Recent NRC Technical Findings

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Research Activity Summary

- Chemical testing closure – silica concentrations
- Latent Debris characterization
- Calcium silicate test-data analysis

ATTACHMENT 4

Silica Concentration Measurements

- Energy-Dispersive Spectrometry indicated the unintentional presence of silica in crystalline zinc surface corrosion
  - Leaching from borosilicate glass containers?
  - Contamination of laboratory DI water?
  - Contamination of stock chemicals?
- Final set of quiescent corrosion tests using polypropylene bottles
  - DI water only with no metal test material
    - 2 bottles, 4 days at 40°C, => ~4 mg/L silica each
  - Fiberglass in simulated cooling water
    - 3 bottles, 1.5g NUKON / 1 liter, pH between 9.7 and 10.2, 4 days at 40°C, => silica concentrations from 30 to 37 mg/L
    - Evidence of leaching but no rate estimate attempted
  - Zinc coupons in simulated cooling water
    - 3 bottles, 4 days at 40°C and 3 bottles, 4 days at room temp => 0.057 $g/m^2/h$ rate averaged over 4 days
    - Silica ranged from 5 to 22 mg/L from NaOH and HCl used to adjust pH. Leached from previous glass containers

Latent Debris Characterization

- Have accepted samples from 2 of 6 potential volunteers
- Variety of collection techniques, sample areas, sample locations and quantity of debris from site to site
  - Filter paper swipes, manual brush sweeping, HEPA filter vacuum cartridges, collected and drained pressure-wash effluent
  - LANL is *not* attempting to scale samples to plant inventory
- Site 1:
  - 7.4 g total from 14 carefully documented swipe locations
  - Looking for qualitative sample-specific differences, but must aggregate to characterize
- Site 2:
  - ~2.2 kg total in 6 vacuum-filter cartridges
  - Adequate quantity for direct small-scale head-loss measurement

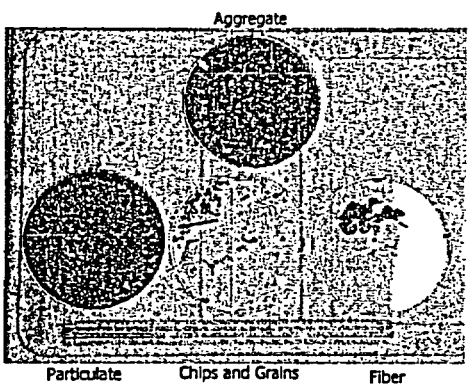
Conditions of Participation:
Provide bulk contact activity and MCA gamma spectrum for review before shipment
Package and deliver compliant with DOT shipping regulations
Pay shipping cost

Characterization Objectives

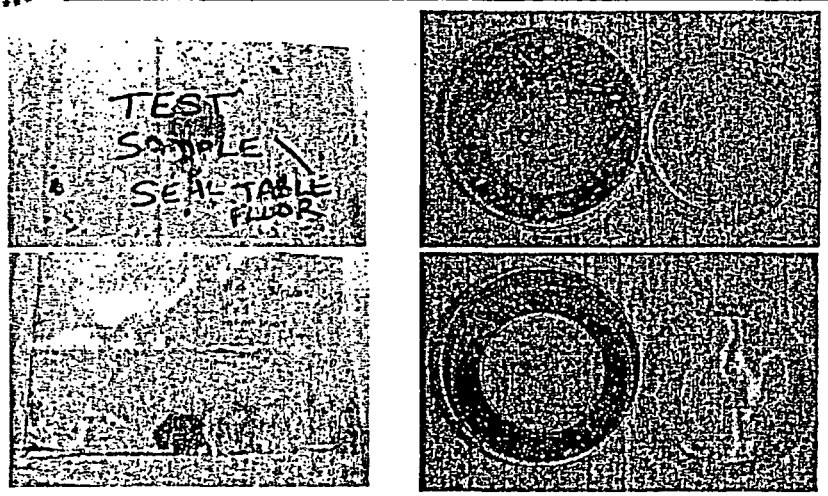
- **Collect representative samples of PWR-containment Pre-LOCA (Latent) debris**
  - Some question whether debris samples include adequate proportion of fines that would be entrained by spray
- **Characterize debris to assess potential contribution to debris-bed buildup on sump screen**
  - Transportability
  - Hydraulic properties relevant to head loss
- **Develop a recipe for surrogate latent debris to enable large-scale head-loss tests @ UNM**
  - Attempting to relate microphysical properties of debris to macrophysical properties of soil mechanics

Debris Characterization Protocol

- Confirmatory gamma spec
- Coarse separation into fiber and particulate (manual)
- Wet sieves to determine particle size distribution
- Measure fiber and particulate surface area/volume ratio via N_2 adsorption methods
- Using optical microscope to bin fibers by length, shape, diameter (automated)
- Measure settling velocity in quiescent column
- Conduct small-scale pressure drop tests to determine porosity



LANL Trash Collection



Site 1 Site 2

Calcium Silicate Data Analysis

- **Test Objectives:**
  - Establish technical basis for applying the NUREG/CR-6224 head loss correlation to debris beds containing calcium silicate insulation debris (these beds typically include fibrous debris as well as cal-sil)
  - Generate head loss data to support confirmatory evaluations of sump screen performance for plants with calcium silicate insulation

Tests Conducted Under Direction of LANL at Facility Operated by Civil Engineering Department of University of New Mexico

NUREG/CR-6224 Head-Loss Correlation

- **Developed during BWR strainer blockage study**
  - Predicts head loss for fibrous/particulate debris beds
  - Validated for NUKON and BWR iron oxide corrosion products
  - Correlation was loosely applied to other misc. forms and combinations of debris
- **Correlation requires debris-specific input parameters, e.g. specific surface area (S_v)**
- **Some input parameters best determined by applying correlation to head-loss test data and deducing appropriate values**
- **Application of correlation to calcium silicate has been handicapped by lack of appropriate data to help determine valid material parameters**

$$\varepsilon_m = 1 - (1 + \frac{\rho_L}{\rho_p}\eta)(1 - \varepsilon_o)\frac{dL_o}{dL_m}$$

$$\varepsilon_f = 1 - \frac{c_o}{\rho_f}$$

$$c = \alpha_c \left(\frac{dH}{dL_o}\right)^\gamma$$

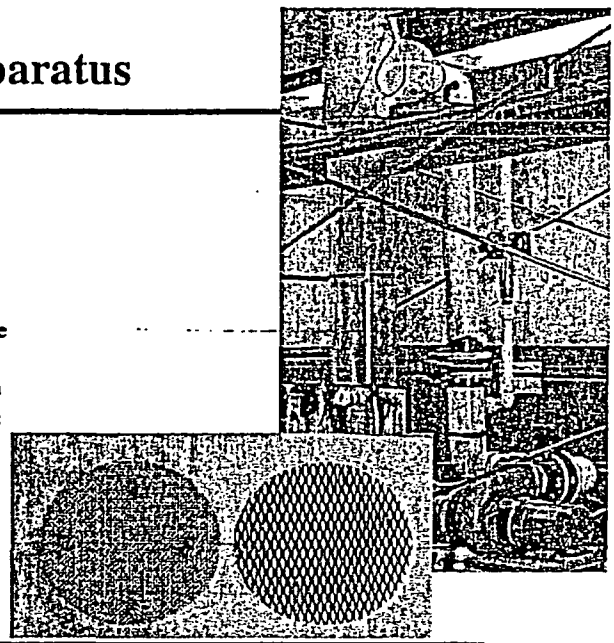
$$S_v = S_f \left[\frac{1 + \frac{\rho_L}{\rho_p}\eta\frac{S_w}{S_f}}{1 + \frac{\rho_L}{\rho_p}\eta}\right]$$

$$dL_m = dL_o \frac{c_o}{c_{blanket}}(\eta + 1)$$

$$\frac{dH}{dL_o} = C\left[3.5S_v^2(1-\varepsilon_m)^{1/2}[1+57(1-\varepsilon_m)^3]\mu V + 0.66S_v\frac{(1-\varepsilon_m)}{\varepsilon_m}\rho_w V^2\right]\left[\frac{dL_m}{dL_o}\right]$$

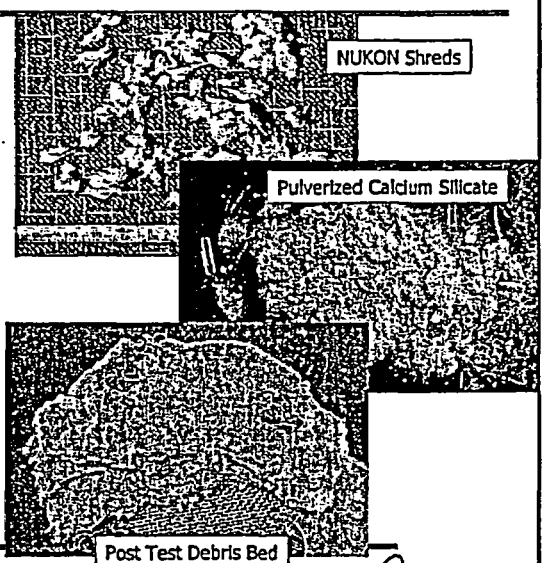
Test Apparatus

- **Enclosed Test Loop**
  - 12" transparent test section
  - 1/8" mesh screen
  - Circulation pump
  - Flow regulation valve
  - Head loss, flow, and temp instrumentation
  - Top access for debris insertion
  - Bottom drain port
- **Room temperature (~70 °F) or heated water (~125 °F)**



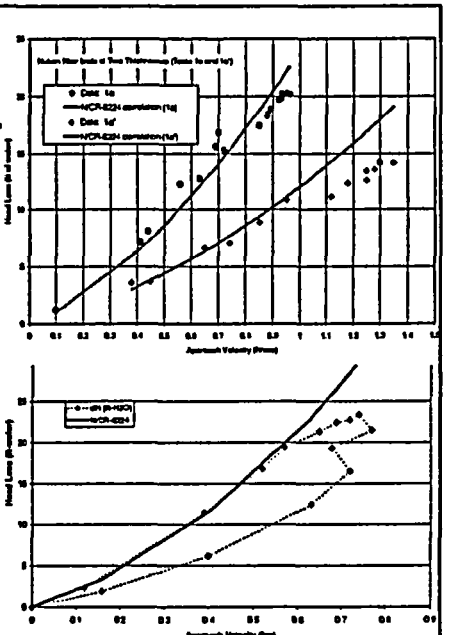
Test Parameters/Procedures

- Test Parameters
  - Quantity of NUKON debris
  - Quantity of calcium silicate debris
  - Water temperature
  - Approach velocity
- Test Procedures
  - Debris preparation
  - Fill & establish initial flow (initially low)
  - Slowly introduce debris to establish uniform bed
  - Incrementally increase flow
  - For each increment, wait for stability and record head loss and flow rate
  - Incrementally reduce flow and measure head loss and flow rate



Qualification Testing

- NUKON (Only)
  - NUREG/CR-6224 correlation validated in BWR strainer blockage study
  - Input parameters known
  - Good agreement between correlation and UNM NUKON test data
- Tests of NUKON and Surrogate Particulate
  - Dirt from concrete lab floor
  - Correlation agreement obtained assuming
    - Complete filtration at higher head loss corresponding to decreasing velocities (incomplete particulate filtration with increasing velocity)
    - $S_v = 190{,}000\ ft^2/ft^3$ (particulate)
    - $S_v = 171{,}000\ ft^2/ft^3$ (fiber)
  - Demonstrated deduction process for determining specific surface area from head loss data



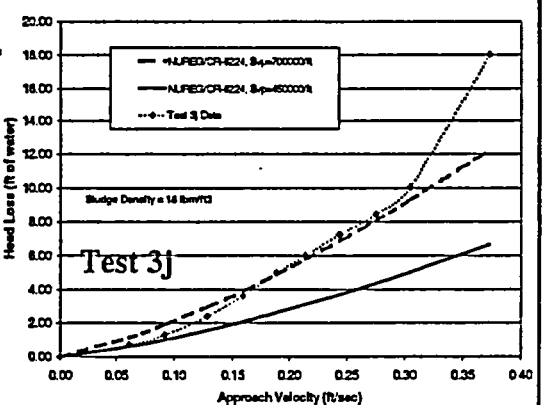
Calcium Silicate/NUKON Testing

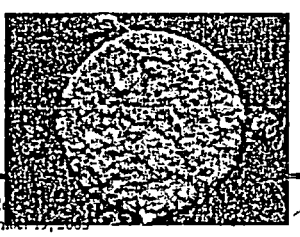
Four Categories of Test Results

- **Qualification Testing**
  - NUKON fiber glass only with well known parameters (fiber Sv = 171,000 ft^2/ft^3)
  - Good agreement between correlation and UNM test data
- **Well-behaved tests indicating higher specific surface area**
  - Cal-Sil S_v near 700,000 ft^2/ft^3
- **Well-behaved tests indicating lower specific surface area**
  - Cal-Sil S_v near 450,000 ft^2/ft^3
- **Poorly behaved tests**
  - Nonreproducible or erratic behavior
  - Problems include nonuniform debris beds, incomplete filtration of calcium silicate from flow, and measurement of nonequilibrium conditions
  - Cal-Sil S_v of 450,000 ft^2/ft^3 generally overestimates ΔP for these cases

Well Behaved Test Indicating Higher Specific Surface Area

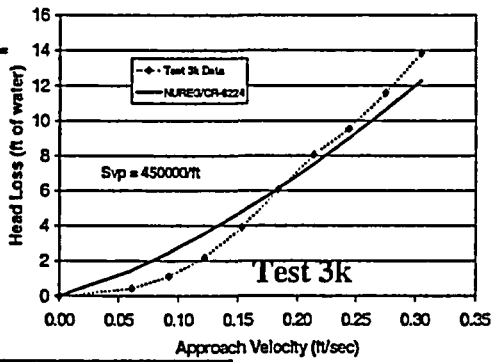
- Medium fiber bed (0.86")
- High head losses
- Complete or nearly-complete filtration easier for thicker fiber beds
- Indicates S_v of about 700,000 ft^2/ft^3 with exception of final data point
- Ratio of mass of calcium silicate to mass of NUKON was 0.5

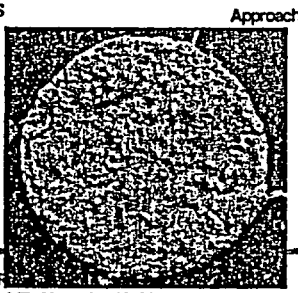


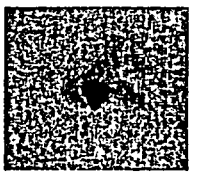


Well Behaved Tests Indicating Lower Specific Surface Area

- Medium fiber bed (0.86") with particulate to fiber mass ratio of 1.0
- Test indicates a lower value for S_v ~450,000/ft.
- Debris bed relatively uniform except high head loss caused penetration holes that allowed partial flow to bypass debris
- Therefore, S_v likely to be under predicted







Testing Problems Encountered

- Testing Problems
  - Calcium silicate particulate is very fine causing difficulties in filtering particulate from flow. Unless most of the calcium silicate resides in bed, the quantity in bed is unknown.
  - Calcium silicate lumps can disintegrate during testing causing a shifting in bed configuration
  - Heavy loadings of calcium silicate can exceed flow limits of test apparatus
  - Difficulties were encountered in establishing uniformity in debris bed, however, successful procedures did evolve
- When conducting additional tests, procedural refinements will improve estimate of calcium silicate head loss input parameters
  - Using data from these tests, bed conditions will be chosen to circumvent earlier problems, leading to more uniform debris beds and more complete filtration
  - Procedures will be refined based on testing experience

Test Conclusions

- It appears that the NUREG/CR-6224 correlation can predict calcium silicate head losses once appropriate input parameters are determined
- High head losses associated with calcium silicate appear to be caused by its high specific surface area, which is related to its small particle size
- A few additional tests needed with refined test procedures to improve estimate of correlation input parameters using the substantial testing experience gained to date
- Caution: The composition of calcium silicate varies with manufacturer, therefore, head loss behavior may also vary