Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids

Ann Lane
Westinghouse Electric Company
412-374-6571

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Outline

- Purpose
- Scope
- Bench Testing Parameters
- Dissolution Tests
- Precipitation Tests
- Chemical Model
- Particulate Generator
- Transition to Sump Screen Testing

Purpose

Two-fold goal for WOG Chemical Effects testing:

1. Evaluate post-accident chemistry in containment sump pool
   - Bound plant temperature and pH conditions
   - Use representative containment materials and buffering agents
2. Provide input on chemical precipitates for screen vendor testing
   - Determine types and amounts of chemical precipitates which may form
   - Provide method for obtaining these precipitates for head loss testing

Scope

- Use industry surveys to define bench testing parameters, including:
  - Temperatures
  - pH values
  - Containment materials
  - Buffering agents
- Perform dissolution and precipitation tests presented in the Test Plan
- Develop chemical model from the test results for plant-specific prediction of chemical effects
- Develop and qualify particulate generator to produce representative precipitates for head loss testing

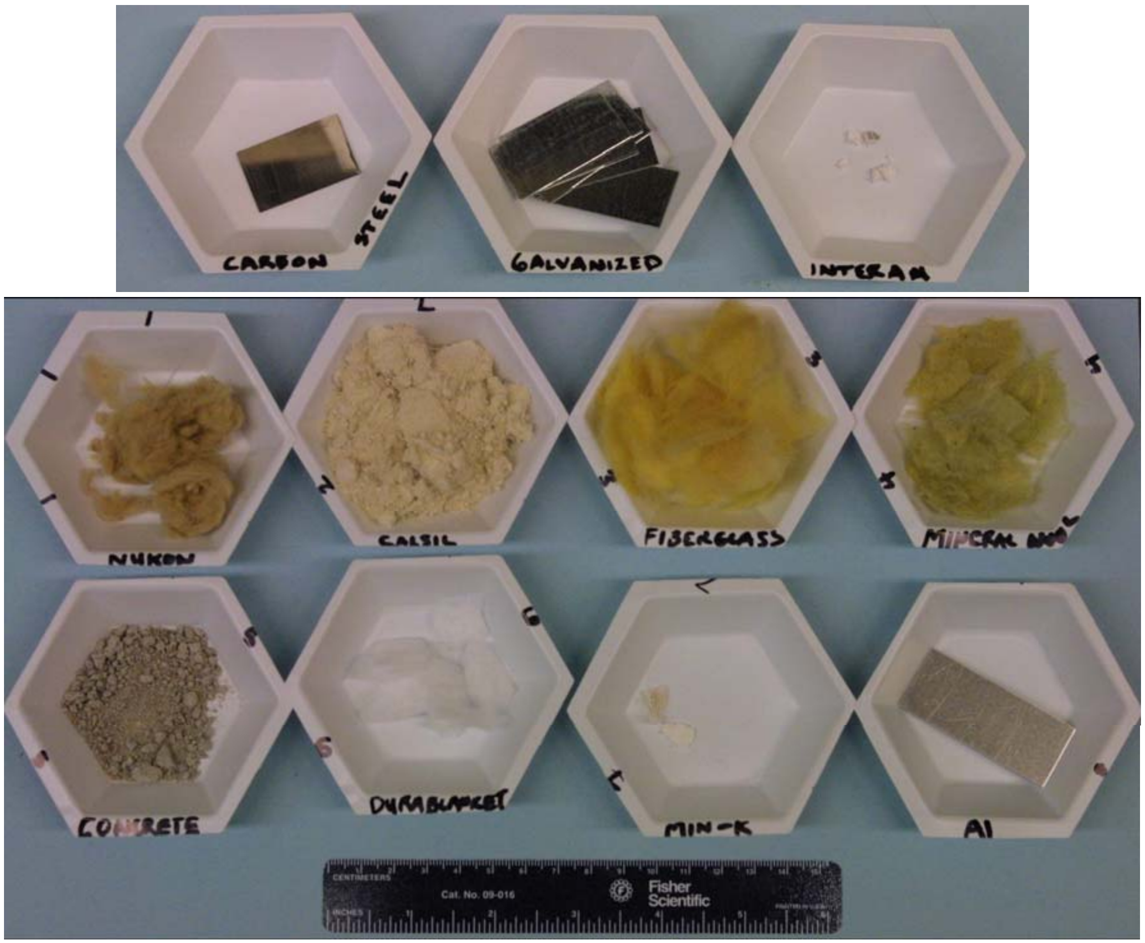
Bench Testing Parameters

- Dissolution tests temperature
  - High = 265 °F
  - Low = 190 °F
- Precipitation tests temperature = 80 °F
- pH range
  - Maximum = 12
  - Minimum = 4.1
- Containment materials for testing
  - Selection and representative amounts based on plant survey responses

Containment Materials Classification

Material Class	Materials in Class	Representative Material
Aluminum	Aluminum alloys, aluminum coatings	Aluminum (pure)
Aluminum silicate	Cerablanket, FiberFrax Durablanket, Kaowool, Mat-Ceramic, Mineral Fiber, PAROC Mineral Wool	FiberFrax Durablanket
Calcium silicate	Asbestos, Cal-Sil insulation, Kaylo, Marinite, Mudd, Transite, Unibestos	Cal-Sil Insulation
Carbon Steel	All carbon and low alloy steels	SA 508 Cl 2
Concrete	Concrete	Ground Concrete
E-glass	Fiberglass insulation, NUKON, Temp-Mat, Foamglas, Thermal Wrap	NUKON, Unspecified Fiberglass
Amorphous Silica	Min-K, Microtherm	Min-K
Interam E Class	Interam E Class	Interam E-5
Mineral wool	Min-Wool, Rock Wool	Min-Wool
Zinc	Galvanized steel, zinc coatings	Galvanized Steel
Copper	All copper alloys	None
Nickel	All nickel alloys	None
Organic Mastics	CP-10, ThermoLag 330-1	None
Other Organics	Armaflex, Kool-Phen, Benelex 401, RCP Motor Oil	None
Reactor Coolant Oxides	nickel ferrite and other oxides	None

Tested Materials



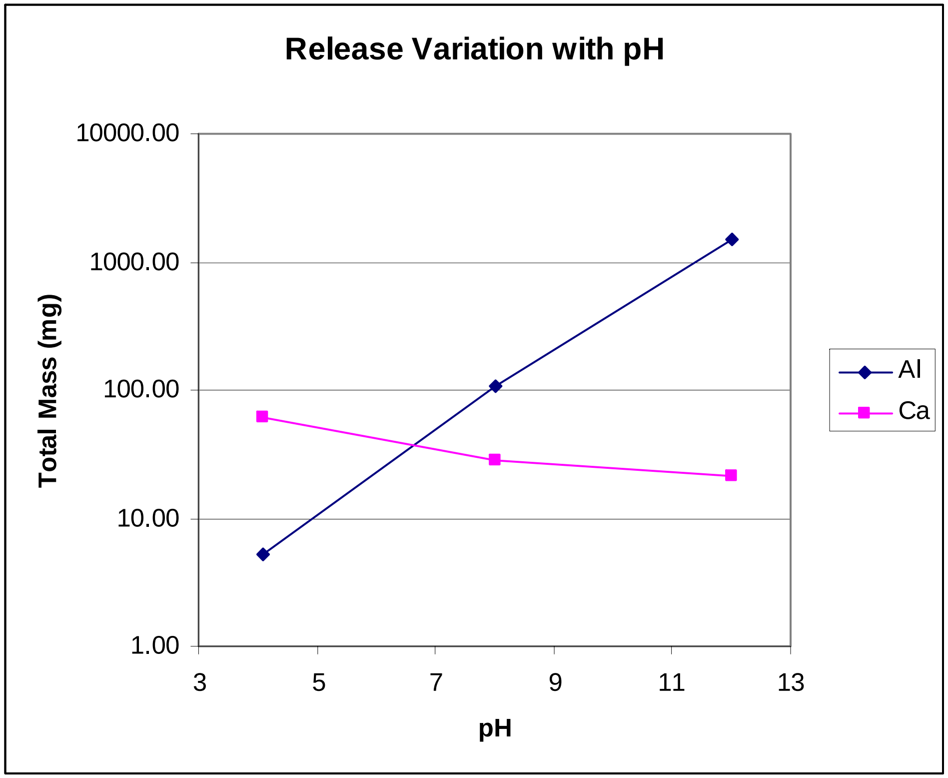
- Carbon
- Galvanized steel
- Interam
- Nukon Fiberglass
- Cal-Sil
- Unknown Fiberglass
- Microtherm
- Concrete
- FiberFrax Durablanket
- Min-K
- Aluminum

Dissolution Tests

- Eight reaction chambers and two solution reservoirs were used
- Elements with highest mass release:
  - Aluminum
  - Calcium
  - Silicon
- Cal-Sil and metallic aluminum provided the highest potential mass release

Mass Release Dependence on pH

- Variation in calcium and aluminum mass release with pH
- Determined from all runs at each pH
- Opposite trends observed:
  - Greater Ca release at low pH values
  - Greater Al release at high pH values



Precipitation Tests

Sixty precipitation tests were performed:

- 33 of the 60 tests were dedicated to determining if any precipitate formed due to exposure of containment materials to simulated coolant and cooling of the dissolved solution
  - 10 tests formed precipitate under this scenario
- Trisodium phosphate (TSP) and sodium tetraborate were separately added in 22 tests to adjust the solution pH to 8
  - The dissolved solutions for Cal-Sil and concrete formed phosphate precipitate when TSP was added
  - No solutions formed precipitate due to the addition of sodium tetraborate
- Of the 5 combinations of dissolved solutions made, only the combination of Cal-Sil and fiberglass formed a precipitate due to chemical reaction

Precipitation Test Results

Precipitation tests with measurable amounts of precipitate:

PPT Run	Precipitation Method	Precipitate Determined from SEM Analysis
1	Precipitation from cooling, Al pH 4	Hydrated AlOOH
2	Precipitation from cooling, Al pH 8	Hydrated AlOOH
3	Precipitation from cooling, Al pH 12	Hydrated AlOOH
12	Precipitation from cooling, Other Fiberglass, pH 12	NaAlSi3O8 with minor calcium aluminum silicate
13	Precipitation from cooling, Concrete, pH 4	Calcium aluminum silicate - Al rich
14	Precipitation from cooling, Concrete, pH 8	Calcium aluminum silicate
16	Precipitation from cooling, Mineral Wool, pH 4	Hydrated AlOOH
22	Precipitation from cooling, FiberFax, pH 4	Hydrated AlOOH
24	Precipitation from cooling, FiberFax, pH 12	NaAlSi3O8
30	Precipitation from cooling, Galvanized, pH 12	Zn2SiO4 (Willemite) with Ca and Al impurities
35	PPT of Phosphates, CalSil	Calcium phosphate and a silicate
38	PPT of Phosphates, Powdered Concrete	Calcium phosphate with AlOOH
60	pH 12 265 Fiberglass with high calcium from pH 4 CalSil	Sodium calcium aluminum silicate

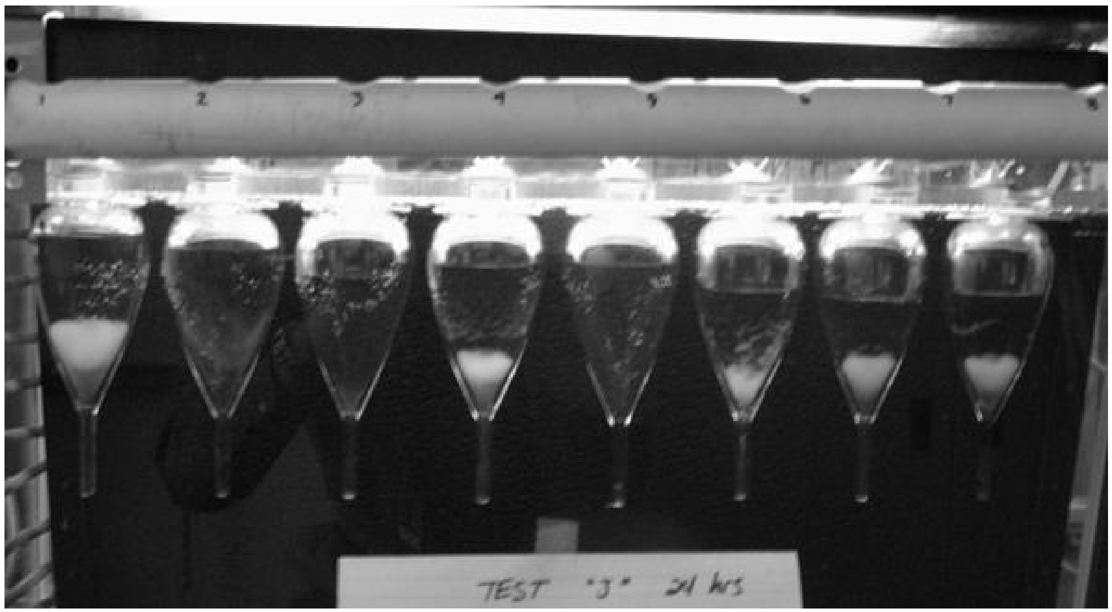
Predominant chemical precipitates: aluminum oxyhydroxide, sodium aluminum silicate, calcium phosphate (for plants which use TSP)

Precipitate Characterization

- Qualitative measure of settling rates of precipitates formed in bench testing:
  - Aluminum oxyhydroxide precipitates had the lowest settling rate, while calcium phosphate precipitates settled more quickly
  - Sodium and calcium aluminum silicate precipitates had settling rates in-between those determined for AlOOH and $Ca_3(PO_4)_2$
- In conclusion, the precipitates formed do not settle quickly, and so cannot be discounted as a concern for sump screen performance
- Aluminum and aluminum silicate precipitates were determined to have slightly higher filtration constants than the calcium phosphate precipitates

Precipitates Formed by Cooling

Example of precipitates formed by cooling of dissolved solutions to 80°F ~24 hours after exposure to post-LOCA simulated coolant:



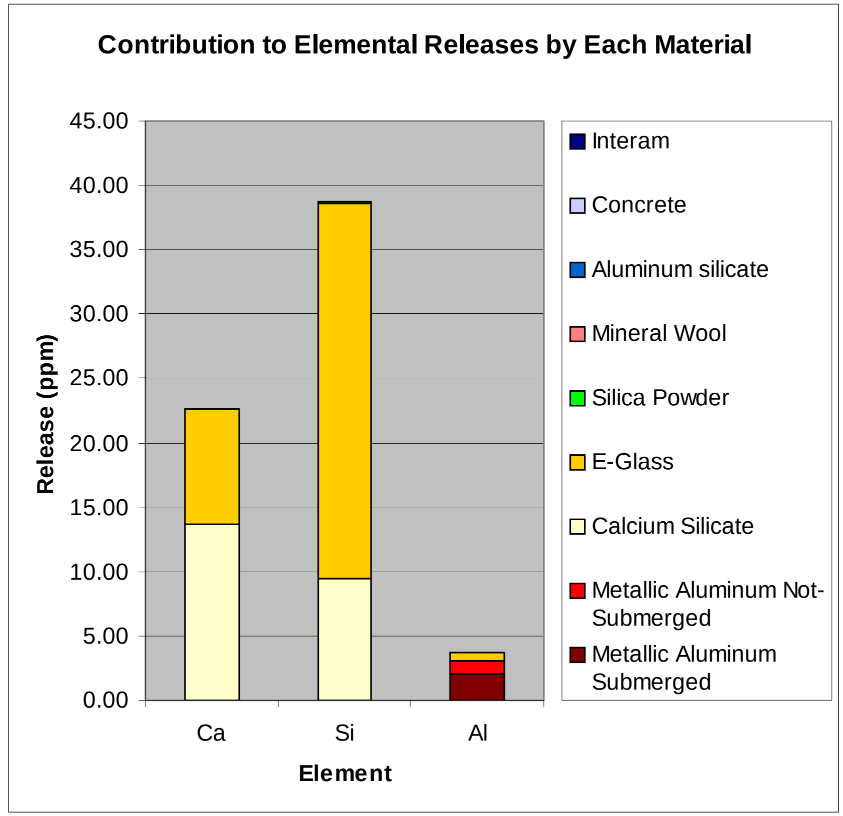
Chemical Model Development

- Inputs:
  - Post-LOCA temperature and pH values
  - Concentration of containment materials
  - Mass release from containment materials exposed to simulated coolant determined from results of dissolution testing
- Evaluations:
  - Determination of release rate equations as a function of pH, temperature, and concentration of each containment material
  - Determine quantity and type of precipitates formed from elements released using stoichiometric relations and solubility properties
- Outputs:
  - Elemental releases from containment materials as a function of time
  - Precipitates formed under post-LOCA conditions as a function of time

Chemical Model Results

Predicted mass release of Al, Si and Ca from plant-specific containment materials concentrations

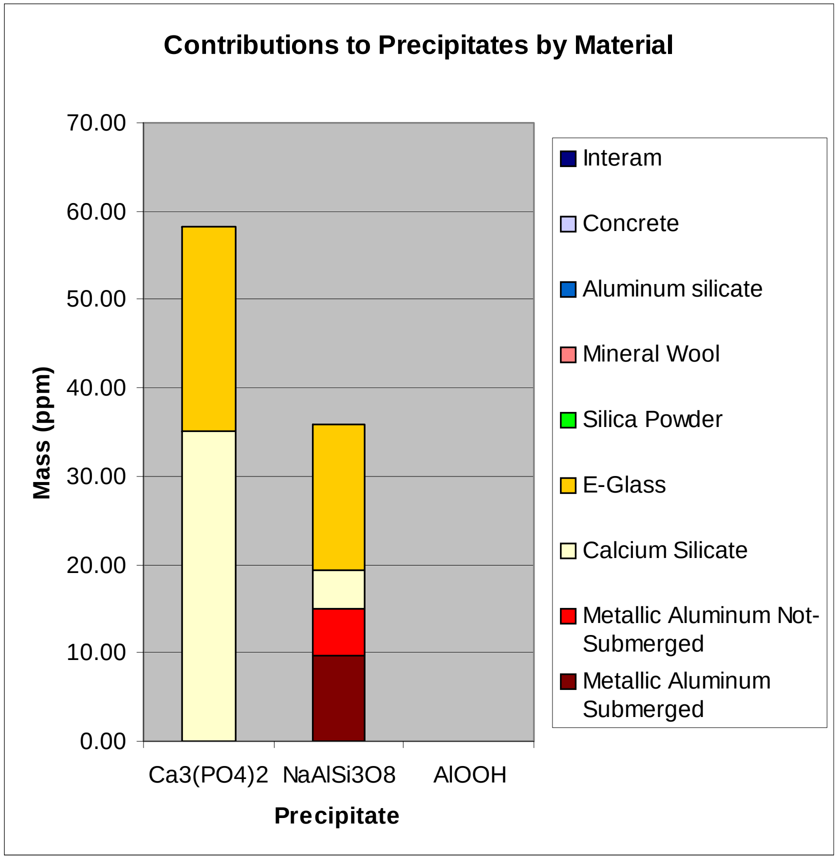
- Example of elemental releases for TSP plant
  - Largest contributors to Ca and Si releases are Cal-Sil and fiberglass
  - Corrosion from both submerged and non-submerged aluminum



Chemical Model Results

Predicted precipitate formation from mass release of Ca, Si and Al

- Example of precipitate formation for TSP plant
  - Significant amount of calcium phosphate formed from Cal-Sil
  - Large amount of sodium aluminum silicate formed from combination of Cal-Sil, fiberglass, and aluminum



Model Verification and Conservatisms

- Model predictions for Al corrosion agree with GENNY (an established containment hydrogen prediction code)
- Model predictions for Al corrosion agree with ICET #1
- Model predictions for Al corrosion at pH values not included in the bench tests agreed well with additional lab testing.
- Conservative because least corrosion resistant aluminum alloy tested with no oxide film.

Model Verification and Conservatisms

- Model predicts that 95% of CalSil dissolves within 100 hours for a generic TSP plant in agreement with Argonne tests.
- Calcium concentrations predicted by model for Argonne tests were 1 – 2X measured Argonne levels.
- Conservative because all aluminum is assumed to precipitate.
- Conservative because silicate inhibition of aluminum corrosion not included.

Particulate Generator Development

Purpose: to create prototypical precipitates for use in sump screen testing

- Particulate generator design dependent on:
  - Size of test facility
  - Determined plant-specific precipitate mix
- A setup similar to that shown below may be modified for these variations by adjusting the number and/or size of the mixing tanks and transfer pumps

Particulate Generator Testing

- The filtration and settling behaviors of the generated precipitates were determined to be similar to those observed for precipitates formed in bench testing
- Testing confirmed that the quality and temperature of the water used to prepare the particulates is not critical to obtain similar characteristics to the precipitates
- Critical parameter in implementation of particulate generator:
  – Limitation on degree of concentration of particulates in mixing tank to avoid agglomeration of particulates
  – If large quantities of particulates are required, the particulates may need to be prepared in batches

Alternatives to Particulate Generator

If alternative materials are to be used for sump screen performance testing, the acceptability of these surrogate materials to simulate the amorphous and hydrated precipitates formed in bench testing must be demonstrated

- Settling tests may be performed to demonstrate similar or conservative settling behavior to the precipitates formed
- Also, filterability tests may be needed to demonstrate a similar impact on head loss
- Suggested minimum acceptance criteria for these tests are provided for each major precipitate

Transition to Sump Screen Testing

- Plant-specific prediction of precipitate formation using the chemical model and the following inputs:
  - Containment material amounts
  - Recirculation water volume
  - Post-accident sump and spray pH transients
  - Post-accident sump and spray temperature transients
  - Indication if TSP is used as a buffering agent
- Chemical model output provides types and quantities of precipitates for sump screen performance testing
- Precipitates for screen testing may be generated using the particulate generator or surrogate materials may be obtained
  - If surrogate materials are obtained, additional testing such as settling and filterability tests may be necessary
- Once the representative precipitates have been obtained, the intention is to scale and introduce the precipitates to the flume as another debris source

Summary

- Elements with largest contribution to mass release from containment materials:
  - Calcium
  - Aluminum
  - Silicon
- Key precipitates formed:
  - Sodium aluminum silicate
  - Aluminum oxyhydroxide
  - Calcium phosphate (for plants which use TSP)
- Chemical model predicts plant-specific formation of precipitates as a function of time
- Particulate generator may be used to generate prototypical precipitates for sump screen performance testing