U.S. EPR Pre-Application Review Meeting: Setpoints Analysis Methods Topical Report

AREVA NP Inc. and the NRC
October 10, 2007

Introduction

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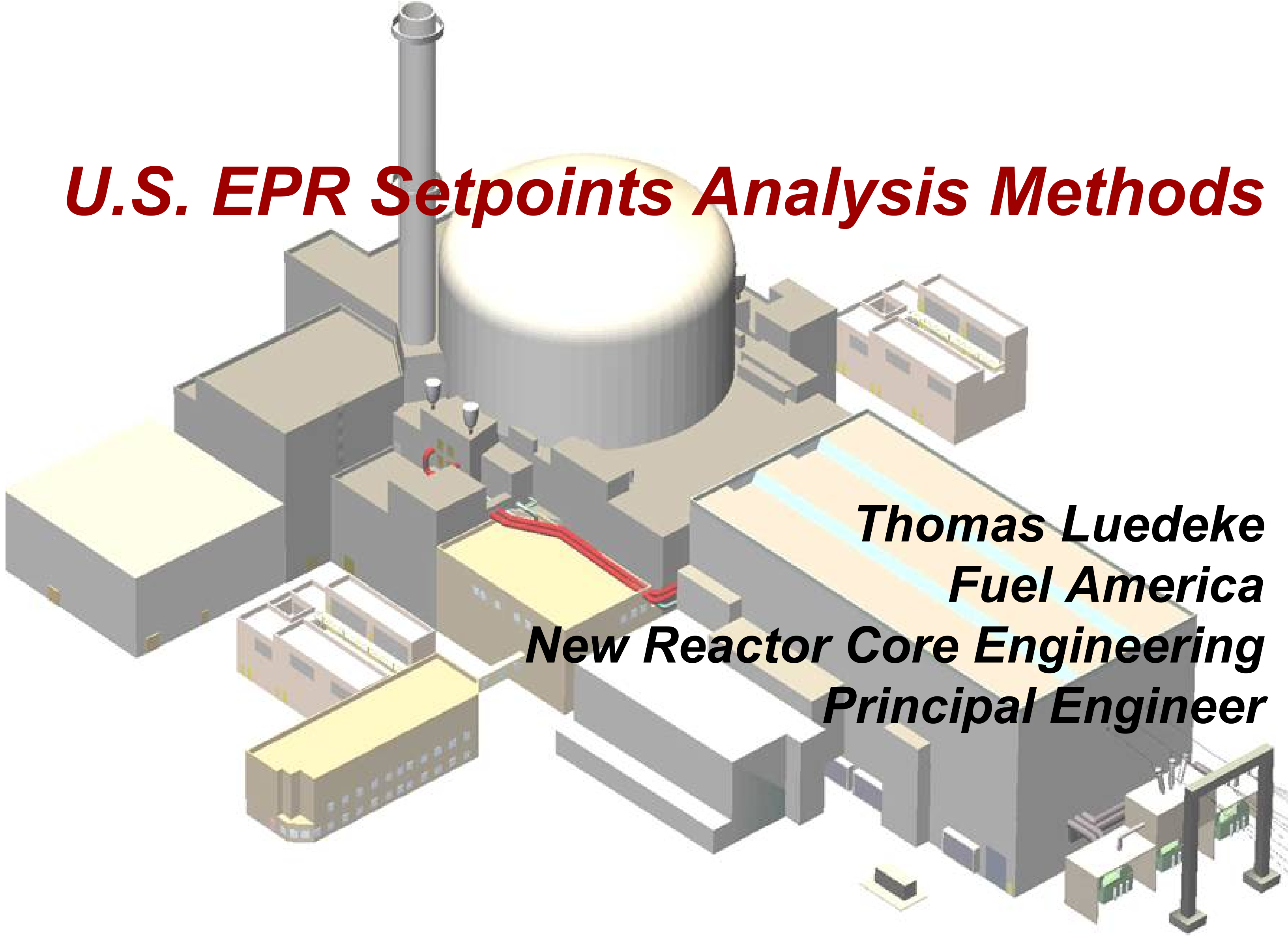
Meeting Objectives

- Discuss the U.S. EPR setpoints analysis methods topical report and coordination with the DCD
- Provide introduction to topical report contents and organization
- Obtain timely NRC feedback and interactions to support informed development of the DCD

Topics

➢ **Introduction**	**Sloan**
➢ **Non-Proprietary Presentation**	
◆ Topical report overview	Luedeke
◆ Regulatory basis for methodology	Luedeke
◆ Nuclear incore instrumentation	Luedeke
◆ Overview of incore trip and LCO functions	Luedeke
◆ Uncertainties affecting incore trip functions	Luedeke
➢ **Proprietary Presentation**	
◆ SPND calibration for DNBR and LPD	Luedeke
◆ Setpoint methodology overview	Luedeke
➢ **Summary and next steps**	**Sloan**

U.S. EPR Setpoints Analysis Methods



Thomas Luedeke
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Setpoint Topical Report

What to Expect

- **ANP-10287P, "*Incore Trip Setpoint and Transient Methodology for U.S. EPR*"**
  - **Documents the analytical methodology to be used for establishing and confirming setpoints for the incore-based trip and LCO functions in the U.S. EPR**
  - **Analogous to existing AREVA NRC-approved setpoint topical reports for Westinghouse and Combustion Engineering PWRs**
    - **EMF-92-081PA, Revision 1, *Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors***
    - **EMF-1961PA, Revision 0, *Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors***

Setpoint Topical Report
What to Expect

- **Topical scope**
  - Detailed description and design basis for incore trip function
    - Low DNBR Channel LSSS and DNB LCO
    - High LPD Channel LSSS and LPD LCO
  - Uncertainty variables considered in methodology
  - Overview of setpoint methodology
    - Establishing setpoints for static functions
    - Confirmation of dynamic compensation settings
  - Additional details related to neutronics aspects of methodology
  - Overview of interface between incore instrumentation systems and incore trip setpoint methodology
    - SPND calibration principles and power distribution input to incore trip/LCO functions

Regulatory Basis for Methodology

Regulatory Basis

Overview

- **Regulatory basis for setpoint methodology**
  - **10 CFR 50.36 (Definitions)**
  - **10 CFR 50 Appendix A (GDC)**
  - **GDC II:10, GDC II:13, GDC II:20, GDC II:25, GDC III:29**
  - **Regulatory Guide 1.105**
    - **BTP 7-12, Revision 5**
  - **NUREG-0800**
    - **§4.2, §4.3, §4.4**
    - **§15**
  - **Other issues**
    - **RIS 2006-17**

Nuclear Core Instrumentation Systems

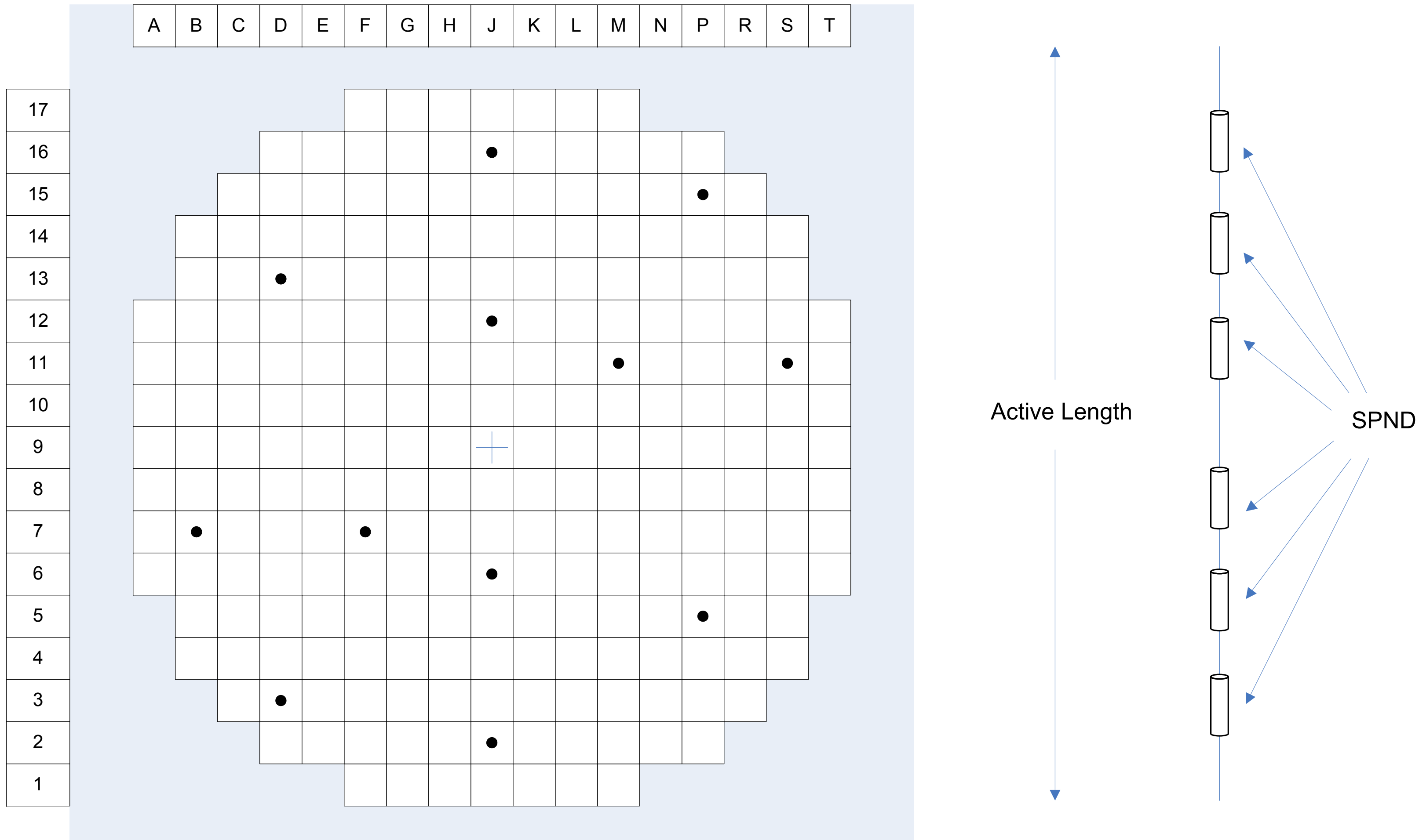
Nuclear Instrumentation Systems

- **Detailed design information on Power Density Detection System (PDDS) and Aeroball Measurement System (AMS) system provided in ANP-10271P (*U.S. EPR Nuclear Incore Instrumentation Systems Report*), submitted**
- **Detailed design information for core monitoring software provided in ANP-10282P (*POWERTRAX/E Online Core Monitoring Software for the U.S. EPR Report*), to be submitted**
- **Additional information on interface between SPND and incore LSSS/LCO functions provided in the proprietary portion of presentation**

Nuclear Instrumentation Systems

- The nuclear core instrumentation systems form the basis for the incore trip and LCO functions
  - PDDS – continuous core monitoring
  - AMS – on demand neutron flux mapping
- PDDS utilizes fixed strings of self-powered neutron detectors
  - ^{59}Co SPND detectors with prompt response
  - Twelve radial locations, six core-symmetric pairs
  - Six SPND per detector string, axially distributed to optimize reconstruction of power shapes of particular concern to DNBR and LPD

Nuclear Instrumentation Systems



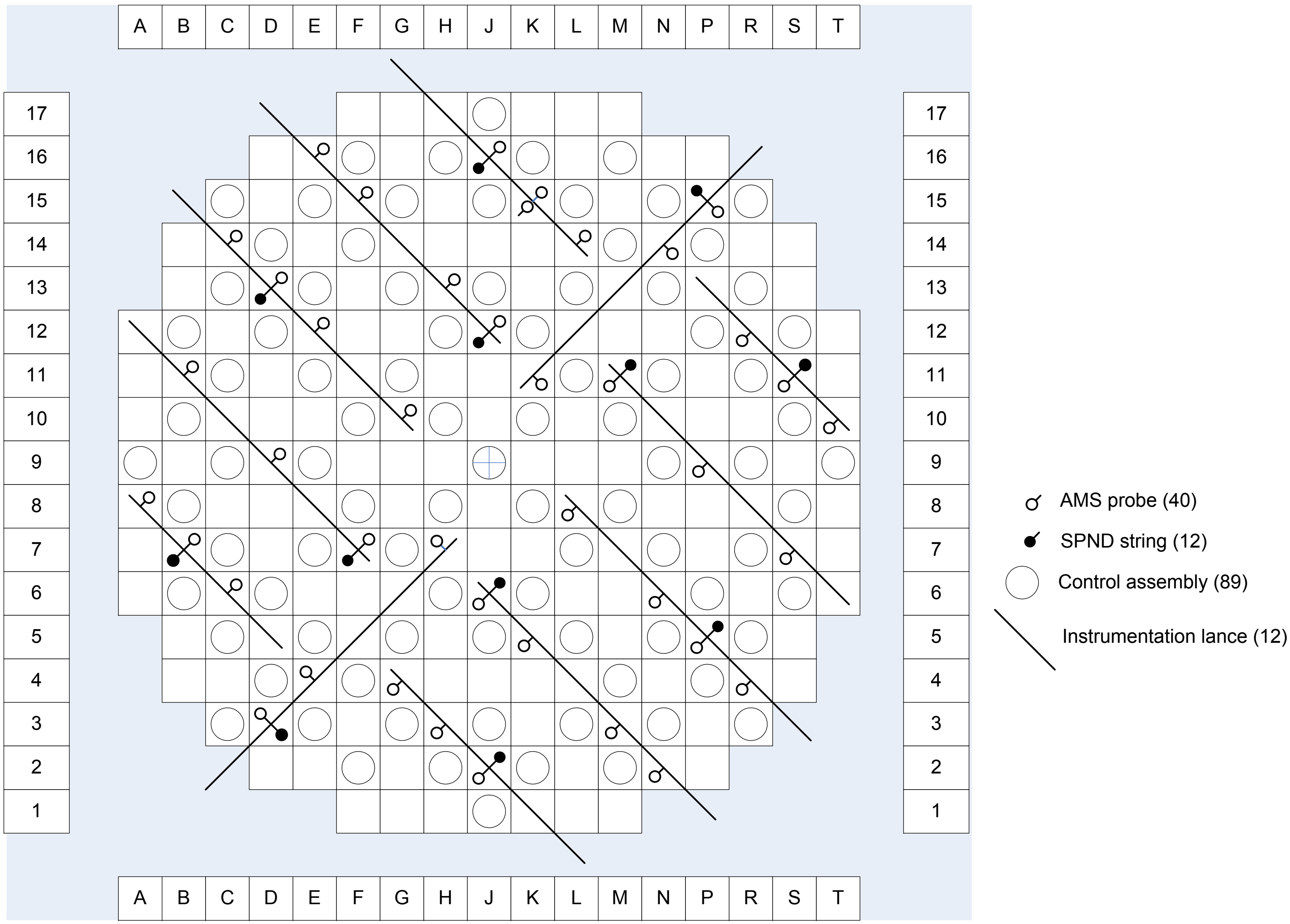
12 SPND strings, 6 SPNDs per strings

= 72 fixed incore detectors

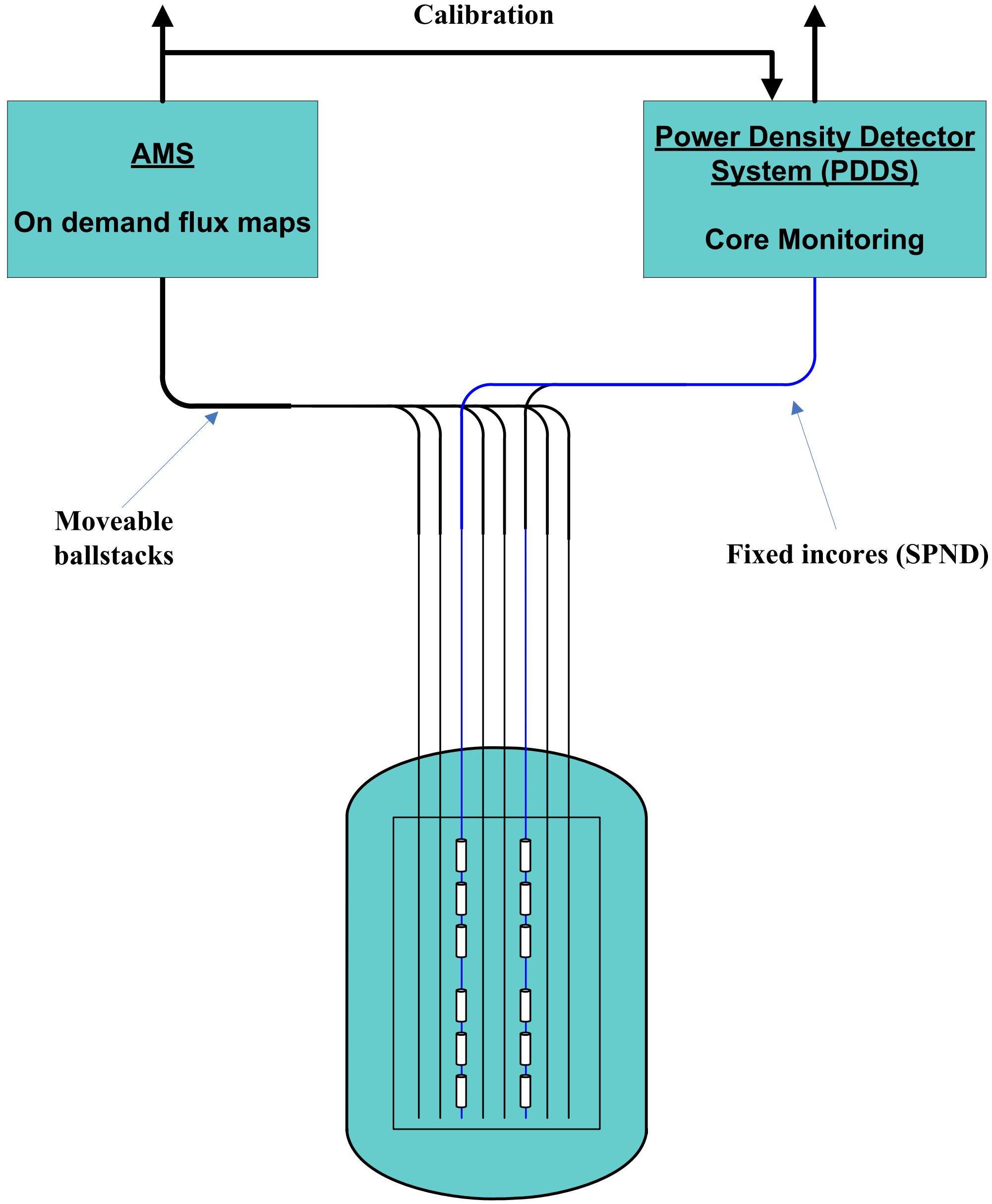
Nuclear Instrumentation Systems

- Periodic flux maps are conducted using the Aeroball Measurement System (AMS)
  - Neutron activation of moveable stacks of small (1.7 mm) stainless steel balls containing ^{51}V
  - 40 radially distributed AMS probes
  - MEDIAN calculation module in POWERTRAX/E used to reconstruct 3D power distribution using AMS data
- The incore-based trip and LCO setpoints are based upon AMS-calibrated power density distributions from PDDS system

Nuclear Instrumentation Systems



Nuclear Instrumentation Systems



Overview of Incore Trip and LCO Functions

Incore Trip and LCO Functions

Overview

- **The U.S. EPR design utilizes DNBR and LPD monitoring and protection capability using the incore detector system**
  - **Contemporary PWR designs monitor DNBR and LPD LCOs using incore detectors, but base DNBR and LPD protection on readings of the excore detectors**
  - **The U.S. EPR bases DNBR and LPD protection capabilities upon <u>incore</u> power distribution measurement**
    - **Use of fixed incores for power distribution information allows elimination of sizeable uncertainties associated with excore power readings**
    - **Low DNBR and High LPD Channel protection functions are based on real-time 3D power distributions determined by many sensors within that power distribution, rather than by a few sensors far removed from it**

Incore Trip and LCO Functions
Overview (continued)

- **The U.S. EPR incore trips and LCOs which are the subject of this topical report are as follows:**

Function	Design Purpose
Low DNBR Channel LSSS	Active protection of DNB safety limit
DNBR limitation	Active defense against Low DNBR Channel LSSS
DNB LCO	Graduated defense of steady-state DNBR margin
High LPD Channel LSSS	Active protection of LPD/CS safety limit
HLPD limitation	Active defense against High LPD Channel LSSS
LPD LCO	Graduated defense of steady-state LPD margin

Incore Trip and LCO Functions

Overview (continued)

- **To maintain operational capability in the scenario with inoperable SPNDs, these functions are adaptive with respect to SPND failures**
  - **Distinct setpoints are established to accommodate SPND failures**
  - **Setpoints are adjusted automatically in response to failed SPNDs**
  - **Identified failure combinations representing particular challenges to SAFDLs will be addressed with Technical Specification requirements**

Incore Trip and LCO Functions

LPD Protection Overview

- **The LPD safety limit is protected by three levels of protective functionality:**
  - **High LPD (HLPD) Channel LSSS**
    - **Provides active protection (reactor trip) against violation of fuel centerline melt/clad strain safety limits**
  - **HLPD Limitation Function**
    - **Designed to intercede with active actions (partial trip and turbine runback) to prevent a High LPD Channel trip**
    - **Increases plant availability by potentially avoiding ascension from shutdown state**

Incore Trip and LCO Functions

LPD Protection Overview (continued)

- **LPD LCO**
  - **Protects LPD limit established by LOCA analysis, and….**
  - **… other events characterized by transient LPD degradation and which are not directly protected by the High LPD Channel LSSS**
  - **Implemented as a graduated sequence of actions via distinct sets of setpoints**
    - **LCO1 setpoint violations (passive actions): Control room alarms and blocks of actions that exacerbate LPD**
    - **LCO2 setpoint violations (active actions): Control bank insertion, reduce turbine demand**

Incore Trip and LCO Functions
LPD Protection Overview (continued)

Incore Trip and LCO Functions
High LPD Channel LSSS – Design Basis

- **The High LPD Channel LSSS protects against slow to moderately fast AOO events characterized by significant uncontrolled LPD degradation:**
  - **SRP 15.1.3 (Excess Load Increase)**
  - **SRP 15.4.2 (Bank Withdrawal at Power)**
  - **SRP 15.4.3 (Dropped RCCA or Bank)**
  - **SRP 15.4.3 (Statically Misaligned RCCA)**
  - **SRP 15.4.3 (Single RCCA Withdrawal)**
  - **SRP 15.4.6 (Boron Dilution)**
- **May intercede in postulated accidents, but not formally part of design basis**

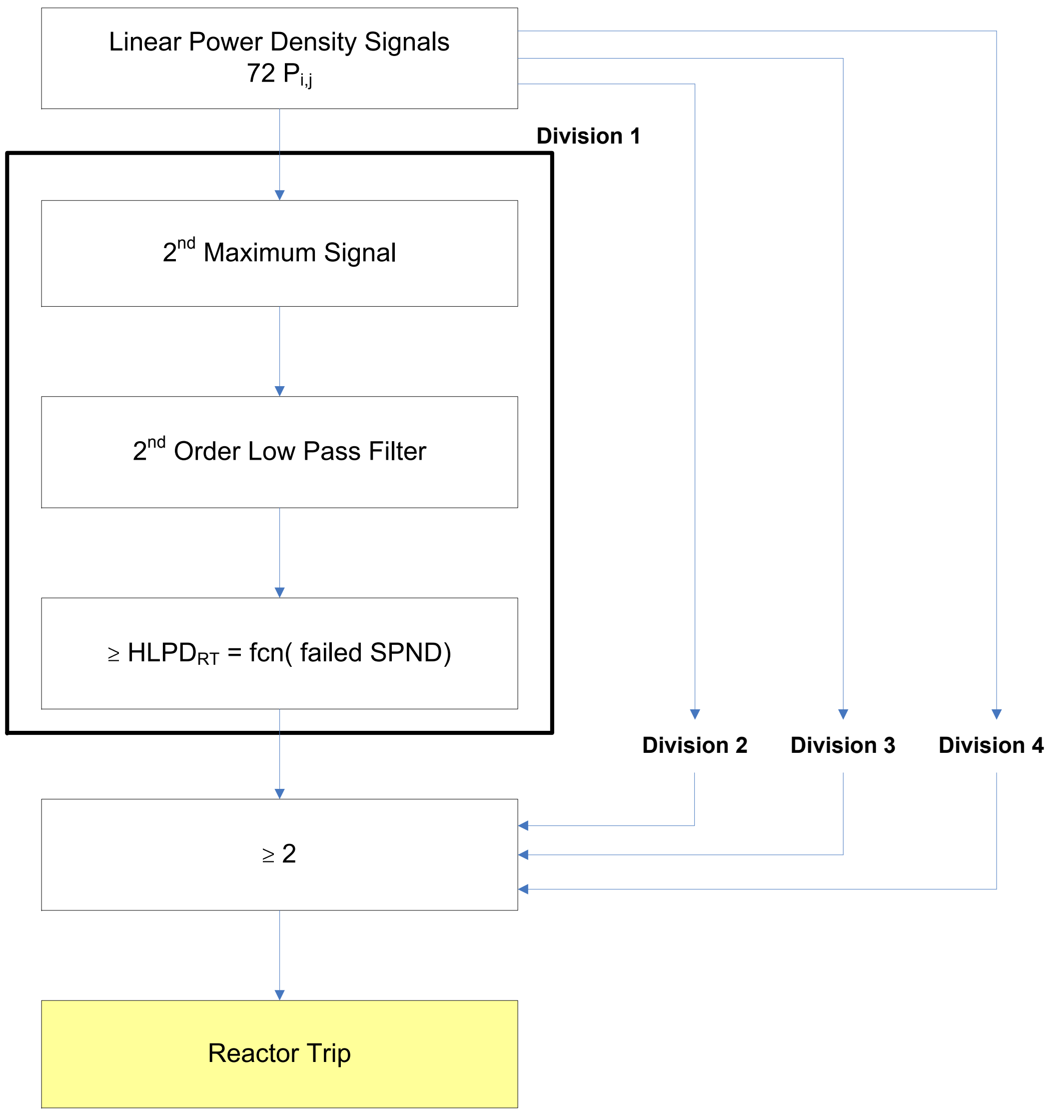
Incore Trip and LCO Functions

High LPD Channel LSSS – Functional Description

- **High LPD Channel LSSS Process Inputs**
  - **Each protection system division utilizes the totality of the available SPND signals, calibrated for peak LPD**
  - **To avoid spurious actuation of the trip, the LPD signal with the highest value is discarded**
  - **The remaining available signals are passed through a second-order low pass filter to reduce noise and compensate for trip processing delays**
  - **The highest remaining signal from each division is then compared to the High LPD channel LSSS setpoint, and produces a reactor trip signal if the setpoint is exceeded**

Incore Trip and LCO Functions

High LPD Channel LSSS – Simplified Functional Diagram



Incore Trip and LCO Functions
LPD LCO – Design Basis

- **Limiting Conditions for Operation on LPD**
  - **Designed to survey the peak LPD in the core during normal operation, and ensure that sufficient steady-state LPD margin is reserved**
  - **Peak LPD in upper and lower halves of the core (as determined by the calibrated SPND signals) is monitored and compared against distinct setpoints**
    - **This provides independent protection against events which characteristically challenge LPD in the upper or lower halves of the core, without degrading operating margin**

Incore Trip and LCO Functions

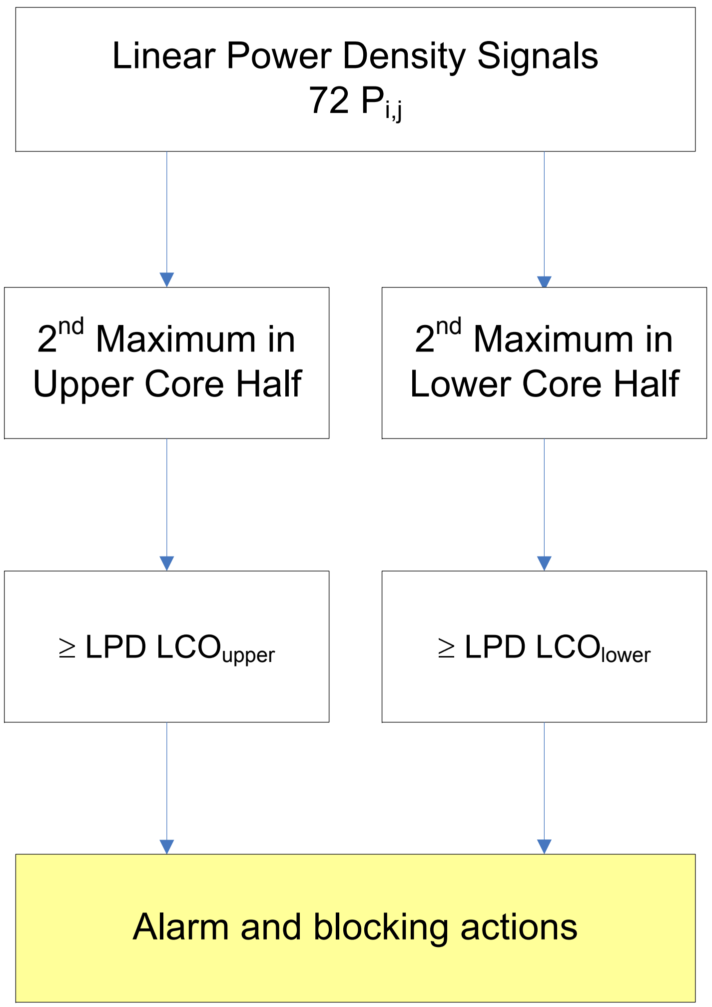
LPD LCO – Functional Description

LPD LCO

- To avoid spurious actuation of the LCO, the highest measured LPD signal in both the top and bottom halves of the core is discarded
- The remaining signals are passed through a second-order low pass filter to reduce noise and compensate for processing delays
- The highest remaining signal in each half of the core is then compared to the LPD LCO setpoints for that region
- Violation of the LPD LCO setpoints results in alarms and automatic actions to mitigate further LPD degradation

Incore Trip and LCO Functions

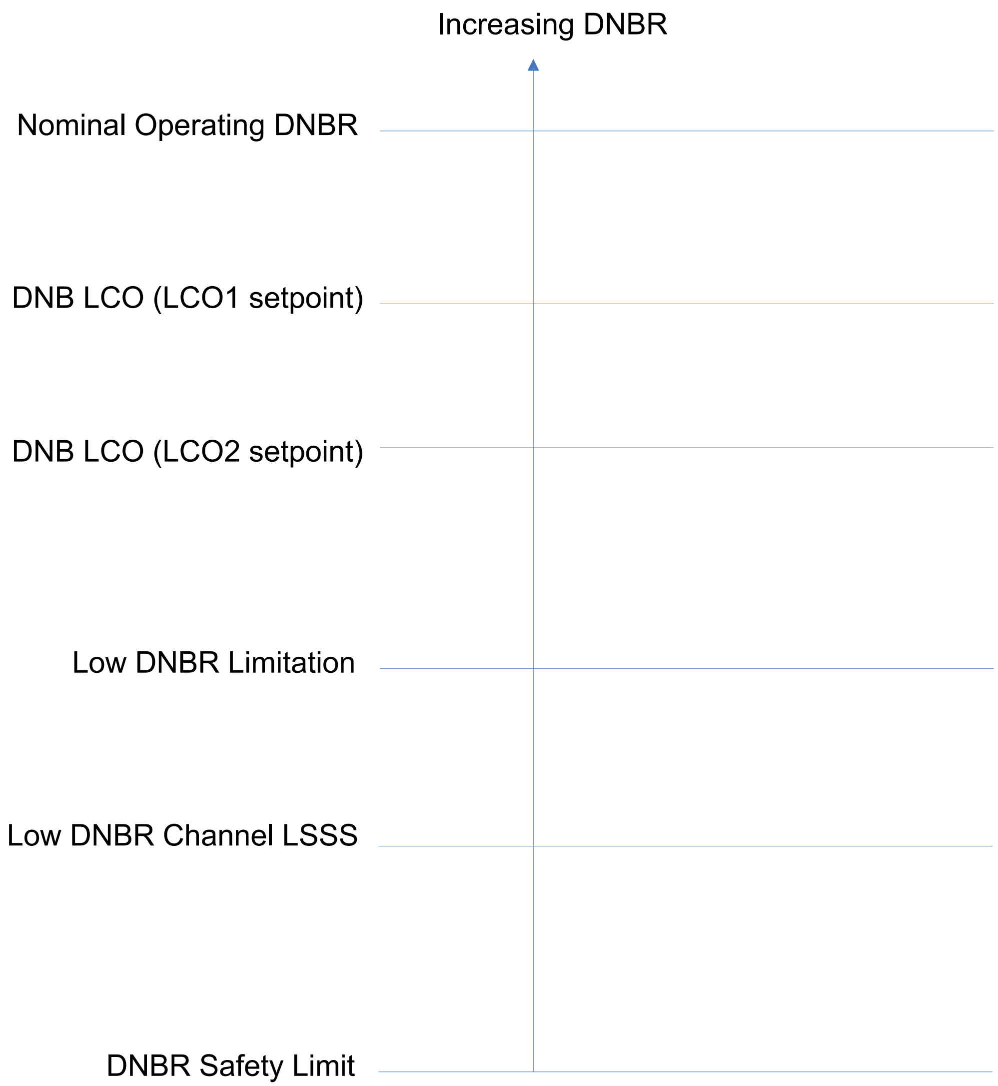
LPD LCO – Simplified Functional Diagram



Incore Trip and LCO Functions
DNBR Protection Overview

- **Protection against DNBR is afforded by three levels of online functions:**
  - **Low DNBR Channel LSSS**
    - **Provides active protection for transients in which DNBR degradation can be resolved via the monitored process variables**
  - **Low DNBR Limitation**
    - **Designed to intercede with active actions to prevent the Low DNBR Channel trip from occurring**
  - **DNB LCO**
    - **Reserves DNBR margin during normal operation**
    - **Split into two setpoints representing graduated actions**

Incore Trip and LCO Functions
DNBR Protection Overview (continued)



Incore Trip and LCO Functions

Low DNBR Channel LSSS – Functional Description

- **Low DNBR Channel LSSS**
  - Represents the highest functional level of DNB protection
  - Trips the reactor when an uncontrolled decrease in the synthesized online DNBR value occurs
  - Ensures that DNB is avoided, at 95% probability, with 95% confidence
  - Part of safety grade Protection System

Incore Trip and LCO Functions

Low DNBR Channel LSSS – Functional Description

- **The low DNBR channel monitors the following plant parameters:**
  - **Pressurizer pressure (*4 sensors, one signal per division*)**
  - **Cold leg temperature (*4 sensors, one loop signal per division*)**
  - **RCP rotational speed (*4 sensors, one loop signal per division*)**
  - **72 incore SPND (*all available signals seen by each of the four divisions*)**

Incore Trip and LCO Functions

Low DNBR Channel LSSS – Functional Description

- **The low DNBR channel monitors additional plant parameters to add specific protections against control rod misoperation AOO events**
  - **RCCA position (*one signal per RCCA, 89 total signals apportioned into four divisions*)**
  - **SPND imbalance (radial core tilt), calculated from SPND signals**

Incore Trip and LCO Functions

Low DNBR Channel LSSS – Design Basis Events

- The Low DNBR channel protects against slow to moderately fast off-normal AOO events:
  - SRP 15.1.1 (Feedwater Temperature Decrease)
  - SRP 15.1.2 (Feedwater Flow Increase)
  - SRP 15.1.3 (Excess Load Increase, slower end of spectrum)
  - SRP 15.4.2 (Bank Withdrawal at Power, slower end of spectrum)
  - SRP 15.4.6 (Boron Dilution)
  - SRP 15.6.1 (Inadvertent Opening of Pressurizer Relief/Safety Valve)

Incore Trip and LCO Functions
Low DNBR Channel LSSS

- **The supplementary signals are designed to afford specific protections against the following additional events:**
  - **SRP 15.4.3 (Dropped RCCA or Bank)**
  - **SRP 15.4.3 (Statically Misaligned RCCA)**
  - **SRP 15.4.3 (Single RCCA Withdrawal)**

Incore Trip and LCO Functions

Low DNBR Channel LSSS – Functional Description

- **Single closed-channel model used for online DNBR calculations**
  - **Single closed-channel model tuned to match MDNBR and exit quality predictions from design subchannel analysis code**
  - **Hot channel power density profile provided by calibrated SPND signals**
  - **Dynamic compensation used to remove transport and signal processing delays**
  - **Uncertainties in predictive capability taken into account in setpoint analysis**

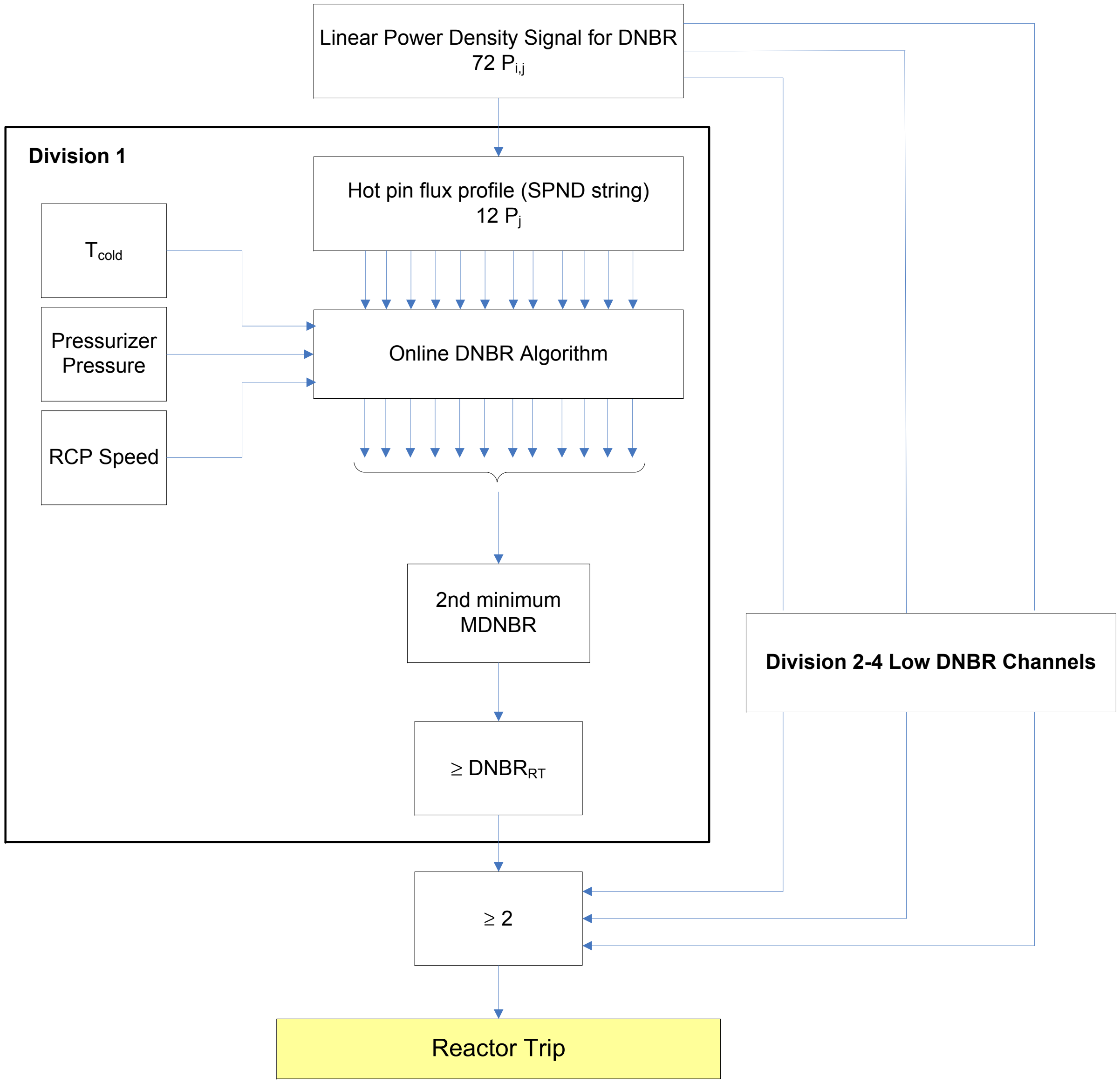
Incore Trip and LCO Functions

Low DNBR Channel LSSS – Functional Description (continued)

- To avoid spurious actuation of the trip, the minimum MDNBR signal is discarded (unless a dropped rod or excessive SPND imbalance signal is present)
  - 2^{nd} minimum signal is passed through a second-order low pass filter to reduce noise and compensate for processing delays
  - Compared against one of multiple setpoints, based on number of inoperable SPND detectors
  - Violation of the Low DNBR channel setpoint results in a reactor trip signal

Incore Trip and LCO Functions

Low DNBR Channel LSSS – Simplified Function Diagram

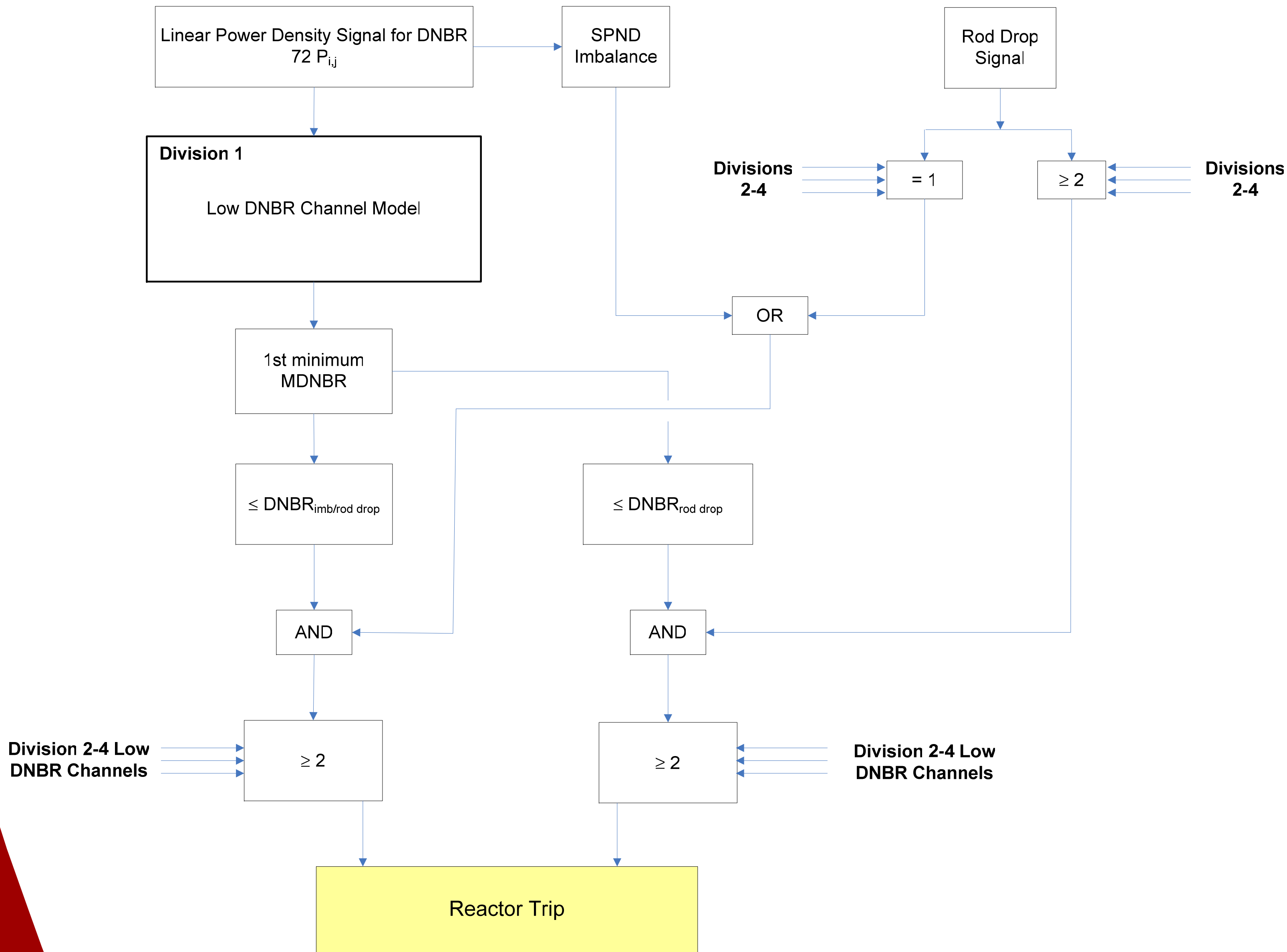


Incore Trip and LCO Functions

Low DNBR Channel LSSS – Asymmetric Response

- The Low DNBR Channel LSSS will afford protection against events characterized by power distribution asymmetries (SRP 15.4.3)
  - Excessive SPND imbalance – radial flux tilt due to dropped or withdrawn control rod
  - Dropped rod indication in one or more core quadrants via rod position measurement
  - Feedwater flow malfunctions, control rod misoperations
- Produces an automatic transition to higher DNBR setpoint
  - Violation of the Low DNBR channel setpoint results in a PS trip signal

Incore Trip and LCO Functions
Low DNBR Channel LSSS – Asymmetric Trip



Incore Trip and LCO Functions
DNB LCO – Design Basis

- The DNB LCO represents the lowest functional level of DNB protection (monitoring)
- Restricts MDNBR during normal operation
  - When Low DNBR channel cannot actively protect an event then initial DNBR margin defined by the DNB LCO and/or system trips must afford DNBR protection
  - DNB will be prevented, with 95% probability at 95% confidence for any DNB LCO basis event initiated from at or above the setpoint
  - It affords this protection in conjunction with other LCO restrictions, the totality of which is the defined operational envelope

Incore Trip and LCO Functions

DNB LCO – Design Basis (continued)

- **DNB LCO in the U.S. EPR is split into two distinct setpoints, representing a graduated sequence of automatic actions:**
  - **LCO1 – Control room alarms, block generator demand increase, block RCCA withdrawal**
  - **LCO2 – Reduce generator demand, insert control bank to reduce power**

Incore Trip and LCO Functions

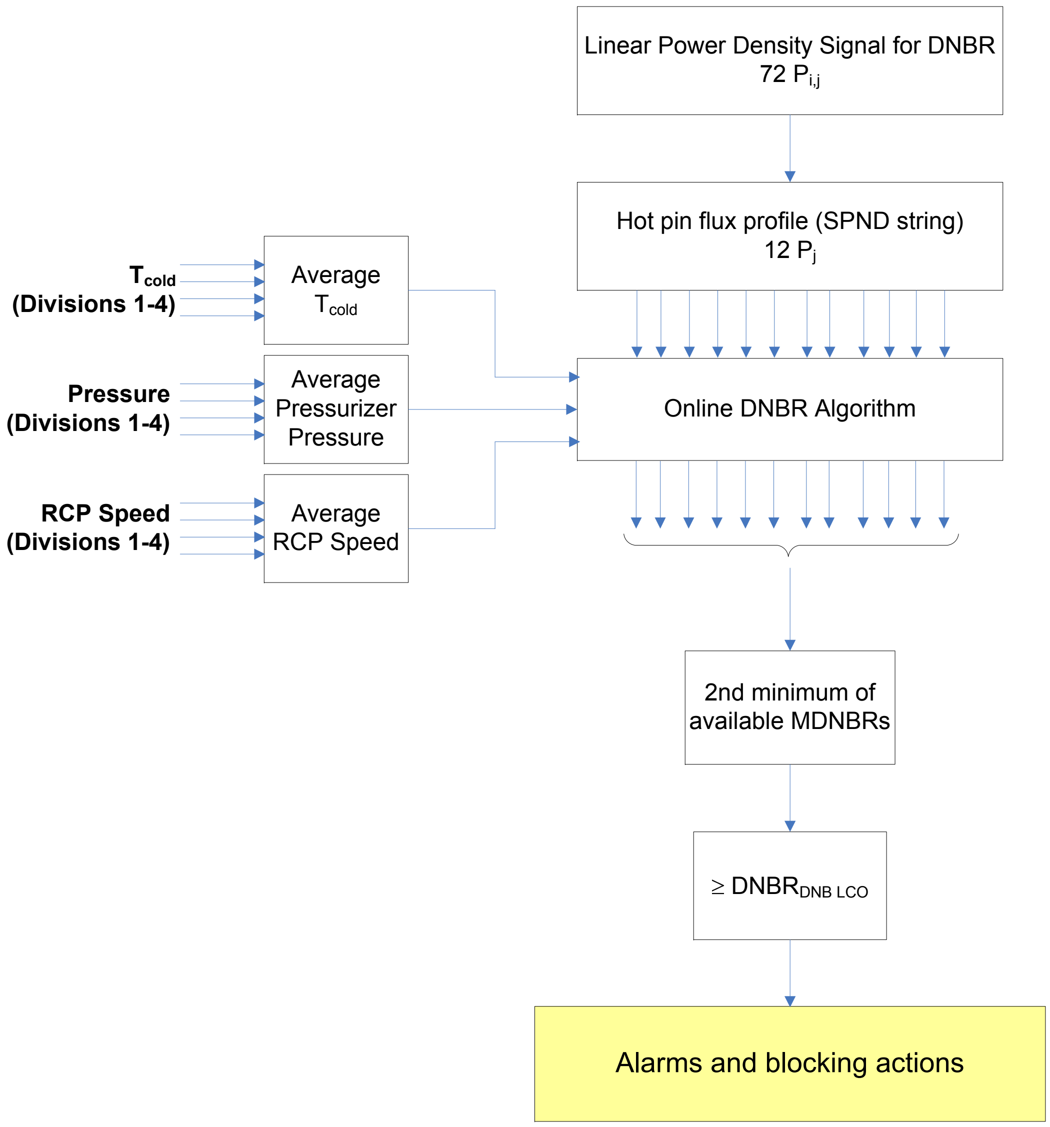
DNB LCO – Design Basis Events

- **The DNB LCO affords protection against events relying in part or wholly upon initial DNBR margin, and which are not directly protected by the Low DNBR Channel LSSS:**
  - **SRP 15.3.1 (Loss of Forced Reactor Coolant Flow)**
  - **SRP 15.1.3 (Excess Load Increase, high reactivity insertion rates)**
  - **SRP 15.4.1 (Bank Withdrawal from Low Power/Subcritical)**
  - **SRP 15.4.2 (Bank Withdrawal at Power, high reactivity insertion rates)**

Incore Trip and LCO Functions
DNB LCO – Functional Description

- **DNB LCO utilizes the same algorithm as the Low DNBR Channel LSSS (but evaluated in RCSL)**
  - **Always evaluated on a 2nd minimum DNBR basis**
  - **Utilizes averaged temperature, pressure and RCP speed signals to reduce uncertainties**
  - **Multiple setpoints to accommodate SPND failures**
  - **Response time requirements less stringent than Low DNBR channel LSSS**

Incore Trip and LCO Functions
DNB LCO Violation



Uncertainties Affecting Incore Trip Functions

Uncertainties for Incore Trip/LCO Functions

- Process measurement parameters
  - Pressurizer pressure measurement uncertainty
  - Cold leg RTD measurement uncertainty
  - RCP speed measurement uncertainty (including flow calibration)
  - SPND measurement uncertainty
- CHF correlation uncertainties
  - P/M statistics from correlation
- Online DNBR algorithm uncertainties
  - Differences in MDNBR and exit quality predictions between licensing subchannel analysis code and simplified online algorithm

Uncertainties for Incore Trip/LCO Functions

- **Fuel uncertainties**
  - **Variability in radial and total peaking due to pellet manufacturing tolerances (engineering uncertainty)**
  - **Rod/assembly bow peaking effects**
- **Calibration of PDDS**
  - **Core thermal power measurement**
  - **Incore monitoring system reconstruction of AMS flux map data**
    - $F_{\Delta H}$
    - F_Q
  - **SPND burnup decalibration**
- **Epistemic uncertainties due to computer codes**
- **Sensitivity to changes in T/H conditions for neutronics data**

Setpoint Topical Methods

(Proprietary Portion of Presentation)

Incore Detector System

Principles of SPND Calibration

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Incore Detector System
Principles of SPND Calibration

Incore Detector System

Principles of SPND Calibration – DNBR Calibration

Incore Detector System

Principles of SPND Calibration – LPD Calibration

Incore Detector Systems
Principles of SPND Calibration

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Setpoint Methodology

Setpoint Methodology

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Setpoint Methodology

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Setpoint Methodology

Setpoint Methodology
Low DNBR Channel LSSS

[ ]

Setpoint Methodology
Establishing the DNB LCO

Setpoint Methodology

Transient Analysis for Incore Trips

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Setpoint Methodology
Transient Analysis for Incore Trips

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Setpoint Methodology

Transient Analysis for Incore Trips

Setpoint Methodology

Confirmation of Dynamic Compensation Settings

Setpoint Methodology
Confirmation of Dynamic Compensation Settings

Setpoint Methodology
DNBR Undershoot Evaluation

Setpoint Methodology

DNB/LPD LCO Transient Allowance Assessment

Setpoint Methodology
DNB/LPD LCO Transient Allowance Assessment

Setpoint Methodology
Check LCO Allowances

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Setpoint Methodology
Neutronics Inputs

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Setpoint Methodology
Neutronics Inputs (continued)

- **Core power distribution inputs correspond to wide range of postulated conditions that the protection system must defend against**
  - **Range of normal operating 3D power distributions accounting for:**
    - **Conservative xenon transients**
    - **Variations in axial offset**
    - **Power level**
    - **Control rod insertion**
  - **Range of potential accident conditions:**
    - **Misaligned control rod and banks**
    - **Dropped control rod and banks**
    - **Asymmetric coolant heatups**
    - **Asymmetric coolant cooldowns**

Setpoint Methodology

3D Power Distribution Reconstruction

- **The methodology used to derive uncertainties in reconstructed power distributions is the same as that approved for PRISM with POWERTRAX/W (EMF-96-029PA)**
  - **Assembly power distribution inferred from measured locations**
  - **Detectors failed one at-a-time and power distribution in failed location is inferred**
  - **Power uncertainty for inferred location determined based in difference between measured and inferred power values**
  - **Same is done for $F_{\Delta H}$, F_Q**

Setpoint Methodology

3D Power Distribution Reconstruction

- **Database incorporates flux map measurements from two European reactors utilizing the AMS taken over 10 cycles of operation**
  - **Uncertainty statistics characterized over this database of measurements**

AREVA

Conclusions

- **ANP-10287P, *Incore Trip Setpoint and Transient Methodology for U.S. EPR* will document the methodology used to establish setpoints for the incore DNBR and LPD protection/monitoring functions for the U.S. EPR**

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- **The topical will substantiate the neutronic, thermal-hydraulic, and statistical aspects of the methodology**

Summary and Next Steps

Sandra M. Sloan

Summary

- Setpoints generated using established statistical methods
- Consistent with the requirements of 10 CFR 50, Appendix A and Regulatory Guide 1.105
- NRC feedback will inform development of the topical report and the DCD

Next Steps

- **Next meeting:**
  - **October 25 pre-submittal meeting: Reactivity Insertion Accident Topical Report**
- **Submittal of U.S. EPR Setpoints Analysis Methods Topical Report (by December 2007)**
- **Submittal of U.S. EPR Reactivity Insertion Accident Topical Report (by December 2007)**
- **Submittal of POWERTRAX/E Online Core Monitoring Software for the U.S. EPR Report (by December 2007)**

Acronyms

AMS	Aeroball Measurement System
ANSI	American National Standards Institute
AO	Axial Offset
AOO	Anticipated Operational Occurrences
APS	Axial Power Shape
CS	Clad Strain
DC	Design Certification
DCD	Design Control Document
(M)DNB(R)	Minimum Departure from Nucleate Boiling (Ratio)
ISA	Instrument Society of America
LCO	Limiting Conditions for Operation
(H)LPD	(High) Linear Power Density
LOCA	Loss of Coolant Accident

Acronyms

LSSS	Limiting Safety System Settings
MEDIAN	Measurement Dependent Interpolation Algorithm using Nodal Expansion Method
RCSL	Reactor Control, Surveillance, and Limitation System
PDDS	Power Density Detection System
PS	Protection System
RCCA	Reactor Cluster Control Assembly
RCP	Reactor Coolant Pump
RTD	Resistance Temperature Detector
SAFDL	Specified Acceptable Fuel Design Limit
SPND	Self-Powered Neutron Detectors