LTR-SEE-I-10-78 NP-Attachment

Transmittal of NRC Presentation, 'Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid: Westinghouse Evaluation of PWROG Test Result Differences.'

May 2010

Westinghouse Electric Company LLC
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Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid: Westinghouse Evaluation of PWROG Test Result Differences

May 19, 2010

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Executive Summary

- **Issue:** Containment sump debris results for a AREVA fuel assembly, tested at CDI, are considerably different than the results obtained for a Westinghouse fuel assembly tested at STC.
- **Test facilities:** Differences are minor and are not believed to be responsible for the issue.
- **Fuel Design**: Significant differences in the fuel design are considered to be the cause of the observed differences.

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Agenda

- Background
- Comparison of Fuel Designs
- Comparison of Test Facilities
- Conclusions

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Acronyms

- BN: bottom nozzle
- CDI: Continuum Dynamics, Inc.
- DFBN: debris filtering bottom nozzle
- ECCS: emergency core cooling system
- FA: fuel assembly
- LTCC: long-term core cooling
- NRC: U.S. Nuclear Regulatory Commission
- P:F: particulate-to-fiber ratio
- RAI: request for additional information
- STC: Science and Technology Center

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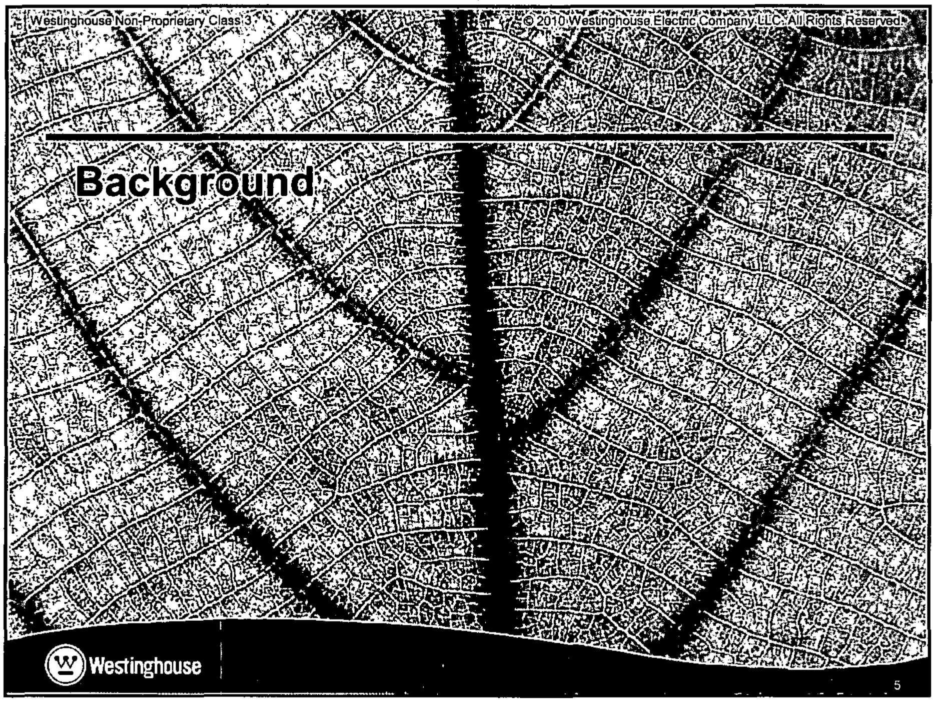

Background: Generic Letter 2004-02

- GL 2004-02 issued which required that utilities address the adverse affects of containment debris not filtered by the sump screens in the recirculation flow on long-term core cooling (LTCC).
- GL required that utility response include:
  - Basis for concluding that adequate ECCS flow is available for long-term core cooling in the presence of debris blockage at flow restrictions (fuel assemblies) downstream of the sump screens (i.e. downstream effects)
  - Description of modifications, if needed, to provide for adequate ECCS flow to ensure LTCC
- Industry sponsored guidance for fuel effects
  - WCAP-16793-NP

Background: WCAP-16793-NP Basis

- Demonstrate with reasonable assurance that long-term core cooling requirements of 10 CFR 50.46 are satisfied with debris and chemical products in the recirculating coolant delivered to the core from the containment sump
- Applicable to the fleet of PWRs, regardless of the NSSS design (that is, B&W, CE, or Westinghouse)
- Revision 0 was presented to the ACRS in March 2008.
- Revision 1 was developed to address ACRS concerns.
  - Fuel assembly testing
  - Determination of debris load limits

Background: Fuel Test Program

- To demonstrate that the head loss at the core inlet and fuel assembly, due to a potential buildup of fine debris from the containment sump, does not exceed the available head thereby ensuring long term decay heat removal.

$$\Delta P_{available} > \Delta P_{debris}$$

- The ΔP_{debris} is determined by PWROG-sponsored fuel assembly (FA) containment sump debris testing
- Westinghouse and AREVA conducted the FA containment sump debris tests at independent facilities.
  - AREVA fuel tested at Continuum Dynamics, Inc. (CDI).
  - Westinghouse fuel tested at Science and Technology Center (STC).
- A detailed, common test protocol, developed with input from NRC staff, was followed at both test facilities.

Background: Fuel Assembly Test Method

- Very Conservative Test Methodology
  - Test article is conservative compared to "actual" plant condition.
  - Assumed flow rates are significantly higher than boil-off flow needed at the switch-over time.
  - Did not credit "alternate" flow paths.
  - Did not credit actual temperature conditions that would improve results (less chemical precipitation, boiling, etc.)
  - Did not credit the repeated filtering of the debris. Debris would be filtered out through repeated passes through the sump screen which is not credited.

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Background: Request for Additional Information

- Upon review of WCAP-16793-NP, Rev. 1 and supporting FA test reports, the staff requested additional information (RAI).
- 43 RAIs submitted.
  - 16 required additional test data.
  - Generic test program developed by PWROG to address RAIs.

Background: Original Comparison of Test Results

- In response to NRC RAIs on WCAP-16793, R1, AREVA and Westinghouse compared fuel assembly ΔP results from respective tests.
- Comparison of test results for high particulate loads had very similar trends.
- It was concluded that generic testing could be conducted with the Westinghouse FA to address RAIs.
- Confirmatory testing would be conducted with AREVA FA upon update of the maximum allowable debris loads.

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Background: Confirmatory Testing

- Particulate-to-fiber (p:f) ratio key factor in how debris collects on the fuel assemblies
- Tests at high p:f ratios similar between facilities/FA designs
- Tests at low p:f ratios considerably different:
  - Westinghouse FA demonstrated up to 150 g of fiber would not impede LTCC
  - AREVA FA demonstrated 15 g of fiber would not impede LTCC
- Reason for difference could either be:
  1. Fuel design features
  2. Test facility features

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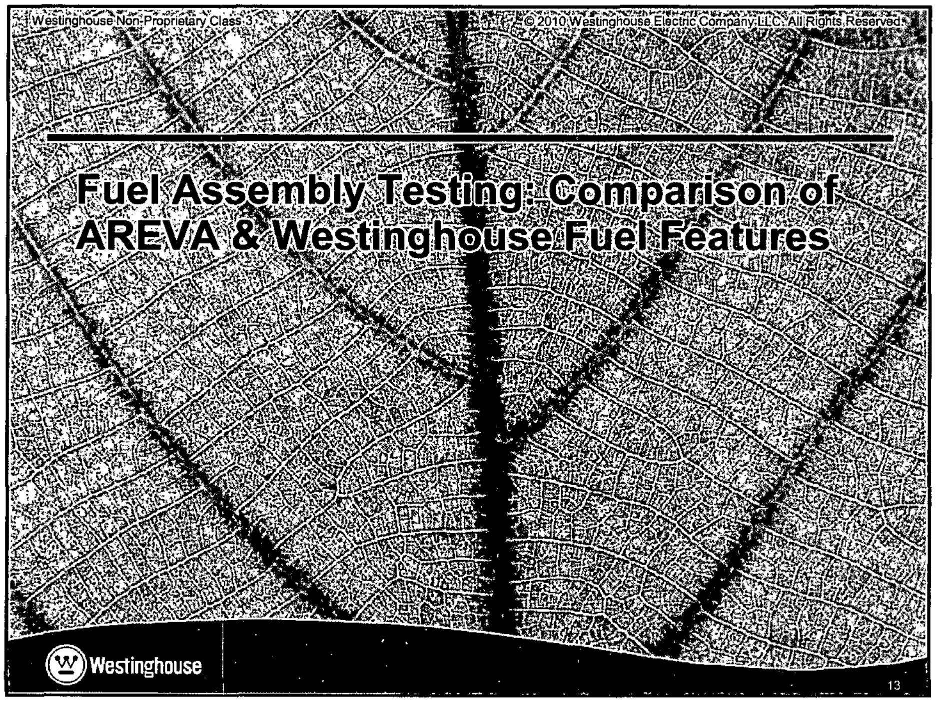

FA Testing: Causes of Differences

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FA Testing: Debris Bed Formation

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FA Testing: Debris Bed Formation

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FA Testing: What about the fuel?

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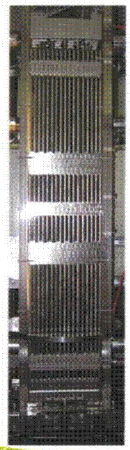
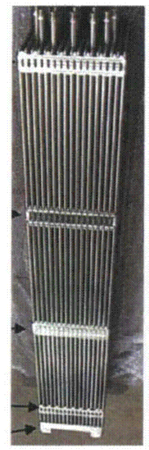
Westinghouse FA



AREVA FA



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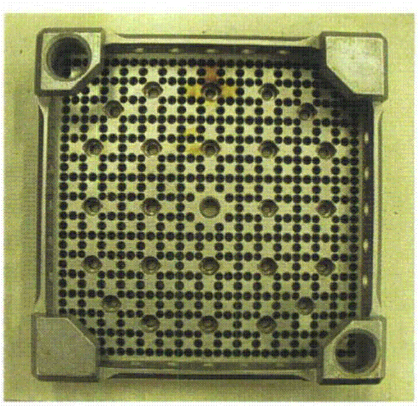
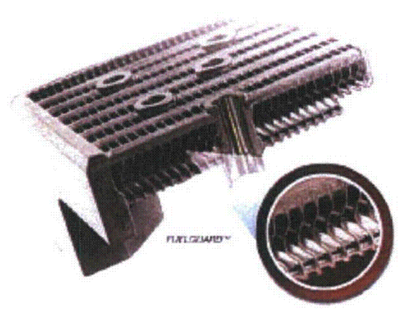
FA Testing: Westinghouse and AREVA BN Designs

Westinghouse DFBN



AREVA FUELGUARD



Pictures available in public domain

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FA Testing: Effect of Bottom Nozzle Designs

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FA Testing: Westinghouse FA Flow Areas

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FA Testing: Westinghouse FA Velocity

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FA Testing: Representative Westinghouse BN Flow Field

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FA Testing: [ ][a,c]

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FA Testing: Comparison of Results (High P:F Ratio)

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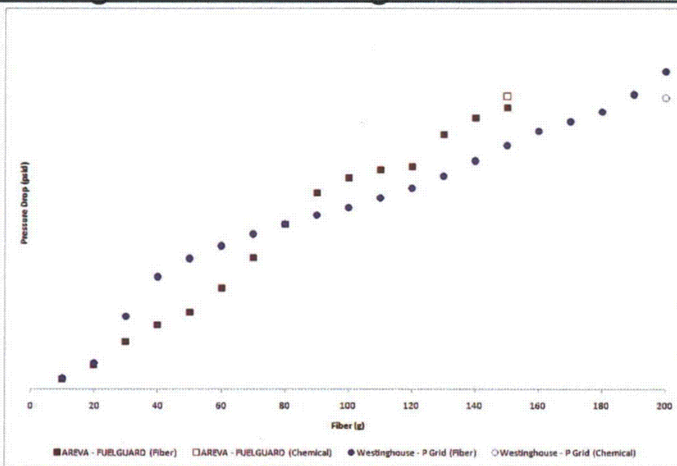
FA Testing: Results at High P:F Ratios



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FA Testing: Comparison of Results (Low P:F Ratio)

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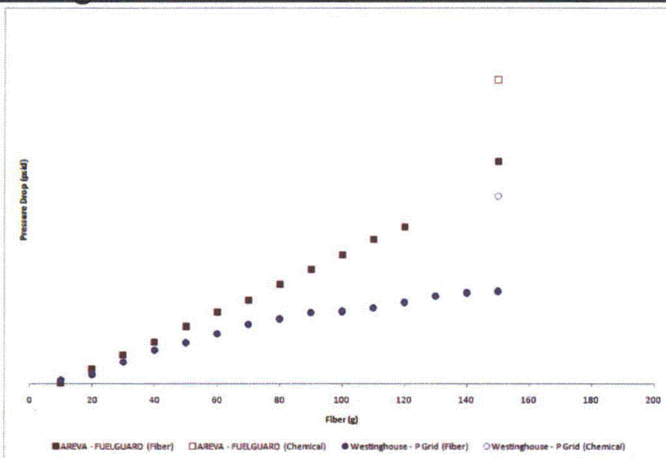
FA Testing: Results at Low P:F Ratios



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FA Testing: Comparison of FA designs

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FA Testing :Conclusions from Comparisons

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FA Testing: Representative Westinghouse BN Flow Field

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Summary of Significant Design Differences

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Fuel Assembly Testing: Comparison of AREVA & Westinghouse Test Facilities

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Facility Comparison Overview

- Hardware
- Debris
- Procedure

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Hardware Comparison: Overall Loop

- Each loop consists of:
  - Mixing tank
  - Flow meter
  - Test vessel to house fuel assembly
  - Pressure instrumentation
  - Data collection system
- Flow path is the same

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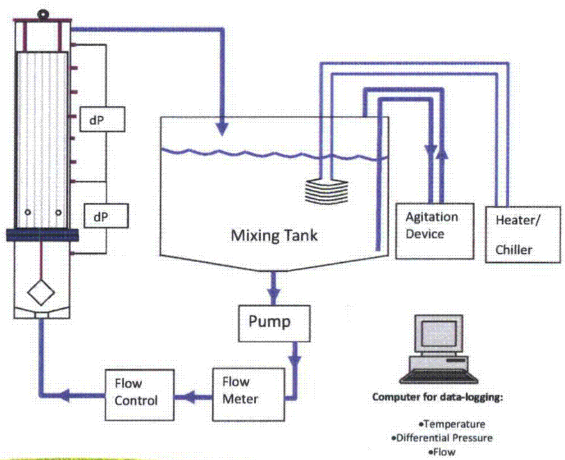
Hardware Comparison: Test Loop Overview



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Hardware Comparison

Design Difference		Westinghouse (STC)	AREVA (CDI)	Impact
Mixing Tank	***Surroundings***	• Open to atmosphere	• Open to atmosphere	• None – Same at both facilities
	Agitation	• Dedicated recirculation device	• Mechanical agitation device	• Debris is thoroughly mixed at both facilities. • Agglomeration of debris is not observed upon introduction into test vessel. • Upon dismantlement, debris is not found throughout equipment.
	Liquid Volume	• Initial = 100 gal • Final = 120 gal	• Initial = 100 gal • Final = 120 gal	• None – Same at both facilities
	Requirements of test protocol are met at both facilities.			
Flow	***Flow Control***	• Flow restrictor	• Discharge valve	• None • Both facilities control flow within 10% of the desired flow rate. • Hot-leg break tests were conducted at 44.7 gpm at both facilities.
		Requirements of test protocol are met at both facilities.		

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Hardware Comparison (cont.)

Design Difference		Westinghouse (STC)	AREVA (CDI)	Impact
Lower Plenum	***Height***	• 24 inches	• 12 inches	• Both designs perform desired function of dispersing flow throughout test vessel.
	Flow Disrupter	• Cube placed along diagonal in flow stream • Slanted bottom surface	• Inverted cone placed in flow stream	
	Lower Core Support Plate	• Thickness = 2 inches • Hole Diameter = 2.75 inches	• Thickness = 1 inch • Hole Diameter = 2.75 inches	
	• Purpose of lower plenum and lower core support plate is to prevent jetting of flow from mixing tank into FA. • Height difference does not affect how debris collects throughout FA. • Both designs perform this function. • Requirements of test protocol are met at both facilities.			

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Hardware Comparison (cont.)

Design Difference		Westinghouse (STC)	AREVA (CDI)	Impact
Construction	***Actual Half Gap Dimension (distance between FA and vessel wall)***	• Average = 22.5 mils	• Average = 17.5 mils	• Test protocol stated gap must be 20 mils ± 8 mils • Larger gap does not impact overall results. • Testing conducted at CDI to evaluate impact of larger gap. • **No discernible difference** between results obtained from test with 17.5 mil gap and test with 40 mil gap.
	Requirements of test protocol are met at both facilities.			

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Debris Comparison

Design Difference		Westinghouse (STC)	AREVA (CDI)	Impact
Particulate	*Type*	• Silicon carbide	• Silicon carbide	• None – Same at both facilities.
	Size	• Average = 9.5 μm	• Average = 9.5 μm	• None – Same at both facilities.
	Requirements of test protocol are met at both facilities.			
Fiber	*Type*	• Nukon*	• Nukon*	• Discovered A tested with unbaked Nukon • W supplied A with baked Nukon prepared by W • W fiber did not change results
	Size	• Within distribution defined by test protocol	• Within distribution defined by test protocol	
	Requirements of test protocol are met at both facilities.			
Chemical	*Type*	• AlOOH	• AlOOH	• None – Same at both facilities.
	QA	• Meet settling criteria defined by WCAP-16530-NP-A	• Meet settling criteria defined by WCAP-16530-NP-A	• None – Same at both facilities.
	Requirements of test protocol are met at both facilities.			

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Procedure Comparison

Design Difference	Westinghouse (STC)	AREVA (CDI)	Impact
Coolant Introduction	• Filtered city water • Initially filled with 100 gal	• Filtered city water • Initially filled with 100 gal	• None – Same at both facilities.
	• Circulate for 30 minutes	• Circulate for 30 minutes	• None – Same at both facilities.
	Requirements of test protocol are met at both facilities.		
Particulate Introduction	• Mixed with water from mixing tank	• Mixed with water from mixing tank	• None – Same at both facilities.
	• Circulate for 30 minutes	• Circulate for 30 minutes	• None – Same at both facilities.
	Requirements of test protocol are met at both facilities.		
Fiber Introduction	• 10 grams mixed with water from mixing tank	• 10 grams mixed with water from mixing tank	• None – Same at both facilities.
	• Circulate for minimum of 2 turnovers	• Circulate for minimum of 2 turnovers	• None – Same at both facilities.
	Requirements of test protocol are met at both facilities.		
Chemical Introduction	• Slowly added in ten gallon increments	• Slowly added in ten gallon increments	• None – Same at both facilities.
	• Final volume = 120 gal	• Final volume = 120 gal	• None – Same at both facilities.
	Requirements of test protocol are met at both facilities.		

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Summary of Facility Similarities

Design Feature	Westinghouse (STC)	AREVA (CDI)	Impact
Mixing tank – prevent settling	• Conical bottom • Constant agitation	• Constant agitation	• None – both facilities meet design requirements
Flow direction – upward	• Upward	• Upward	• None – same at both facilities
Flow recirculation	• 100% recirculation	• 100% recirculation	• None – same at both facilities
Placement of FA in test vessel	• Centered	• Centered	• None – same at both facilities
Lower plenum – prevent settling	• Sloped bottom • Diamond flow disrupter	• Inverted cone flow disrupter	• None – design at both facilities precludes settling of debris in lower plenum
Velocity (HL)	• 0.2 ft/s	• 0.2 ft/s	• None – same at both facilities
Loop volume	• 100 gal	• 100 gal	• None – same at both facilities
Water	• Filtered tap water	• Filtered tap water	• None – same at both facilities
Lower core support plate pattern	• Same as Westinghouse 17x17	• Same as Westinghouse 17x17	• None – same at both facilities
Rod material	• Zr	• Zr	• None – same at both facilities

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Summary of Facility Similarities (cont.)

Design Feature	Westinghouse (STC)	AREVA (CDI)	Impact
Flow measurement/ controlability	• Yes	• Yes	• None – both facilities meet design requirements
Temperature measurement/ controlability	• Yes	• Yes	• None – both facilities meet design requirements
Pressure drop measurements	• Across entire FA and bottom nozzle	• Across entire FA and bottom nozzle	• None – same at both facilities. Instruments calibrated and maintained per facility QA req.
Debris type	• Same	• Same	• None – same at both facilities
pH	• Between 6.5 and 9	• Between 6.5 and 9	• None – generally same at both facilities

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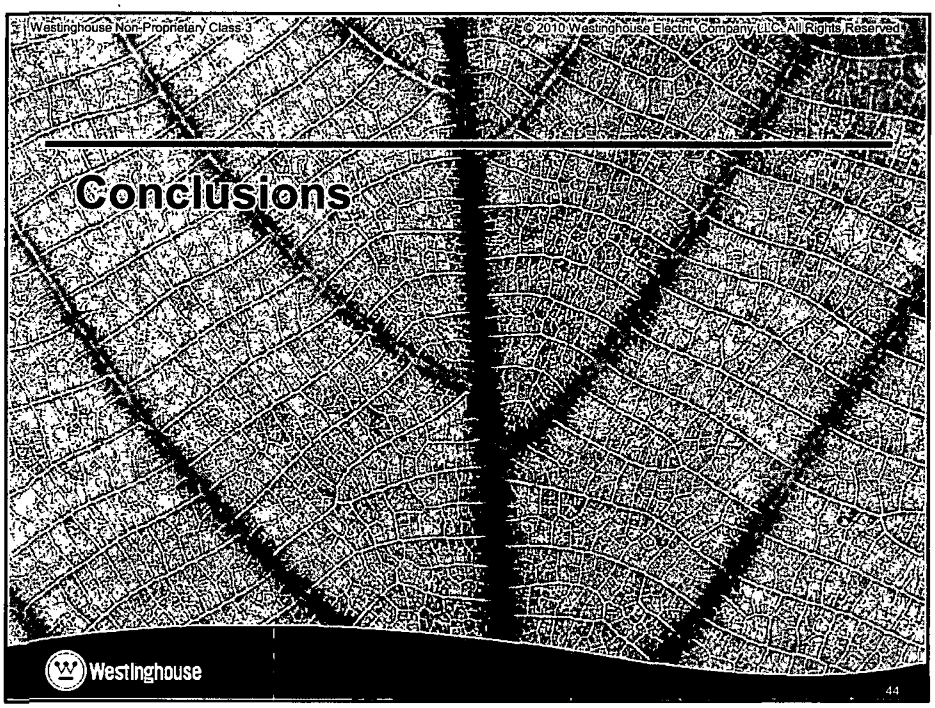
Facility Comparison Summary

- The test facilities used by Westinghouse and AREVA to conduct FA testing meet the requirements of the PWROG test protocol concerning the major components of the test loops, debris sources and test procedures.
- It is concluded only **minor** differences exist and there is nothing to indicate these differences would impact the distribution of debris throughout the FA.
- The predominant difference in the results is caused by differences in the **fuel assembly design**.



Conclusions

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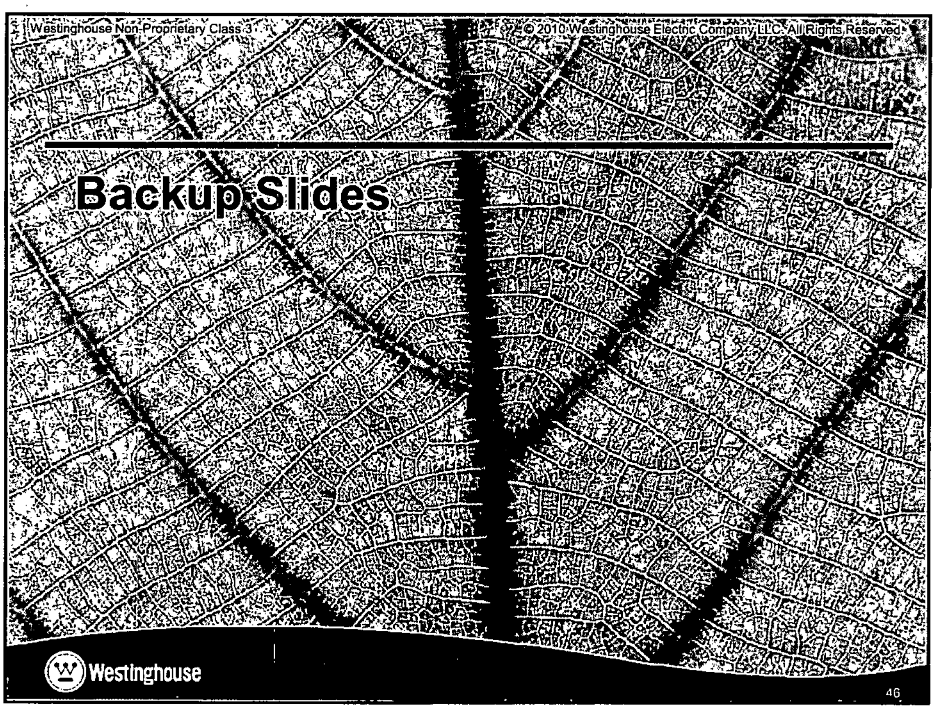
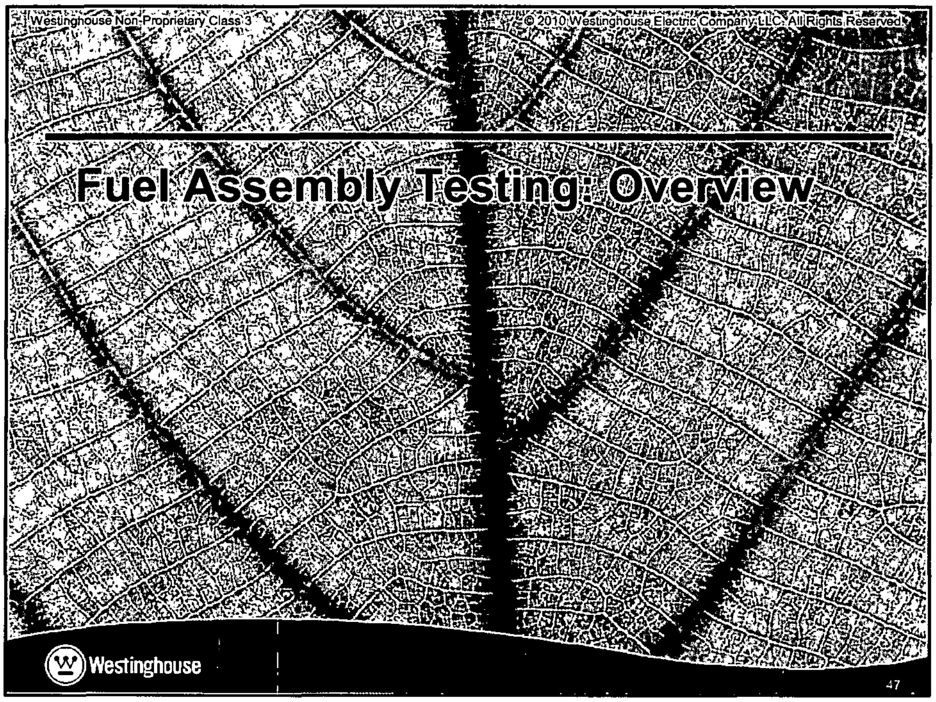
- Fuel Designs

- It is the difference between fuel designs that caused the disparity in results collected at low p:f conditions.
- Considerable Westinghouse test data is sufficient to preclude the need for an uncertainty factor.
  - A large uncertainty factor on Westinghouse fuel would mask a true difference in fuel assembly performance.
- **Results obtained at both facilities are valid.**





FA Testing Overview

- Debris can build up at the core inlet
- In order to determine if sufficient flow will reach the core to remove core decay heat through a potential inlet blockage, it must be demonstrated that the head available to drive flow into the core is greater than the head loss at the inlet due to a possible debris buildup

$$\Delta P_{available} > \Delta P_{debris}$$

- $\Delta P_{available}$ is a plant-specific value. PWROG is providing a tool for utilities to determine their actual $\Delta P_{available}$
- ΔP_{debris} is determined by testing.

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Pressure Drop from Debris

- The head loss through a possible debris buildup at the core inlet is a function of the amount and type of debris that reaches the RCS

$$\Delta P_{debris} = f(\text{debris type, debris amount})$$

- Multiple combinations of debris can reach the RCS.
  - The amount and combinations at any given time are related to the plant design and timing of the arrival of the various debris
  - A 30-day debris load is tested in order to produce a bounding limit

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Pressure Drop from Debris

- A fiber bed must be present to collect the particulates at the core entrance
  - Otherwise, the particulates will simply pass through and no blockage will occur
- The presence of fiber is the limiting variable.
- However, amount of particulate influences resulting ΔP.

Formation of Debris Bed

- Fiber by itself is fairly porous, even with very small fibers.
- The particulates can fill the small gaps among the fibers and decrease the porosity of the bed.
  - Testing was conducted with 10μm silicon carbide particles.
  - Small particles are conservative to test with as they fill the interstitial gaps and result in the lowest porosity.

Thickness of Debris Layers

- If no particulate is present, then the debris bed will be made up entirely of the fiber layer.
- If particulates are present in abundance (high particulate-to-fiber ratio (p:f)), then the debris bed will be fully saturated with particulates. In this instance, the addition of chemical has little to no impact on the total head loss.
- In the event of low p:f cases, the number of particulates is not great enough to fully saturate the fiber. In this instance, the addition of chemical will impact the total head loss.

FA Test ΔP_{debris} Limit

- FA tests are designed to define debris limits such that spillover will not occur.
- Pressure drop caused by debris will be limited to the available driving head defined by the liquid level at or just below the spillover elevation with all of the flow still going though the core.

Description of $\Delta P_{available}$

- ECCS must pass through core to exit break.
- Driving force is manometric balance between the liquid in the downcomer and the core.
- As debris bed builds in the core, the liquid level will begin to build in the cold-legs and flow will spill back through the reactor coolant pumps into the pump suction piping, SG inlet plenum and SG tubes.
- As level begins to rise in the SG tubes, the elevation head to drive the flow through the core increases.
- Driving head reaches its peak right before the flow begins to spill over the shortest SG tubes (Westinghouse & CE) or reaches HL spillover elevation (B&W).

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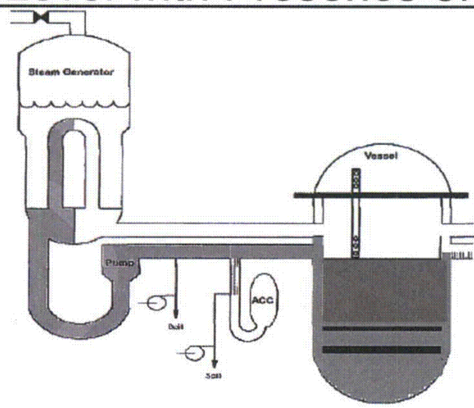
Liquid Level with Presence of Debris



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Cold Leg Acceptance Criteria

- **Fiber $\leq$ 18 g per FA**
  - The plant-specific flow split will be used to translate this value into the equivalent RCS fiber load.
    - Flow split is the ratio of boiloff rate to the total ECCS flow.
  - The flow split is a plant-specific value. The PWROG is providing a tool for utilities to determine their actual flow split.
- **$\Delta P_{available} \geq$ 1.7 psid**
  - The $\Delta P_{available}$ is a plant-specific value. The PWROG is providing a tool for utilities to determine $\Delta P_{available}$.

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Hot-Leg Acceptance Criteria

- Plant is assured of meeting FA test criteria as long as fiber load (in g) is bounded by:

$$RCS\ FiberLoad / FA = \min\left[\left(\frac{\Delta P_{available} - 7.5}{0.0667}\right), 150\right]$$

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