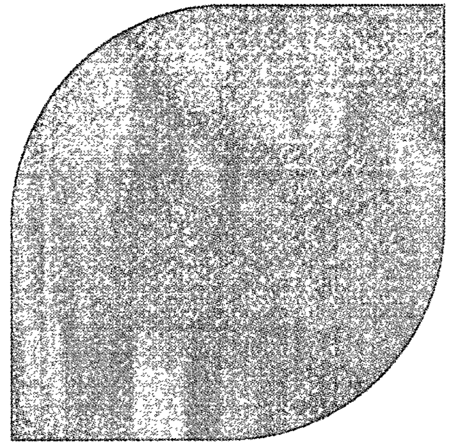
GSI-191 – NRC Update
May 19, 2010

AREVA

Agenda

- Introduction
  - Gordon Wissinger
- Comparison of Test Loops
  - Dr. Victor Hatman
- Conclusion
  - Gordon Wissinger
- Questions/NRC Feedback



Introduction

Gordon Wissinger

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Introduction

- Early industry efforts to evaluate in-vessel effects were based on engineering judgment:
  - NEI 04-07
  - WCAP-16406-P, Chapter 9
  - WCAP-16793-NP, Rev. 0
- These approaches were extensively questioned by NRC and ACRS
  - Questions rooted in the lack of certainty, or test data, to support the evaluations that were provided
- Consequently, PWROG undertook a fuel assembly test program

Introduction

- PWROG developed a test protocol to specify
  - Test requirements
  - Test procedure
  - Ensure consistent results among different test facilities
- Early test results indicated that the test protocol served this purpose
  - High p:f ratio tests matched well between Westinghouse and AREVA
- Tests at low p:f ratios did not match well, which raised the question:
  - "What is causing the difference in results?"

Introduction

- **AREVA, in consultation with Westinghouse, undertook an extensive review of the test loops and testing process to try and answer this question**
- **Results have been documented and delivered to PWROG and NRC**
- **Conclusions identified 3 areas that may provide the answer:**
  - **The Test Loops**
    - While both test loops followed the test protocol, certain differences may be substantial enough to produce different results.
  - **Fuel Assembly Tested**
    - AREVA tested a 17x17 FA with 0.374" OD rods
    - W tested a 17x17 FA with 0.360" OD rods
  - **Fuel Assembly Design**

Comparison of Test Loops

Victor Hatman

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GSI-191 – Test Protocol

▶ Test Protocol – Background Information

- **The test protocol has identified two sets of tests:**
- **Baseline Tests – necessary to establish:**
  - Selection of one limiting fuel debris capture design from AREVA and Westinghouse
  - Definitions of correlations / multipliers to link the limiting design to other designs of same vendor - emphasis on Bottom Nozzle
  - The "limiting" design feature is perceived to be the Bottom Nozzle (BN) – the concern was (at the time the tests were defined) that the BN would clog and starve the core
- **Acceptance Criteria Tests – needed to establish fiber limits for the AREVA and Westinghouse designs**
  - The limits are based on break type, and plant design
  - Hot Leg Breaks: at 45 gpm (or 6.25 gpm for CE plants), pressure drop < 13 psi, target fiber load 150 grams / Fuel Assembly (FA)
  - Cold Leg Breaks: at 3 gpm, pressure drop < 1.5 psi (target fiber load 18 grams / FA)
  - The limits are expressed in grams of fiber per FA

GSI-191 – Test Protocol

- **Hot Leg Break Test Results at a Glance**
  - **Low particulate-to-fiber (p/f) ratios are limiting**
  -

Link to Hot Leg Break

GSI-191 – Test Protocol

- **Cold Leg Break Test Results at a Glance**
  - Lower p/f ratios are limiting
  - The Cold Leg Break Tests meet the fiber and dP limits
  - The results for AREVA fuel show a lower dP than for the Westinghouse fuel at the same fiber loading

Link to Cold Leg Break

GSI-191 – Test Comparison

- **Test Loop, Process, and Article Comparison**
  - **The comparison was organized along the lines of the test protocol**
  - **5 groups of requirements were assessed**

1. **Flow Rate:**
   - the minimum flow rate that has to be maintained throughout the test depends on the plant type and break location
2. **Sequence of debris tests**
   - Establishes the sequence in which tests have to be performed
3. **Test Equipment**
   a. Loop Design Features – Comparison Summary – Detailed Comparison - establishes requirements for the loop where the test is being conducted
   b. Test Article – Comparison Summary - establishes requirements for the test assembly and test vessel
   c. Measurement and Control Capabilities – establishes requirements for measurement equipment (accuracy, precision and range), and for temperature and flow rate control
4. **Mechanical Debris and Chemical Precipitate Preparation**
5. **Test Procedure**

GSI-191 – Comparison Summary

▶ Test Loop Differences Summary

- ◇ **Lower Plenum length and turbulator are different**
  - not clear whether this can cause the difference in test results
  - the main pump supplies the pressure drops, and the hole pattern in the Simulated Core Support Plate is the same
- ◇ **Side Gaps are different – not likely a major factor**
- ◇ **Pumps and agitators are different but satisfy requirements – effect on debris behavior un-quantified**

GSI-191 – Comparison Summary

- Test article Differences

GSI-191 – Test Comparison

- **Un-quantified Potential Differences and Effects**
  - **Effects of Tests Loop on Fiber Behavior**
  - **The stirrer may have an influence on fiber length distribution by shredding longer fibers that stick on spacer first.**
  - **The pump type may have an influence on fiber behavior.**
    - Some pumps work in a way that agglomerates fibers and enhance blockage, while other pumps shred fibers to smaller sizes
    - Fiber length distribution downstream the pump may not be the same as upstream
  - **Fiber length distribution evolution over the time span of the test run is un-known**
  - **Water chemistry at both test locations**
- **The uncertainty introduced by these factors can best be removed by cross-testing**

GSI-191 – Comparison Summary

- **Test Loop Differences**
  - **Lower Plenum length and turbulator are different**
    - not clear whether this can cause the difference in test results
    - the main pump supplies the pressure drops, and the hole pattern in the Simulated Core Support Plate is the same
- **Test Debris Preparation and Introduction Differences**
  - **Chemical precipitate preparation and holding time before test could be a factor**
  - **Tap water chemistry analysis report – not available for both facilities**
  - **Effect of Loop on fiber debris behavior**

GSI-191 – Comparison Summary

- **Test Article Differences**
  - **The Test Protocol required that the test bundles represent <u>limiting</u> designs. The AREVA bundle was indeed selected based on this requirement.**
  - **BN: FUELGUARD/CM TRAPEPR vs. Standard BN + p-grid**
    - The p-grid could create higher turbulence at the Lower End Grid inlet, and this may help part of the debris pass through and settle on the upper grids
  - **Lower End Grid Transparency to debris**
    - AREVA tested the Inconel Mk-BW (six point contact) and the HMP (line contact).
    - Unknown Lower End Grid in the Westinghouse bundle

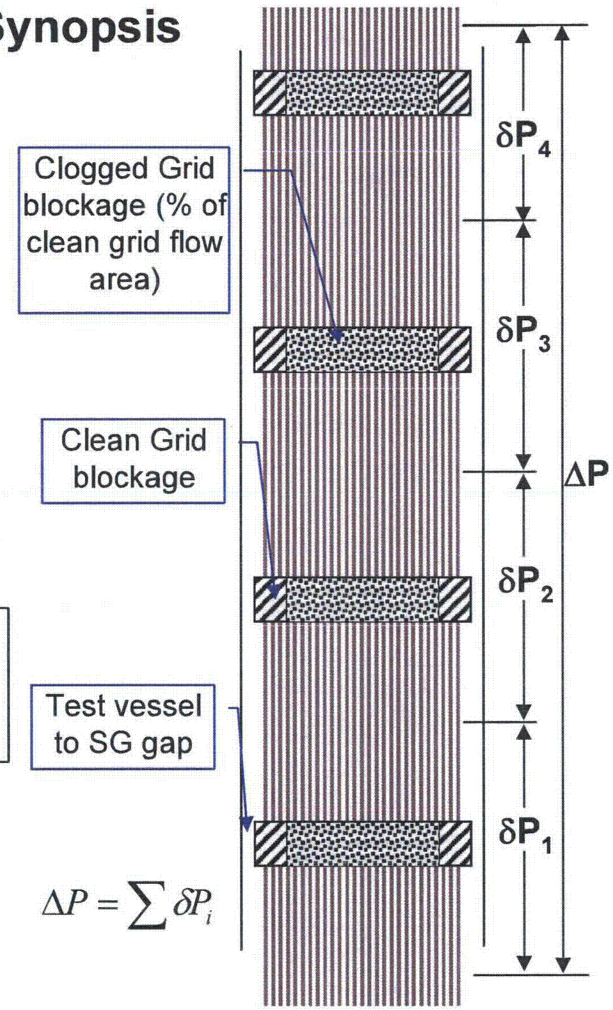
GSI-191 – Blockage Effect on Pressure Loss

Analytical model for blocked grid ΔP calculation - Synopsis

- Inconel Lower End Grid used as clean geometry baseline
- Accounts only for the differences in Fuel Rod OD and shroud-to-spacer grid gaps:

[ ]

- All other geometrical features are assumed the same
- The calculation makes simplifying assumptions for deposit growth (hydraulic diameter, deposit thickness, etc.)
- [ ]
- Calculations were completed for bounding cases:
  - **Fully open and fully closed gap**
  - **45 gal/min and 6.25 gal/min**



$$\Delta P = \sum \delta P_i$$

GSI-191 – Blockage Effect on Pressure Loss

- **The dP across a grid is a highly non-linear function of blockage. As debris blockage increases, the dP grows exponentially**
- **At high blockage levels (over 75%) 6 percentage points difference in blockage can quadruple the pressure drop**

<u>CONCLUSION</u>:

Pressure drop under fiber load blockage is highly non-linear

Any Fuel Assembly design features that can impact blockage (Fuel Rod OD, side gaps, Spacer Grid (SG) transparency, SG inlet turbulence) must be examined in detail

Also it is important to understand the spacer grids and bottom nozzle susceptibility to retain and build up debris

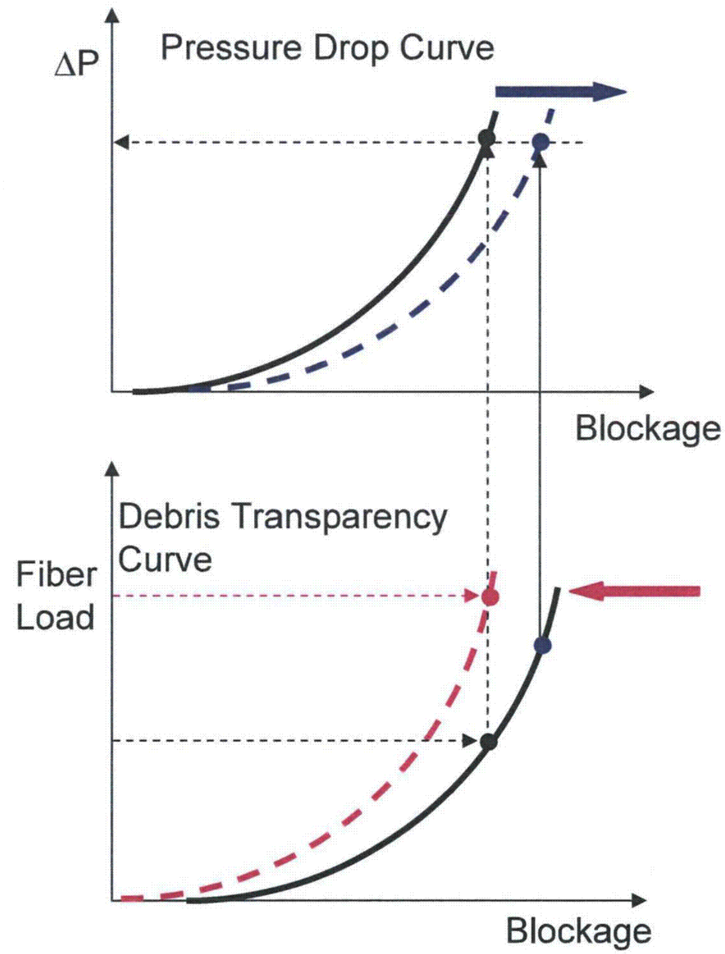
Area plot Model Summary

GSI-191 – Blockage Effect on Pressure Loss

- AREVA Test Results used to data match the analytical model and relate ΔP to blockage and fiber load
- All low p/f tests operate in high blockage regimes
- Correlation between blockage and fiber load very strong
- All other factors (particulate amount, flow rate fiber addition rate – minor effects)
- Still unexplained: the disconnect in Chemical Precipitate ΔP (Run9)

GSI-191 – Blockage Effect on Pressure Loss

- **Relationship Between Pressure Drop and Debris Transparency**
  - **Pressure drop is linked to fiber load via blockage**
  - **To increase the fiber load for a given pressure drop it is necessary to either shift the Pressure Drop Curve to the right, or shift the Debris Transparency Curve to the left**
  - **Factors for the Pressure Drop Curve:**
    - Flow rate, fluid properties, fuel design (flow area, hydraulic diameter, flow restrictors)
  - **Factors for the Debris Transparency Curve:**
    - Fiber condition after running through the loop, fiber size, clumping, water chemistry, fuel design, precipitate condition
  - **The Pressure Drop Curve is more deterministic**
  - **The big uncertainties pertain to Debris Transparency**



GSI-191 – Blockage Effect on Pressure Loss

Implications for the test results

- If two debris load tests come out with one order of magnitude difference in results, it follows that one of the test articles has a shallow Pressure Drop Curve, and/or a steep Debris Transparency Curve.
- Test Loop or process differences must be removed from the uncertainty, in order to be able to concentrate on design differences
  → cross-testing is the only sure way of accomplishing this
- If particular design differences are found to be solely responsible for the test results differences, than acceptance criteria may be refined by considering bounding configurations in each product family

GSI-191 – Blockage Effect on Pressure Loss

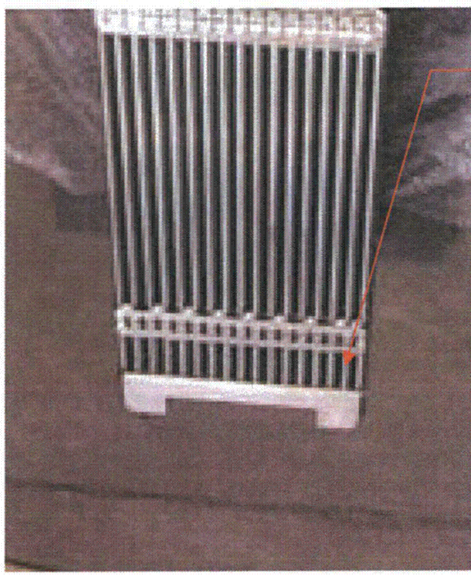
GSI-191 – Fuel Assembly Design Differences

Fuel Rod OD

GSI-191 – Fuel Assembly Design Differences

Flow Field at Lower End Grid Entrance

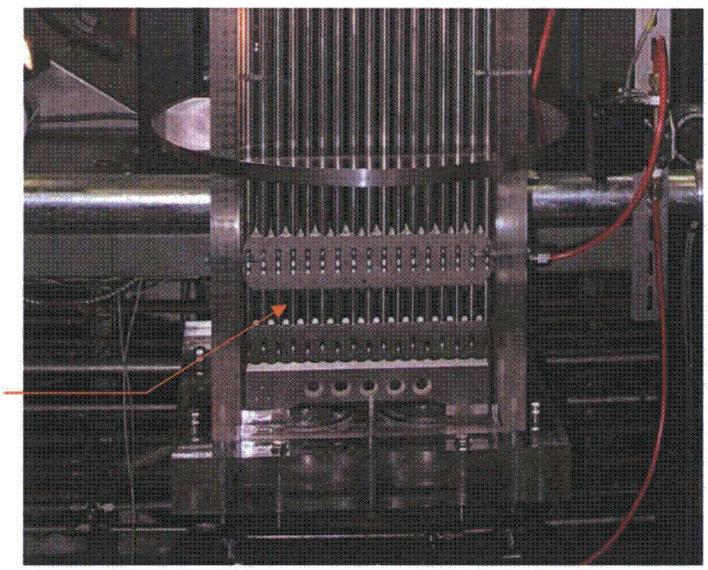
- **All low p/f AREVA tests resulted in clogging the Lower Spacer Grid (SG) → the transparency of the lower SG to debris is a major factor**
- **Qualitatively, the W Test FA has a p-Grid, which is very close to the Lower End Grid entrance – this may create a complex flow situation, which can change debris deposition patterns from the lower grid to the upper grids**
  - The way to rule that out is to first eliminate the loop differences and Fuel Rod OD differences by first cross-testing, and then modifying the FR OD
  - CFD may not work due to lack of capability to model the debris build-up transiently



AREVA TEST FA

Lower turbulence may allow more debris settlement

Proximity of p-Grid may create higher turbulence which may prevent debris settlement



W TEST FA

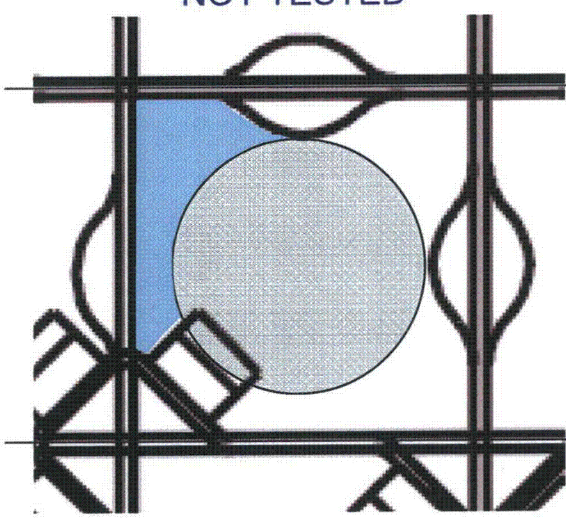
W p-grid details - link

GSI-191 – Fuel Assembly Design Differences

Grid Transparency to Debris

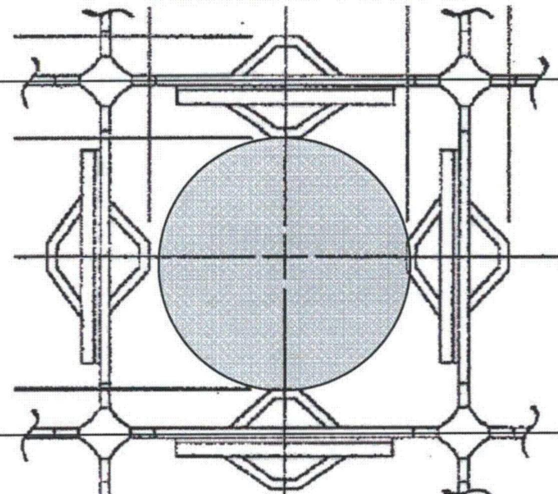
- **All low P/F AREVA tests clogged the lower grid ➔ grid transparency to debris is a major factor**
- **Qualitatively, the lowest debris accumulation should occur with the Bimetallic SG**
  - Flow area is not as fragmented and has fewer forward facing steps for the flow ➔ less opportunity for debris accumulation.
- **AREVA tested the most limiting spacer grid in the product line.**
- **May consider refining the fiber limits to allow for differences between various fuel product lines**

NOT TESTED



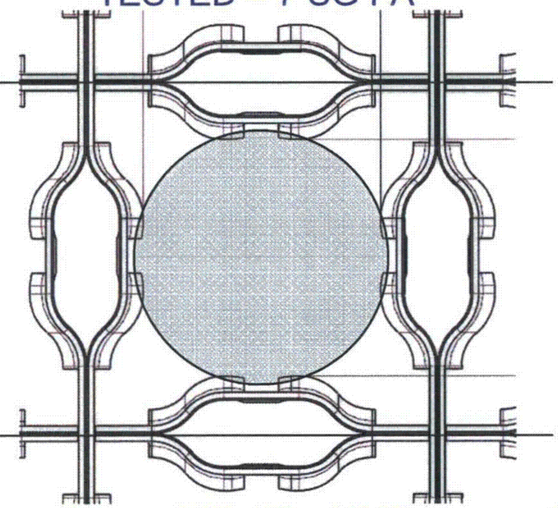
Bimetallic 17x17 – SHA – current production hardware – lowest blockage

TESTED – 4 SG FA



Inconel 17x17 – Mk-BW – current production hardware – highest blockage - conservative

TESTED – 7 SG FA



Inconel 17x17 – HMP – current hardware in lead assemblies – blockage slightly lower

Summary & Conclusion

Gordon Wissinger

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Summary

- AREVA has found nothing to cast doubt on the results obtained from either test facility.
- We are merely trying to understand the difference in results.
  - There are differences in the test loops that raise doubts as to the loops similarity
  - It is not clear that the fuel rod OD does not play a role in producing the differences
- Cross-Testing is the most expedient and cost effective to either:
  - Remove any doubt associated with the engineering arguments presented and clearly indicate that the fuel design is the source of the differences in results or
  - Demonstrate that additional work is needed
- Position on "safety factor"
  - Short of a cross test, it might be difficult to defend a basis for anything more than 15g of fiber for the industry
  - An "arbitrary" factor (anything above 15g of fiber) could have ramifications on future testing of other fuel designs

Path to Closure

- **Support Cross-Testing**
  - ◇ Resolution of Open Questions about the Loop and Debris Differences
- **Support Testing to Determine the Effect of Fuel Rod OD**
  - ◇ 0.360" (W) vs. 0.374" (AREVA)
- **Pursue Alternate Flow Paths**
  - ◇ Project Authorization issued to PWROG for vote
- **Pursue Design Specific Testing**
  - ◇ E.g. CE and B&W plant designs
  - ◇ Project Authorization issued to PWROG for vote

▶Linked Slides

GSI-191 – Background

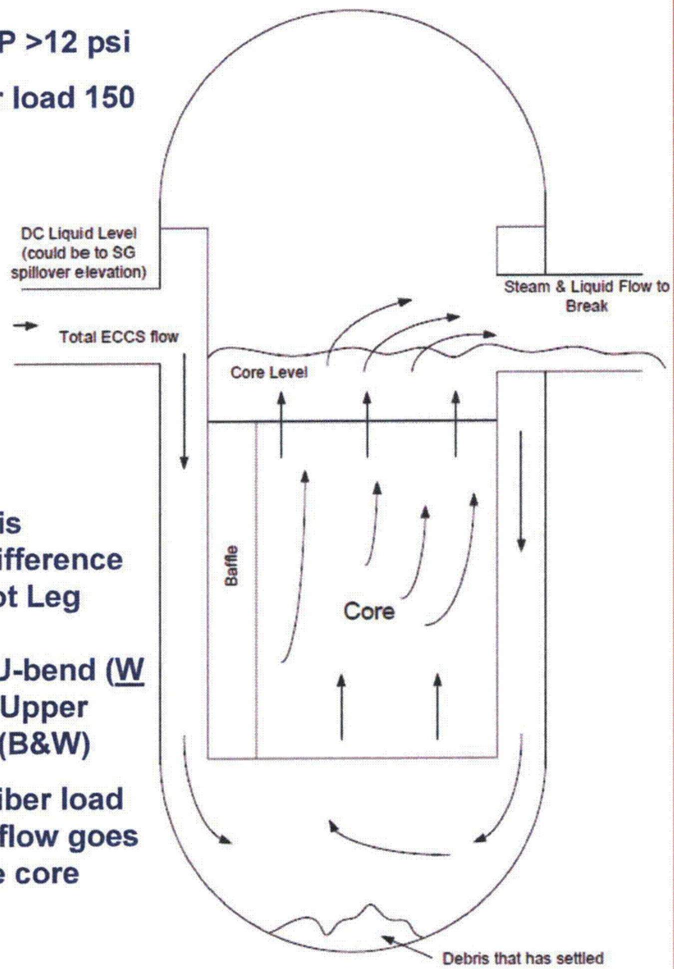
▶ Background

◆

Hot Leg Breaks	Cold Leg Breaks

Hot Leg Breaks

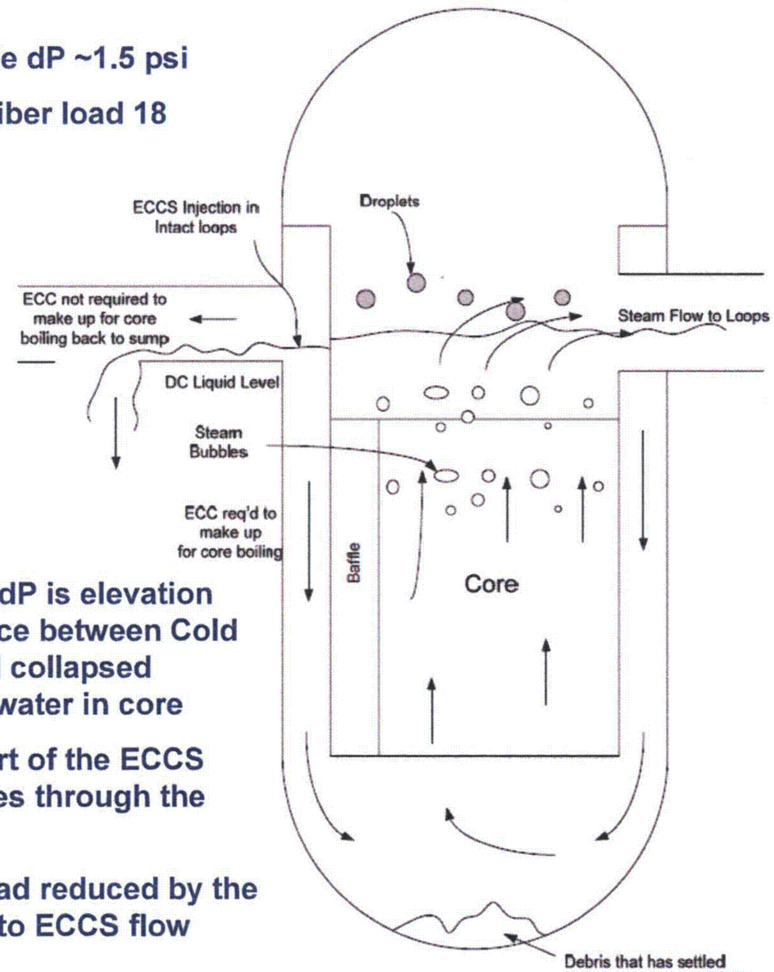
- Available dP >12 psi
- Target fiber load 150 grams



- Driving dP is elevation difference between Hot Leg and Steam Generator U-bend (<u>W</u> and CE) or Upper Tubesheet (B&W)
- Maximum fiber load – all ECCS flow goes through the core

Cold Leg Breaks

- Available dP ~1.5 psi
- Target fiber load 18 grams



- Driving dP is elevation difference between Cold Leg and collapsed boiling water in core
- Only part of the ECCS flow goes through the core
- Fiber load reduced by the boil-off to ECCS flow ratio

GSI-191 – Test Comparison

Test Protocol – Flow Rate - Comparison

- In terms of this criterion, the two tests are in conformance with the test protocol, and not materially different from each other

Plant Type and Break Location	Test Protocol Flow Rate [ ]	AREVA Test Flow Rate [ ]	Westinghouse Test Flow Rate [ ]	Notes
Hot Leg Break W and B&W plants [ ]	44.5	44.7	44.7	
Hot Leg Break CE plants]	6.25	11	6.25	The 11 gpm case ran by AREVA is conservative, and it is not limiting; as such is not considered a material difference for the purposes of this evaluation
Cold Leg Break W, B&W, CE plants [ ]	3	3	3	

GSI-191 – Test Comparison

Test Protocol – Sequence of Debris Tests - Comparison

◇ **This section of the test protocol establishes the test sequence. In it self this cannot affect individual test results, and therefore, the two tests are deemed to be in conformance with the test protocol**

Test Sequence	Test Protocol	AREVA	Westinghouse
1	Baseline Tests	Y	Y
2	Acceptance Criteria Tests	Y	Y
3	Calcium-Silicate Acceptance Criteria Tests	Y	Y
4	Microporous Acceptance Criteria Tests	Y	Y
5	Cold Leg Flow Tests	Y	Y

GSI-191 – Test Comparison

Loop Design Features - Comparison

- The side gaps were thought to be a factor, but additional tests with wider gap showed only marginal improvements

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GSI-191 – Test Comparison

Test Article - Comparison

- Noticeable differences in Test FA features and components: grid design, FR OD

GSI-191 – Test Comparison

Test Protocol – Measurement and Control Capabilities - Comparison

- The two test loops are substantially equivalent in this regard

Test Measurement and Control Feature	Test Protocol Requirement	AREVA	W	Notes
Flow measurement capability	0.2 ft/sec +/- 10%	yes	yes	
Flow controlability	set point +/- 10%	yes (pump)	yes (restrict pipe)	
Temperature control	70 degF +/-10degF	yes	yes	
Temperature measurement range/accuracy	40 to 100 degF +/-5 degF	yes	yes	
Press drop measurements - total	up to 14 psi +/-0.1 psi	yes	yes	differential pressure transducer calibrated with clean water - no correction for debris - deemed negligible
Press drop measurements - over up SGs	1 to 8 psi +/-0.1 psi	yes	yes	
Data sampling rate	at least 300 sec	yes	yes	
HL test termination	allowable dP is met	yes	yes	
CL test termination	1.5 psi across BN	yes	yes	
Turnover time - HL	5x	yes	yes	
Turnover time - CL	2x	yes	yes	
Steady dP	< 2% over last 30 min	yes	yes	

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GSI-191 – Test Comparison

Test Protocol – Debris Preparation - Comparison

- The test protocol is very specific in this regard, leaving little room for deviations.
- Both tests are conforming and equivalent in this regard

Test Article Feature	Test Protocol Requirement	AREVA	W	Notes
Particulate Type	Silicon Carbide			
Particulate Size	10µm +/- 2µm			
Particulate Size distribution	50% between 5 and 15 µm	yes (measured and reported as hystogram)	yes (nominal size of 9.5µm scanning microscope)	for the W test info per WCAP-16793 NP, rev.1
Microporous	Microtherm material should be dry sieved through a #7 mesh screen with a hole size of 0.11"	yes	yes	Not an important factor in this study
CalSil Preparation	Sieve through a #7 sieve / discard the fiber retained by the sieve / characterize particle size distribution using microscopy	yes	yes	Not an important factor in this study
Fiber type	Nukon			
Fiber Length Distribution	<500µm - between 67 and 87%			
	500µm to 1000µm - 8 to 28%	yes	yes	Actually, some of the AREVA tests were performed with W supplied fiber to remove the uncertainty
	over 1000µm - 0 to 15%			
Fiber Preparation	no requirement	1) dilute in water and chop in blender for 60 sec (run 7 for 300 sec) 2) wash in water, filter and dry 3) not baked - used W baked fiber for run 8 and beyond 4) store dry	1) dilute in water and chop in blender for 25 sec 2) wash in water, filter and dry 3) bake over night at 100 C 4) store dry	need to substantiate the baked fiber use for run 8 and beyond

GSI-191 – Test Comparison

Test Protocol – Chemical Precipitate Preparation - Comparison

- The chemical precipitate preparation seems to be the same.
- Some details about the AREVA tests preparation must be substantiated
- No major differences expected in this area.

Test Process Feature	Test Protocol Requirement	AREVA	W	Notes
Precipitate type	AlOOH	yes	yes	
Settling criteria	meets WCAP-16530 and WCAP-16530 SER	yes	yes	
Preparation	no requirements	per WCAP-16530 - no more than 4 days before test	1. Add 5205 g $Al(NO_3)_3 \cdot 9H_2O$ 2. Add tap water to make gallons 3. Stir until aluminum nitrate dissolves 4. Add 1666 grams of sodium hydroxide 5. Stir for one hour before doing settling test	open questions: - ascertain the AREVA chem precipitate preparation and W holding period for the precipitate

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GSI-191 – Test Comparison

Test Protocol – Debris Addition Sequence - Comparison

- The particulate and fiber preparation and introduction are similar.
- Some details about the AREVA chemical precipitate preparation and loop final volume must be substantiated. No major differences expected in this area.

Test Process Feature	Test Protocol Requirement	AREVA	Westinghouse	Notes
Particulates introduction	Particulates in first	yes	yes	
	Wait for 5 turnovers	yes	yes	
Fiber introduction	Fiber in second	yes	yes	
	In 10 grams increments	yes	yes	more recent AREVA tests were carried out with 2 gram fiber
	diluted in water taken from the mixing tank	yes	yes	
	stabilization time after each increment - minimum 5 turnovers (~10 min)	yes	yes	
Chemical Precipitate Introduction	Introduced last	yes	yes	
	in 2 batches - 5 turnovers between	yes	yes	
	concentration - no requirement	11 grams / liter	11 grams/liter	need to substantiate the AREVA concentration - inferred from the added amount of solution
	final loop volume - no requirement	probably the same	120 gallons - W starts with 100 gallons and introduce particulate and fiber - then add 20 gallons of precipitate solution	need to substantiate the AREVA final loop volume
pH	between 6.5 and 9	yes	yes	
Water Chemistry	no requirement	no info available	no info available	

GSI-191 – Blockage Effect on Pressure Loss

<u>Area Blockage vs. Fiber</u> – Test Data Matching

- ◇ Analytical blockage converted to fiber load by fitting one test case
- ◇ Correlation between blockage and fiber load very strong

GSI-191 – Blockage Effect on Pressure Loss

Flow Area vs. blockage vs. pressure drop relationship

[ ]

[ ]

back

GSI-191 – Flow Rate Effect on Pressure Loss

- Between 45 gpm and 6.25 gpm, the blockage tolerance increases by ~7 points
- The effect of lower flow rate is to shift the blockage curve
- CE plants will be able to tolerate more fiber load

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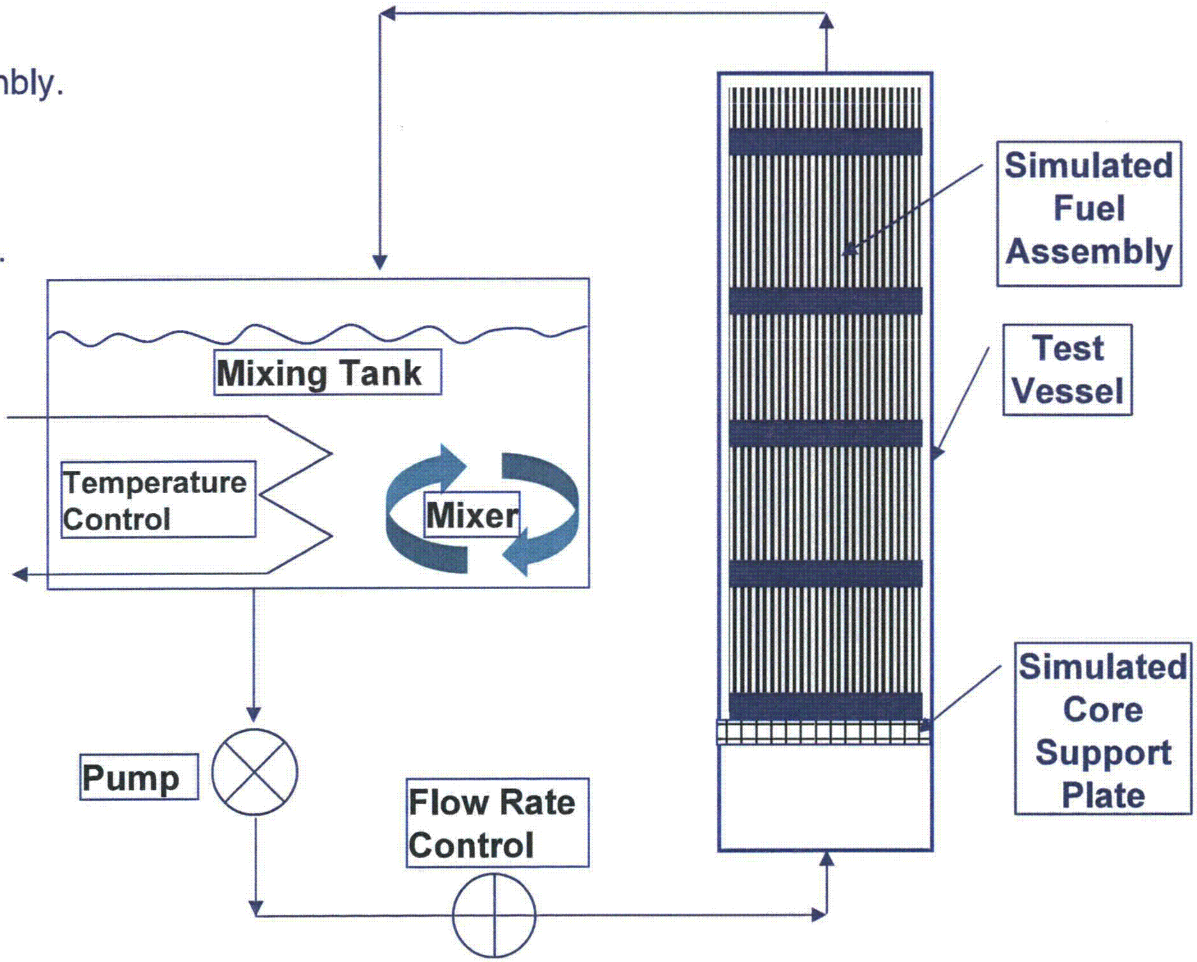
GSI-191 – Blockage Effect on Pressure Loss

GSI-191 – Loop Arrangement

Conceptually, each test loop arrangement contains:

- Simulated fuel assembly.
- Test vessel.
- Mixing Tank.
- Temperature Control.
- Mixing Device.
- Main Pump.
- Flow Rate Control



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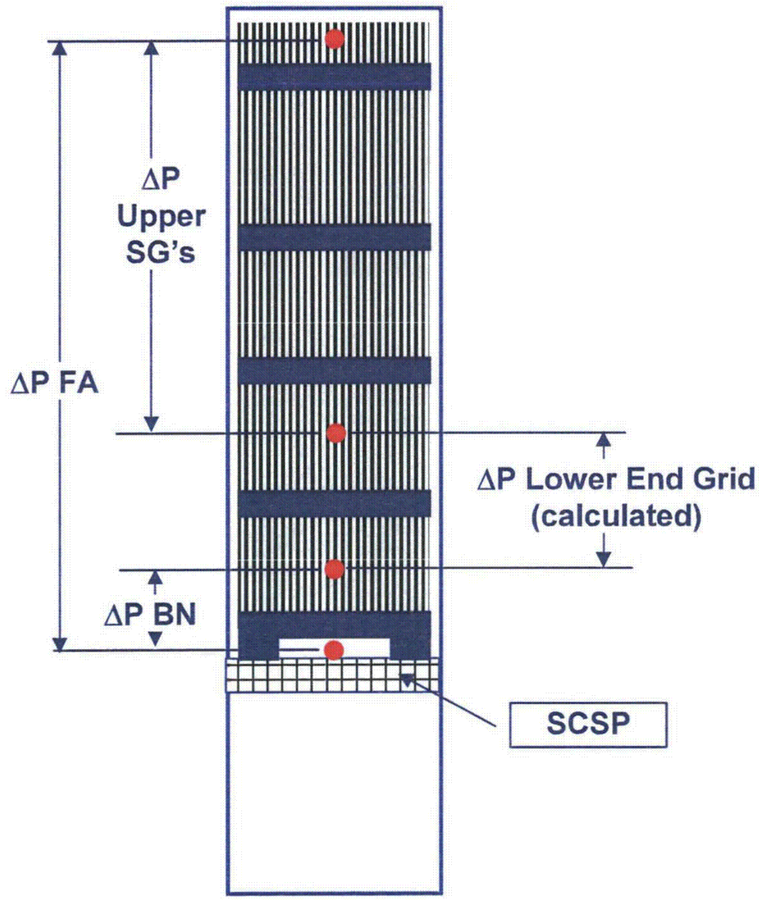
GSI-191 – Measurement Arrangement



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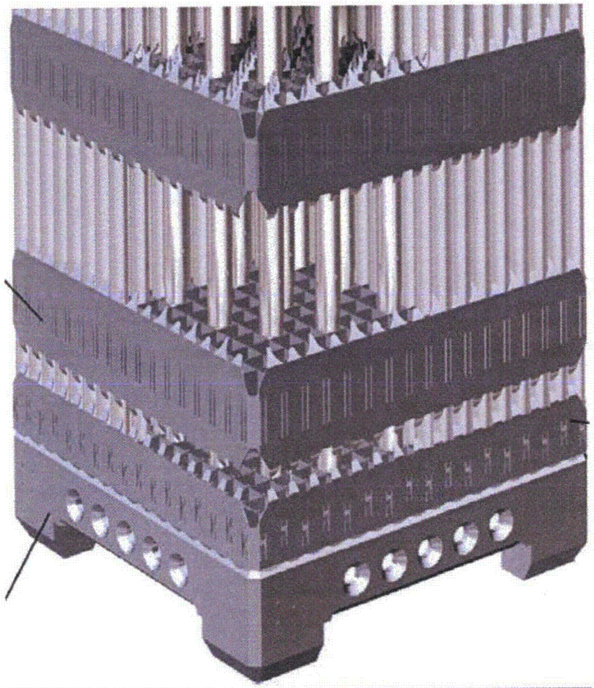
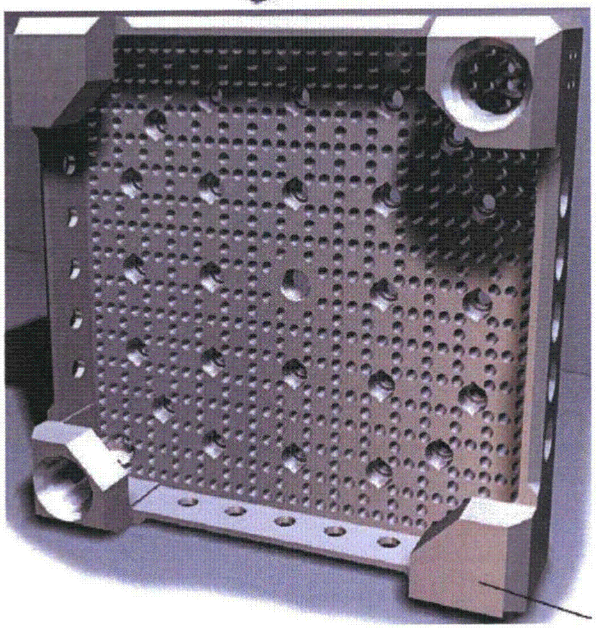
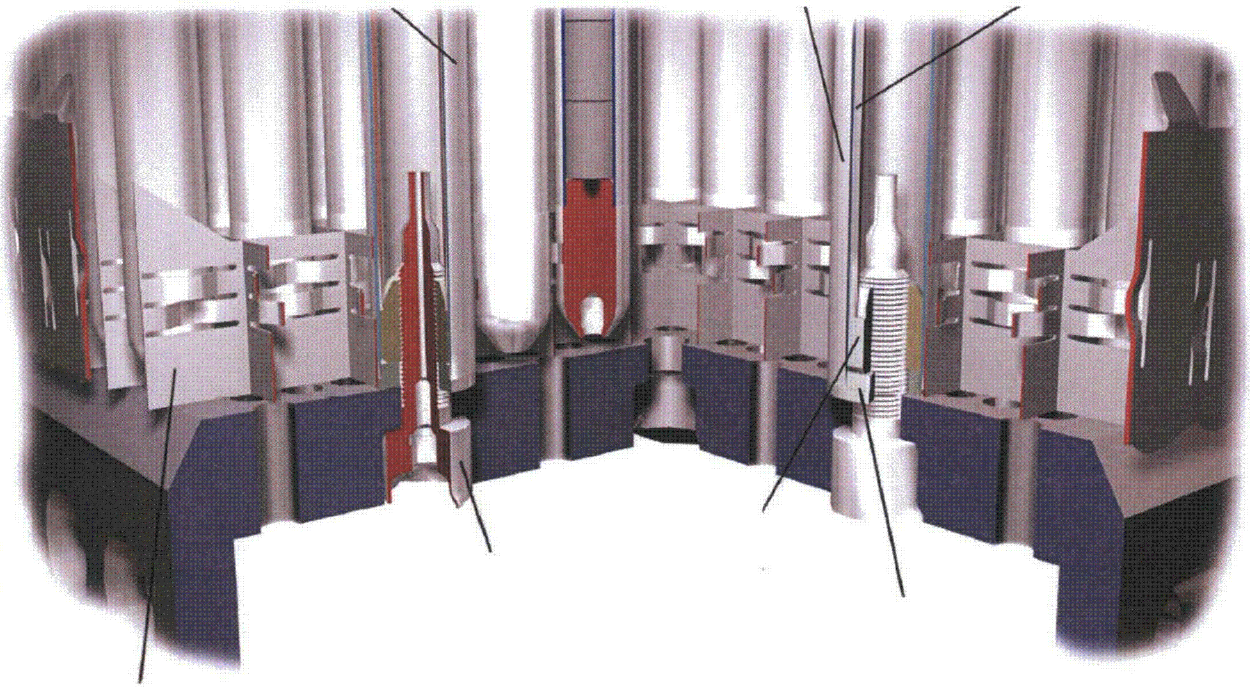
W p-Grid Arrangement



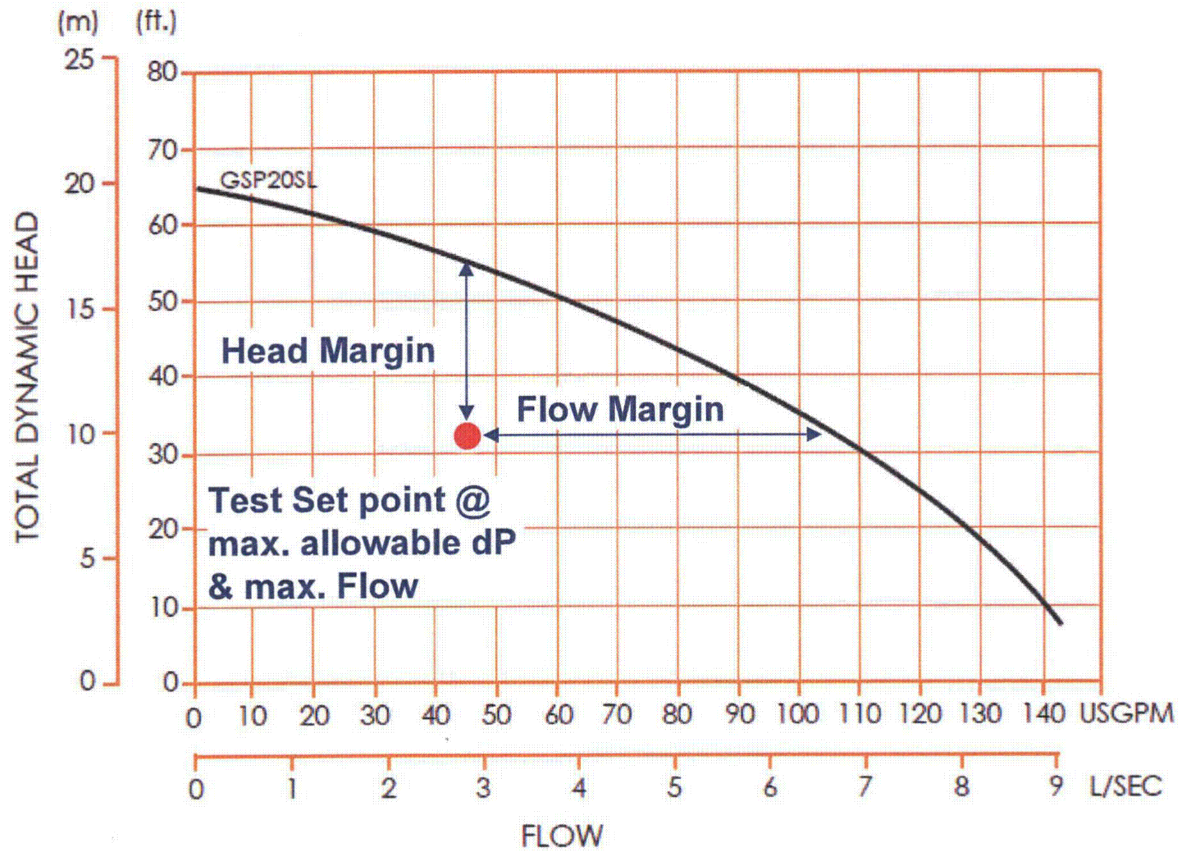


- **Different Flow Field at LEG Entrance**
  - DFBN has an array of holes. Each hole is cris-crossed by the p-grid strips. Some holes are cut in half, some in four
  - Flow-field may be more localized at the holes, and this may help push the debris through the Lower End Spacer Grid



http://www.enusa.es/eng/actividad/pwr.html

GSI-191 – CDI Pump Characteristic



▶Appendix

GSI-191 – Comparison Scope

▶ Study Focus

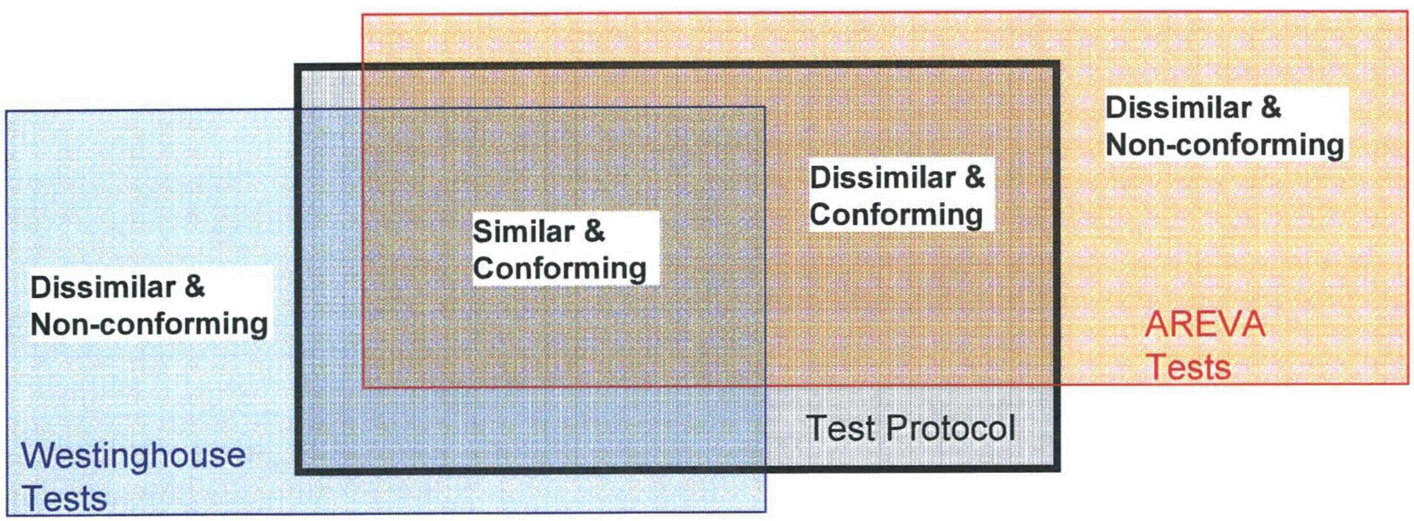
- ◇ **The Fuel Assembly GSI-191 debris settling and head loss tests are governed by a test protocol put together by the PWROG**
- ◇ **This document is concerned with:**
  - The conformity of the two test processes with the test protocol
  - The differences between the two test loops / test procedures / test articles
  - The differences between the debris composition / preparation

▶ Out of Scope Items – This study is <u>not</u> focused on:

- ◇ **The inherent conservatism of the test conditions relative to the actual sequence of events in a postulated accident**
  - The flow rate targets for the test represent a substantial multiple (15x) of the boil-off flow rate needed at the ECCS suction switchover time
  - At switchover, the average water temperature is ~270 °F but the precipitation starts at lower temperatures
  - Below 140 °F it is possible to switch over to H/L injection, and dislodge the debris beds in the core
  - Water can get in the core through alternate flow paths (baffle plate slots, etc…)
- ◇ **The test protocol requirements and parameters justification**

GSI-191 – Comparison Scope

- **Study Focus**
  - **The Fuel Assembly GSI-191 debris settling and head loss tests are governed by a test protocol put together by the PWROG**
  - **This document is concerned with:**
    - The conformity of the two test processes with the test protocol
    - The differences between the two test loops
    - The differences between the two test procedures
    - The differences between the debris composition / preparation
    - The differences between the two test items



GSI-191 – Comparison Scope (cont'd)

- **Out of Scope Items – This study is <u>not</u> focused on:**
  - **The inherent conservatism of the test conditions relative to the actual sequence of events in a postulated accident**
    - The flow rate targets for the test represent a substantial multiple (15x) of the boil-off flow rate needed at the ECCS suction switchover time
    - At switchover, the average water temperature is ~270 °F but the precipitation starts at lower temperatures
    - Below 140 °F it is possible to switch over to H/L injection, and dislodge the debris beds in the core
    - Water can get in the core through alternate flow paths (baffle plate slots, etc...)
  - **The test protocol requirements justification – these will be treated as given**
  - **Test protocol debris definition and introduction sequence – these will be treated as given, and no justification will be sought**

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GSI-191 – Blockage Effect on Pressure Loss

- All AREVA Test Results plotted against analytical curves regressed to fiber load

GSI-191 – Test Data