Pre-Submitaal Meeting for Westinghouse BWR Fuel Licensing Topical Reports CENPD-300-P, Revision 1, "Reference Safety Report for Boiling Water Reactor Fuel and Core Analyses" and WCAP-17137-P "Westinghouse Stability Methodology for the ABWR" (Non-Proprietary)

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Pre-Submittal Meeting for Westinghouse BWR Fuel Licensing Topical Reports

CENPD-300-P Revision 1 "Reference Safety Report for Boiling Water Reactor Fuel and Core Analyses"

WCAP-17137-P "Westinghouse Stability Methodology for the ABWR"

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ABWR Pre-Submittal Meeting Agenda

- Introductions (STP)
- Attendees (STP)
- Desired Outcomes (STP)
- BWR Code Overview (Westinghouse)
- Topical Report Schedule (Westinghouse)
- Transient Topical Interface Overview (Westinghouse)
- Topical Report Presentations (Westinghouse)
  - LTR 10
  - LTR 5

Introduction

- STP Team Attendees

- Scott Head	STPNOC
- Jim Tomkins	STPNOC
- Aaron Heinrich	STPNOC
- Jeremy King	Westinghouse
- Ryan Lenahan	Westinghouse
- Mike Riggs	Westinghouse
- Sven-Birger Johannesson	Westinghouse
- Patricia Quaglia	Westinghouse
- Yun Long	Westinghouse
- Andreas Wikström	Westinghouse
- Camilla Rotander	Westinghouse
- John Blaisdell	Westinghouse
- Nirmal Jain	Westinghouse
- Brad Maurer	Westinghouse
- AL Gutterman	STPNOC

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Introduction

- Desired Outcomes
  - Provide an update to the NRC on the plans for fuel related topical reports
  - Provide NRC reviewers with an understanding of the scope content of each topical report presented today
  - Receive feedback from NRC
    - Topicals presented today
    - Overall process so far

LTR Schedule

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Westinghouse ABWR Code Overview

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Changes Introduced by ABWR and Full-scope Fuel Related FSAR Applications

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Acronyms & Definitions

ABA	Amplitude Bases Algorithm
AOO	Anticipated Operational Occurrences
ATWS	Anticipated Transient Without Scram
BSP	Backup Stability Protection
CPR	Critical Power Ratio
CRDA	Control Rod Drop Accident
DIVOM	Delta CPR Over Initial MCPR Versus Oscillation Magnitude
DR	Decay Ratio
ECCS	Emergency Core Cooling System
FMCRD	Fine Motion Control Rod Drive
GDC	General Design Criteria
GRA	Growth Rate Algorithm
HCOM	Hot Channel Oscillation Magnitude

Acronyms & Definitions (cont'd)

LPRM	Local Power Range Monitor
MCPR	Minimum Critical Power Ratio
OLMCPR	Operating Limit MCPR
OPRM	Oscillation Power Range Monitor
PBDA	Period Based Detection Algorithm
QA	Quality Assurance
RIP	Reactor Internal Pump
SAFDL	Specified Acceptable Fuel Design Limits
SCRRI	Selected Control Rod Run-In
SLMCPR	Safety Limit MCPR (lowest allowed transient CPR)
SP	Setpoint

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LTR 10

CENPD-300-P Revision 1
Reference Safety Report for Boiling Water Reactor Fuel and Core Analyses

Sven-Birger Johannesson

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Reference Safety Report for Boiling Water Reactor Fuel and Core Analyses

- The Westinghouse current NRC licensed methodology for licensing analyses is described in CENPD-300-P-A "Reference Safety Report for Boiling Water Reactor Reload Fuel." The report needs to be updated for the following reasons:
  - To address current and future (ABWR) plants designs
  - Incorporates latest approved/submitted references
  - Include methodology improvements

Topical Table of Contents

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Topical Table of Contents (cont'd)

General Updates/Editorial

- Throughout the Topical “ABB” has been changed to “Westinghouse”
- ABWR included in the list of applicable reactor types
- Superseded references have been removed, and current references have been added
- The methodology described in the report for licensing analyses is extended for first cores
  - New Title: Reference Safety Report for Boiling Water Reactor Fuel and Core Analyses
  - Word “Reload” removed/replaced whenever applicable

Section 1 Introduction

- The changes introduced to this section are only editorial. For example:
  - Added information from Revision 0 RAI answers to clarify that individual methods and methodologies are submitted to the NRC separately, and not part of the CENPD-300-P review and approval
  - Clarified that the methodology applies to plant changes and is based on the current plant licensing basis
  - Topical Reports approved after 1996 have been added and outdated references removed [ ]a,c
  - Reference to the CE's QA has been replaced with the Westinghouse QA program

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Section 3 Mechanical Design

- This section has been updated to be consistent with current mechanical design Topical Reports:
  - WCAP-15836-P-A "Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1"
  - WCAP-15942-P-A "Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors – Supplement 1 to CENP-287"
- For example:

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Section 4 Nuclear Design

- Description of input to other disciplines:
  - Deleted or changed direct references to specific topical reports for other disciplines, e.g. detailed references to Mechanical design methodology should be made in Mechanical design section not in Nuclear design section

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  - Description of input for 3-D transient systems codes for stability is more general to include POLCA-T

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Section 5 Thermal-Hydraulic Design

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- "Resident fuel" is replaced by "Legacy fuel"

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Section 5 Thermal-Hydraulic Design (cont'd)

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Section 6 Reload Safety Analysis

- Changes to include the ABWR design:
  - The generic list of potentially limiting events has been updated to include ABWR applications
  - Text added regarding automatic initiation of the standby liquid control system or the electrical insertion of the control rods via the fine motion control rod drive system in connection with ATWS events
- Other changes:
  - New SAFDLs for average fuel pellet enthalpy (170 cal/g and 150 cal/g) incorporated

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Section 7 Anticipated Operational Occurrences (AOO)

- Fast Transient Methodology
  - The AOO methodology is described in WCAP-17203 "Fast Transients and ATWS Methodology"
    - Added a reference to WCAP-17203 in CENPD-300-P Revision 1
    - The detailed description of fast transient methodology is removed from section 7.4 and included in WCAP-17203

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- Slow Transient Methodology
  - Rod Withdrawal Error is not considered an AOO at power for the ABWR plants. The ABWR are equipped with both automated thermal limit monitor (ATLM) and the multi-channel rod block monitor (RBM). These systems will block inadvertent control rod withdrawal.

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Section 8 Accident Analysis

- 8.3 Control Rod Drop Accident
  - Added reference to POLCA-T
  - Due to plant system differences between BWR/2-6 and ABWR, FMCRD and instrumentation to detect separation of the control rod from the drive mechanism it is concluded that cycle specific CRDA analyses are not necessary for ABWR
- 8.4 Fuel Handling Accident

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Section 9 Special Events Analysis

- 9.2 Core Thermal-Hydraulic Stability

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  - Setpoint vs. HCOM, DIVOM and BSP methodology is developed in the Stability Topical; (WCAP-17137-P)

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Section 9 Special Events Analysis (cont'd)

- 9.3 Overpressurization Protection
  - ASME code compliance
    - The section was changed to make it code-independent such that other transient codes (POLCA-T) can be used for overpressurization event analysis
- 9.5 Anticipated Transients Without Scram (ATWS)
  - Clarified that the ATWS analysis assesses the effects of the new fuel design on both short and long term plant responses for the ATWS transients
  - Methodology for ATWS will be in WCAP-17203-P "Fast Transients and ATWS Methodology"

Appendix A Description of Codes

- Superseded computer code references have been removed, and current approved code references have been added

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Summary

- CENPD-300-P Revision 1 "Reference Safety Report for Boiling Water Reactor Fuel and Core Analyses" is updated
  - To address current and future (ABWR) plants designs including first cores
  - Include new references
  - Include methodology improvements
  - Editorial changes are made to improve clarity and to reflect the current Company name

Questions?

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LTR 5
WCAP-17137-P
Westinghouse Stability Methodology for the ABWR

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Existing Stability LTRs

- Existing Stability Topical Reports
  - CENPD-294-P-A, "Thermal-Hydraulic Stability Methods for Boiling Water Reactors" July 1996
    - Describes the qualification of RAMONA-3 using predictions of stability measurements
  - CENPD-295-P-A, "Thermal-Hydraulic Stability Methodology for Boiling Water Reactors" July 1996
    - Describes general reload stability methodology (as it existed in 1996).
  - WCAP-16747-P-A, "POLCA-T: System Analysis Code with Three-Dimensional Core Model" March 2007 (Final SER received)
    - Appendix B describes the general process used to develop a plant evaluation model and the code's qualification using predictions of stability measurements

Current U.S. Application of Methodology to BWRs

- Follow BWROG Guidelines for Long Term Solution Option III
  - DIVOM methodology for plant-specific core-wide and regional mode (June 2005)
    - Determine limiting exposure
    - Perform regional stability analyses along maximum rodline at limiting exposure simulating a two-pump trip from rated power / minimum flow
    - Generate DIVOM curve including an accounting variations in radial peaking from design values
    - Determine OPRM setpoints
  - Backup stability protection (BSP) for inoperable option III solution (July 2002)
    - Define / confirm exclusion zones on the power / flow map for scram and controlled entry regions
    - Exclusion regions for both nominal and reduced feedwater heating

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Westinghouse Stability Methodology for the ABWR

- The purpose of the Topical Report is to:
  - Describe the methodology Westinghouse uses to implement the Option III stability solution in the ABWR
  - Provide a basis for the PBDA setpoints used in the OPRM

Table of Contents of Topical Report

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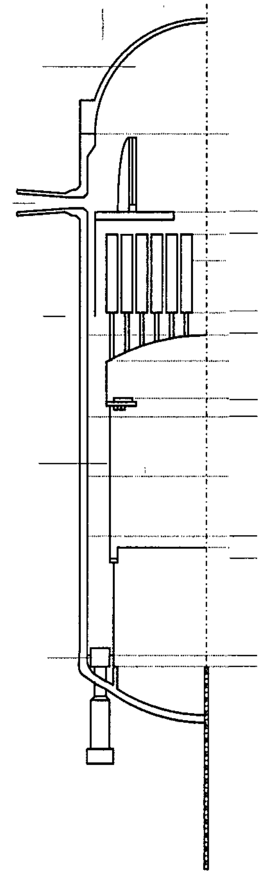
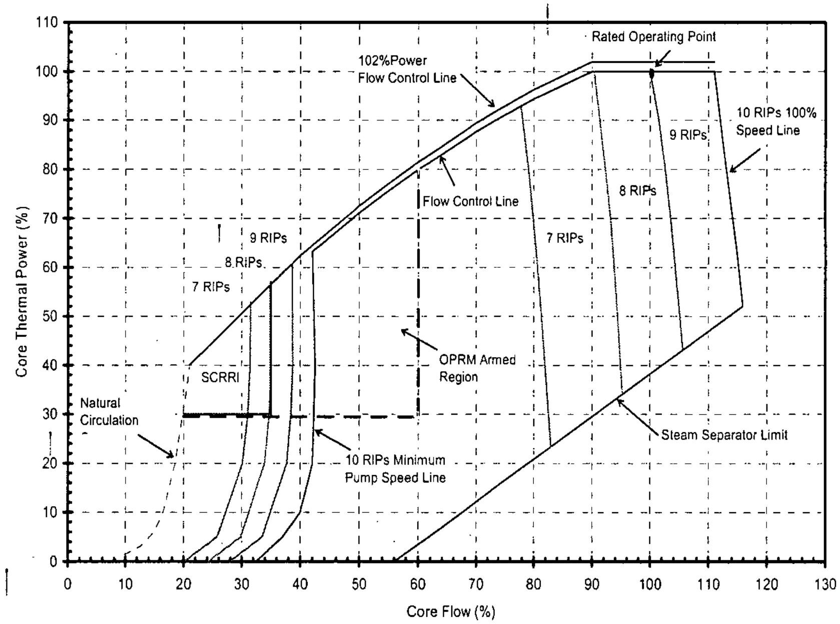
Description of the ABWR

- Ten reactor internal pumps (RIPs) vs. two external recirculation loops with internal jet pumps
  - RIPs have anti-rotation devices to prevent reverse rotation when an RIP is tripped
  - RIPs are powered from two electrical divisions each supplying five pumps
  - At most three RIPs can trip due to a single electrical failure
- Plant can operate at rated power with nine operating RIPs



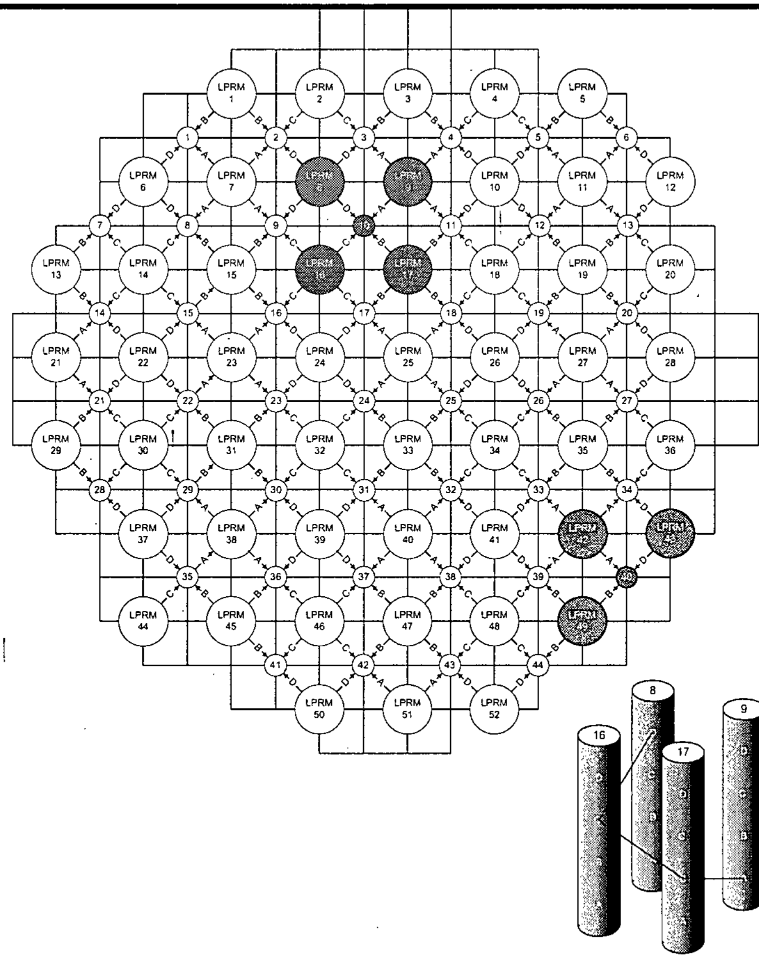
Description of the ABWR (cont'd)

- Stability Protection Features
  - Design – smaller inlet orifices, wider control rod pitch, more steam separators
  - Minimum pump speed line - set to prevent operation in unstable region
  - SCRRI – pre-selected control rods are automatically inserted if event puts plant in defined region
  - OPRM - automatically detects and suppresses power oscillations



Description of the ABWR OPRM

- OPRM Design
  - 44 OPRM cells in ABWR core
  - Each cell measures a normalized neutron flux in a region of the core using neighboring LPRM detectors
  - Each cell has 4 channels comprised of LPRM detectors at 4 elevations from the neighboring LPRMs
  - Trip signals from any 2 of the 4 channels of any OPRM cell will trip the reactor



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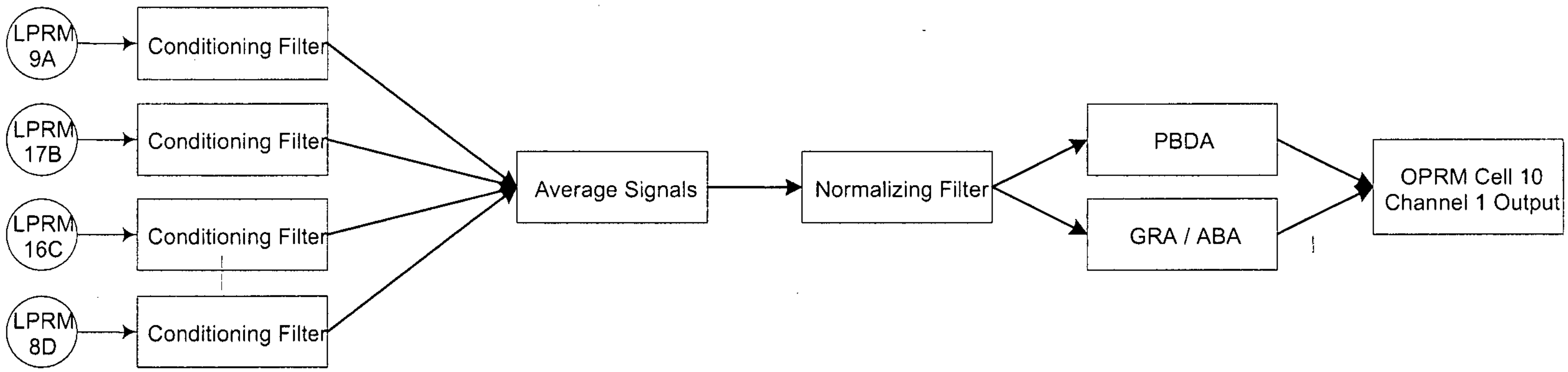
Description of the ABWR OPRM (cont'd)



- Signal conditioning
  - Each LPRM detector signal is passed through a conditioning filter to remove high frequency noise
  - Conditioned signals are summarized and averaged
  - Averaged signals are normalized
  - Normalized signals are passed through detection algorithms

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Growth Rate and Amplitude Based Algorithms (cont'd)

- Consistent with the BWROG guidelines the only algorithm used for safety limits is the PBDA, additional algorithms are used for defense in depth
  - Amplitude based algorithm
    - Searches for oscillations of a certain period
    - Initiates trip when relative signal amplitude exceeds a specified value
  - Growth rate algorithm
    - Searches for oscillations of a certain period
    - Initiates trip signal when growth rate exceeds maximum expected growth rate

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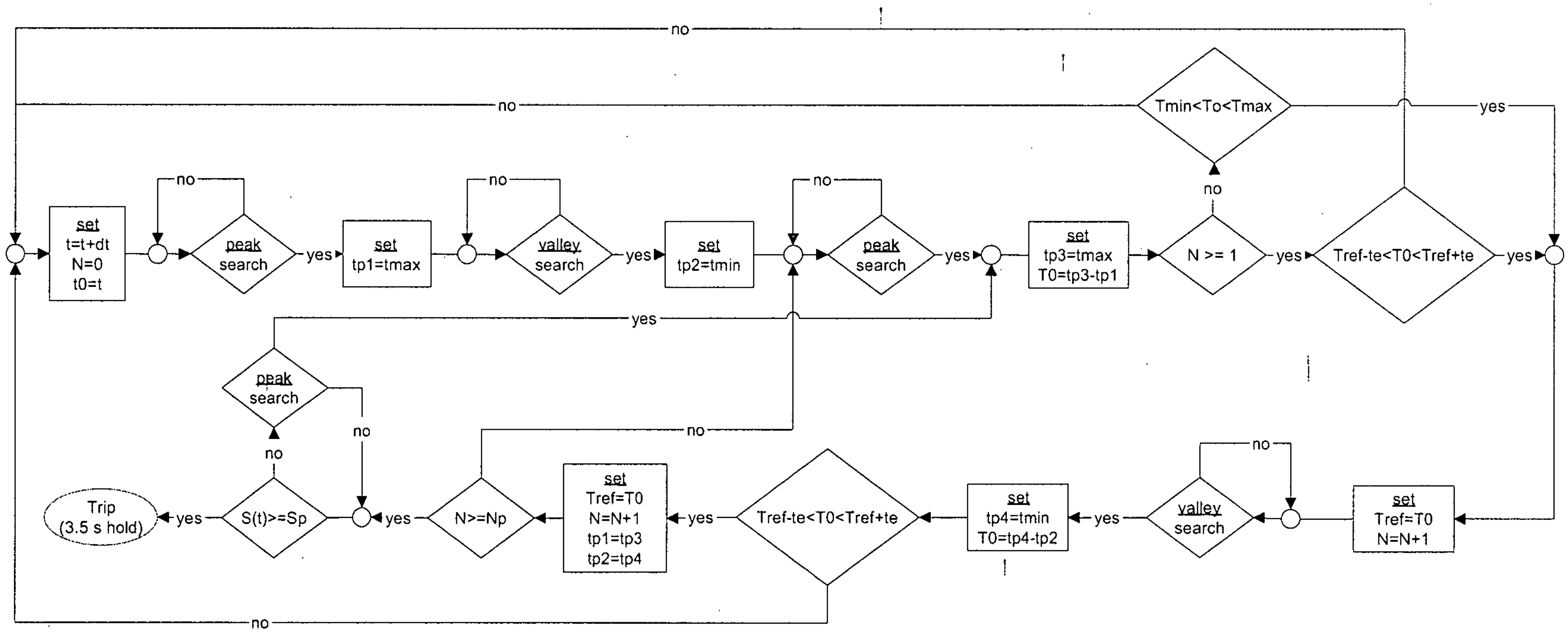
Period Based Detection Algorithm



Period Based Detection Algorithm (cont'd)

- Period based detection algorithm
  - Based on the observation that a given thermal-hydraulic instability will have a period within a small tolerance band
  - The algorithm first determines if an oscillation has an oscillation period between T_{min} and T_{max} [ ]a,c
  - If the next oscillation has the same period as the first, within a small tolerance [ ]a,c, the oscillation is counted
  - If any successive oscillation exhibits a period outside of the tolerance value, the oscillation counts are restarted
  - The counting of successive peaks and valleys continues until the successive count setpoint value is reached [ ]a,c
  - If the number of successive counts is satisfied, and the oscillation amplitude exceeds a setpoint S_p, a channel trip is issued

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Period Based Detection Algorithm (cont'd)

- Successive count setpoint
  - For a given oscillation growth rate and amplitude setpoint, one can determine the number of successive counts to reach the amplitude setpoint
  - A conservative growth rate of [ ]a,c is used to generate the relationship of N_p vs. S_p since that would result in the least number of successive counts for a given amplitude setpoint

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Period Based Detection Algorithm (cont'd)

- Amplitude setpoint vs. hot channel oscillation magnitude
  - A cycle-specific analysis is performed to determine the limiting hot channel oscillation magnitude (HCOM) that would not exceed the MCPR safety limit
    - HCOM is defined as (P-M)/A where P is the previous maximum channel power, M is previous minimum channel power and A is the average channel power
  - A conservative relationship between HCOM and OPRM amplitude setpoint (S_p) provides the link between the cycle-specific analysis and the OPRM amplitude setpoint

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Period Based Detection Algorithm (cont'd)

- Amplitude setpoint vs. hot channel oscillation magnitude
  - [ ]^{a,c} covering a range of dynamic properties (divergence ratio, resonance frequency, power distribution)
  - LPRM signals are extracted → OPRM signals → PBDA [ ]^{a,c}
  - [ ]^{a,c} in core are calculated
  - [ ]^{a,c} for TRIP is calculated and [ ]^{a,c} to largest HCOM in core

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Period Based Detection Algorithm (cont'd)

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- Amplitude setpoint vs. hot channel oscillation magnitude

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[ ]

[ ]

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Description of Methodology

- Computer Codes
  - Westinghouse uses NRC-approved computer codes for performing stability analysis
    - RAMONA-3 – a transient coupled neutronic and thermal-hydraulic code with three-dimensional core physics. Benchmarked against separate effects tests and BWR stability events and tests.
    - POLCA-T – an advanced dynamic system analysis code with three-dimensional core physics. Benchmarked against separate effects tests and BWR plant tests.
  - Both codes have been qualified by comparison of predicted decay ratio / frequency to plant tests / events and separate effects tests

Computer Code Qualification

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Description of Methodology

- Cycle-specific analyses
  - Two kinds of analyses are performed:
    - OPRM PBDA setpoint analysis (DIVOM analysis)
      - This analysis determines the relationship between the oscillating CPR and the oscillating channel power for the hottest channels at the limiting time in the cycle – DIVOM curve
      - Given the safety limit, the initial operating limit, the initial change in CPR due to the assumed transient and the above relationship, a limiting HCOM is determined, from which the setpoints (Sp and Np) are determined
    - Backup stability protection (BSP) analysis
      - This analysis determines / confirms exclusion boundaries on the power flow map that provide administrative controls in the event the OPRM is out of service

DIVOM Methodology

- Acceptance criteria
  - GDC 10 – design with appropriate margin to assure that SAFDLs are not exceeded during any condition of normal operation, including AOOs
  - GDC 12 – design such that power oscillations that can exceed SAFDLs are not possible, or can be reliably detected and suppressed
  - The methodology describes how acceptance criteria are met
    - The PBDA setpoints are established to ensure the reactor will be tripped before oscillations from expected instability transients can grow to an extent that the safety limit MCPR can be exceeded

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DIVOM Methodology (cont'd)

- Assumed transient
  - Since normal operation within the unstable domain is not permitted; [

    ]a,c
  - At most three pumps can trip as a result of a single electrical failure
  - The initial operating point [

    ]a,c
  - At the end of the pump coastdown, and after feedwater temperature has come into equilibrium, [

    ]a,c

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DIVOM Methodology (cont'd)

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DIVOM Methodology (cont'd)

- Cycle Exposure
  - The stability of the core is exposure dependent
  - 3D simulations are generated for a minimum of three exposure points to determine the exposure that yields the [

]a,c

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DIVOM Methodology (cont'd)

- Channel selection
  - [
    ]a,c
  - The DIVOM relationship is determined using [
    ]a,c
- Delta-CPR Calculations
  - An approved CPR correlation for the fuel type being analyzed is used to determine [
    ]a,c

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DIVOM Methodology (cont'd)

- Data processing
  - The [ ]a,c data for [ ]a,c
  - These data are processed to capture [ ]a,c
  - Since channel power and MCPR are not in phase; the change in CPR for a given oscillation is associated with the previous channel power

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DIVOM Methodology (cont'd)

- DIVOM slope determination
  - Plot the ΔCPR/iCPR vs. (P-M)/A pairs for [ ]a,c
- Cycle uncertainty
  - A sensitivity study is used to develop [ ]a,c
  - The slope of [ ]a,c

DIVOM Methodology (cont'd)

- PBDA setpoint determination
  - The slope of the DIVOM curve (S_D) provides a conservative connection between the channel power oscillation magnitude (HCOM) and the change in MCPR
  - The HCOM required to reach [ ]a,c
  - The conservative relationship between OPRM signal magnitude (S_p) and HCOM is used to determine the amplitude setpoint that will ensure the oscillations are suppressed before the safety limit is exceeded
  - The conservative relationship between S_p and N_p is used to determine the number of successive confirmation counts necessary to reach the amplitude setpoint given a conservative diverging oscillation

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BSP Methodology

- Acceptance criteria
  - There are two regions defined by the BSP analysis
    - Region I (the scram boundary) – operation within this region may lead to diverging power oscillations and the plant is scrammed manually
    - Region II (the controlled entry boundary) – a buffer region that provides the operators with an opportunity to transition to a more stable region to avoid scramming the plant
  - Region I boundary – Decay ratio (DR) of limiting stability mode consistent with code acceptance criteria
  - Region II boundary – DR of limiting stability mode provided in the topical

BSP Methodology (cont'd)

- Limiting cycle exposure
  - A series of global mode stability analyses are performed [

    ]a,c
  - Range of exposures covers entire cycle with special emphasis on [ ]a,c

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BSP Methodology (cont'd)

- Global mode exclusion boundaries
  - Determine DR at a series of power/flow statepoints [

    ]a,c
- Evaluate regional mode stability
  - For statepoints corresponding to global mode [

    ]a,c
- Evaluate channel stability
  - For statepoints corresponding to global mode [

    ]a,c

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BSP Methodology (cont'd)

- Limiting mode exclusion boundaries
  - Based on previous studies, determine limiting statepoints corresponding to acceptance criteria
  - Compare results to existing BSP exclusion boundaries
  - If the statepoints are not bounded by the previous exclusion boundaries, the exclusion boundaries have to be changed

BSP Methodology – Preliminary Global Mode Example

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Summary

- Implementation of Option III methodology for the ABWR includes
  - Sp vs. HCOM methodology
  - DIVOM methodology
  - BSP methodology

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Questions?

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