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DIVOM Methodology using RAMONA5-FA Code

Presentation to the Advisory Committee on Reactor Safeguards

January 2011

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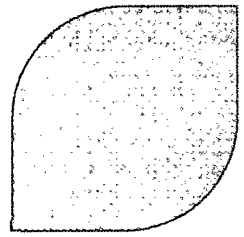
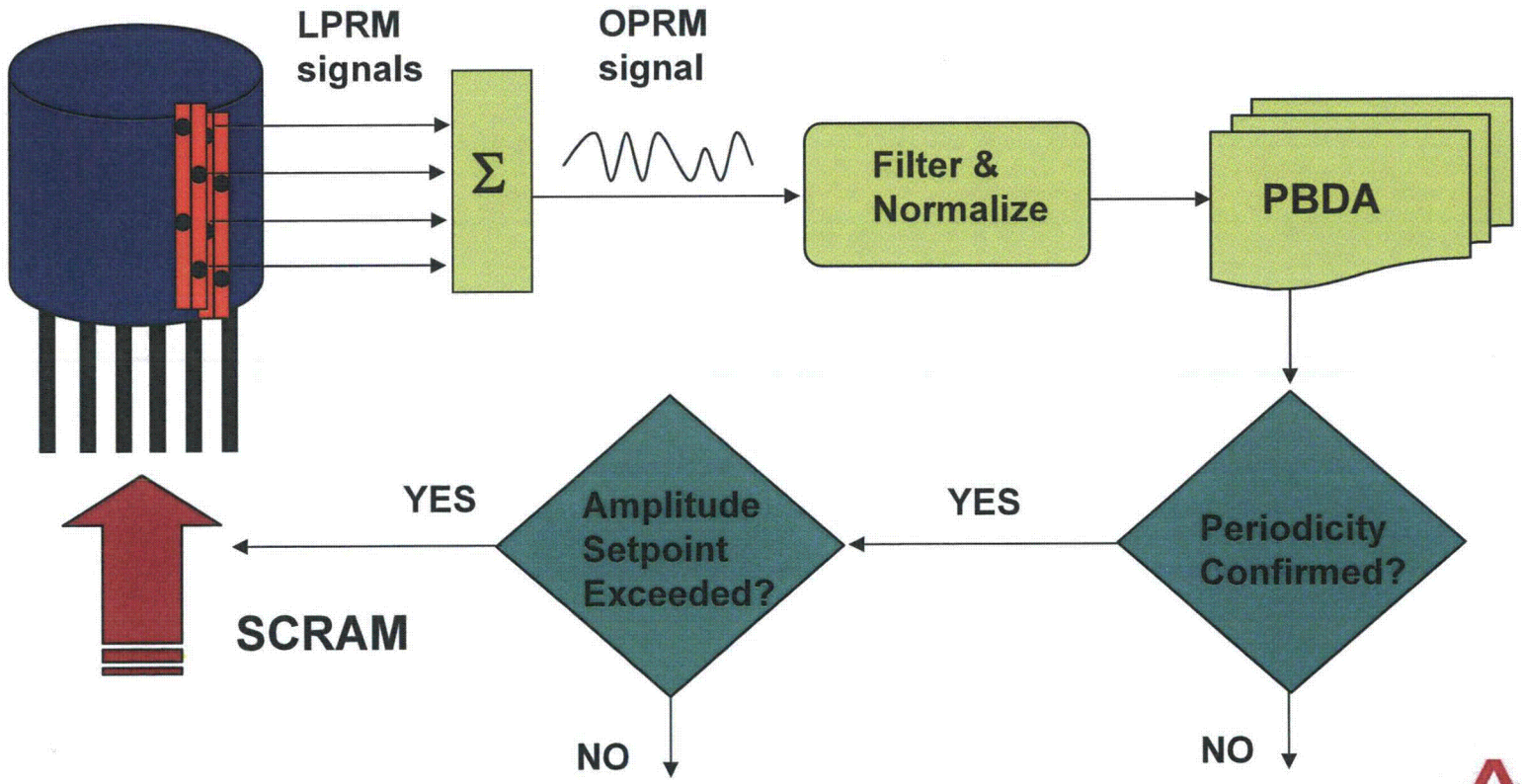
Presentation Objective and Scope



- **Objective:** Support the staff review findings and recommendation to remove the 10% penalty on DIVOM slope calculated by RAMONA5-FA for extended flow control window operation
- **Scope:** Condensed version of the Nov. 17, 2010 presentation to the subcommittee on power uprates and responsive to its feedback
  - ◇ Overview of BWROG and AREVA Detect & Suppress Stability Solution
  - ◇ Addressing the ACRS and Staff Concerns
    - Quantification of HCOM multiplier for MELLLA+ was not clear
    - Effect of bypass boiling on the loss of calibration of the LPRMs
    - Unexplained behavior of the dryout/rewet experimental results
    - RAMONA5-FA code system had not yet undergone a staff review
  - ◇ Dispositioning ACRS and Staff Concerns
    - Clarify the HCOM multiplier role
    - Confirm OPRM detector undamped performance under bypass boiling
    - Explain experimental results on cyclical dryout and updated evaluation
    - NRC audit review of numerical/physical models and closing relations confirm RAMONA5-FA applicability for DIVOM calculations

Overview of BWROG Option III Solution

- Detect & Suppress
- Scram to Protect CPR Safety Limit



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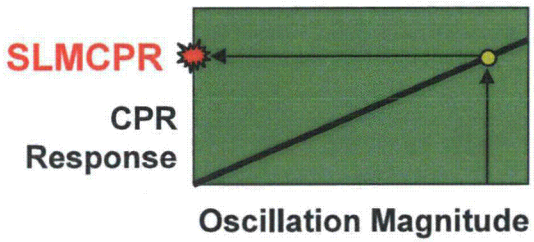
Option III Stability Solution
Original BWROG vs. AREVA Enhanced

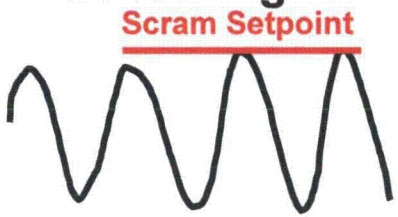
DIVOM



HCOM

Conservative statistical analysis → OM vs. Setpoint

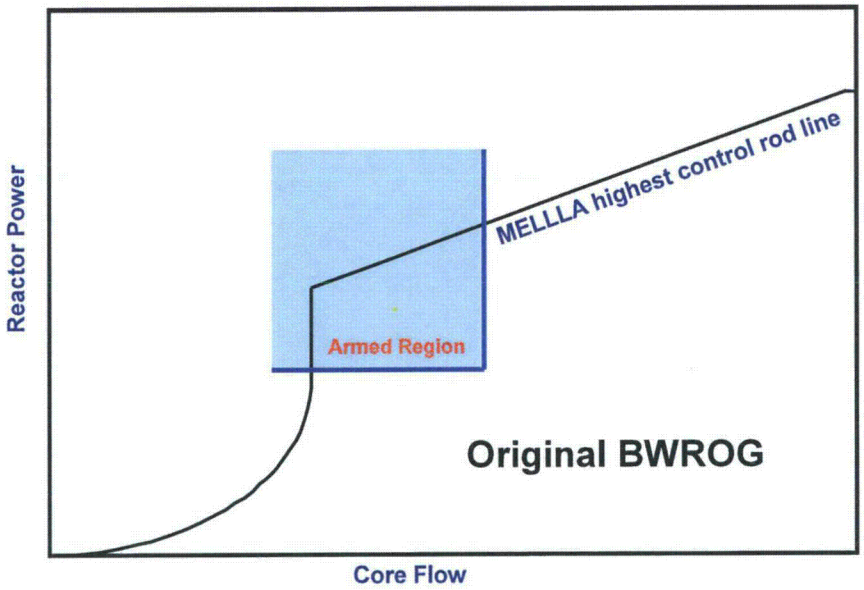
OPRM Signal

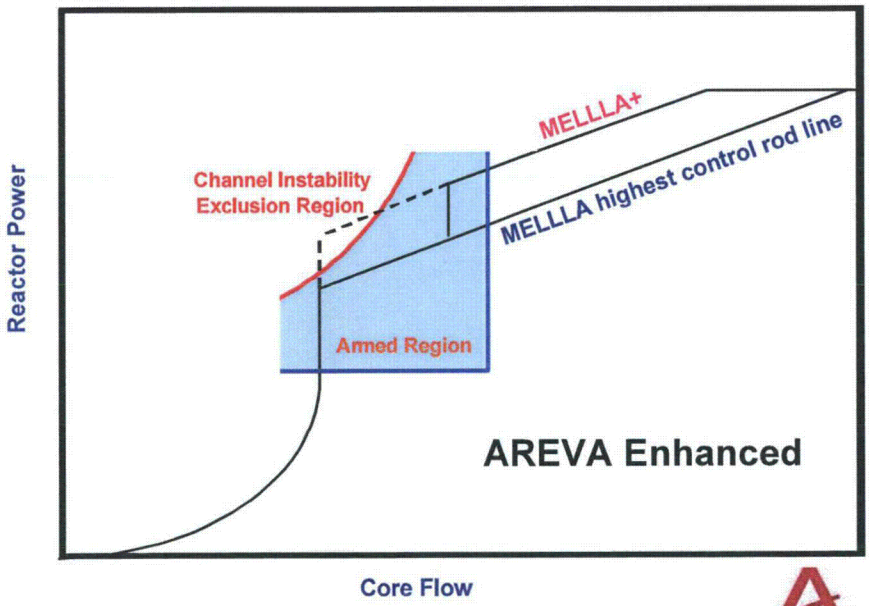


- **OPRM System: same**
- **HCOM Analysis: Revised for MELLLA+ application**
  - Perform new analysis reflecting core loading and stability, or
  - Preferred option to use existing analysis and apply 5% conservative penalty
    - Assessed by consideration of higher MELLLA+ oscillation growth ratio
    - Not taking credit for single channel instability exclusion that limits growth ratios
    - Not taking credit for flatter power shape
- **DIVOM: same numerical methods (using RAMONA5-FA), plus**
  - No ill-defined DIVOM correlation due to single channel instability
- **Operating Domain: Revised**
  - Single channel instability exclusion region protected by hard scram

Applicability Domain of Option III Solutions Original BWROG versus AREVA Enhanced

- Armed region where instabilities are possible
- BWROG is qualified for current operating domains including power uprate, but not for MELLLA+ extended flow window operation
- AREVA Enhanced solution introduces the single channel instability exclusion region protected by scram
  - Well-behaved DIVOM calculation guaranteed
  - Extended applicability to MELLLA+





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Option-III Stability Solution is Conservative

- **Significant conservatism in the methodology**
  - Analysis for the Hot Channel Oscillation Magnitude (HCOM) is conservative
    - Calculates a statistical 95/95 value
    - Conservatively assumes the most responsive OPRM signal fails
  - Protection of the SLMCPR
    - Event is cyclic with a frequency shorter than the fuel rod time constant
    - In case of dryout, clad will rewet within a fraction of the oscillation period
- **Inherent DIVOM conservatisms**
  - A single DIVOM run is a best estimate calculation, however, procedure calls for several calculations at different exposures and varied power and flow points and the most conservative slope is used
  - DIVOM is based on regional mode oscillations where its slope is ~ twice the global mode slope
  - RAMONA5-FA produced DIVOM calculations are robust where the DIVOM curve slopes are generally similar to the original generic slope. Conditions that make DIVOM ill-defined are not allowed.
- **Caution against excessive conservatism**
  - Example: Peach Bottom Unit 3 (Feb. 11, 2005)
    - *Trip signal received, but OPRM system not yet armed*
    - No other indication of oscillations
    - Attributed to overly conservative OPRM setpoint

Bypass Boiling Effect on LPRM Sensitivity

- **Facts:**
  - Boiling in the bypass is possible at natural circulation
  - LPRM loss of calibration -- response is reduced due to loss of neutron moderation in bypass
- **Concern:**
  - Direct energy deposition leads to dynamic oscillatory bypass boiling
  - High void fraction at power peak reduces detector response, and vice versa → underestimated peak-to-peak oscillation magnitude
- **Disposition:**

Bypass Boiling Effect

Simulation of a bypass channel driven by an oscillating power function

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Bypass Boiling Effect

OPRM normalized signal is unaffected by loss of LPRM calibration

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Bypass Boiling Effect

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Experimental Data on Cyclical Dryout

- **Background:**
  - Experimental data were presented showing rod temperature response to flow oscillations in a full scale test bundle (KATHY)
  - Measured oscillating inlet mass flow rate used to drive RAMONA5-FA and calculate CPR response
  - Calculated CPR<1 was shown to "generally" correspond to rising rod temperature

Experimental Data on Cyclical Dryout

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Experimental Data on Cyclical Dryout

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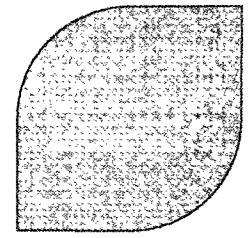
RAMONA5-FA Audit Review



- Auditors (staff and consultants) visited AREVA offices in Richland (Sept. 2008)
- Full access to code source and documentation provided by AREVA staff and consultants
- Test cases designed to stress the code were performed on site
- Test cases involving source code modifications to introduce artificial biases for testing sensitivities were also performed on site
- Timely responses were provided by AREVA to a follow up set of RAI questions
- Draft SER acknowledges the adequacy of RAMONA5-FA for DIVOM calculations and removes the interim penalty of 10% on its slope which was imposed on extended flow window applications pending the audit review

RAMONA5-FA Audit Review

- **Examples of audit review and RAI test cases**
  - ◇ **Comparison of quasi steady-state perturbations to MICROBURN-B2**
    - **Pressure**
    - **Subcooling**
    - **Control rod position perturbation**
  - ◇ **With the exception of control rod position, all nodal and modal neutron kinetics methods showed good performance compared with MICROBURN-B2**
    - **Nodal methods performed well in the control rod perturbation cases**
    - **Modal method was successfully demonstrated to lose accuracy for localized perturbations (control rod movement) due to low order modal expansion**
  - ◇ **Provided validation information for various models**
    - **Validation of the decay heat model**
    - **Comparison of pressure drop data to MICROBURN-B2 and steady-state and transient test data**
    - **Justification of the direct energy deposition models**
    - **Benchmarking calculations of subcooled boiling models**

Minimal DIVOM Sensitivity to Varying Void-Quality Correlations

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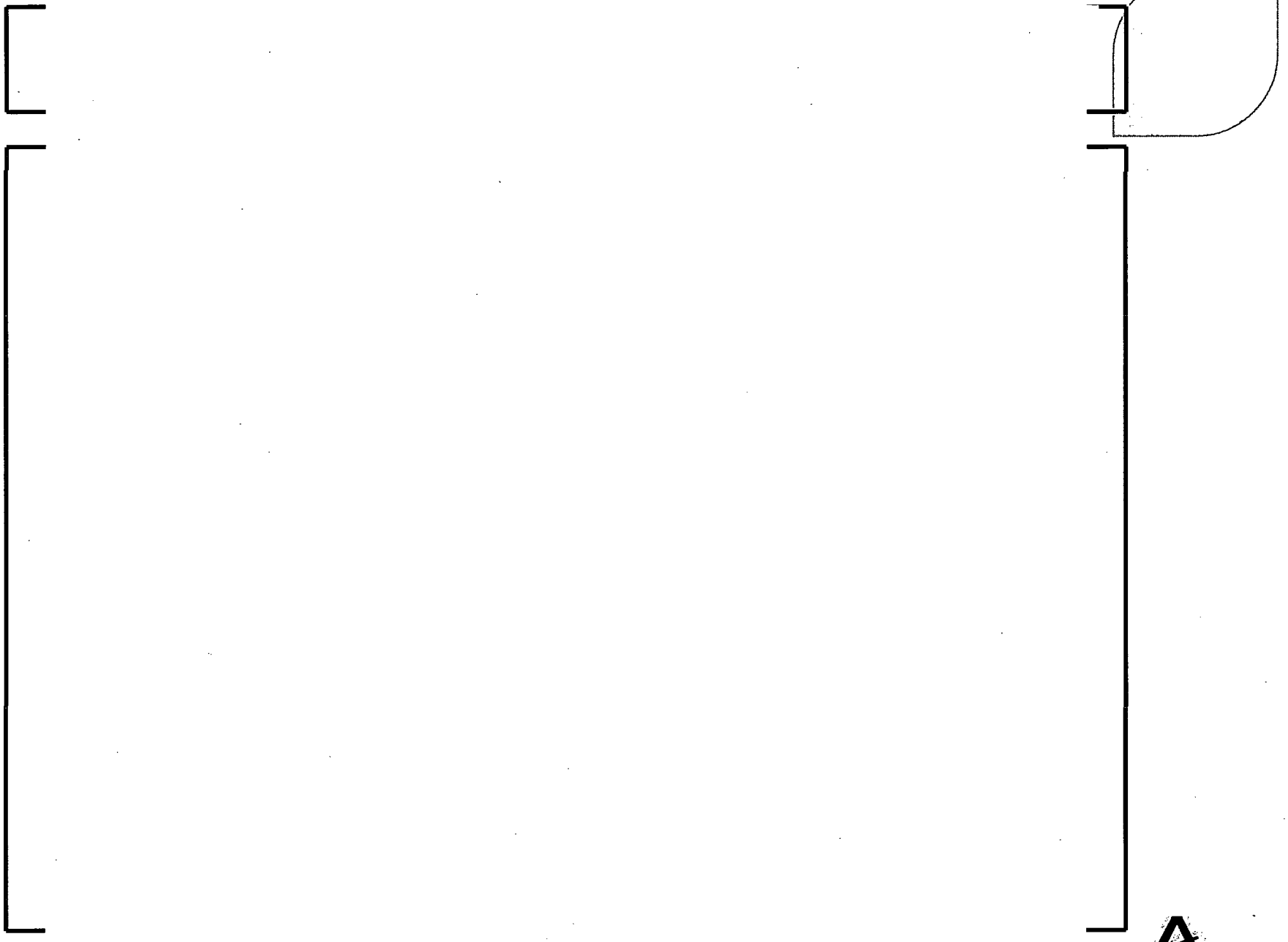

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Closing Remarks

- AREVA has addressed all concerns and requests for additional information regarding its RAMONA5-FA based DIVOM curve methodology
- DIVOM slope change of the order of 10% could be affected only with unreasonable model biases
- No phenomena associated with extended flow window operation were found such that DIVOM slope is impacted
- Rescinding the interim 10% penalty on DIVOM slope for extended flow window applications as recommended by the draft SER is greatly appreciated

Thank You!

Backup Slides

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RAMONA5-FA Thermal-hydraulics In a Nutshell

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Special Topics: Treatment of Area Change

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RAMONA5-FA Thermal-hydraulic Equations

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Ordinary Differential Equations in Time Using Spatial Finite Differences in Space

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