combine.

# Precipitation Testing

Example of Precipitation Test Matrix.

- Solution numbers in the Solution A and Solution B columns refer to dissolution test numbers.

| PPT Run | Solution A | Solution B | Note |
|---|---|---|---|
| 1 | 1 | - | Precipitation from cooling |
| 2 | 3 | - | Precipitation from cooling |
| 3 | 5 | - | Precipitation from cooling |
| 4 | 7 | - | Precipitation from cooling |
| 5 | 9 | - | Precipitation from cooling |
| 6 | 11 | - | Precipitation from cooling |



# Modeling of Chemistry Reactions

- Using the data from the dissolution and precipitation tests:
  - A model will be developed that will predict the amount of filterable chemical precipitate that would form post-accident in the sump with a particular mix of reactive materials.
  - A model that accounts for both the maximum containment temperature and the rate of temperature decay will be used.

## Particulate Generator

- Purpose is to provide screen testers with chemical reactants and mixing procedures that can be used to produce representative particulates for sump screen testing.
- Will generate functional requirements for a particulate generator.
  - Produce a flow of particulates sufficient for testing of model sump screens.
  - Prepare recommendations on construction and use of the particulate generator.
    - Procedure for using plant-specific materials information.
    - Chemical reactants and mixing procedures.
    - Identification of potential equipment for use in constructing the machine.
- Recommended chemical reactants and mixing procedures will be verified using a small-scale particulate generator.
  - Size of a particulate generator is determined by the flume size used for testing.
  - Actual construction of a particulate generator of a size needed for flume testing is in the scope of the screen tester.



## Schedule

- Project Start — November 1, 2005.
- Complete Test Plan — November 7, 2005.
- Complete — December 16, 2005
  - Testing
  - Model Development
  - Particulate Generator
    - Functional Requirements
    - Validation Test
- Complete Draft Report — December 21, 2005
- Issue Final Report — January 15, 2006

# Summary

- A test program has been defined to address post-accident chemical effects.
- Work Scope takes advantage of:
  - ICET test results.
  - Plant-specific data, debris types and mixes.
- Work Scope provides for:
  - Determining plant-specific post-accident chemistry products.
  - Tool to produce particulates for flume testing of replacement sump screens.
  - Specification for adding particulates to flume tests.
- Results are generically applicable across plants with insulation and buffer agents included in bench tests.

*NRC BRIEFING*
*Application of Chemical Effects testing*

*AREVA*

November 2, 2005

---

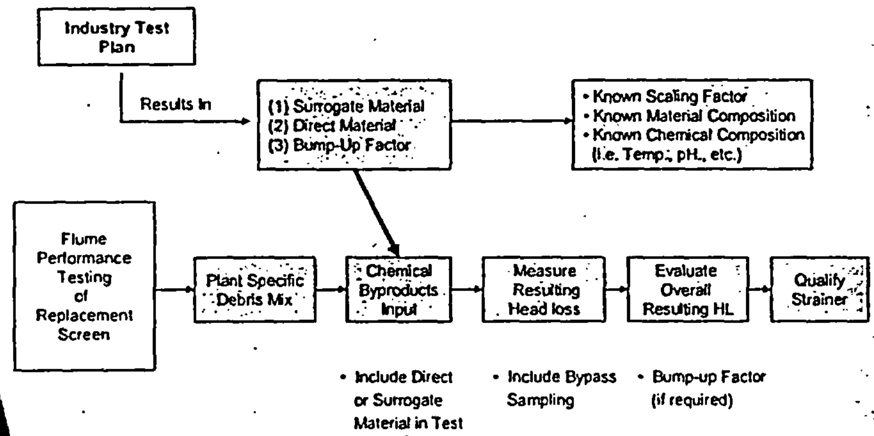
> *Purpose of Test*

- *Evaluate strainer head loss performance with plant specific debris mixes and flow conditions*
- *Apply chemical effect byproducts for integrated effect*
- *"Near-Field", low approach velocity, effect on head loss*
- *By-Pass Sampling, addressing downstream effects*

Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc

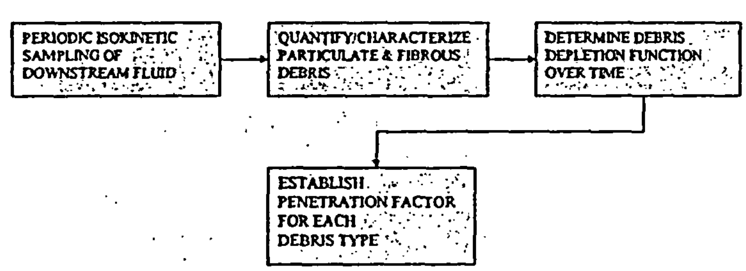
AREVA

## Integration of Chemical Effects Results

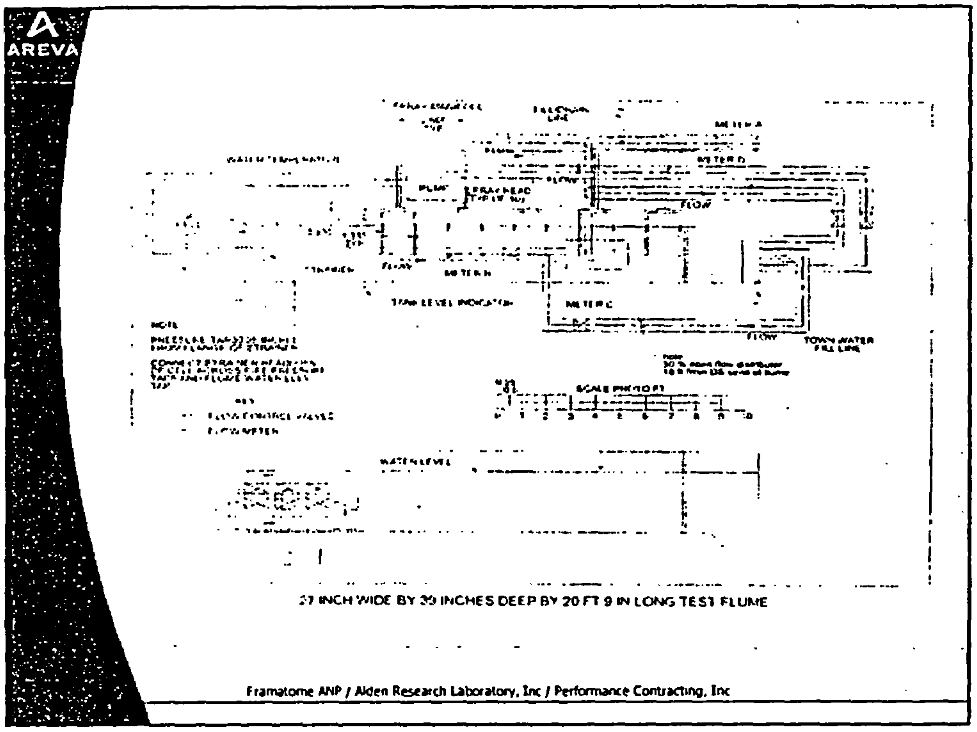


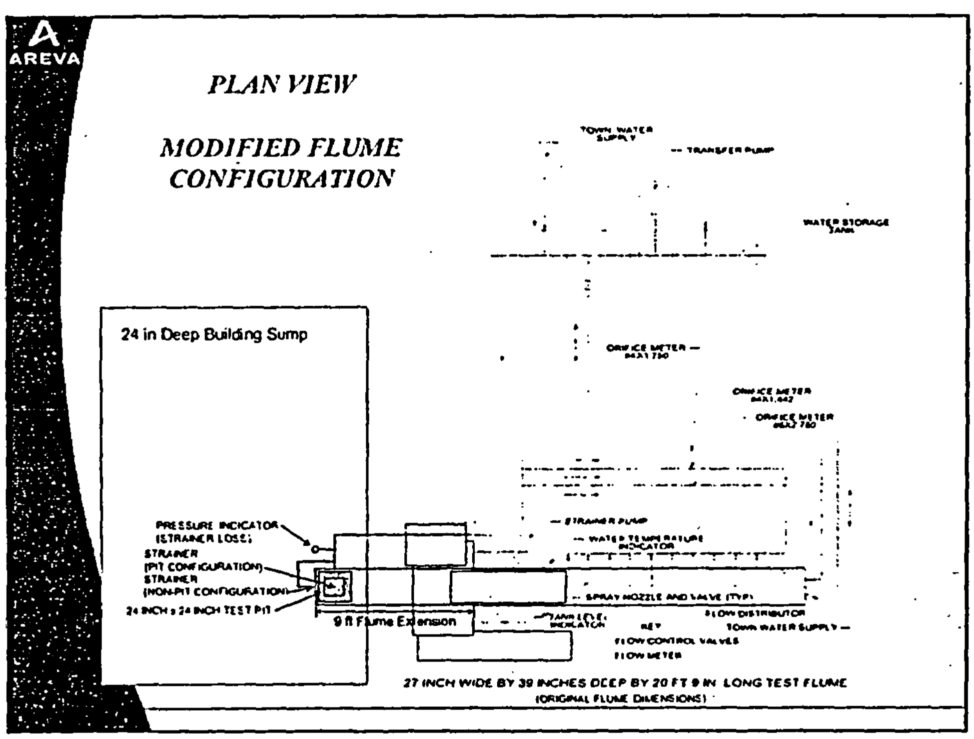

AREVA

## Penetration Fraction Determination




Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc


AREVA
27 INCH WIDE BY 39 INCHES DEEP BY 20 FT 9 IN LONG TEST FLUME
Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc


AREVA
PLAN VIEW
MODIFIED FLUME CONFIGURATION
TOWN WATER SUPPLY
TRANSFER PUMP
WATER STORAGE TANK
ORIFICE METER
24 in Deep Building Sump
STRAINER PUMP
WATER TEMPERATURE INDICATOR
PRESSURE INDICATOR (STRAINER LOSS)
STRAINER (PIT CONFIGURATION)
STRAINER (NON-PIT CONFIGURATION)
24 INCH x 24 INCH TEST PIT
9 ft Flume Extension
SPRAY NOZZLE AND VALVE (TYP)
FLOW DISTRIBUTOR
TANK LEVEL INDICATOR
KEY
TOWN WATER SUPPLY
FLOW CONTROL VALVES
FLOW METER
27 INCH WIDE BY 39 INCHES DEEP BY 20 FT 9 IN LONG TEST FLUME (ORIGINAL FLUME DIMENSIONS)

AREVA

## *Flume Configuration Modifications*

> *Configuration proposed allows testing in three most common arrangements*
>
> - *Horizontal*
> - *Vertical below pit level*
> - *Vertical extending above pit level*

> *Maintain capability to utilize overhead jets to model near break location behavior*

> *Introduction of materials from chemical effects to overall debris mix being evaluated*

Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc

AREVA

## *Penetration Sampling*

> *Proposing to collect penetrated materials downstream of test screen*

> *Quantify/Characterize collected particulate & fibrous debris*

> *Determine debris depletion function over time*

> *Establish penetration factors for each debris type based on plant specific debris mix and flow velocity*

Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc

## *Results to date overview*

> *Low strainer approach velocity displays much lower head loss than NUREG CR 6224 calculations*

> *"Near-Field" effect is consistent under tested velocity conditions*

> *Results in more reasonable passive strainer square footage*

> *Extreme amounts of fiber and particulate do not significantly increase head loss until much higher approach velocities introduced*

Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc

## *"Near Field" effect*

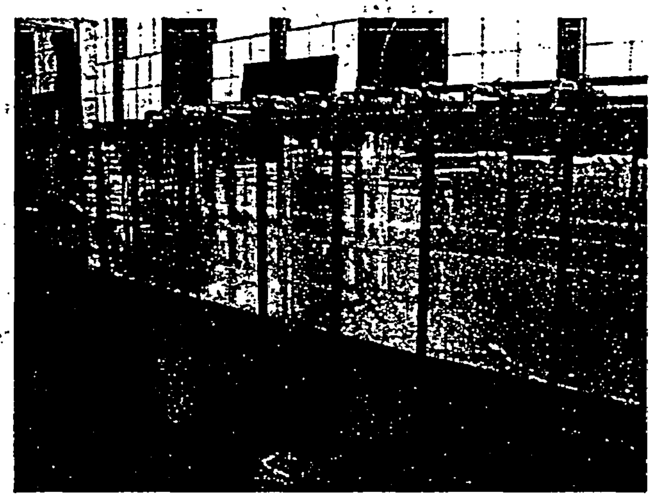
> **Typical Sump headloss evaluation in three parts:**
**Generation**
**Transport**
**Strainer headloss**

> **Analytical assumption is that all debris transported to the vicinity of the strainer actually gets ON the strainer, thus adding to theoretical headloss**

> **FANP testing designed to show that a considerable amount of debris may get close to strainer (i.e., in the "Near Field" region), but extremely low approach velocities lack energy to pull debris onto a strainer or compress the debris on the strainer**

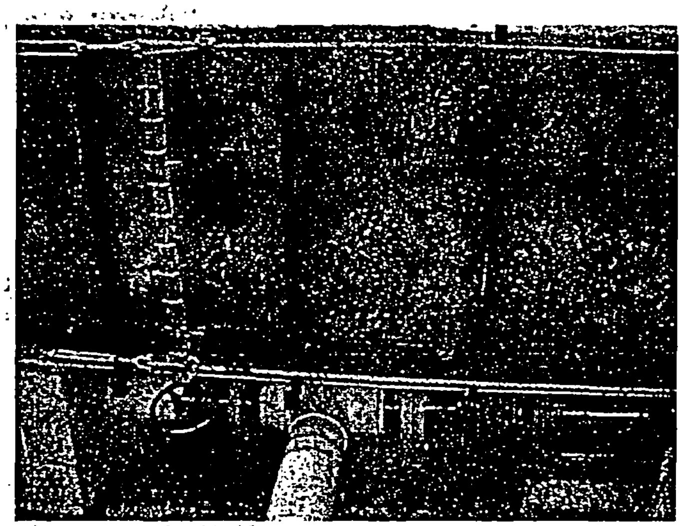
Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc

AREVA



Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc

AREVA



Framatome ANP / Alden Research Laboratory, Inc / Performance Contracting, Inc

Chemical Effects
Impact on Head Loss

NEI/NRC Presentation

1 NOV 2005

ALION
SCIENCE AND TECHNOLOGY

## Outline

- Technical Approach
  - Same as Outlined in Previous Meeting
  - Chemical Product Formation
  - Impact on Head Loss
  - Plant Specific vs. Generic Applications
- Head Loss Impact
  - Test Inputs
  - Test Program
  - Application of Results

## Technical Approach

- Original Four (4) Step Process
  1. Plant Assessment
  2. Supplemental Small Scale Testing
  3. Generic Head Loss Testing
  4. Application to Vendor Head Loss Data

11/1/2005

## Chemical Product Formation

- Chemical Speciation (WOG Effort)
  - Designed to provide type and quantity of chemical by-products for consideration in debris head loss
  - Refines the inputs originally provided into the ICET Program based on current plant information
  - Generates an algorithm for determining the plant specific outputs (chemical precipitants)
  - Combines the plant assessment and supplemental bench top (small-scale) testing steps

11/1/2005

## Validation Head Loss Testing

- Validation Experiments
  - Reference Head Loss w/o Chemical By-Products
  - Debris Head Loss with ICET Products (Archival Material)
  - Debris Head Loss with Replicated Materials



## Alion Generic Head Loss Testing

- Establish output of chemical speciation task
  - Type and quantity of chemical by-products to test
  - Timing of the event (early vs late)
  - Environment considerations (temperature, pH, fluid concentrations)

## Alion Generic Head Loss Testing

- Battery of tests to develop a bump-up factor that can be used for future material changes
  - Reference HL Test without chemical considerations
  - Debris HL Tests would include varying debris bed (small, med, thick)
  - Debris HL Tests would include varying precipitant quantity (low, med, high)
  - Debris HL Tests would include varying temperature (early and late)

11/1/2005

## Alion Generic Head Loss Testing

- Closed Vertical Loop Testing
  - Experiments Run at Temperature and Chemistry
  - Range of flow rates
- Output of Testing
  - Generic Bump-Up Factor Algorithm
  - Potential NUREG/CR-6224 parameters

11/1/2005

# Plant Specific Head Loss Testing

- Two Head Loss Tests Considered:
  - Closed Vertical Loop Testing
    - Prototypical Approach Velocities
    - Prototypical debris quantities (with chemical products)
    - Point Validation of Head Loss Algorithm
  - Tank Testing
    - Prototypical Approach Velocities
    - Prototypical debris quantities (with chemical products)
    - Prototypic Hardware
    - Validation of Screen Hardware Performance
  - Also, Flume Testing
    - Validate settling/transport considerations (separate from head loss)

## Background

- Previous NRC head loss test results (ICET 3 environment) discussed during 9/30/05 public meeting.
- Staff requested information from plants containing trisodium phosphate (TSP) and calcium silicate insulation.
- Industry expressed interest in upcoming test conditions
- Staff has determined next test conditions considering lower calcium silicate loadings and other unknowns (e.g., effects of bed layering)

# Chemical Effects
# Head Loss Testing Update

## GSI-191 Public Meeting
## November 2, 2005

**Paul Klein, NRR**

# Next Head Loss Tests – ICET 3 Environment

- Assess the head loss effects of simultaneous versus sequential chemical product/debris arrival for TSP/Cal-Sil plants

- Test 1 (mixed bed):
  - Cal-Sil loading approx. 0.2 g/L (added as cal-sil)
  - Cal-Sil premixed with test solution to permit some formation of chemical product
  - TSP addition to simulate TSP dissolution from baskets
  - Bed built partially dissolved cal-sil, fiberglass and calcium phosphate arriving simultaneously
  - Monitor pressure drop as cal-sil continues to dissolve
  - Cycle flow rate representative range

# Next Head Loss Tests – ICET 3 Environment

- Test 2 (layered bed) expected to result in max head loss for the target dissolved calcium level:
  - Create standard boric acid solution plus TSP
  - Add Nukon fiberglass
  - Meter in $CaCl_2$ to achieve same dissolved calcium as Test 1 (from 0.2 g/L cal-sil)
  - Monitor pressure drop
  - Cycle flow rate

# Future Plans

- Completion of head loss testing in ICET 3 environment
- Head loss testing in other environments, starting with ICET 1 (NaOH and fiberglass)

# Test Plan:

# Bench Testing of Chemical Effects Supporting the Evaluation of Replacement Containment Sump Screen Designs

**STD-MC-05-15**

**Revision 3**

**October 26, 2005**

Westinghouse Electric Company, LLC
P. O. Box 355
Pittsburgh, PA 15230 - 0355

# Table of Contents

# Introduction

## *Background*

Pressurized Water Reactor (PWR) containment buildings are designed to both contain radioactive materials releases and facilitate core cooling in the event of a Loss of Coolant Accident (LOCA). The cooling process requires water discharged from the break and containment spray to be collected in a sump for recirculation by the Emergency Core Cooling System (ECCS) and Containment Spray System (CSS). Typically, a containment sump contains one or more screens in series that protect the components of the ECCS and CSS from debris that could be washed into the sump. Debris generated by the action of the discharged water, and the latent containment debris inside containment, may be transported to the containment sump when the ECCS and CSS are realigned from injecting water from the Refueling or Borated Water Storage Tank (RWST or BWST). There is a high level of concern that this debris may form a debris bed at the sump screen that would sufficiently impede the recirculating flow as to challenge long-term core cooling requirements.

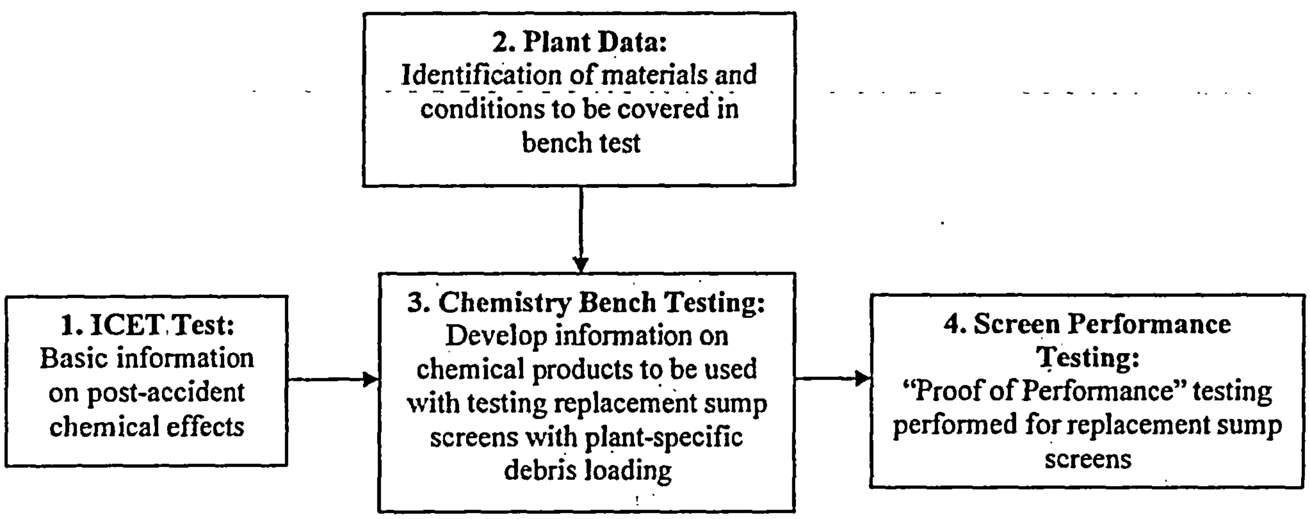
The NRC identified its concern regarding maintaining adequate long-term core cooling in Generic Safety Issue GSI-191. Generic Letter 2004-02, issued in September 2004, identified actions that utilities must take to address the sump blockage issue. The NRC's position is that plants must be able to demonstrate that debris transported to the sump screen after a LOCA will not lead to unacceptable head loss for the recirculation pumps, will not impede flow through the ECCS and CSS, and will not adversely affect the long-term operation of either the ECCS or the CSS. Generic Letter GL 2004-02 also identifies that all mitigating actions by plants, if required, to enable licensees to demonstrate acceptable ECCS and CSS performance, be implemented by the end of December 2007.

## *Program Overview*

As discussed below, the Integrated Chemical Effects Test (ICET) program (Reference 1) used five (5) test runs to study the long-term chemical reactions that may occur post-accident in a

containment sump pool that was representative of plants having one of three (3) buffer agents and two (2) types of insulation mixes; 100% fiberglass and an 80% / 20% mix of calcium silicate and fiberglass insulations. Thus, while extremely useful and informative, the ICET test data is limited. Furthermore, as the ICET test parameters were defined prior to the availability of plant-specific debris generation and transport calculations, the amount of reactants simulated in the ICET tests may be overly conservative. An assessment of the corrosion products that would be generated with more representative debris quantities is appropriate. Thus, this test plan is to supplement and augment information obtained from the ICET. The information flow associated with this program is shown schematically in Figure 1, below.

**Figure 1. Schematic for Information Flow for Chemistry Effects Bench Tests**




Briefly summarizing the information flow, starting from the left-hand side of Figure 1;

1. The ICET tests provide basic information on post-accident sump chemical effects. That information includes the conditions and materials used in the test and the data that was collected, as well as conditions and materials not included in the ICET test and is used both as input to set the bench test conditions, and to define the plant-specific information requested of plants.

2. Using plant-specific input, specific materials and amounts of materials are selected for the bench testing.

3. The bench testing is conducted for the purpose of characterizing the type and amount of chemical products that are produced. The chemical products themselves are characterized with respect to settling.

4. This chemical product information generated from the bench testing is used as an input to performance testing to be conducted by licensees and vendors of replacement sump screens.

The merit of this approach to testing for this issue has been demonstrated in bench testing performed by Westinghouse in late September 2005. Separate effects bench tests with two simulated post-accident chemistry conditions were performed. A draft review of the results from both tests suggests that bench testing for chemical effects will provide useful and usable data to support both understanding of post-accident chemical effects and the performance testing of replacement sump screens.

The characterization of the chemical products from bench testing is also intended to support and be used in the downstream effects evaluation of chemical products on the ECCS and CSS flow path, and equipment (pumps valves, etc.) in that flow path.

## *Purpose of Bench Tests*

The purpose of this test plan is to develop information to supplement and augment the information obtained from the ICET program. In five (5) tests, the ICET program examined the long-term chemical reactions, and the associated chemical reaction products, that may occur in a simulated containment sump environment using two (2) types of thermal insulation materials and three (3) buffer agents. The insulation mixes and the buffering agents studied in the ICET program are given in the table below.

**Table 1. Summary of ICET Test Matrix**

| Thermal Insulation | Buffer Agent | | |
|---|---|---|---|
| | Sodium Hydroxide | Trisodium Phosphate | Sodium Tetraborate |
| 100% Fiberglass | ICET Test 1 | ICET Test 2 | ICET Test 5 |
| 80% Calcium Silicate / 20% Fiberglass | ICET Test 4 | ICET Test 3 | |

Knowing that the number of tests to be run as part of the ICET program was limited, criteria were established to guide the selection of test parameters.

1. The selection of the insulation types and buffer agents used in the ICET test were based on industry survey information and made with the objective of testing the most dominant types of thermal insulations and buffer agents that would react in the containment sump pool post-accident.

2. The selection of the amount of insulation to be used in the test was based on early data regarding the volume of debris that would be generated from a postulated high energy line break and selected to be representative of the fleet of PWR plants licensed to operate in the US.

Thus, the ICET test results are not all-inclusive of all insulation types that might be in containment, and may excessively account for insulation debris in the containment sump.

# Supplemental Chemistry Effects Program

Therefore, an additional chemistry effects test program is to be performed. The purpose of this additional program is to supplement and augment the data obtained from the ICET program. Specifically, more representative values of the following parameters will be used:

1. Types of insulation; micro-therm, min-k, and other lesser-used insulations will be evaluated for post-accident chemical effects.

2. Amount of insulation; debris generation calculations, not available when the ICET test plan was generated, will be used to guide the selection of appropriate quantities of debris to be used in the testing.

3. Temperature effects; the ICET test evaluated long-term chemical effects by maintaining a constant temperature of 140 °F. This test program will evaluate chemical effects at sump water conditions representative of early (within 30 minutes of the postulated break) in the transient. Using conservative licensing-basis assumptions, sump liquid temperatures are calculated to reach values of up to about 260 °F during this 20-40 minute period.

Additional values, taken from recent analytical work performed to support responses to Generic Letter GL 2004-02 will be used, when available and appropriate, to guide the selection of test parameters.

The tests described here do not include an investigation of all possible chemical reactions of containment materials. The ICET program and the known properties of containment materials have been used to select a number of tests that target the chemical reactions expected to generate the most precipitate. The selection of materials is based on amount of material that may react, and the reaction capability of the material. A technical basis for not including certain materials in the program (i.e., known reactions, minute quantities, etc.) will be prepared for those materials.

## *Test Approach*

The tests described here will be done at the "bench level" scale. This will allow testing to be completed in a time and cost effective manner.

First, using standard techniques, the dissolution rate and solubility limit for each of the containment materials of interest will be measured.

1. This will be done as a function of pH and temperature.

2. Interactions between dissolved matter from the various materials to form precipitates will then be measured as well as precipitate formation upon cooling.

3. This data will be used to construct a model that will take plant specific containment material mixes and conservatively predict amounts and character of precipitates that will form for a large break LOCA.

This information is essential for subsequent testing performed to demonstrate sump screen margin in flume tests. Equipment will be designed that can then produce the type and quantity of precipitates needed for such tests.

Additional information, taken from recent analytical work performed to support responses to Generic Letter GL 2004-02 will be used, when available and were possible, to guide the selection of test parameters.

The tests described here do not include an investigation of all possible chemical reactions of containment materials. The ICET program and the known properties of containment materials have been used to select a number of tests that target the chemical reactions expected to generate the most precipitate.

The approach used to develop the test plan was to produce reasonable but conservative estimates for precipitate formation. Dissolution rates will be measured for each containment material individually. These rates are expected to be higher than that obtained from containment material mixtures. This is because the dissolution of one material will have either no effect or an inhibiting effect on the dissolution of other materials. For instance:

1. It has been shown that Cal-Sil inhibits the dissolution of aluminum (ICET Test 4), but the region of influence for some LOCAs will not include Cal-Sil, even at a plant with a large volume of Cal-Sil.

2. Similarly, trisodium phosphate will inhibit the dissolution of Cal-Sil, but the trisodium phosphate in containment will take a finite period of time to dissolve, during which the Cal-Sil will dissolve at a high rate.

The bench testing will be performed at temperatures up to a maximum value determined from industry surveys of containment pool temperatures that are expected after a large break LOCA before recirculation. This allows reactions during the first hours of a LOCA to be considered.

Consideration of the dissolution and precipitation reactions in separate bench-scale tests simplifies the interpretation of results and enables the use of the precipitation in chemical modeling. If integrated testing was performed with complex mixtures of materials, dissolution and precipitation occur simultaneously, making weight loss and gain information minimally useful. Integrated tests, while realistic, produce complex mixtures of products that are difficult to analyze.

## *Dissolution Testing*

The dissolution of each of the following materials will be measured at temperatures determined from industry surveys with a range of pH values that are experienced in the post LOCA environment.

1. The maximum pH will be 12 and will be generated with sodium hydroxide. This is the maximum pH expected for the containment spray solution in a plant using NaOH pH buffering.

2. An intermediate pH of 8 will be tested. This is a typical containment pool pH after complete addition of the pH buffering agent.

3. The minimum pH will be 4 and will be generated with 2800 ppm boric acid and 100 ppm HCl. This is the lowest pH expected before complete dissolution of TSP or addition of sodium hydroxide.

The pH values listed are starting values. The pH will vary as the containment materials dissolve.

Materials to be tested include, as a minimum:

- Aluminum sheet
- Cal-Sil insulation
- NuKon-fiberglass
- Previously untested fiberglass (Temp Mat)
- Powdered concrete
- Mineral Wool (e.g. K-Wool)
- Microporous Insulation (e.g. Kool-phen-K)
- Fire Retardant Material (e.g. FiberFrax)

The list of materials to be tested will be reviewed against plant input currently being collected. Based on that comparison, the list will be amended accordingly.

The total amount of material dissolving after at least two different periods of time will be measured. It is anticipated that these time periods will have the following range:

1. The short time will be 30 minutes. This is generally representative of the time from the initiation of the break to initiation of realigning of the ECCS to the recirculate from ion mode from the containment sump with all trains of ECCS operating.

2. The long time may be 60 minutes. This is generally representative of the time from the initiation of the break to before initiation of realigning the containment sump to recirculate from the containment sump with only one train of ECCS operating.

**Trisodium Phosphate Dissolution Rate**

The exact timing of measurements will depend in part on the dissolution rate expected for trisodium phosphate. Information will be collected on the dissolution rate anticipated for trisodium phosphate after a LOCA, and if necessary, a dissolution rate test will be performed with and without the presence of calcium in solution.

**Nickel and Iron from the RCS**

Nickel and iron dissolution from the RCS will not be included in this testing. Normal PWR shutdown chemistry evolutions have shown the iron will be released at insignificantly low levels. Nickel concentrations as high as 12 ppm may be expected, but nickel is quite soluble in all of the postulated post-LOCA chemical environments and does not need to be included in studies related to head loss.

**Table 2. Dissolution Test Matrix** (Temperatures in the table may change based on plant surveys)

| | Test Conditions | | | Measurements | | | |
|---|---|---|---|---|---|---|---|
| **Run** | **Material** | **Solution** | **T (°F)** | **0.5 hr** | **0.75 hr?** | **1 hr** | **1 hr** |
| 1 | 1. Aluminum sheet | 2800 ppm B H3B03 + HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 2 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 3 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 4 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 5 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 6 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 7 | 2. Cal-Sil Insulation | 2800 ppm B H3B03 +HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 8 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 9 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 10 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 11 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 12 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 13 | 3. NUKON Fiberglass | 2800 ppm B H3B03 +HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 14 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 15 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 16 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 17 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 18 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 19 | 4. Other Fiberglass | 2800 ppm B H3B03 +HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 20 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 21 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 22 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 23 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 24 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 25 | 5. Powdered Concrete | 2800 ppm B H3B03 +HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 26 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 27 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 28 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 29 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 30 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 31 | 6. Mineral Wool | 2800 ppm B H3B03 +HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 32 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 33 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 34 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 35 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 36 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 37 | 7.Microporous Insulation | 2800 ppm B H3B03 +HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 38 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 39 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 40 | | pH 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 41 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 42 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 43 | 8. Fiber Fax | 2800 ppm B H3B03 +HCl | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 44 | | 2800 ppm B H3B03 +HCl | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 45 | | pH 8 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 46 | | pH I 8 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 47 | | pH 12 NaOH | 240 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |
| 48 | | pH 12 NaOH | 190 | Sol. ICP | Sol. ICP | Sol. ICP | Coup. Mass |

Sol. ICP = analysis of dissolved elements by ICP. Coup. Mass = Mass loss of the starting material

## *Precipitation Testing*

The dissolved material from the Materials Dissolution Testing produced at maximum temperatures determined from industry surveys and will be cooled to 140 °F to test for chemical precipitate formation.

The pH of the boric acid solutions will also be adjusted to pH = 8 in separate tests using sodium tetraborate and trisodium phosphate.

The following characteristics of the precipitate will be measured using standard techniques:

- Precipitate mass
- Precipitate settling rate
- Settled precipitate volume
- Precipitate filterability

The potential for interaction between the different containment materials to produce precipitation beyond that produced from a single material will be investigated with screening tests that measure the mass of precipitates only. Up to 10 combinations of material dissolution products will be made before cooling and pH adjustment. The selection of the combinations will be made on the basis of the most likely reactions. The results of the dissolution tests will guide the selection of solutions to combine.

The precipitation test matrix is shown in the following table.

**Table 3. Precipitation Test Matrix**

| PPT Run | Solution A | Solution B | Note |
|---|---|---|---|
| 1 | 1 | - | Precipitation from cooling |
| 2 | 3 | - | Precipitation from cooling |
| 3 | 5 | - | Precipitation from cooling |
| 4 | 7 | - | Precipitation from cooling |
| 5 | 9 | - | Precipitation from cooling |
| 6 | 11 | - | Precipitation from cooling |
| 7 | 13 | - | Precipitation from cooling |
| 8 | 15 | - | Precipitation from cooling |
| 9 | 17 | - | Precipitation from cooling |
| 10 | 19 | - | Precipitation from cooling |
| 11 | 21 | - | Precipitation from cooling |
| 12 | 23 | - | Precipitation from cooling |
| 13 | 25 | - | Precipitation from cooling |
| 14 | 27 | - | Precipitation from cooling |
| 15 | 29 | - | Precipitation from cooling |
| 16 | 31 | - | Precipitation from cooling |
| 17 | 33 | - | Precipitation from cooling |
| 18 | 35 | - | Precipitation from cooling |
| 19 | 37 | - | Precipitation from cooling |
| 20 | 39 | - | Precipitation from cooling |
| 21 | 41 | - | Precipitation from cooling |
| 22 | 43 | - | Precipitation from cooling |
| 23 | 45 | - | Precipitation from cooling |
| 24 | 47 | - | Precipitation from cooling |
| 25 | 1 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 26 | 7 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 27 | 13 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 28 | 19 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 29 | 25 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 30 | 31 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 31 | 37 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 32 | 43 | TSP pH 8 | Precipitation of Calcium and Magnesium Phosphates |
| 33 | 1 | Borax pH 8 | Precipitation due to pH Increase |
| 34 | 7 | Borax pH 8 | Precipitation due to pH Increase |
| 35 | 13 | Borax pH 8 | Precipitation due to pH Increase |
| 36 | 19 | Borax pH 8 | Precipitation due to pH Increase |
| 37 | 25 | Borax pH 8 | Precipitation due to pH Increase |
| 38 | 31 | Borax pH 8 | Precipitation due to pH Increase |
| 39 | 37 | Borax pH 8 | Precipitation due to pH Increase |
| 40 | 43 | Borax pH 8 | Precipitation due to pH Increase |
| 41-50 | X | Y | Combinations will be selected on basis of dissolution tests |

Note: Solution numbers in the Solution A and Solution B columns refer to dissolution test numbers.

# Test Operations

## Test Performer

The organization responsible for performing the bench tests described in this document is the Westinghouse Science and Technology Center (STC). Additional support will be obtained from other qualified facilities, as needed, and will perform under the direction of STC, to support and maintain the schedule identified below.

## Procedures

It is anticipated that industry standard practices will be sufficient to collect the data identified in this document. Actions that are different from industry standard practices will be documented.

## Equipment and Instrumentation

The following is a general description of equipment and instrumentation that will be used in this test program.

1. A collection of heated, reaction vessels, each having a volume of less than 1 gallon, will be used for the dissolution testing.

2. Settling experiments will be conducted in a graduated cone.

3. The filtration will be performed with a commercial glass fiber filter and will be performed at temperature. SEM/EDS techniques may be used to examine the collection of filtrate, if determined to be appropriate. This will allow identification of the filtrate material as well as the mode of filtrate collection.

## Documentation

Log books will be maintained to record the activities associated with the performance of each test.

A final report will be prepared and issued documenting the testing performed.

## Photographs

As a minimum, digital photographs will be taken as follows:

Materials Dissolution Testing

1. Test samples, before being placed in solution
2. Test samples at the end of the test

Precipitation Generation Testing

1. Precipitate settling rate; an attempt will be made to "mark" and "time phase" the photos to illustrate settling
2. The amount of settled precipitate; to illustrate the volume of precipitate

# Schedule

Bench Testing

| | |
|---|---|
| Completion of Bench Testing | December 2, 2005 |
| Issue Final Bench Test Report | January 15, 2005 |

It is anticipated that licensees will evaluate the performance of a replacement sump screen with their plant-specific debris loading. The following steps will be taken to facilitate the use of the bench test data by licensees in this evaluation;

1. To the extent possible, bench testing will be scheduled to support licensee evaluations of replacement sump screen performance, and,

2. Information will be made available to affected licensees as quickly as possible upon completion of each bench test.

# References


1. Test Plan: Characterization of Chemical and Corrosion Effects Potentially Occurring Inside a PWR Containment Following a LOCA, Revision 13, July 20, 2005
2. Generic Letter GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors," September 13, 2005