DUKE ENERGY
MCGUIRE & CATAWBA NUCLEAR STATIONS

GSI-191
Discussion

Presentation to the NRC
November 24, 2008

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AGENDA

- GSI-191 Project Team
- Strainer Design and Layout
- Testing
- NRC-Provided Feedback on Duke Testing
- High Level Conservatisms
- Conclusions

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GSI-191 Project Team

- Duke Energy Corporation
  - Licensee and project oversight
- Enercon Services, Inc.
  - Project Management, Strainer Design, Testing, Calculations and Evaluations
- Alion Science and Technology
  - Testing, Calculations and Evaluations
- Transco Products, Inc.
  - Strainer Manufacturer
- Westinghouse Electric Company
  - Calculations and Evaluations
- Wyle Laboratories
  - Chemical Effects Testing

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ECCS Sump Strainer Design

- No Sump Pit
  - Two horizontal suction pipes at approximate sump floor elevation
  - Original strainer was a screen box style
- Strainer Plenum Characteristics
  - Single common train plenum design
  - Structurally qualified to 7 psid
  - Grating installed over plenums for vortex protection and personnel passage
  - Fully submerged at minimum sump water level at start of recirculation
- Top Hat Characteristics
  - Top Hat strainer modules with internal Debris Bypass Eliminator
  - Perforated plate surface area with 3/32-inch diameter holes
  - Horizontally mounted in columns, typically 2 modules high
  - Structurally qualified to 10 psid

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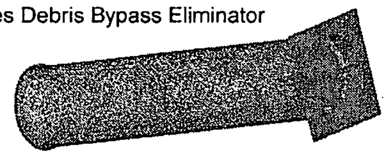
Top Hat Strainer Module

- 8" outer diameter, 6" inner diameter
- Lengths from 24" to 45"
- Incorporates Debris Bypass Eliminator



The Debris Bypass Eliminator is a knitted stainless-steel wire mesh with an open weave, designed to fit tightly between the inner and outer Top-Hat perforated plate straining surfaces. This mesh captures fine fibrous debris and limits bypass.

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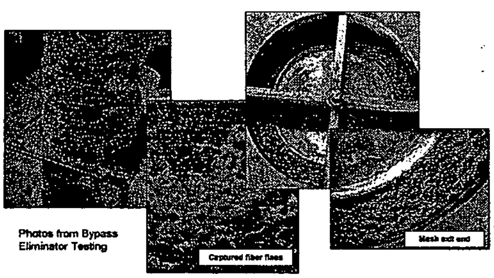
Debris Bypass Eliminator

Bypass eliminator provides a second filtration mechanism after the Top Hat 3/32" dia perforated plate. Most of the fiber that bypasses the perforated plate is captured by the wire mesh material.



Photos from Bypass Eliminator Testing

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Typical Top Hat Debris Loading

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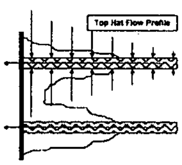
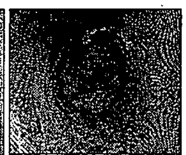
- With suction forces being highest at the plenum end of the Top Hat, there is a preferential flow profile along the length of the Top Hat.
- Due to this preferential flow, debris will initially collect at the base plate, causing the debris bed thickness to taper off along the Top Hat length.
- It has been observed that the debris bed collected on the inner surface area of the Top Hat strainer module tends to collapse and is ultimately compressed into a dense fiber plug at the base of the Top Hat, leading to clean strainer surface.




Tapered Debris Bed on Outer Surface from IPT


Fiber Plug on Inner Surface from IPT

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McGuire Modifications

Duke Energy.

Nominally 1700 ft² strainer on each Unit

- Unit 1: Fall 2007 Refueling Outage
  - 1,239 ft² Installed Inside Crane Wall
  - 521 ft² Installed Outside Crane Wall (Pipe Chase)
- Unit 2: Fall 2006/ Spring 2008 Refueling Outages
  - 1250 ft² Installed Inside Crane Wall
  - 523 ft² Installed Outside Crane Wall (Pipe Chase)

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McGuire ECCS Sump Strainer

Duke Energy.


Note: For clarity, the vortex grating and enclosure surfaces are not shown

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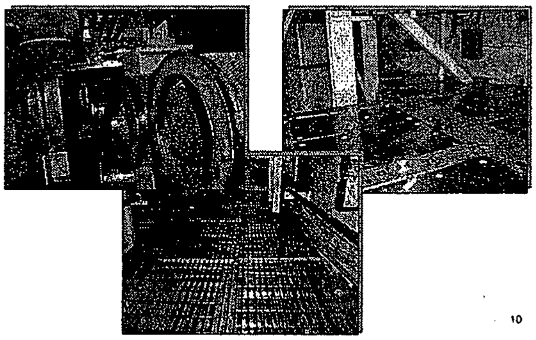
MNS ECCS Sump Strainer



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Catawba Modifications

Nominally 2400 ft^2 strainer on each Unit

- Unit 1 Spring 2008 Refueling Outage
  - 2,540 ft^2 Installed in Pipe Chase
- Unit 2 Fall 2007 Refueling Outage
  - 2,418 ft^2 Installed in Pipe Chase

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Catawba ECCS Sump Strainer

Note: For clarity, the vortex suppression rack is not shown

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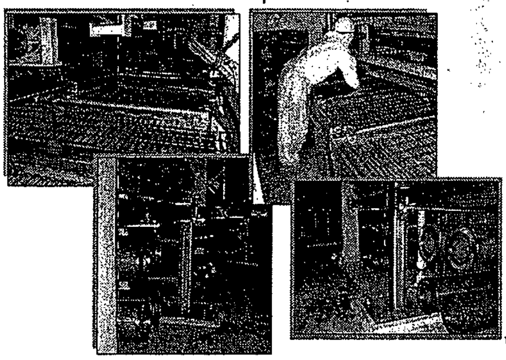
CNS ECCS Sump Strainer



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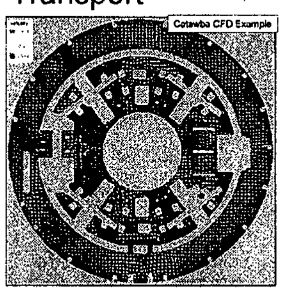
Strainer Layout Debris Transport

- Flow must travel to Pipe Chase through crane wall holes mostly centered at 3 ft above containment sump floor (serves as debris trap)
- Indirect flow path from inside the crane wall to the strainer Top Hats
- Sump strainer positioned in a remote area, in relatively low velocity pool conditions



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ECCS Sump Strainer Testing

- **Top Hat Array Head Loss Tests (Conventional debris)**
- **Fiber Bypass Tests**
  - Fiber Bypass testing of a prototypical module
  - Bypass material characterization/quantification
- **Vortex Tests**
  - Top Hat module with and without vortex suppression grating at various flows
- **Duke Vertical Loop Tests (Chemical Effects)**
- **Integrated Prototype Test (Chemical Effects)**

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Top Hat Array
Head Loss Testing

- Seven tests on 2×3 or 1×3 module array configurations
- 3 tests performed for potential thin-bed effects (encompassed McGuire and Catawba predicted debris loading)
- 4 tests for larger debris loads up to 9 inch bed thickness
- Testing included higher than expected particulate-to-fiber ratio

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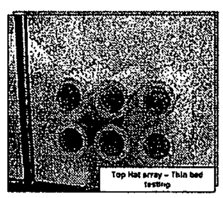
Top Hat Array
Head Loss Testing

Thin Bed Testing (three tests)

- A ⅜" bed thickness test, and a ½" stepped to 2" bed thickness test with maximum particulates (2 tests)
- Predicted Duke fiber loading is less than 2" (CNS: 0.55", MNS: 1.75")
- One test at ⅛" stepped to ⅜" bed thickness with homogenous debris mixture incrementally added
- Representative approach velocities modeled with additional flow sweeps up to 2x expected average


Top Hat array – Thin bed testing

➢ No evidence of a thin bed effect was observed in any of the tests performed on the Top-Hat array

➢ Complex geometry resists formation of a thin non-porous bed with high head loss

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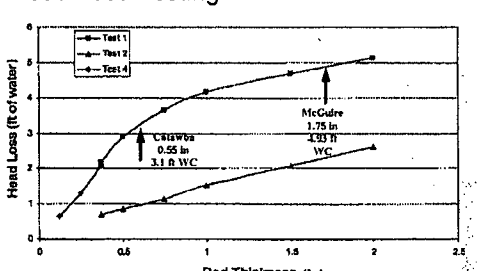
Top Hat Array
Head Loss Testing



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Top Hat Array
Head Loss Testing

- Array Test data corrected to calculated strainer approach velocity at the expected sump pool temperature.
  - For Catawba, 2.93 ft WC at 90°F and 0.0211 fps
  - For McGuire, 6.19 ft WC at 90°F and 0.0283 fps

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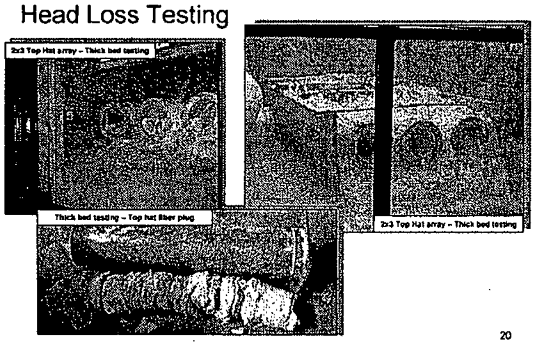
Top Hat Array
Head Loss Testing



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Duke Vertical Loop Test

Duke Vertical Loop (chemical effects) Test
- Late 2006 to mid-2007
- Vertical Loop Test design. Flat screen.
- Multiple tests were performed with either pre-prepared precipitates or soluble aluminum using WCAP-16530 methodology
- Pre-prepared precipitates showed high head losses.
- Soluble aluminum did not precipitate.
- Conclusions supported the original NRC sponsored testing (ICET #5) regarding aluminum precipitates (precipitates formed at concentrations well above MNS/CNS predicted values).

Vertical Loop Testing provided insights for Integrated Prototype Test parameters

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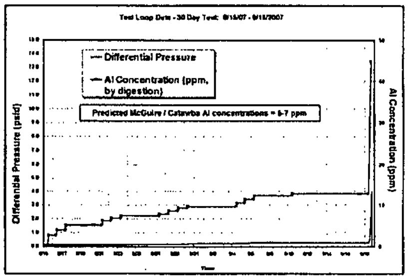
Duke Vertical Loop Test

Duke Energy.



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Integrated Prototype Test (Chemical Effects)

Duke Energy.

- 30-day Test with single prototypical Top Hat in lower position
- Demineralized water with ~2,200 ppm Boron, adjusted to pH 7.9 with sodium tetraborate
- Post-LOCA temperature profile
- 1.75-inch conventional debris bed
- Injected soluble aluminum nitrate per bounding representative profile confirmed by Vertical Loop Test
- Chemical loading concentration scaled to Top Hat module surface area
  - Tank size dictated testing with a single Top Hat module to preserve test fidelity and avoid excessive conservatism
  - Pool volume to strainer surface area ratio was approximated to model containment concentrations

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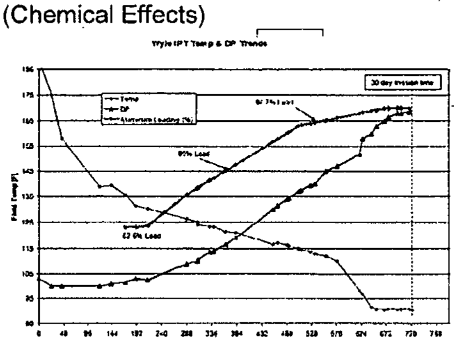
Integrated Prototype Test (Chemical Effects)

Duke Energy.



Integrated Prototype Test (Chemical Effects)

Duke Energy.

Chemical Effects Evaluation

- Only trace amounts of chemical precipitate were detected by SEM (Scanning Electron Microscopy) and EDS (Energy Dispersive Spectroscopy) examination.
- Total head loss change is small (<0.25%/hour)
- Increase in head loss is due to debris bed compression and compaction (small pieces and fines/particulates) over time at maximum flowrate.

Lack of chemical precipitates is supported by similar results documented for sodium tetraborate, aluminum, and low density fiberglass in ICET #5 and the Duke Vertical Loop Test.

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NRC-Provided Feedback on Duke Testing

Duke Energy.

- Integration of IPT and Array Testing Results
- Prototypical Debris Bed Formation
- Flow Fields
- Debris Agglomeration
- Incomplete Debris Transport

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Integration of IPT and Array Testing Results

Duke Energy.

IPT Data Evaluation

- Data collected during a temperature excursion was used to evaluate the flow regime at elevated temperatures independent of other parameters
- Flow sweep was used to evaluate the flow regime at low temperatures
- Based on Reynolds Number, the transitional flow regime is assumed to be linear with respect to the ratio of density to viscosity (over the temperature range of interest)
- From the head loss data and temperature correction methodology, a temperature dependent correction factor is developed for debris bed degradation and any chemical effects identified in this testing

Applying the developed "integrated prototype test correction factor" and temperature compensation to the Array Test data will allow for a prediction of the total ECCS Sump Strainer head loss for McGuire and Catawba.

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Integration of IPT and Array Testing Results

- Array Test results used to determine "fiber and particulate" head loss.
  - MNS $_{\text{Array test}}$ = 6.19 ft H_2O
  - CNS $_{\text{Array test}}$ = 2.93 ft H_2O

    (corrected to proper approach velocity & 90°F)
- IPT Correction Factors
  - At 90°F (fully laminar flow regime): *1.71*
  - At 120°F (57% turbulent): *1.41*
  - At 190°F (fully turbulent): *1.0*

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Integration of IPT and Array Testing Results

Integrated results of the Array test and IPT account for full fiber and particulate loading with bed compression and potential chemical effects:

MNS = 6.19 ft (Array test) *1.71 = 10.58 ft H_2O
CNS = 2.93 ft (Array test) *1.71 = 5.01 ft H_2O

(This is the 30-day debris loaded Top Hat head loss at 90°F)

Note that resultant head loss is substantially higher than either Array Test or IPT predicts individually.

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Integration of IPT and Array Testing Results

Debris loaded Top Hat head loss is added to clean strainer plenum head loss, to determine total strainer head loss:

Clean strainer plenum head loss =
- MNS-1 = 4.61 ft H_2O
- MNS-2 = 5.08 ft H_2O
- CNS-1 = 3.21 ft H_2O
- CNS-2 = 3.11 ft H_2O

Total strainer head loss at 90°F = (includes effect of 30-day compressed debris bed)
- MNS = 10.58 ft H_2O + 5.08 ft H_2O = 15.66 ft H_2O
- CNS = 5.01 ft H_2O + 3.21 ft H_2O = 8.22 ft H_2O

Total strainer head loss at 190°F = (includes effect of uncompressed debris bed)
- MNS = 4.69 ft H_2O + 5.08 ft H_2O = 9.8 ft H_2O
- CNS = 2.22 ft H_2O + 3.21 ft H_2O = 5.4 ft H_2O

190°F represents sump pool temperature at initiation of ECCS Recirculation phase. Prototypically, the strainer is clean at this condition; reported head loss results assume developed but uncompressed debris bed.

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Prototypical Debris Bed

Duke Energy

Array Testing

- During Thin Bed Array Testing, particulate was initially added and allowed to mix in the test tank.
- The recirculation flow was stopped and a fine fiber slurry (prepared with leaf shredder and paint mixer) was created and introduced into the tank.
- Recirculation flow was re-established and a fiber bed was allowed to form.
- Once head loss was stable, additional fiber was added in batches until the desired bed thickness reached.
- Fiber that did not transport to the array was mildly stirred to be re-suspended and allowed to transport.

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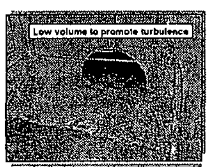
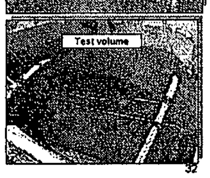
Prototypical Debris Bed

Duke Energy

IPT

- During debris introduction, the test tank volume was minimized to promote turbulence and enhance debris bed formation. (conservative, non-prototypical)
- Once dP stabilized, the tank was filled to the test volume which placed the Top Hat in a prototypically low velocity flow field.
- The approach velocity was consistent with bounding prototypical strainer approach velocity.
- Debris bed continued to compress over approximately 24 hours as the tank was heated to the test profile temperature.





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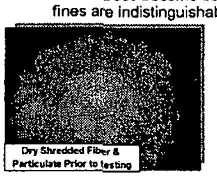
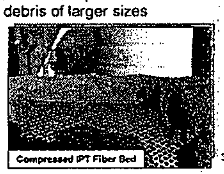
Prototypical Debris Bed

Duke Energy

- Debris bed formation within IPT is conservative with respect to expected plant conditions
  - At onset of ECCS recirculation phase, debris has not yet transported.
  - Initial ECCS flow is from RHR only, full ECCS flow is not reached until Spray pumps are realigned to the sump.
  - Debris beds become compressed over time, and individual fines are indistinguishable from debris of larger sizes



Dry Shredded Fiber & Particulate Prior to testing



Compressed IPT Fiber Bed

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Flow Fields

Duke Energy.

- Array testing (conventional debris loads) generated flow fields primarily perpendicular to Top Hat modules
  - Tank design brought inflow from front, top, and sides of strainer modules at representative approach velocities
  - 2×3 array configuration allowed cross flow field and minimized effect of flow turbulence on the array
  - Approach velocities are sufficiently low to avoid disruption of the debris bed (i.e. no bore hole formation)
- Integrated Prototype testing (chemical effects) generated flow fields primarily parallel to Top Hat module
  - Tank design brought inflow primarily from front and top of strainer module at representative approach velocity
  - Physical separation between tank return and top hat ensured prototypical approach velocity
  - Walls adjacent to top hat representative of bordering modules

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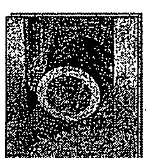
Flow Fields

Duke Energy.

- Flow Fields are consistent with respect to expected plant conditions.
  - Actual strainers are in a remote location protected from turbulence.
  - Top Hats are installed with multiple orientations relative to expected flow fields.
  - Without mechanically induced turbulence incomplete debris transport occurs during testing regardless of flow orientation.

Array test with flow perpendicular to Top Hats



IPT with flow parallel to Top Hat

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Debris Agglomeration During IPT

Duke Energy.

- Fiber was purchased in a pre-baked and shredded form.
- Fiber was then separated into several buckets and mixed with a paint mixer along with particulate surrogate.
- Debris was introduced continuously into the tank, directly in front of the Top Hat strainer module.
- During debris introduction, the test tank volume was minimized to promote turbulence and enhance debris bed formation.

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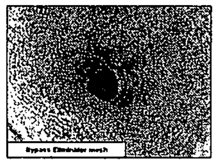
Debris Agglomeration During IPT

Duke Energy.

- Overall Fiber delivery to the Top Hat module is consistent with respect to expected plant conditions.
  - Small pieces and fines were delivered to the Top Hat strainer module.
  - SEM and EDS analysis of the post test debris bed showed compacted fiber and sediment.
  - Fiber fines were captured within the bypass eliminator mesh.



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Incomplete Debris Transport

Duke Energy.

- Fibrous debris load for the IPT was based on "worst case" uniform bed thickness between the 2 plants.
- Approximately 25% of fibrous debris introduced in the IPT did not transport to the Top Hat module.
- Prepared debris was introduced directly in front of the free end of the Top Hat strainer module and was allowed to transport in a turbulent low volume pool.
- Closure Guidance methodology (March 2008) invokes potentially non-prototypical debris introduction measures to facilitate debris transport.

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Incomplete Debris Transport

Duke Energy.

IPT debris transport is consistent with expected plant conditions

- Given plant specific differences in fibrous debris quantities and strainer surface area, the IPT is considered representative of the debris loading expected for Catawba.
- Typically the strainer array is 2 Top Hats high. IPT Top Hat was located consistent with the lower position, where higher fiber loads are expected.
- Top Hat strainer module complex geometry is designed to resist uniform debris bed development, which would lead to clean strainer surface area.
- Debris profile on the Top Hat strainer module followed the expected behavior of a complex geometry.

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High Level Testing Conservatisms

Duke Energy.

- Combination of bounding parameters (fiber, particulates, and chemical debris) from each plant into one test.
- Maximized predicted aluminum concentration (minimum pool volume, minimum safeguards flowrate).
- Full ECCS and Spray flow modeled for entire 30 day period.
- Assumed full debris bed established at onset of recirculation.
- Higher than expected debris loading.
  - Coating thickness assumptions
  - Assumed additional fiber debris generated beyond predicted ZOI
  - No credit for shielding/shadowing (i.e., walls, equipment, piping)

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Summary and Conclusions

Duke Energy.

- IPT and Array Test protocol utilized a mixture of fines and small pieces of fiber, prepared in accordance with guidance available at the time of testing
- IPT debris introduction was conservatively non-prototypical and provided insights regarding flow turbulence, bed compression, and chemical effects
- No evidence of chemical precipitates on IPT fiber bed
- Resultant strainer head loss is representative of a full fiber and particulate load, and incorporates the time-dependent effects of debris bed compression and potential chemical effects
- Resultant strainer head loss is substantially higher than either the Array Test or IPT predicts individually

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Duke Energy.

Thank you! Questions?

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