GSI-191 U.S. EPR™ Downstream Effects Public Meeting

Draft

Gordon Wissinger
Advisory Engineer
July 7, 2010

EPR™ by AREVA

AREVA

Agenda

- Debris Accumulation in Core – Cold Leg Injection
  - ◇ Disposition of hot & cold leg breaks during first 60 minutes after break
- Debris Accumulation in Core – Simultaneous Injection
  - ◇ Disposition of hot & cold leg breaks 60 minutes after break and beyond
  - ◇ Proposed plan for additional testing
- Conclusion

Draft

Debris Accumulation in Core – Cold Side Injection

Draft

EPR™ by AREVA

AREVA

FA Testing

- In order to define the maximum debris load that can be tolerated in the core, testing was performed.
- The purpose of this testing was to justify acceptance criteria for the mass of debris that can reach the RCS and not impede long-term core cooling flows to the core.
- These acceptance criteria were used in part to demonstrate adequate flow for long term decay heat removal

Draft

Methodology

- The fiber load is maximized
- Particulate-to-fiber ratio is varied to determine maximum pressure drop
- Chemical precipitate is added after fiber and particulate
- A maximum flow rate produces the highest pressure drop through a debris bed
  - Therefore, the highest flow rate should be used to assess various break and ECCS configurations
  - Further, this flow rate should be maintained at a constant value throughout the test
- The test loop should continually recirculate debris such that it will have multiple opportunities to catch on an obstruction and block flow

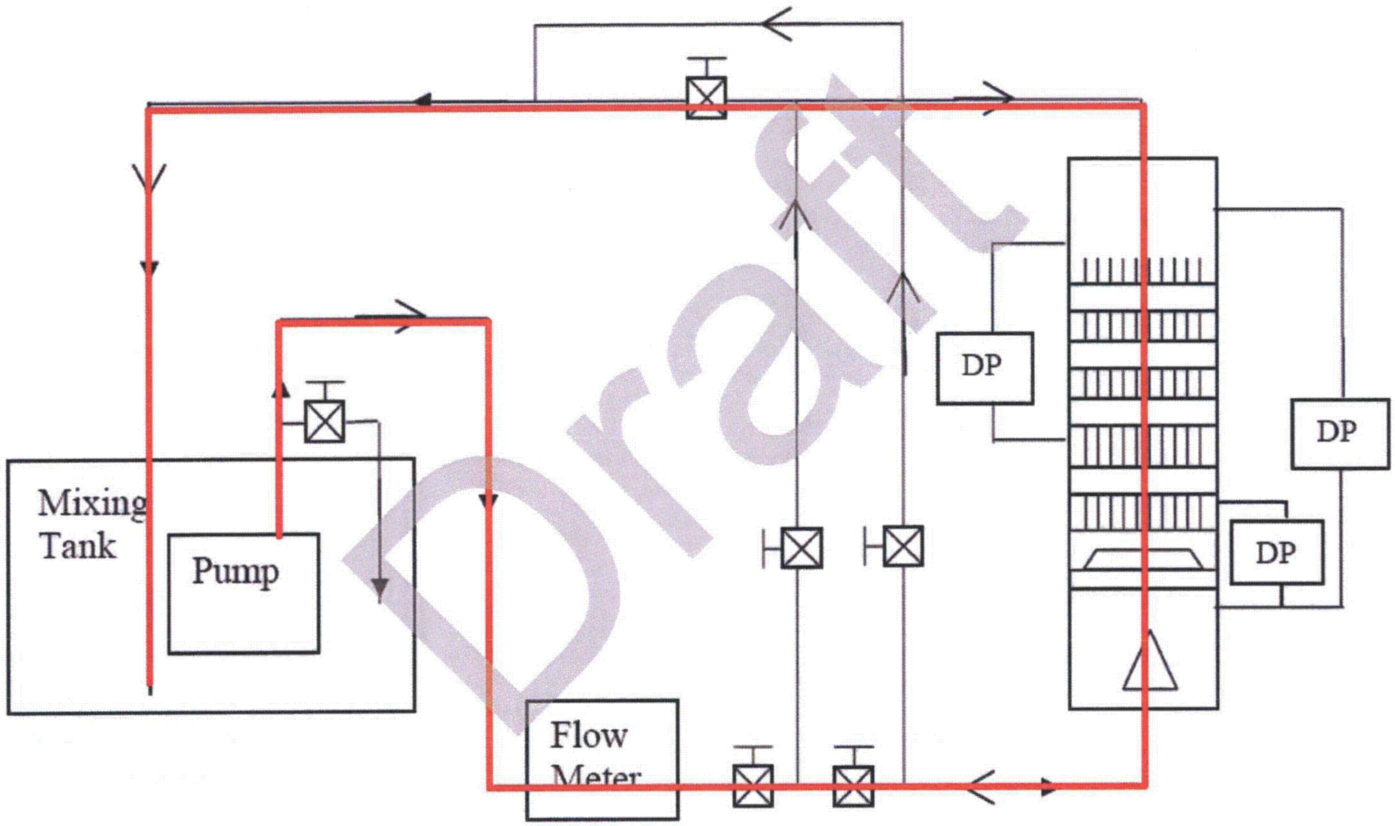
Draft

Test Facility

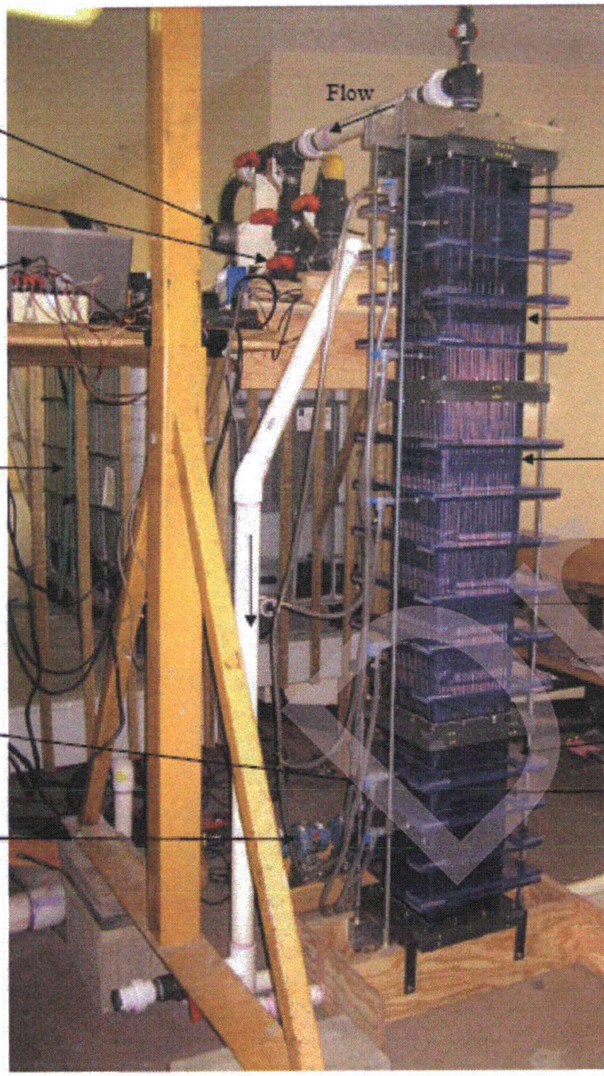
- AREVA contracted with Continuum Dynamics Incorporated (CDI) to perform U.S. EPR tests
  - Same firm that performed this test for the PWROG
  - Same loop and FA used in PWROG testing used for U.S. EPR testing

Draft

CDI Test Loop – Schematic debris introduced to core inlet



CDI Test Loop – Photographs



Draft

Test Process

- ▶ Select a flow rate
- ▶ Select particulate load
  - ◇ Add all particulates first
- ▶ Add fiber in 10 g increments
  - ◇ Add incrementally to determine if "thin bed" occurs
  - ◇ Add until pre-defined pressure or mass of fiber is exceeded
- ▶ Select chemical precipitate load
  - ◇ Add chemical in increments

Draft

Materials Tested

- Types of debris that might reach the RCS:
  - Fiber
  - Particulate
  - Chemical precipitate formed from chemical reactions within sump fluid

Draft

Materials Tested

- **Fibrous debris that might reach the RCS**
  - **Based on sump screen bypass samples obtained from sump screen testing, the size of fibers that reach the RCS are on the order of the openings of the fuel assembly debris filters and smaller**
  - **Size distribution tested below based on PWROG data**
  - **Shredded Nukon used**

Fiber length	*Target*	*Range*
$< 500\ \mu m$	*77%*	*67 – 87%*
$500 - 1000\ \mu m$	*18%*	*8 – 28%*
$> 1000\ \mu m$	*5%*	*0 – 15%*

Note: 500 μm ~ 20 mils

Materials Tested

- **Particulates that might reach the RCS**
  - **Based on sump screen bypass samples, the size of particulates that reach the RCS are on the order of the openings of the fuel assembly debris filters and smaller**
  - **Sump debris transport calculations make the debris quite small – on the order of 10 – 20 microns**
  - **Silicon Carbide with a mean diameter of 10 microns selected**

- **Precipitates formed by chemical interaction**
  - **Similar to particulates and smaller**
  - **AlOOH used to bound the chemical species formation expected**

Draft

Inputs and Boundary Conditions

- ▶ **Test fluid temperature = 70˚F**
  - ◇ **Lower temperature increases the fluid viscosity**
- ▶ **Core Flow Rates**
  - ◇ **Pressure drop varies as a function of flow rate through the debris bed**
    - Darcy's Law suggests a linear relationship
    - Darcy's Equation suggests a flow squared relationship
    - In either case, pressure drop increases with flow rate
  - ◇ **Therefore, the flow rate is maximized**
    - For CL Break – 3.8 gpm/FA
      - Maximum boiloff rate at highest core power & earliest time
    - For HL Break – 71.4 gpm/FA
      - maximum ECCS flow rate

Draft

Inputs and Boundary Conditions

- **Available Driving Head**
  - **Defines the acceptance criteria for each test.**
  - **If the pressure drop through the debris bed exceeds the available driving head, then it is assumed that the core will begin to uncover and heat up**
  - **While this condition retains some margin of conservatism, it is a reasonable acceptance criterion to use as a starting point**
  - **The available driving head is dependent on the break location and plant geometry**
  - **U.S. EPR available driving head**
    - Cold Leg Break >1.36 psid
    - Hot Leg Break >18.2 psid

Draft

Inputs and Boundary Conditions

- **Quantity of Debris**
  - **Defined by debris generation calculation**
  - **Fiber that reaches the RCS determined by sump strainer bypass testing**
  - **All particulate and chemical precipitates assumed to reach the RCS**
  - **Debris that reaches the core is dependent on the break location and ECCS configuration**
  - **U.S. EPR 30-day fiber load**
    - Cold Leg Break: 0.015 lbm/FA (6.8 g)
      - Debris that reaches the core is based on core boiloff rate to ECCS flow split
    - Hot Leg Break: 0.076 lbm/FA (34.5 g)
      - All debris reaches the core

Draft

Results – Cold Leg Break

- 4 Tests run to evaluate cold leg breaks with cold side injection
- p:f ratio ranged from 5:1 to 132:1
- No debris captured by FUELGUARD
- All debris captured at lower end grid (LEG) for limiting p:f ratio
- U.S. EPR-specific test with 7.5 g of fiber showed no head loss in FA
- PWROG test at limiting p:f ratio and 18 g of fiber/FA showed a dP of less than 0.53 psid after chemical precipitate addition
  - Bounds the fiber load of 6.8 g/FA expected for USEPR
  - dP adjusted for U.S. EPR flow rate ~0.85 psid

Draft

Conclusion – Cold Leg Break w/ Cold Side Injection

- Up to 18 g of fiber per fuel assembly will not result in inadequate core cooling following a cold leg break with cold side injection for the U.S. EPR

Draft

Results – Hot Leg Break

- 12 Tests run to evaluate hot leg breaks with cold side injection
- p:f ratio ranged from 1:1 to 88:1
- No debris captured by FUELGUARD
- Limiting results obtained when all debris captured at LEG
  - Occurs at p:f ratios of less than ~10:1
  - Limiting p:f ratio = 1:1 (determined by PWROG testing)

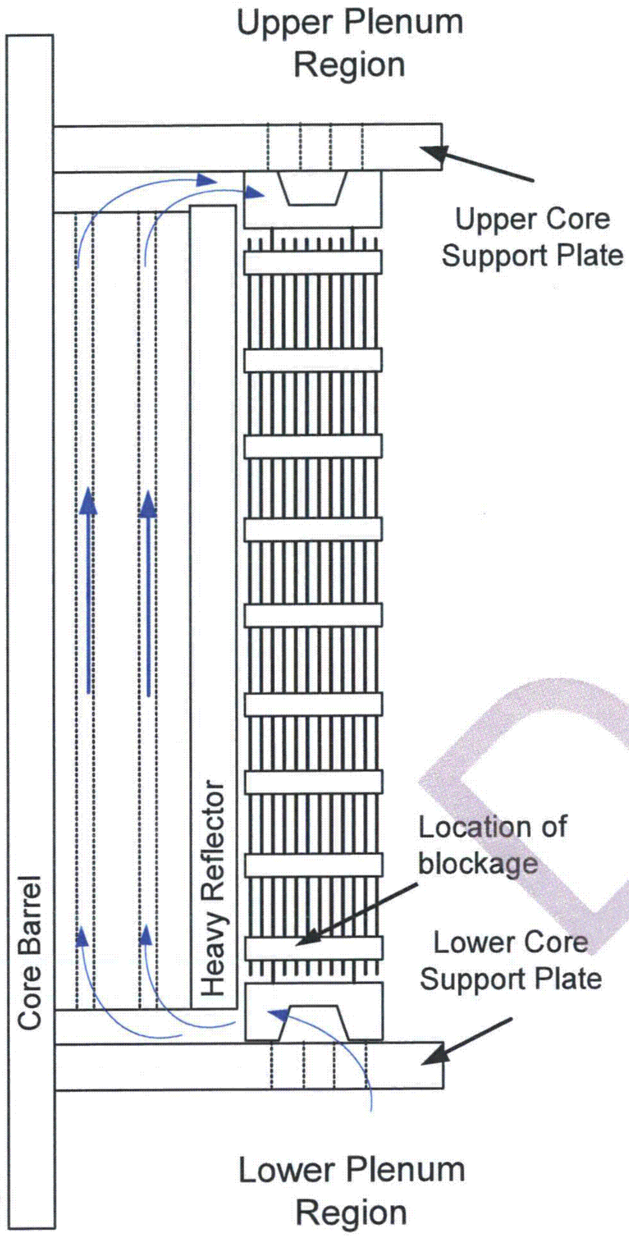
Draft

Results – Hot Leg Break

- U.S. EPR-specific test showed a dP = 9.6 psid
  - 36 g of fiber
  - p:f ratio = 12.5:1
  - Distributed debris bed
- PWROG testing indicated that at a p:f ratio of 1:1, "complete" blockage at LEG could occur for fiber loads > 20 g/FA
  - Complete blockage does not occur until chemical precipitate is added
- Test 7-FG-FPC showed dP < 6.3 psid for 60 of fiber & particulate (i.e. before chemical precipitate was added)
  - dP adjusted for U.S. EPR flow rate ~16 psid
  - Below the available driving head of 18.1 psid
- Therefore, U.S. EPR core can tolerate up to 36 g of fiber with p:f ratio of 1:1 before chemical precipitates are added
- However, blockage might occur after chemical precipitate addition

Draft

Results –
Hot Leg Break



- **If complete blockage of the core occurs after chemical precipitate addition, then LTCC is still assured by considering flow through the heavy reflector region**

[ ]

Draft

Results – Hot Leg Break

- **Conservatisms:**
  - **The RCS fiber load was determined by allowing the fiber to continually recirculate in the test flume**
    - No credit for accumulation on the fuel
  - **The RCS fiber load of 34.5 g fiber load is over the entire 30 days evaluated – less fiber will enter the RCS during the first hour of cold side injection**
    - 15 g of fiber is easily tolerated (dP < 7 psid after chemical precipitate addition)
  - **Assumes complete blockage occurs in <u>ALL</u> 241 fuel assemblies**
    - Does not credit variable flow patterns in RV lower plenum and core

Draft

Conclusion – Hot Leg Break w/ Cold Side Injection

- Up to 34.5 g of fiber per fuel assembly will not result in inadequate core cooling following a hot leg break with cold side injection for the U.S. EPR

Draft

Debris Accumulation in Core – Simultaneous Injection

Draft

EPR™ by AREVA

AREVA

FA Testing

- In order to define the limiting debris load that can be tolerated in the core, testing is proposed.
- The purpose of this testing is to justify acceptance criteria for the type and mass of debris that can reach the RCS and not impede long-term core cooling flows to the core.
- These acceptance criteria will be used in part to demonstrate adequate flow for long term decay heat removal

Draft

Methodology

- **All debris that passes through the sump screens is assumed to arrive in the core after 1 hour**
  - Maximizes the debris available during HLI
- **Further, all debris that arrives over 30 days should be tested as if it arrives in the RCS at the first opportunity.**
  - It takes a finite time for debris to transport from the break location to the RCS
  - Further, the mixing of fluid and debris on the heavy floor and the filtration of the retention baskets and strainers will cause the debris to arrive in the RCS over time
  - Therefore, testing the maximum, 30-day debris load is conservative
- **A maximum flow rate produces the highest pressure drop through a debris bed**
  - Therefore, the highest flow rate should be used to assess various break and ECCS configurations
  - Further, this flow rate should be maintained at a constant value throughout the test
- **The test loop should continually recirculate debris such that it will have multiple opportunities to catch on an obstruction and block flow**

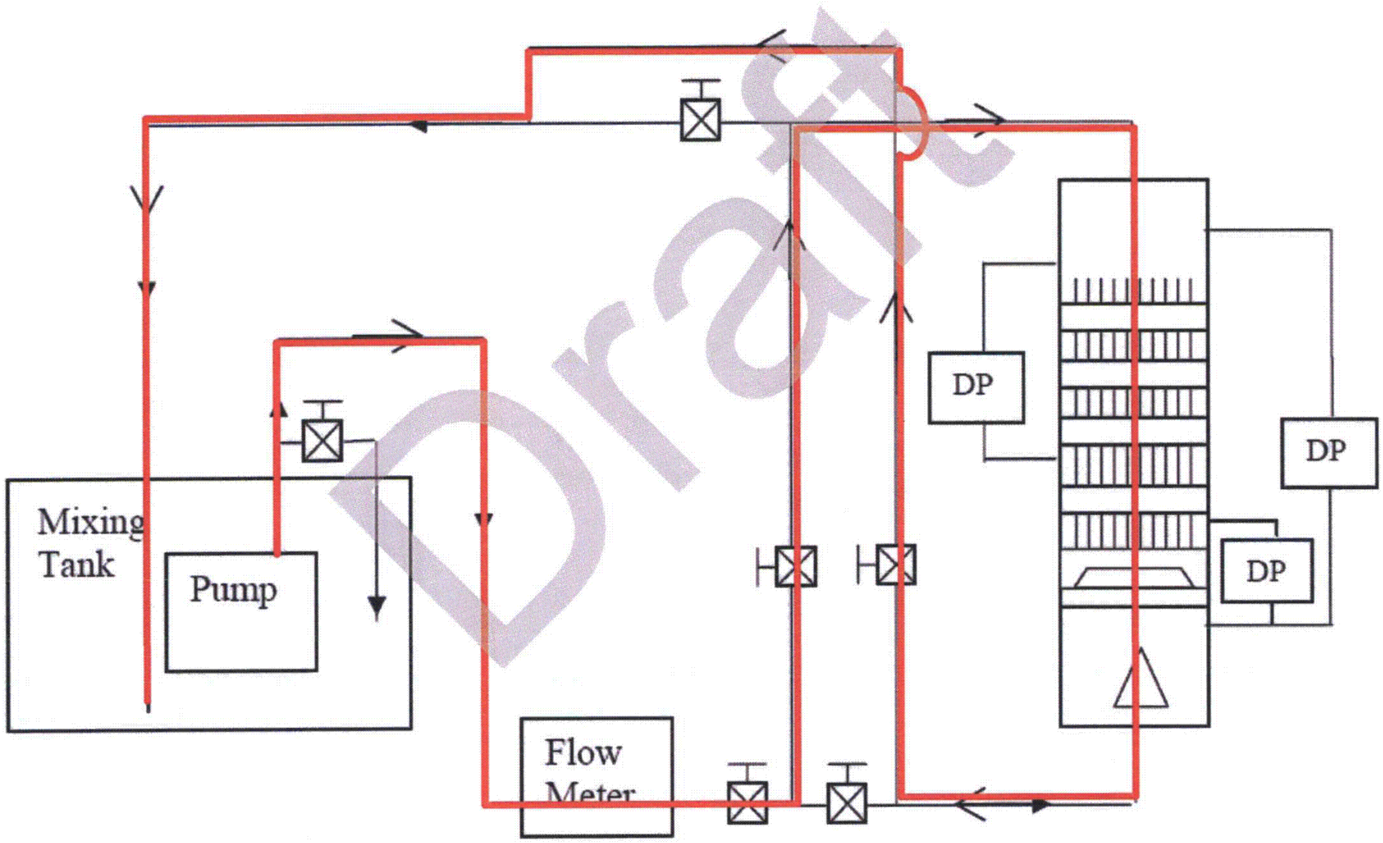
Draft

Test Facility

- AREVA contracted with Continuum Dynamics Incorporated (CDI)
  - Same firm that performed this test for the PWROG
  - Same loop and FA used in PWROG testing used for U.S. EPR testing
- Can/will modify the loop for proposed additional HLI tests

Draft

CDI Test Loop – Schematic debris introduced to core exit



FA to be Tested HLI Tests

- **Fuel assembly – U.S. EPR specific**
  - **Partial length (~50" long)**
  - **FUELGUARD bottom nozzle**
  - **HMP lower and upper end grids**
  - **2 HTP intermediate spacer grids**
  - **Top nozzle**
  - **Thimble plug assembly**
  - **25 guide tubes w/ 0.482" OD**
  - **264 fuel rods w/ 0.374" OD**
- **Test loop will include:**
  - **Upper core plate with Type B hole**
  - **Flow diverter in upper plenum of test vessel**

Draft

Inputs and Boundary Conditions

- **Core Flow Rates**
  - **Pressure drop varies as a function of flow rate through the debris bed**
    - Darcy's Law suggests a linear relationship
    - Darcy's Equation suggests a flow squared relationship
    - In either case, pressure drop increases with flow rate
  - **Therefore, the flow rate is maximized**
    - Based on MHSI to hot legs & condensation potential
  - **Flow Rates**
    - Cold Leg Break – 125 gpm/FA
    - Hot Leg Break – <125 gpm/FA

Draft

Inputs and Boundary Conditions

- **Available Driving Head**
  - **Defines the acceptance criteria (i.e. pressure drop incurred by debris) for each test.**
  - **If the pressure drop through the debris bed exceeds the available driving head, then it is assumed that the core will begin to uncover and heat up**
  - **While this condition retains some margin of conservatism, it is a reasonable acceptance criterion to use as a starting point**
  - **The available driving head is dependent on the break location and ECCS configuration**
    - Cold Leg Break: >8.3 psid
    - Hot Leg Break: bounded by other break/ECCS configurations

Draft

Inputs and Boundary Conditions

- **Quantity of Debris**
  - **Defined by debris generation calculation**
  - **Fiber that reaches the RCS determined by sump strainer bypass testing**
  - **All particulate and chemical precipitates assumed to reach the RCS**
  - **Debris that reaches the core is dependent on the break location and ECCS configuration**
  - **30-day fiber load to core**
    - Cold Leg Break: 0.11 lbm/FA (49.9 g)
    - Hot Leg Break: bounded by other break/ECCS configurations

Draft

Testing to Date

- **One HLI test was done in October 2009**
  - **No upper end fitting or upper core plate tested**
  - **Used 23 g of fiber/FA (too low)**
  - **p:f ratio = 15:1 (possibly too high)**
  - **Debris load was distributed among lower 3 spacer grids**
    - No debris at UEG

Draft

Additional Testing

- Include upper end fitting and upper core plate
  - Ensure that the flow reaching the FA is prototypical for HLI
- Evaluate the higher fiber load
  - Need to test to actual fiber load expected based on bypass testing
- Evaluate additional p:f ratios
  - PWROG testing for cold side injection indicated that low p:f ratios produced limiting results by promoting the formation of a single debris bed at the LEG
- Establish whether distributed debris load is the norm
  - PWROG testing for cold side injection indicated that low p:f ratios produced limiting results by promoting the formation of a single debris bed at the LEG
  - Not clear if the flow rate or the p:f ratio or both is driving the distributed bed seen in the one U.S. EPR-specific test

Draft

Proposed Test Series 1

- ◇ **Flow rate = 125 gpm (maximum)**
- ◇ **Fiber load = 50 g (maximum)**
- ◇ **Vary p:f ratio to determine**
  - If single debris bed forms at UEG
  - Limiting p:f ratio

- ◇ **Test 1a: p:f ratio = 1:1**
  - Limiting at core inlet
  - Led to formation of a single debris bed on LEG
- ◇ **Test 1b: p:f ratio = 3:1**
- ◇ **Test 1c: p:f ratio = 7:1**

Draft

▶ Reason for tests:

- ◈ **Determine if the dP < 8.3 psid for max expected fiber load at max flow rate**

▶ Possible outcomes:

- ◇ **If dP < 8.3 psid in all cases, then**
  - Limiting p:f ratio will have been determined for max flow rate
  - Go to Test Series 2 to ensure similar results at a lower flow rate
- ◈ **If dP > 8.3 psid in any case (need to run all 3), then**
  - May need to reduce fiber load until acceptable results are obtained
  - Results from this sequence will define limiting p:f ratio

Proposed Test Series 2

- Flow rate = 64 gpm (minimum)
- Fiber load = 50 g (maximum)
- Vary p:f ratio to determine
  - If single debris bed forms at UEG
  - Limiting p:f ratio
- Test 2a: p:f ratio = 1:1
  - Limiting at core inlet
  - Led to formation of a single debris bed on LEG
- Test 2b: p:f ratio = 3:1
- Test 2c: p:f ratio = 7:1

Reason for tests:

- **Only required if dP < 8.3 psid for all p:f ratios in Test Series 1**
- **Determine if the dP < 8.3 psid for max expected fiber load at min flow rate**

Possible outcomes:

- **If dP < 8.3 psid in all cases, then**
  - Limiting p:f ratio will have been determined for min flow rate
  - No additional testing required
- **If dP > 8.3 psid in any case, then**
  - May need to reduce fiber load until acceptable results are obtained
  - Results from this sequence will define limiting p:f ratio

Draft

Summary of Test Matrix

Test	Flow Rate (gpm)	Nukon (g)	Particulate (g)	p:f ratio	Comments
1a	125	50	50	1:1	If dP < 8.3 psid in all cases, go to Test Series 2 If dP > 8.3 psid in any case, need to reassess
1b	125	50	150	3:1	
1c	125	50	350	7:1	
2a	64	50	50	1:1	If dP < 8.3 psid in all cases, no additional testing required If dP > 8.3 psid in any case, need to reassess
2b	64	50	150	3:1	
2c	64	50	350	7:1	

Draft

Debris Accumulation in Core – Conclusions

Draft

EPR™ by AREVA

AREVA

Conclusion

- Cold leg break w/ cold side injection
  - Up to 18 g of fiber per fuel assembly will not result in inadequate core cooling following a cold leg break with cold side injection for the U.S. EPR
- Hot leg break w/ cold side injection
  - Up to 34.5 g of fiber per fuel assembly will not result in inadequate core cooling following a hot leg break with cold side injection for the U.S. EPR
- Breaks w/ simultaneous injection
  - Additional testing proposed

Draft

AREVA

Draft