ECCS PWR Sump Screen Qualification and Testing Information

Prepared for USNRC

May 24, 2006

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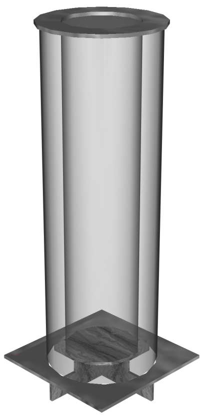
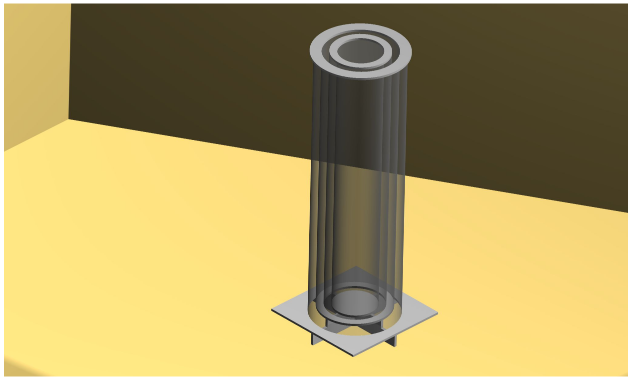
Outline of Information

- General Topics
  - Facility/Test description
  - Strainer design parameters
  - Licensees supported
  - Summary of key observations to date
- Specific Topics
  - Scaling/Selection of prototype
  - Debris preparation methodology
  - Debris introduction methodology
  - Head loss due to chemical effects
  - Screen by-pass testing
  - Termination criteria





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Facility/Test Description

- Dedicated GSI-191 Hydraulics and Chemical Effects Test Lab
- Located: Warrenville, IL
- 3000 sq. ft laboratory space for conducting experiments in debris transport, erosion, debris head loss, prototypical array and chemical effects testing
- Performing testing for 10 US and 2 foreign plants

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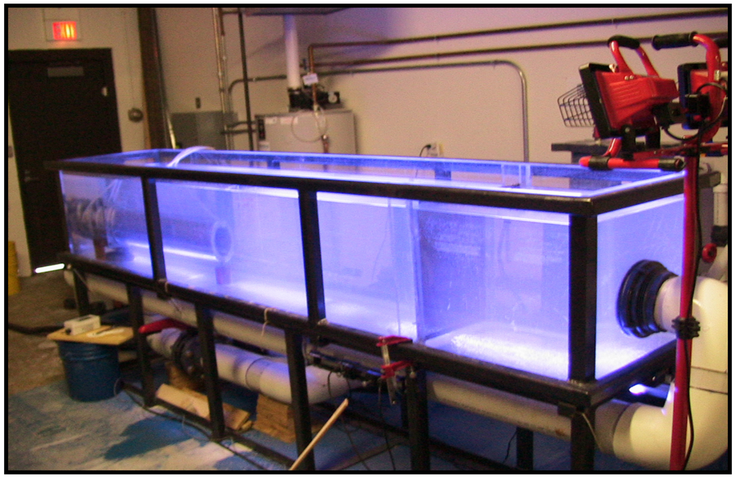
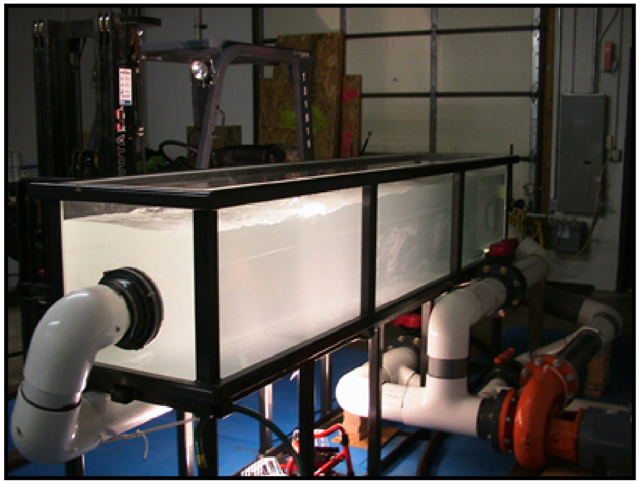
Transport Testing

- Flume
  - 2' x 2' x 10' long
  - 250 gal
  - Bulk velocities up to 1.5 fps
  - 900 gpm centrifugal pump w/VFD
  - Ultrasonic Flow Meter
  - Thermocouples
  - Pressure Transmitters (L/M/H)
  - 5 micron filter for by-pass test
  - Instrumentation NAVLAP certified
- Single strainer testing
- Interceptor performance testing
- RMI transport testing
- Vortex testing





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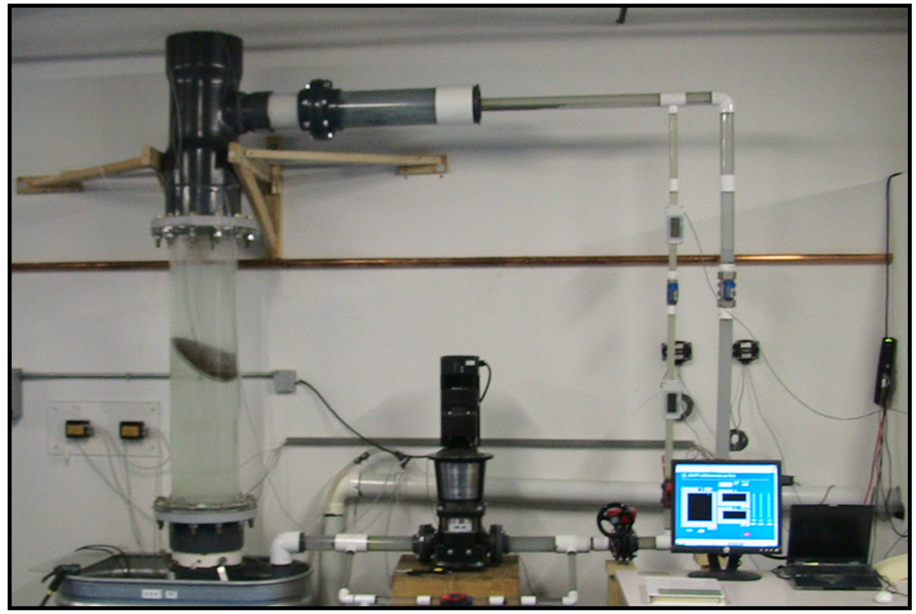
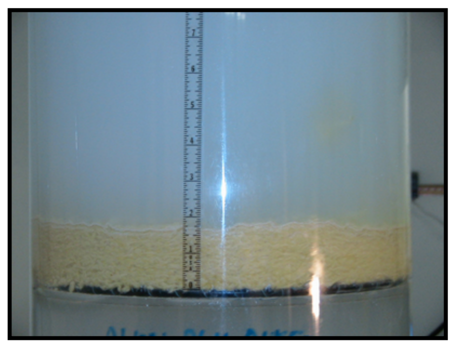
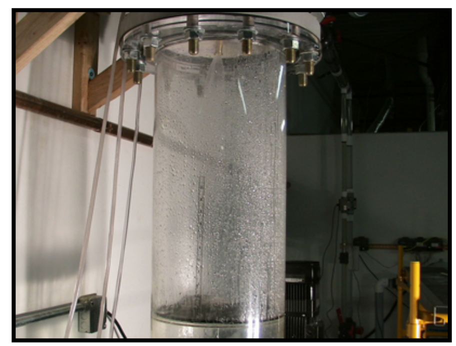
Material Head Loss Testing

- Vertical Test Loop
  - 12” diameter plate
  - 75 gal capacity
  - Approach velocities up to 0.5 fps
  - 200 gpm centrifugal pump w/VFD
  - 5 micron filter for by-pass test
  - Spray attachment
  - Ultrasonic Flow Meters
  - Turbine Flow Meters
  - Thermocouples
  - Pressure Transmitters
  - Instrumentation NAVLAP certified
- NUREG/CR-6224 validation
- Screen by-pass testing
- Spray erosion testing







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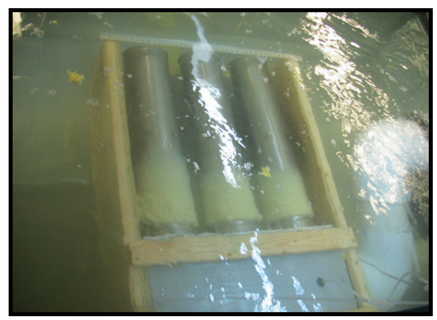
Prototype Tank Testing

- Test Tank
  - 6’ x 8’x 10’
  - 3500 gal
  - 2500 gpm centrifugal pump w/VFD
  - 5 micron filter for by-pass test
  - Heating and Cooling Control
  - Constant Turbidity Measurement
  - Ultrasonic Flow Meters
  - Thermocouples
  - Pressure Transmitters (L/M/H)
  - Turbine Agitator
  - Instrumentation NAVLAP certified



- Full scale prototype testing
- Screen by-pass testing

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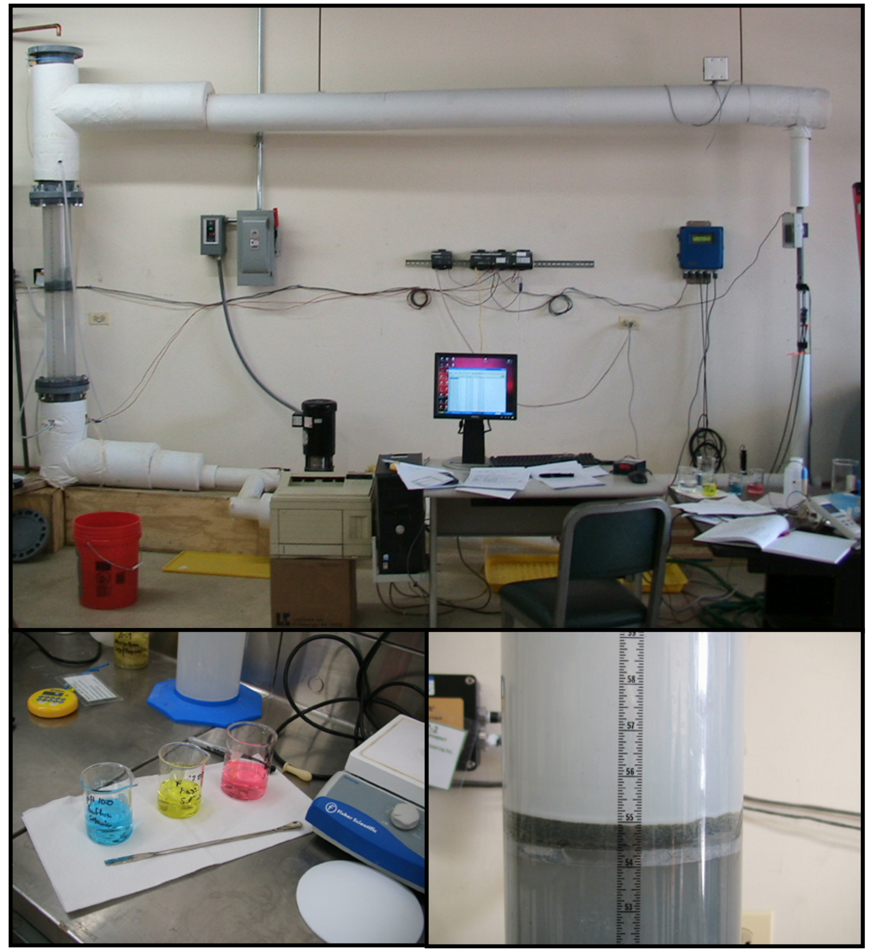
Chemical Effects Head Loss Testing

- Vertical Test Loop
  - 6” diameter plate
  - 16 gal capacity
  - Approach velocities up to 0.6 fps
  - 55 gpm centrifugal pump
  - Heating/Cooling (T_{max} = 160 deg F)
  - Ultrasonic Flow Meter
  - Thermocouples
  - Pressure transmitters
  - pH transmitter
  - Instrumentation NAVLAP certified
- Flat plate head loss testing for impact of chemical effects
- DI/RO water environment
- Sump chemistry environment



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Bench Testing

- Scanning Electron Microscopy (SEM) – Appendix B
- Particle density measurements
- Size distribution for particulates
- Bed density measurements
- Inductively Coupled Plasma (ICP)
- Dissolution testing under various pH
- Settling velocity of materials
- WCAP particulate generation
- Surrogate validation

Replacement Strainer Design Parameters

Plant	Approximate Screen Size (ft^2)	Approx. Flow Rate (gpm)	Screen Approach Velocity (ft/sec)	Perforated Plate Hole Diameter (inch)	NPSH Margin (ft of H_2O)	Buffering Agent
Duke – Catawba Units 1 and 2	2,200	16,000	0.016	3/32	7	Sodium Tetra borate
Duke – McGuire Units 1 and 2	1,500	16,000	0.023	3/32	12	Sodium Tetra borate
Progress – Crystal River 3	1,100	8,500	0.017	1/8	1	Trisodium Phosphate
Progress – Harris	2,300 per sump Two Sumps	6,400	0.006	3/32	3.1	Sodium Hydroxide
Progress - Robinson	4,200	3,800	0.002	3/32	5.5	Sodium Hydroxide
Exelon – TMI	2700	8700	0.007	3/32	1.3	Sodium Hydroxide
First Energy – Beaver Valley Unit 1	2,800	14,500	0.012	3/32	4.6	Sodium Hydroxide
First Energy – Beaver Valley Unit 2	3,400	13,000	0.009	3/32	1.6	Sodium Hydroxide
First Energy – Davis Besse	1,200	11,000	0.020	3/16	1.5	Trisodium Phosphate
Entergy – Indian Point Unit 2	3,150 – IR Sump	7,100	0.005	3/32	1	Trisodium Phosphate
	1,180 –VC Sump	3,500	0.007	3/32	8	
Entergy – Indian Point Unit 3	3,150 – IR Sump	5,300	0.004	3/32	0.6	Sodium Hydroxide
	1,420 –VC Sump	4,100	0.006	3/32	7.6	
Edison – San Onofre Units 2 and 3	990 per sump Two Sumps	3,500	0.008	3/32	4	Trisodium Phosphate

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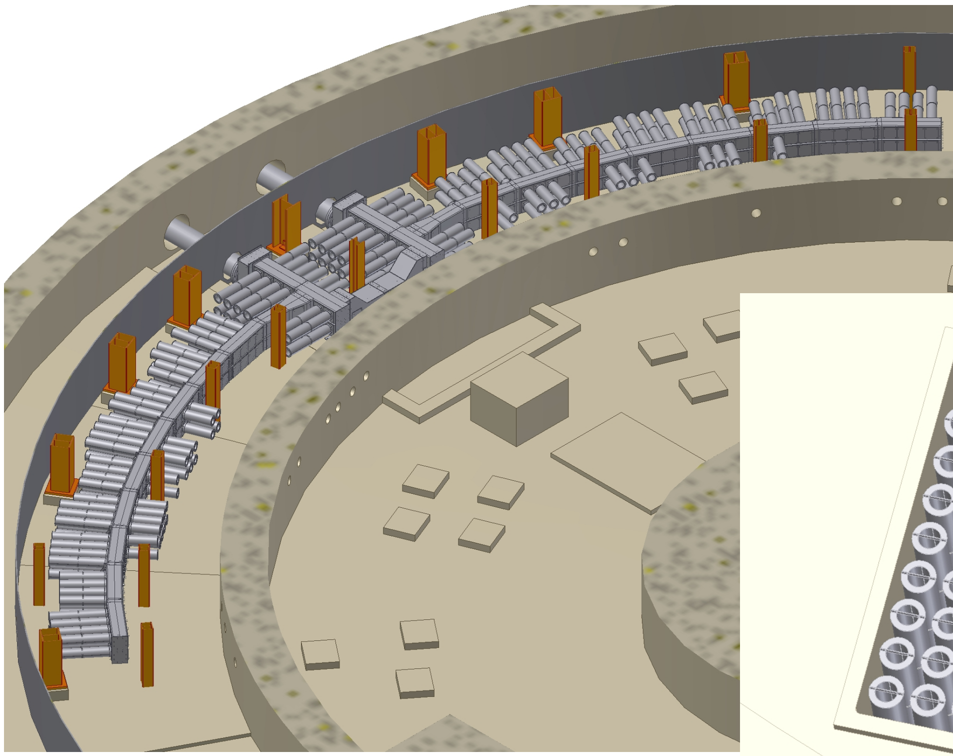
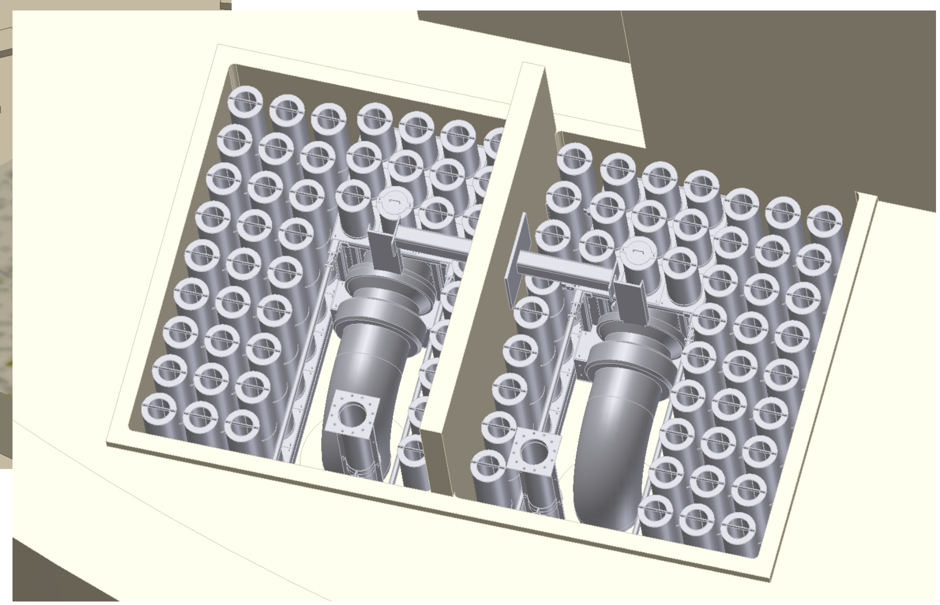
Replacement Strainer Designs





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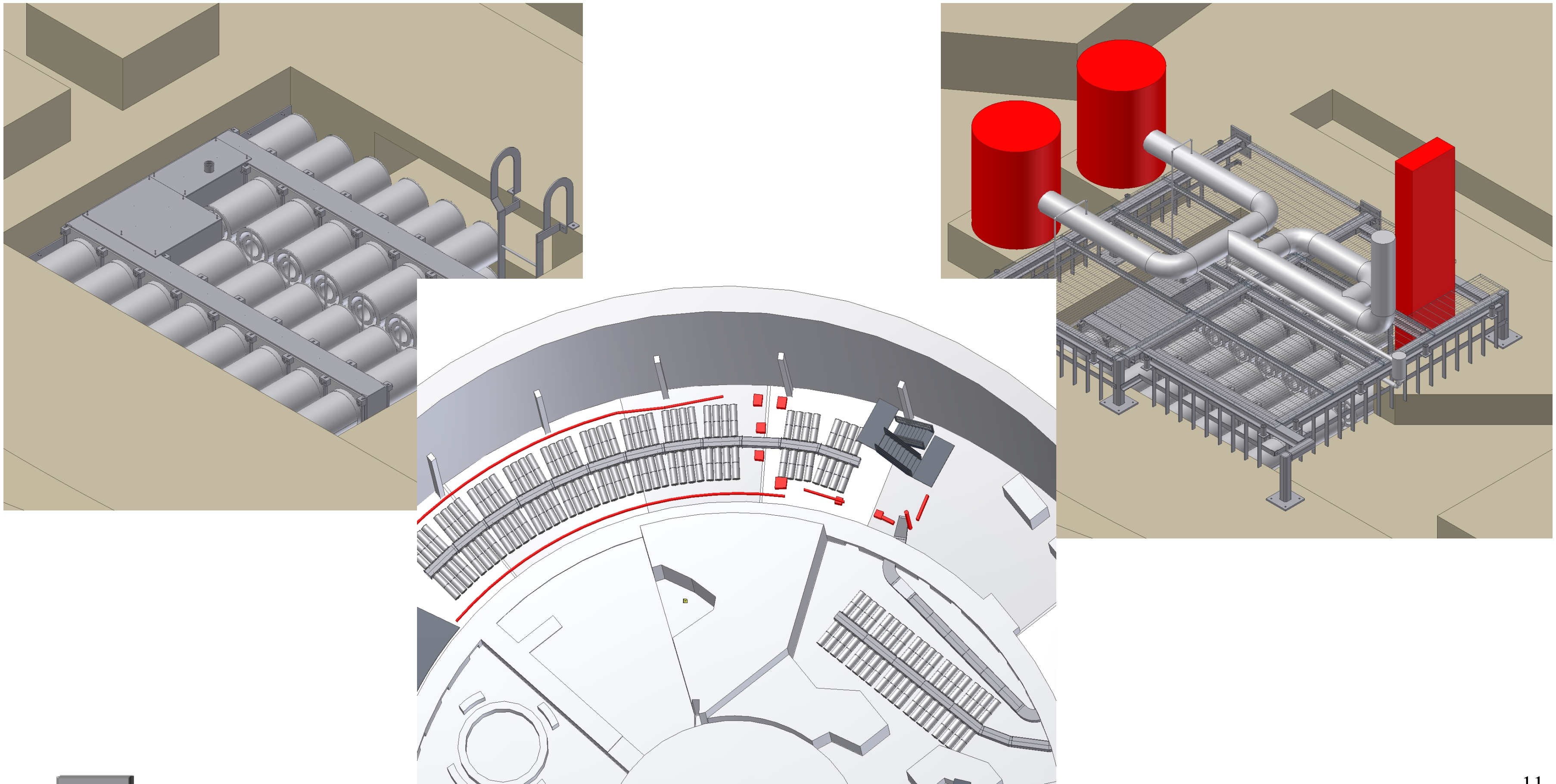

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Status of Testing

Plant	Prototype Debris Testing	Chemical Effects Testing
Duke – Catawba Units 1 and 2	Completed	In process
Duke – McGuire Units 1 and 2	Completed	In process
Progress – Crystal River 3	N/R	TBD
Progress – Harris	TBD	TBD
Progress - Robinson	Scheduled	Scheduled
Exelon – Three Mile Island	Scheduled	Scheduled
First Energy – Beaver Valley Unit 1	In process	Scheduled
First Energy – Beaver Valley Unit 2	Scheduled	Scheduled
First Energy – Davis Besse	N/R	TBD
Entergy – Indian Point Unit 2	Completed	Scheduled
Entergy – Indian Point Unit 3	Scheduled	Scheduled
Edison – San Onofre Units 2 and 3	In process	Scheduled
Entergy – Waterford 3 *	N/A	In process
FPL – St. Lucie Units 1 and 2 *	N/A	Scheduled
FPL – Turkey Point Units 3 & 4*	N/A	Scheduled
FPL – Seabrook*	N/A	Scheduled

* Alion only performing chemical effects testing

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Testing Methodology

Two Part Array testing:

1. **Low fiber regime**: all particulate material introduced into tank and stirred. Fiber batched in quantities equivalent to 1/8” thick beds up to 1” thick
2. **High fiber regime**: fiber + particulate batched in quantities with constant mass/particulate ratio to provide homogenous debris bed buildup up to maximum load.

Key Observations to Date

- Tendency of material to settle without agitation
- Pool hydraulics relatively easy to maintain
- Particulate surrogate inhibits good visualization
- Debris introduction and preparation can affect results
- Geometry effects can be pronounced:
  - Array orientation
  - Spacing between adjacent screen assemblies
  - Wall, floor, structural boundaries
  - Debris settling within pits

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Specific Topics

- Scaling and Selection of Prototype
  - Full scale section of replacement screen tested
  - Full size top-hats used in all testing
  - Sides on array to simulate boundary conditions
  - Tank turbulence/hydraulics are part of pre-test
  - Ensure “no settling” of debris
  - Water levels are consistent with containment level cover
  - Approach velocities are average approach velocities (Q/A) consistent with full scale section – no scaling of velocity

Modular Strainer Set Up

- High fiber load tests will partially fill the interstitial volumes.
- Interstial volume calculations result in very conservative head loss calculations.
- Test data can be approximated by use of a reduction in surface area.
- Use of full size Top Hats and plenums allow direct extrapolation of test data to plant array design.

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Temperature

- Temperature correction accomplished by NUREG/CR-6224 head loss correlation
  - Essentially the flow is laminar through debris beds – ratio of water viscosity
  - Turbulent term contribution is generally < 1%
- Non-uniform debris accumulation minimizes the presence of “bore holes”

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Modular Strainer Setup

- Full scale section of prototype
- Circumscribed debris accumulation not scaled

- Velocity need not be scaled as all debris is accumulated on the screen

Debris Preparation

- In accordance with controlled procedures
- Fiberglass – NUKON, TempMat
  - Shredded, boiled/baked, thoroughly stirred
- Microporous – Cal-Sil, Min-K, Microtherm
  - Procured in powder/pulverized form
- Coatings
  - So-Cal-Sil -
  - Paint Chips -
- Dirt/Dust
  - Silica Sand

Debris Preparation Methodology

- The debris quantities are based on the transport of "fines" or "small" as per NEI-04-07.
- The debris characteristics used in testing comport with the sizing of "fines" or "small" as per NEI-04-07.
- Latent dirt/dust debris in accordance with SER Appendix VII recipe.

Debris Preparation Methodology (cont.)

- Fiber:
  - All fiber is boiled for 15 minutes.
  - Fiber is then placed in a bucket with water and stirred with a paint stirrer until there are no large clumps left. Fiber spans the range of NUREG/CR-6224 sizes 1 through 4.
  - Fiber introduced in small batches released a few inches under the surface of the tank.

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Debris Preparation Methodology (cont.)

- Particulate:
  - Particulate is placed in a 5 gallon bucket with water and stirred with a paint stirrer for at least 10 minutes.
  - Bucket examined to ensure no "clumps" of particulate and that all particulate have been placed in solution.
  - Particulate laden water introduced in small batches released a few inches under the surface of the tank.

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Debris Introduction Methodology

- Debris mixed based on test plan
  - Fiber alone, particulate alone, or
  - Combined fiber+particulate batch
- Debris introduced depending on actual screen layout
  - On-grade installation vs. Sump pit
  - Debris introduced at discharge into tank to ensure thorough mixing and entrainment
  - Tank hydraulics ensure material is in suspension but not disturbed on the array.
  - No "near-field" effect or settling of debris
  - Debris accumulates on screen based on approach velocity

Debris Introduction Methodology (cont.)

- Test Tank
  - Debris is introduced to the tank in an area of high velocities near the pump return line.
  - Adjustable tank internal mixing is added to areas of low velocities, typically opposite to the pump return line.
  - Walls surrounding the top hat strainers prevent turbulence from the return flow and internal mixing from negatively affecting debris deposition.
- Test Flume
  - Debris is introduced to the flume upstream of the single top hat strainer.
  - Internal flume mixing occurs either manually or with an internal sparger.

- The goal for both the Tank and Flume is to deposit the majority of the debris on the strainer surface area within the approach velocity limits

Array Test Conduct/Termination Criteria

- Array testing may start with a flow sweep to establish the clean strainer head loss.
- The lowest flow is established and steady state is ensured.
- The first debris addition is added slowly to ensure dispersal.
- Once debris addition is terminated the countdown begins for 5 pool turnovers.
- After 5 pool turnovers, the criteria for the next debris batch addition or test termination is an increase in head loss < 1% in 10 minutes.
- Optional: Flow increase at the end of the test
- Optional: Decrease water level for vortex investigation

Head Loss due to Chemical Effects

- Approach based on bump-up factor to existing large scale array test results
- Utilize vertical test loop (flat plate) to determine head loss impact associated with chemical effects (precipitants and fluid effects)
- Plant specific data (pH, temperature, debris type and quantities)
- Precipitants based on WCAP Methodology
- Vertical loop tests are run to determine the impact each constituent has on head loss
- Scaled debris loads (type and bed thickness) are used from the full scale test to ensure consistency between two data sets

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Chemical Model

- Quantity and type of chemical precipitants determined from WCAP and plant specific inputs
- Debris quantities scaled to vertical loop screen area – approach velocities consistent with full screen
- Chemical precipitants are developed from the WCAP chemical particulate generator (no surrogates) and settling rates validated

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Head Loss Testing - Chemical

- Head loss impact due to precipitants and fluid chemistry investigated both separately and integrated in the vertical loop
- Investigating layered versus mixed precipitant debris beds
- Testing in both sump chemistry and DI or RO water
- Current investigations are steady state
- Planned investigations are time dependent

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Chemical Test Environment

- Vertical loop test environment
  - DI/RO water at room temperature
  - Sump environment at pH, debris material, boron concentration with maximum temperature of 160 deg F

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Chemical Surrogates

- Chemical precipitates generated using WCAP
- Generating all 3 chemical precipitants – not assuming sodium aluminum silicate is similar to aluminum oxyhydroxide
- Currently investigating WCAP precipitate stability in sump environment
- Currently investigating behavior of Carboline coating in sump environment and reaction with chemical precipitates
- Current testing using silicon carbide as coating particulate

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Aqueous chemical modeling

- The thermodynamic engine developed by OLI Systems is the most comprehensive commercial database available today
  - this model provides general simulation capability giving accurate prediction for almost any aqueous chemical mixture over the range:
    - Temperature: -50 to 300 C
      Pressure: 0 to 1500 bar
      Ionic strength: 0 to 30 molal

Aqueous chemical modeling

- We look to use modeling tools to increase our understanding of aqueous systems related to chemical effects
  - Evaluate the potential for modeling these chemical systems by comparing computational results with the experimentation
  - Look to better understand the impact that leaching/dissolution rates of various insulation mixtures that were observed during the ICET & WCAP studies
  - Provide a basis to quantify these issues, evaluate their significance, and define the work necessary to acquire any required additional information
  - Better define pH, temperature profiles used to describe LOCA scenarios
  - Better characterize fluid transport properties for recirculating flows
  - Investigate the impact of alternative buffering compounds may have in a particular plant scenario
  - Provide fundamental information related to corrosion of submerged metal

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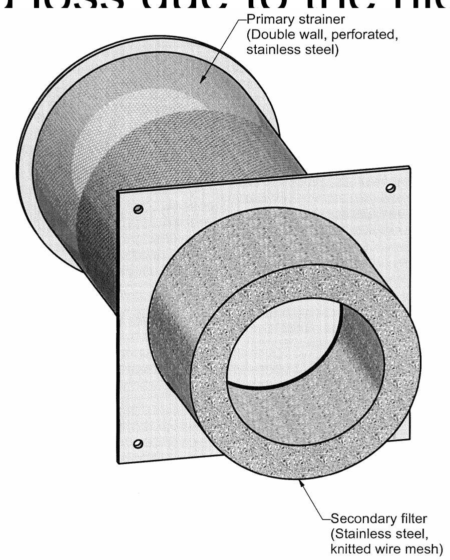
Screen By-Pass

- Enercon's Debris Bypass Eliminator *
  - Knitted Wire Mesh Construction
  - Inserted within Enercon's Top-Hat Strainer Modules
  - Porous media (approximately 98% porosity) that reduces the quantity and size of fibers bypassing Enercon's perforated plate top hat strainer modules
  - Minimal increase in clean strainer head loss due to the high porosity of wire mesh material

Patent Pending



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Fiber Debris Bypass

- Enercon's Debris Bypass Eliminator
  - Testing indicates that the fibers penetrating the strainer perforated plate openings exhibit a trapping effect on the surface of the wire mesh material

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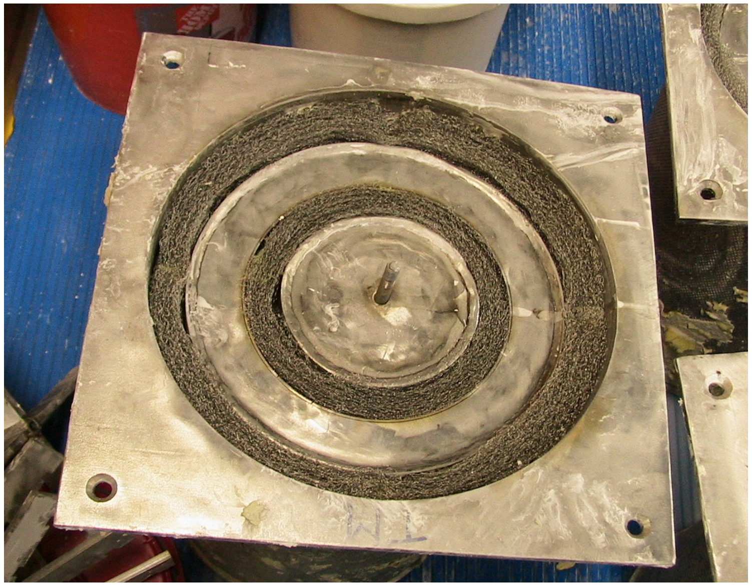
Fiber Debris Bypass (cont.)

- Enercon's Debris Bypass Eliminator
  - Since most of the fiber is captured near the surface of the wire mesh material, very little fiber is observed at the ends of the mesh material exiting the strainer Top-Hat modules



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Fiber Debris Bypass (cont.)

- Fiber Debris Bypass Testing
  - Fiber Debris Bypass Testing performed using a downstream bag filter (approximately 100% capture at 5 microns)
  - Testing performed with and without Enercon's Bypass Eliminator inserted within the Top Hat Strainer Modules
  - Testing performed at approach velocities ranging from 0.004 ft/sec to 0.075 ft/sec
  - Nukon fiber insulation used in the testing
  - Fiber lengths captured in the bag filters were examined using an optical microscope

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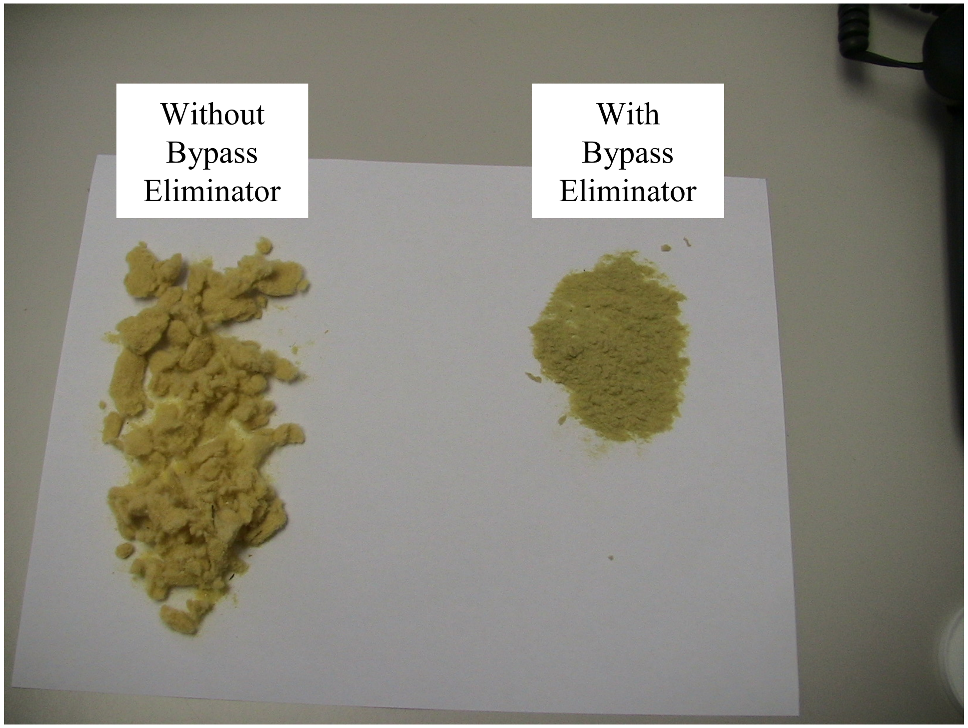
Fiber Debris Bypass (cont.)

- Fiber Debris Bypass Testing
  - Significant reduction in the quantity of fiber bypass when the knitted wire mesh bypass eliminators were inserted into the strainer top hat modules



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Fiber Debris Bypass (cont.)

- Fiber Debris Bypass Testing
  - Without the bypass eliminator, the long fibers that were collected exhibited matting into balls of fiber
  - With the bypass eliminator, the fibers that were collected were short straight fibers

Fiber Debris Bypass (cont.)

- Fiber Collected without Bypass Eliminator

Fiber Debris Bypass (cont.)

- Fiber Collected with Bypass Eliminator

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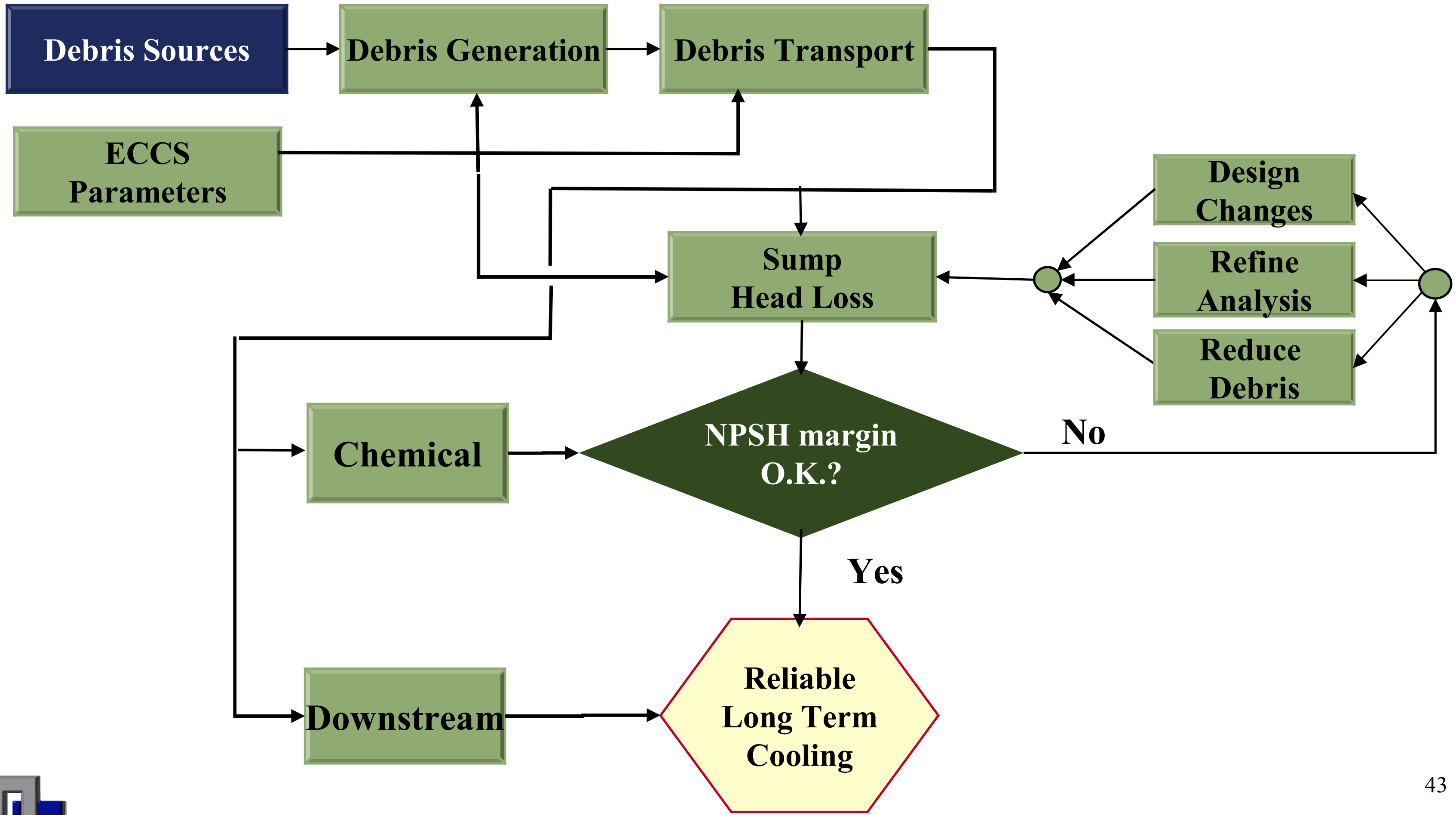
Fiber Debris Bypass (cont.)

- Microscopic Examination of Fiber Bypass Length
  - Without the bypass eliminator
    - Fibers at the edge of fiber balls ranged from 1000 - 3000 microns in length
    - Shorter fibers were observed inside the balls of fiber
    - Displayed fiber characteristics - clumping and bridging properties
  - With the bypass eliminator
    - Eighty to ninety percent of fibers were shorter than 500 microns
    - Nearly all fibers were shorter than 1000 microns
    - Displayed particulate characteristics - dust like properties

Fiber Debris Bypass (cont.)

Typical fibrous debris entrapped on Debris By-Pass Eliminator.

Sump Screen Sizing



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