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Subject: **Submittal of ABWR Licensing Topical Report (LTR) NEDO-33336 "Advanced Boiling Water Reactor (ABWR) Stability Evaluation"**

Reference: Letter MFN 017-97, J. Quirk to NRC, *ABWR Design Control Document, Revision 4*, dated March 28, 1997, Docket No. 52-001

This LTR is one of the ABWR-related LTRs GE plans to submit and which have been discussed in South Texas Project 3&4 project meetings with the NRC. In support of the ABWR Design Centered Working Group (DCWG) plans, GE requests a generic review and approval of the subject LTR in advance of any future combined license application (COLA) submittals. Note that the submittal is a supplement to GE's LTR, *"Advanced Boiling Water Reactor (ABWR) APRM Oscillation Monitoring Logic, NEDO-33328, March 2007"*. Generic Technical Specification (TS) changes are included in the scope of this LTR. Appendix A to the LTR provides the justification for the changes under the ABWR design certification rule.

This LTR reviews the DCD description of the oscillation power range monitoring (OPRM) design and analyses and describes the proposed changes to the analyses based on operating experience and Boiling Water Reactor Owner Group (BWROG) recommendations. General Electric believes that all applicants would benefit from following the BWROG recommendations and that the NRC can and should provide a generic review and approval in advance of any COLA submittal referencing the USABWR DCD. Future applicants such as STP 3 & 4 could then reference the LTR in their combined license application.

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If you have any questions about the information provided here, please contact me at 910-602-1885.

Sincerely,

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Revision 0

LICENSING TOPICAL REPORT

Advanced Boiling Water Reactor (ABWR) Stability Evaluation

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1.0 Introduction

This Licensing Topical Report (LTR) requests US Nuclear Regulatory Commission (NRC) approval of a generic change to the design certification for the US Advanced Boiling Water Reactor (ABWR) design. This LTR provides the analysis to implement the long-term stability solution designated as Option III by the BWR Owner's Group (BWROG) for the ABWR. Since the ABWR design certification was completed there have been some changes in the analysis techniques for Option III and these are proposed to be applied to the ABWR. The hardware design changes associated with implementation of the Option III solution for the ABWR were provided by GE's LTR, "*Advanced Boiling Water Reactor (ABWR) APRM Oscillation Monitoring Logic, NEDO-33328, March 2007*" (Reference 10.1). This LTR complements the hardware LTR provided by GE.

This LTR provides the analytical basis associated with the previously identified hardware changes regarding the detection and suppression of Thermal-Hydraulic Instability (THI) oscillations. This stability analysis is performed using GE 14 fuel, which provides comparable results when compared to the DCD referenced GE 7 fuel bundles (P8x8R) as shown in LTR "*GE14 Compliance with Amendment 22 of NEDE-24011-P-A (GESTAR II)*" (Reference 10.2).

This LTR requests an approval of generic Technical Specification (TS) changes. The nuclear safety evaluation in this LTR includes the required TS and associated Tier 2 changes.

This LTR reviews the DCD description of the Oscillation Power Range Monitor (OPRM) design and analyses and describes the proposed changes to the analyses based on operating experience and BWROG recommendations. The NRC has endorsed the OPRM Option III analysis bases described in this LTR. This LTR proposes an amendment to the ABWR DCD and promotes standardization of ABWR certified design material based on BWROG recommendations previously reviewed by the NRC staff for operating plant reloads (Reference 10.3).

As the regulatory processes for generic amendment of approved and certified reactor designs such as the ABWR (10CFR52 Appendix A) are currently in the state of flux, GE understands that a generic change may not be feasible for the NRC to grant until the planned revision to 10CFR52.63 becomes effective. If the NRC does not make the planned revisions to 10CFR50.63, future COLA applicant(s) would then intend to seek specific departures from the DCD based on the content of this LTR. NRC review of the technical content of this LTR is requested with the understanding that this LTR and subsequent discussions between GE and NRC staff may form the basis for site-specific departures requested in one or more future Combined Operating License Applications.

1.1 Acronyms

3PT	Three Pump Trip
ABWR	Advanced Boiling Water Reactor
ABA	Amplitude Based Algorithm
APRM	Average Power Range Monitor
BSP	Backup Stability Protection
BWR	Boiling Water Reactor
BWROG	BWR Owner's Group
COLR	Core Operating Limit Report
CPR	Critical Power Ratio
DCD	Design Control Document
DIRPT	Delta CPR over Initial CPR for Reactor Pump Trip
DIVOM	Delta CPR Over Initial MCPR Versus Oscillation Magnitude
DR	Decay Ratio
EPU	Extended Power Uprate
FMCPR	Final Minimum Critical Power Ratio
GDC	General Design Criteria
GE	General Electric Company
GRA	Growth Rate Algorithm
GR3	Maximum allowable growth rate used in GRA
GSF	Generic Shape Function
HCOM	Hot Channel Oscillation Magnitude
HFCL	High Flow Control Line
ICA	Interim Corrective Actions
IMCPR	Initial Minimum Critical Power Ratio
LTR	Licensing Topical Report
LTS	Long Term Solution
LPRM	Local Power Range Monitor
MCPR	Minimum Critical Power Ratio
MSF	Modified Shape Function
NCL	Natural Circulation Line
NRC	Nuclear Regulatory Commission
OLMCPR	Operating Limit Minimum Critical Power Ratio
OLTP	Original Licensed Thermal Power
OPRM	Oscillation Power Range Monitor
P/A	Peak to Average
PBDA	Period Based Detection Algorithm
RIP	Reactor Internal Pump
RPS	Reactor Protection System
SCC	Successive Confirmation Counts
SLMCPR	Safety Limit Minimum Critical Power Ratio
SRP	Standard Review Plan
SS	Steady State
THI	Thermal-Hydraulic Instability

2.0 Description of the Design

2.1 Thermal-Hydraulic Stability Background

Under certain conditions, boiling water reactors (BWRs) may be susceptible to coupled neutronic/thermal-hydraulic instabilities. These instabilities are characterized by periodic power and flow oscillations and are the result of density waves (i.e., regions of highly voided coolant periodically sweeping through the core). If the flow and power oscillations become large enough, and the density waves contain a sufficiently high void fraction, the fuel cladding integrity safety limit could be challenged.

There were various options developed to respond to the BWR stability issue. The initial options were manual scrams based on location in the power/flow map. The solutions evolved, based on more sophisticated hardware and analysis techniques. The majority of the operating plants now use Option III. The Option III stability long-term solution (LTS), developed by the BWROG (References 10.4 and 10.5), is the required stability solution for the ABWR design. ABWR-specific features are incorporated into the Option III solution.

This NRC-approved solution consists of hardware and software that provide for reliable, automatic detection and suppression of stability-related power oscillations. Control rod insertion is initiated to terminate the oscillations prior to any significant amplitude growth.

The combination of hardware, software, and system setpoints provides protection against violation of the Safety Limit Minimum Critical Power Ratio (SLMCPR) for anticipated reactor power oscillations. Thus, compliance with General Design Criteria (GDC) 10 and 12 of 10CFR50, Appendix A is accomplished via automatic action. The proposed changes are consistent with the proposed Standard Review Plan (SRP) 15.9 (Reference 10.6).

For the Option III LTS, the OPRM trip logic function of the Average Power Range Monitor (APRM) system is enabled. The OPRM trip logic function provides protection against exceeding the SLMCPR in the event of thermal-hydraulic power oscillations. The OPRM monitors core thermal-hydraulic instabilities by real-time interrogation of OPRM cells, which are composed of closely packed Local Power Range Monitor (LPRM) detectors within the reactor core. A trip signal is issued if oscillatory changes in the neutron flux are detected while operating within the OPRM trip-enabled region, defined as below 60% rated core flow and above 30% rated power as shown in Figure 1. The OPRM trip function is required to be operable when the plant is operating in the power/flow region where thermal-hydraulic oscillations might occur. Alarms in the main control room are also provided to alert the operator of an increase in the number of confirmed period counts so action can be taken to avoid a potential scram for a slowly developing Thermal-Hydraulic Instability (THI) event.

Both core-wide and regional mode oscillations will be reliably detected and suppressed while the oscillation magnitude is still relatively low. In order to detect all expected THI power oscillation modes, the outputs from a small number of LPRMs in the same area of the core are combined into one OPRM cell signal. Thus, small regions of the core are effectively monitored for instabilities.

The intended function of the OPRM function of the Neutron Monitoring System is to automatically suppress stability-related power oscillations to provide a high confidence at 95%/95% level that the MCPR safety limit would not be violated for anticipated THI oscillations.

Initial fuel loading and each subsequent refueling of the reactor require confirmation the OPRM will perform its intended function. A plant cycle-specific Option III stability analysis is performed to determine the appropriate OPRM setpoints by following guidance from NEDO-32465-A, "BWR Owners' Group Reactor Stability Detect and Suppress Solutions Licensing Basis Methodology for Reload Applications," (Reference 10.4) and the BWROG Guideline on Regional Mode Oscillation (Reference 10.7). The analysis considers both steady state (i.e. normal) startup operation and the case of internal pump trip from rated power. The resulting stability-based Operating Limit MCPRs as a function of OPRM setpoint are reported in the separated Licensing Report (included in the DCD). The actual OPRM setpoint is selected such that required margin to the MCPR Safety Limit is provided without stability being a limiting event.

If the OPRM trip function should become inoperable, Backup Stability Protection (BSP) requirements will be implemented for a limited period of time in accordance with the Technical Specifications. The BSP methodology and requirements are described in Reference 10.8.

System Input Description

The basic unit of the Option III hardware/software system is the OPRM cell. The ABWR design uses the 4P cell assignment, 4 LPRMs per OPRM cell and the core periphery using 3 LPRMs per OPRM cell. The signals from the individual LPRM detectors in a cell are averaged to produce the OPRM cell signal. The signals are filtered, processed and evaluated for evidence of stability-related oscillations. If sufficient evidence exists that the reactor is experiencing unstable operation, the Reactor Protection System (RPS) initiates a reactor scram.

The cell signal is filtered to remove noise components with frequencies above the range of stability-related power oscillations. This is accomplished by passing the signal through a two-pole Butterworth conditioning filter. This conditioned signal is filtered again using the same second-order Butterworth filter with a 0.95 second time constant to produce a time-averaged signal. This time-average value is used to produce a normalized signal by dividing the conditioned signal by the time-averaged value.

2.2 Option III Analysis of the Certified Design

The licensing basis detection algorithm is called the Period Based Detection Algorithm (PBDA). The PBDA monitors groups of LPRMs and determines whether stability-related oscillations exist by detecting periodic behavior typical of reactor instability events. Upon confirmation that instability exists, the PBDA initiates a RPS scram when the signal oscillation amplitude exceeds a specified value.

To provide defense-in-depth, the Option III solution includes two additional detection algorithms that provide added protection against unanticipated power oscillations. These defense-in-depth detection algorithms are:

1. Amplitude Based Algorithm (ABA), and
2. Growth Rate Algorithm (GRA).

These algorithms are capable of providing automatic protection of the SLMCPR when the algorithms' trip conditions have been met. However, because these defense-in-depth algorithms supplement the Option III licensing basis, no Technical Specification actions are required in the event they are not operable.

PBDA Description

The PBDA is based on the observation that the neutron flux of an unstable core will oscillate with a well-defined period. The PBDA uses a combination of period confirmations counts and oscillation amplitude to determine if a trip is required. A RPS trip signal is generated if:

1. The number of consecutive period confirmations exceeds its setpoint value (N_P), and
2. The normalized signal (Peak to Average -P/A) exceeds a specified setpoint.

The value of the setpoint is sufficiently above the noise level to minimize the likelihood of an inadvertent reactor scram. Therefore, the PBDA will generate a trip when the oscillatory behavior is consistent with the presence of instability and the peak to average cell signal has exceeded the trip setpoint.

PBDA Parameters

Two parameters, that affect the period confirmations in the PBDA, are the period tolerance and the conditioning filter cutoff frequency. For the ABWR design, the period tolerance is set at 100 msec while the conditioning filter cutoff frequency may be set at either 1.0 Hz or 1.5 Hz (Table 1). Reference 10.9 provides the basis for the effectiveness of the 1.0 Hz and 1.5 Hz filter setting in conditioning the signal. The licensee will determine which filter setting to implement based on plant operations.

Bypass Voiding on OPRM Setpoints

The primary effect of bypass region voiding on the LPRMs is to reduce the detector response, assuming the same power in the fuel surrounding the LPRM detector. This reduction is due to a decrease in the neutron moderation caused by the presence of voids, which decreases the thermal neutron flux incident on the detectors for the same neutron flux generated in the adjacent fuel. This effect is greatest for the highest elevation LPRM detector (D level) where the highest bypass voiding occurs. In Reference 10.10, the impact of bypass voiding is bounded by a conservative penalty of 5% on the OPRM amplitude setpoint. This penalty is included as a biased uncertainty in the OPRM amplitude setpoint determination.

2.3 Certified Design Licensing Methodology

The three elements of the Option III licensing methodology are:

1. Pre-Oscillation MCPR: This element of the methodology captures the cycle specific MCPR margin to the safety limit prior to the onset of oscillations.

2. Hot Channel Oscillation Magnitude (HCOM): This element of the methodology captures the effect of plant characteristics, trip system definition and setpoint values on the magnitude of the hot channel power oscillations (before termination by the scram).

3. MCPR Performance of the Hot Channel: This element of the methodology captures the effect of fuel design on a fuel bundle's response (ΔCPR) to an oscillation. A plant and cycle specific three-dimensional TRACG analysis will be performed to establish this CPR relationship, referred to as the DIVOM curve.

From these elements, the final MCPR (FMCPR) can be determined:

$$FMCPR = IMCPR - IMCPR * (\Delta * m_{DIVOM})$$

where

IMCPR = initial MCPR

Δ = HCOM

m_{DIVOM} = DIVOM slope

These three elements (IMCPR, HCOM and m_{DIVOM}) comprise the Option III application methodology.

Pre-Oscillation MCPR

In evaluating the pre-oscillation MCPR or IMCPR, two separate scenarios are considered. The first scenario is a coast down to the lowest core flow that could be obtained following a pump trip event from the rated power/minimum flow condition. The ABWR has 10 reactor internal pumps (RIPs). A trip of more than three RIPs will trip the reactor. Therefore the lowest core flow that could be obtained along the upper flow boundary is a trip of three RIPs with the remaining seven operating at minimum pump speed. The IMCPR for this scenario is the MCPR that exists with seven RIPs operating at minimum pump speed and after the feedwater temperature reaches equilibrium. It is assumed that the reactor is operating at the Operating Limit Minimum Critical Power Ratio (OLMCPR) prior to the coast down in core flow.

In the second scenario, the plant is assumed to be in steady-state operation at 45% core flow on the highest allowable rod line. It is assumed that the reactor is operating at the rated OLMCPR corresponding to the specified power and flow conditions.

An appropriate stability based OLMCPR will be established for both scenarios for each operating cycle. This methodology has been modified to address ABWR design and is described in Section 2.4.

Hot Channel Oscillation Model

The Hot Channel Oscillation Magnitude (HCOM) methodology is described in Reference 10.4. These oscillation magnitudes may be used to establish the appropriate PBDA amplitude trip setpoint (i.e., a setpoint which provides adequate MCPR safety limit protection given the existing plant operating limits).

Defense-in-Depth Algorithms

As described in References 10.4, 10.5 and 10.11, the Option III solution includes three separate algorithms for detecting stability related oscillations: the PBDA, the GRA and the ABA. All three algorithms perform calculations on each OPRM cell signal to determine if a trip is required. The OPRM cell parameter examined by the algorithms is defined as the peak of the oscillations divided by the average value (P/A).

The growth rate and amplitude based algorithms are not needed to protect the SLMCPR, therefore they are not part of the licensing basis for the Option III solution. This function is accomplished solely by the PBDA. The growth rate and amplitude algorithms offer defense in depth by providing protection for oscillations characteristics which have not been observed and are not expected to occur.

Amplitude Based Algorithm

The value of the OPRM cell relative signal (P/A) is compared at each hardware time step to a threshold setpoint, S_1 (greater than 1.0). If the relative signal exceeds S_1, then the algorithm checks to determine if the relative signal decreases to a second setpoint, S_2, within a time period typical of an instability oscillation.

If the signal goes below S_2 in the expected time window (T_1) then the algorithm looks for the next peak in the relative signal. Then, if the relative signal exceeds the trip setpoint, S_{max}, in the expected time window (T_2), a trip is generated for that OPRM cell (and hence for that RPS channel). The ABWR-specific values are provided in Reference 10.1.

Growth Rate Algorithm

The Growth Rate Algorithm examines OPRM cell signal for rapidly growing oscillations. This algorithm basically follows the same logic as the ABA. After exceeding S_1 and decreasing below S_2 in the expected time window, a setpoint calculated from the peak of the previous cycle (P_1) and the desired maximum allowable growth rate (GR_3):

$$S_3 = GR_3 * (P_1 - 1.0) + 1.0$$

If the signal goes above S_1, then below S_2 in the expected time window, and then exceeds S_3 within the expected time window, a trip is generated for that OPRM cell. The GRA uses the same values for S_1, S_2, T_1, and T_2 as the ABA and are provided in Reference 10.1 for the ABWR.

2.4 Current BWROG/GE Licensing Methodology

This section describes the changes and/or additions to the BWROG licensing methodology associated with the Option III analysis since the time of the ABWR certification. They are described by function or event.

Pre-Oscillation MCPR -Pump Trip Scenario

It is assumed that the plant is operating at rated power on the highest allowable rod line. The stability based OLMCPR for the three-pump trip scenario is defined as the operating limit that results in a FMCPR equal to the SLMCPR. There are two components in determining the FMCPR: First, the change in CPR during the three-pump trip coastdown, and second, the change in CPR during the oscillation, prior to disruption of the oscillation by automatic control rod insertion.

The IMCPR for this condition is defined as:

IMCPR = OLMCPR*(1 + DIRPT),

where:

$DIRPT = (MCPR_{MIN} - MCPR_{Rated}) / MCPR_{Rated}$

$MCPR_{MIN}$ = MCPR following a reduction along the highest allowable rod line

$MCPR_{Rated}$ = MCPR at rated power at the minimum allowable flow (highest allowable rod line), with 7 RIPs at minimum pump speed.

Once the IMCPR is determined, the Final MCPR (FMCPR) is determined as a function of the licensing basis hot channel oscillation magnitude and the MCPR performance ("DIVOM") curve during an oscillation. The FMCPR is given by,

$FMCPRi = IMCPR*(1 - \Delta_i*m_{DIVOM})$, where

Δ_i = licensing basis HCOM for OPRM setpoint i

m_{DIVOM} = CPR channel power performance curve (DIVOM) slope for the applicable fuel

The stability based OLMCPR for the three pump trip event from rated conditions {OLMCPRi(3PT)} as a function of OPRM setpoint, is determined by setting the FMCPR equal to the SLMCPR:

$OLMCPRi\ (3PT) = SLMCPR / [(1 - m_{DIVOM}*\Delta_i)*(1 + DIRPT)]$

Typical initial core results (utilizing GE 14 fuel) for an ABWR are shown in Table 2.

Steady State Oscillation Scenario

The steady state oscillation scenario assumes the plant is operating at 45% core flow on the highest allowable rod line. Therefore, a pump trip analysis is not required and the IMCPR is assumed to be equal to the OLMCPR at that operating condition.

Based on this assumption and setting FMCPR equal to the SLMCPR, the stability based OLMCPR for limiting steady-state conditions {OLMCPRi (SS)}, is:

$$OLMCPRi\ (SS) = SLMCPR / (1 - m_{DIVOM} * \Delta_i)$$

Typical results for an ABWR are shown in Table 3.

Hot Channel Oscillation Magnitude Model

The ABWR specific analysis of the licensing basis Hot Channel Oscillations Model (HCOM) is provided in Appendix B. Results are included for two different conditioning filter cutoff frequencies, 1.0 Hz and 1.5 Hz, and an averaging filter cutoff frequency of 0.167 Hz (corresponding to a time constant of 0.95 seconds).

Table 4 contains the calculated licensing basis HCOM (Δ) values, as a function of amplitude setpoint for the Option III configuration defined in Table 5. For any OPRM amplitude trip setpoint between 1.05 and 1.15, a linear interpolation scheme can be used to obtain the corresponding HCOM. These oscillation magnitudes may be used to establish the appropriate PBDA amplitude trip setpoint (i.e., a setpoint which provides adequate MCPR safety limit protection given the existing plant operating limits). The PBDA confirmation count setpoint is related to the PBDA amplitude setpoint as shown in Table 6.

CPR Channel Power Relationship (DIVOM)

The Option III solution methodology uses TRACG to determine the relationship between the hot channel CPR as a function of the hot channel power oscillation (Reference 10.4). The relationship between the normalized oscillation magnitude [(PM)/A] and the fractional change in MCPR (ΔCPR/IMCPR) is referred to as the DIVOM (Delta CPR Over Initial MCPR Versus Oscillation Magnitude) curve.

The DIVOM curve is used in conjunction with the other two elements of the methodology, which calculate the HCOM and the initial hot channel MCPR.

The DIVOM curve, which is fairly linear, represents the thermal-hydraulic responsiveness of the fuel to a given oscillation magnitude. Thus, a steeper slope is more adverse than a flatter slope. A "generic" curve was established in Reference 10.4, which was reasonably bounding for all GE fuel types and operating conditions at that time.

The original generic analysis of Reference 10.4 was based on nominal core designs with relatively low enriched fuel, low energy cycles with small batch fractions and rated core power levels at or slightly above original licensed thermal power (OLTP) conditions (i.e., not Extended Power Uprate conditions). TRACG evaluations by GE have shown that the generic DIVOM curves may not be conservative for more current fuel and core designs and operating conditions. Specifically, a non-conservative deficiency has been identified for high peak bundle power-to-flow ratios. This deficiency may result in a non-conservative DIVOM slope relative to the generic regional mode DIVOM curve, resulting in a non-conservative Option III trip setpoint.

GE issued a Part 21 Notification (Reference 10.12) that identified this deficiency in the generic DIVOM curve in 2001. Subsequently, the BWROG developed a guideline (Reference 10.7) for calculating a plant- and cycle-specific DIVOM to respond to the important parameters affecting the DIVOM slope (e.g., cycle exposure, power/flow conditions, feedwater temperature, radial peaking, xenon concentration, etc.).

The results demonstrate the plant- and cycle-specific DIVOM evaluation for the ABWR (based on GE 14 fuel) yielded a slope of 0.60 for the initial core. This is the slope used to determine the OPRM amplitude setpoints shown in Tables 2 and 3 in this LTR. The actual OPRM amplitude and confirmation count setpoints will be provided in each cycle-specific Core Operating Limits Report (COLR).

Backup Stability Protection

The ABWR BSP may be used when the OPRM system is declared inoperable. The BSP methodology (Reference 10.13) evolved from the Interim Corrective Action (ICA) methodology (Reference 10.8). The ICA regions established in 1994 were based on OLTP conditions, and generally shorter cycle lengths and relatively smaller batch size requirements. These empirically established regions were defined based on relative core flow and rod line points and not on specific stability criteria. New high-energy core designs have reduced stability margins to some extent, and the ICAs as implemented in Option III on a long-term basis were not designed for these trends. The BSP methodology addresses this concern.

Improved BSP Features

The improved BSP features that address the potential inadequacy of the long-term Option III solution ICAs are as follows:

- The size of the base BSP regions is equivalent to the current ICA regions.
- The BSP regions are reduced from three ICA regions (Scram, Exit, Controlled Entry) to two regions (Scram and Controlled Entry).
- Decay ratio criteria are established for plant/cycle-specific confirmation, and as necessary, adjustment of the base BSP regions.
- Operator actions in the two BSP regions are similar to the operator actions currently defined for the ICA Scram and Controlled Entry regions.
- Operator awareness is required when operating within 10% of rated core flow or power from the BSP Controlled Entry region.

Details of the BSP region generation and operator actions are provided in Reference 10.13.

Modified Shape Function

The MSF is a boundary shape function that is applied to two state points along the High Flow Control Line (HFCL) and the Natural Circulation Line (NCL). The state points must satisfy the specified stability criteria of the region boundary procedure. The MSF is an alternative to the Generic Shape Function (GSF) that is defined in Reference 10.13. The MSF is defined as:

$$P = P_B \left[\frac{P_A}{P_B} \right]^{\left[\left(\frac{W - W_B}{W_A - W_B} \right) \right]}$$

where:

P = percent rated power

P_A = percent rated power at point A (HFCL)

P_B = percent rated power at point B (NCL)

W = percent rated core flow

W_A = percent rated core flow at point A (HFCL)

W_B = percent rated core flow at point B (NCL)

BSP Regions Plant Specific Application

The BSP Regions are established by applying the MSF to two intercept statepoints, one on the HFCL and the other on the NCL. These statepoints are selected based on the more limiting of the original ICA regions (Reference 10.8) and a best-estimate stability calculation using the ODYSY frequency domain code (Reference 10.14).

Illustrative results of the ODYSY decay ratio calculation are shown in Table 7 and Figure 2 based on a GE 14 core design. The calculated state points are plotted against ODYSY acceptance criteria map shown in Figure 2.

Figure 3 shows the proposed implemented BSP boundaries. In this particular case, the BSP analysis shows that the original ICA intercepts, A1-ICA, A2-ICA and B2-ICA, are more bounding than the best estimate calculated state points. Therefore, these state points, plus the ODYSY calculated state point, B2, are used to construct the BSP regions shown in Figure 3.

BSP Reload Application

A plant- and cycle-specific assessment is required to confirm the applicability or update the BSP option for reload-specific fuel, core design, and operating strategy. A conservative representation of the BSP Regions may be established to minimize the need for cycle-specific updates. The actual BSP boundaries will be provided in each cycle-specific COLR.

3.0 Justification for Changes

3.1 OPRM Algorithm Parameter Changes

The proposed DCD changes

- o Butterworth signal time constant
- o PDBA parameter changes,
- o DIVOM cycle specific analysis, and
- o OPRM backup stability protection.

are consistent with NRC regulations and guidance based on the following:

Butterworth Signal Filter Time Constant

Changing the Butterworth signal filter time constant for the average signal from 6.0 to 0.9549 seconds increases the responsiveness of the average signal and reduces its distance from the input signal. This reduces the transition band from about 26 to 6 seconds immediately after the fast transient initiation. As found in the analysis documented in GE DRF A13-00317, there is only a small conservative penalty to plant availability in implementing the shorter time constant, therefore use of a time constant of 0.9549 second provides adequate amplitude setpoint protection even for highly aggressive instability scenarios.

PBDA Parameter Changes

Reference 10.15 justified that the recommended changes to the PBDA period variables (f_c, ε, T_{max} & T_{min}) do not contribute to exceeding the SLMCPR for all anticipated instability events. Nor do the proposed changes produce a significant increase in the probability of a spurious scram. Since an OPRM cell signal trip requires both counts above the Successive Confirmation Counts (SCC) setpoint and amplitude above the amplitude trip setpoint, it is highly unlikely that the SCC and amplitude trip setpoints would be exceeded simultaneously in multiple OPRM cells in multiple OPRM channels except during an actual instability event.

3.2 OPRM Backup Stability Protection

GE performed an evaluation under 10CFR21 on Option III use of the Interim Corrective Actions (ICAs) stated in BWROG-94079 (Reference 10.8) and found that continued use of the ICAs when the OPRM is inoperable does not create a significant hazard (Reference 10.13). In addition, using the plant/cycle-specific BSP regions as part of the Option III solution implementation ensures long-term applicability. The BSP regions are generated based on the ICA regions. The BSP regions (using the generic shape function of fitting power/flow state points representing a constant decay ratio) and the ICA regions are equivalent since the minimal stability requirements are essentially the same.

4.0 Qualification Information

The hardware qualification is documented in Advanced Boiling Water Reactor (ABWR) APRM Oscillation Monitoring Logic LTR (Reference 10.1).

5.0 Operating Experience

The analysis methods described in this report have been incorporated in operating plants' OPRMs. The predictions and setpoints have been validated during the Perry OPRM instability event in December 2004 (Reference 10.9). The Perry oscillation mode was core-wide and the reactor was tripped by the PBDA. The PBDA performed as expected since the OPRM peak over average P/A was at the amplitude trip setpoint when the reactor scram was initiated. Most of the OPRM cells performed as expected, exhibiting very few SCC resets. The Perry THI event did not produce any safety hazard and the SLMCPR was protected by the Option III OPRM system. The Perry event confirms the BWROG recommendations for stability monitoring and licensing basis are valid.

6.0 Nuclear Safety Review

The OPRM analysis changes will increase plant safety and reliability. As discussed in Section 2.4 (CPR Channel Power Relationship (DIVOM)), TRACG evaluations by GE have shown that the generic DIVOM curves, specified in the original analysis methods for the DCD, may not be conservative for more current fuel and core designs and operating conditions. Specifically, a non-conservative deficiency has been identified for high peak bundle power-to-flow ratios. This deficiency may result in a non-conservative DIVOM slope relative to the generic regional mode DIVOM curve, resulting in a non-conservative Option III trip setpoint.

In addition, as discussed in Section 2.4 (Backup Stability Protection), the ICAs as implemented in Option III on a long-term basis were not designed for newer high-energy core designs and resulted in a reduction of stability margins.

The application of the current GE stability analysis techniques for the ABWR as described in this LTR will eliminate these concerns.

The OPRM design incorporates the changes proposed by the BWROG Stability Solution Option III as stated in References 10.4, 10.5, 10.11 and 10.13. The proposed changes are consistent with GDC requirements, BWROG evaluations and recommendations based on operating experience. The proposed changes are based on more explicit analyses and the current licensing methodology on the thermal-hydraulic stability. These changes have been reviewed and approved by the NRC for operating plants. As described above, the analyses, which justified adoption of these changes for operating plants, are applicable to the ABWR (Reference 10.5).

The proposed changes do not involve a departure from Tier 1 or Tier 2* information. Generic changes to the ABWR Generic TS are necessary to implement the Stability Solution Option III. NRC approval is required to implement the TS changes. The OPRM system conforms to all regulatory guides stated in Tier 2 Section 7.6.2.1.2(3) with the same interpretations and clarification identified in Sections 7.2.2.2.1(7), 7.3.2.1.2, and 7.1.2.10.

Appendix A provides the justification for changes to the DCD.

7.0 Consistency with ABWR Design Control Document (DCD)

There is no design departure from the Tier 1 DCD. The design changes described in this LTR are generic changes to the ABWR Generic TS and Tier 2 certified design information. The proposed changes incorporate the BWROG long-term Option III stability solution into the ABWR design certification. The DCD and the Generic Technical Specifications markups are shown in Appendix C.

8.0 Descriptions of DCD Markups

The DCD markups provided in Appendix C identify the specific changes proposed by this LTR. The proposed changes are at the same level of detail as the original DCD.

The bracketed information [ ] in the Technical Specifications are preliminary, pending design detailing. These brackets are similar to the brackets that are contained in the generic Technical Specifications in the current DCD.

8.1 Tier 2 DCD Markups

Tier 2 4.4.3.3.3 Regions of the Power/Flow Map

Tier 2 4.4.3.7 Thermal Hydraulic Stability Performance

Tier 2 4.4.8 References

Tier 2 Figure 4.4-1 Power-Flow Operating Map Used for System Response Study

Tier 2 Figure 4.4-2 Power-Flow Operating Map Used for System Response Study (9 RIPs Operating)

Tier 2 Figure 4.4-4 Stability Controls and Protection Logic

8.2 Generic TS DCD Markups

TS 16.3.3.1.1 Safety System Logic and Control (SSLC) Sensor Instrumentation

TS Bases 16.3.3.1.1 Safety System Logic and Control (SSLC) Sensor Instrumentation
Applicable Safety Analysis 2.f

TS Bases 16.3.3.1.1 Safety System Logic and Control (SSLC) Sensor Instrumentation
ACTIONS

9.0 Conclusions

The proposed design changes are consistent with the BWROG recommendations and improve the OPRM design, system performance requirements, and nuclear safety.

As discussed more fully in Appendix A to this LTR, the proposed changes will promote increased standardization. Therefore, GE requests that the NRC amend the ABWR DCD to incorporate the changes. NRC approval is required for these generic changes to the Generic Technical Specifications.

10.0 References

10.1 Advanced Boiling Water Reactor (ABWR) APRM Oscillation Monitoring Logic, NEDO-33328, March 2007.

10.2 GE14 Compliance With Amendment 22 of NEDE-24011-P-A (GESTAR II), NEDC-32868P, September 2000.

10.3 Resolution of Reportable Condition for Stability Reload Licensing Calculations Using Generic Regional Mode DIVOM Curve , to USNRC Document Control Desk from BWR Owner's Group - K.S. Putman, Chairman, dated September 30, 2003.

10.4 BWR Owners' Group Reactor Stability Detect and Suppress Solutions Licensing Basis Methodology for Reload Applications, NEDO-32465-A, August 1996.

10.5 BWR Owners' Group Long-Term Solutions Licensing Methodology, NEDO-31960-A, November 1995.

10.6 Boiling Water Reactor Stability, U.S. Nuclear Regulatory Commission, NUREG-0800, Standard Review Plan Section 15.9, March 2007.

10.7 Plant-Specific Regional Mode DIVOM Procedure Guideline, GE-NE-0000-0028-9714-R1, June 2005.

10.8 BWR Owners' Group Guidelines for Stability Interim Corrective Action, BWROG-94079, June 1994.

10.9 Perry 12/23/04 Instability Event OPRM Performance Evaluation, GE-NE-0000-0041-0403-R0, June 2005.

10.10 Interim Methods for Constant Pressure and Extended Power Uprate and Maximum Extended Load Line Limit Analysis Plus Applications, NEDC-33173P, January 2006.

10.11 BWR Owners' Group Long-Term Stability Solutions Licensing Methodology, NEDO-31960-A, Supplement 1, November 1995.

10.12 Stability Reload Licensing Calculations Using Generic DIVOM Curve, Safety Communication SC01-02, to USNRC Document Control Desk from J. Post, dated August 31, 2001.

10.13 Backup Stability Protection for Inoperable Option III Solution, OG-02-0119-260, July 2002.

10.14 ODYSY Application for Stability Licensing Calculations Including Option I-D and II Long Term Solutions, NEDE-33213P, June 2007.

10.15 *Stability Option III Period Based Detection Algorithm Allowable Settings*, Safety Communication SC03-20, to USNRC Document Control Desk from J. Post, dated October 4, 2003.

Table 1 PBDA Parameters

Parameters	Acceptable Range
Period Tolerance (seconds)	0.100
Conditioning Filter Cutoff Frequency (Hz)	1.0 to 1.5

Table 2 OPRM Amplitude Setpoint Versus OLMCPR for 3 Pump Trip Scenario

OPRM Amplitude Setpoint	OLMCPR(3PT)*
1.05	1.2479
1.06	1.2734
1.07	1.2999
1.08	1.3276
1.09	1.3565
1.10	1.3867
1.11	1.4172
1.12	1.4490
1.13	1.4823
1.14	1.5172
1.15	1.5538

* Assumes a SLMCPR of 1.09, DIVOM slope of 0.60 and conditioning filter cutoff frequency of 1.5 Hz.

Table 3 OPRM Amplitude Setpoint Versus OLMCPR for the Steady State

OPRM Amplitude Setpoint	OLMCPR(SS)*
1.05	1.2098
1.06	1.2360
1.07	1.2628
1.08	1.2908
1.09	1.3201
1.10	1.3520
1.11	1.3828
1.12	1.4164
1.13	1.4517
1.14	1.4888
1.15	1.5270

Table 4 Hot Channel Oscillation Magnitude Results

OPRM Amplitude Trip Setpoint (Peak/Average)	Licensing Basis HCOM with 1.0 Hz Cutoff†	Licensing Basis HCOM with 1.5 Hz Cutoff†
1.05	0.171	0.158
1.10	0.334	0.309
1.15	0.490	0.455

* Assumes a SLMCPR of 1.09, DIVOM slope of 0.60 conditioning filter cutoff frequency of 1.5 Hz.

† The cutoff frequency of the Butterworth 2-pole conditioning filter

Table 5 Parameters used in the Statistical HCOM Determination

	Description	Value
1.	Fuel	GE 14
2.	RPS Trip Logic (1 out of 2 twice) or (2 out of 4)	2 out of 4
3.	Scram Delay Time (msec)	
	a. Response time of OPRM hardware	400 msec
	b. Response time of RPS	90 msec
	c. CRD delay to start of rod motion	200 msec
	d. Time to insert control rods 2 feet into the core at minimum Tech Spec speed	550 msec
	Total Scram Delay (msec) (sum a, b, c, & d)	1240 msec
4.	LPRM-to-OPRM cell assignment scheme from Reference 10.1	4P
5.	Minimum number of LPRMs required for an OPRM cell to be operable (1 or 2)	2

Table 6 PBDA Trip Setpoints

Confirmation Count Setpoint	Amplitude Setpoint
6	≥ 1.04
8	≥ 1.05
10	≥ 1.07
12	≥ 1.09
14	≥ 1.11
16	≥ 1.14
18	≥ 1.18
20	≥ 1.24

Table 7 ODYSY Decay Ratio Results for Nominal Feedwater Temperature Operation

BSP Boundary Intercept	% Rated Power	% Rated Flow	Evaluation Line	Core DR	Highest Channel DR
Scram Region					
A_1	56.8	27.1	HFCL	0.796	0.500
A_1-Base (proposed)	66.4	40.0	HFCL	Base BSP Manual Scram Region Boundary Intercept	
B_1 (proposed)	41.3	20.8	NCL	0.789	0.498
B_1-Base	46.9	20.8	NCL	Base BSP Manual Scram Region Boundary Intercept	
Controlled Entry Region					
A_2	58.7	29.7	HFCL	0.783	0.495
A_2-Base (proposed)	73.9	50.0	HFCL	Base BSP Manual Controlled Entry Region Boundary Intercept	
B_2	34.1	20.5	NCL	0.798	0.382
B_2-Base (proposed)	32.8	20.8	NCL	Base BSP Manual Controlled Entry Region Boundary Intercept	

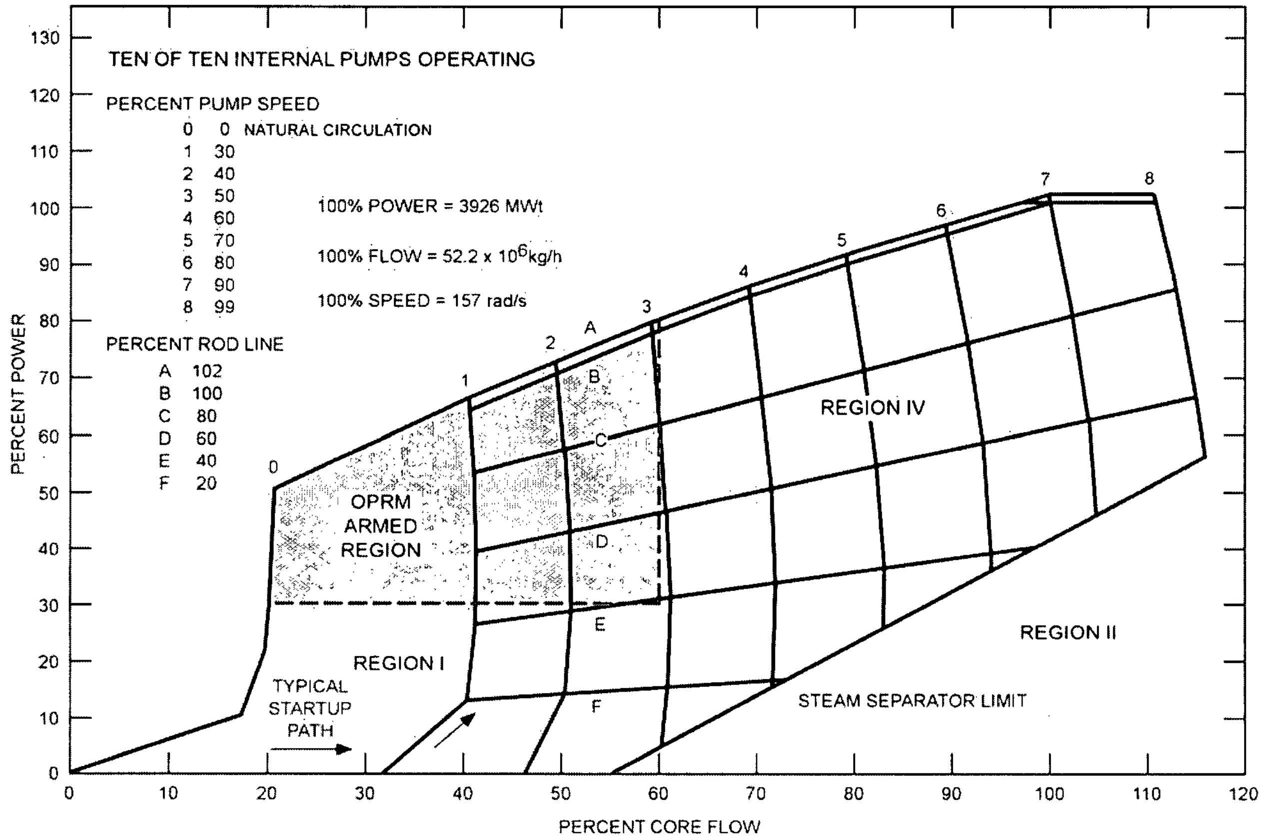

Figure 1 OPRM Armed Region

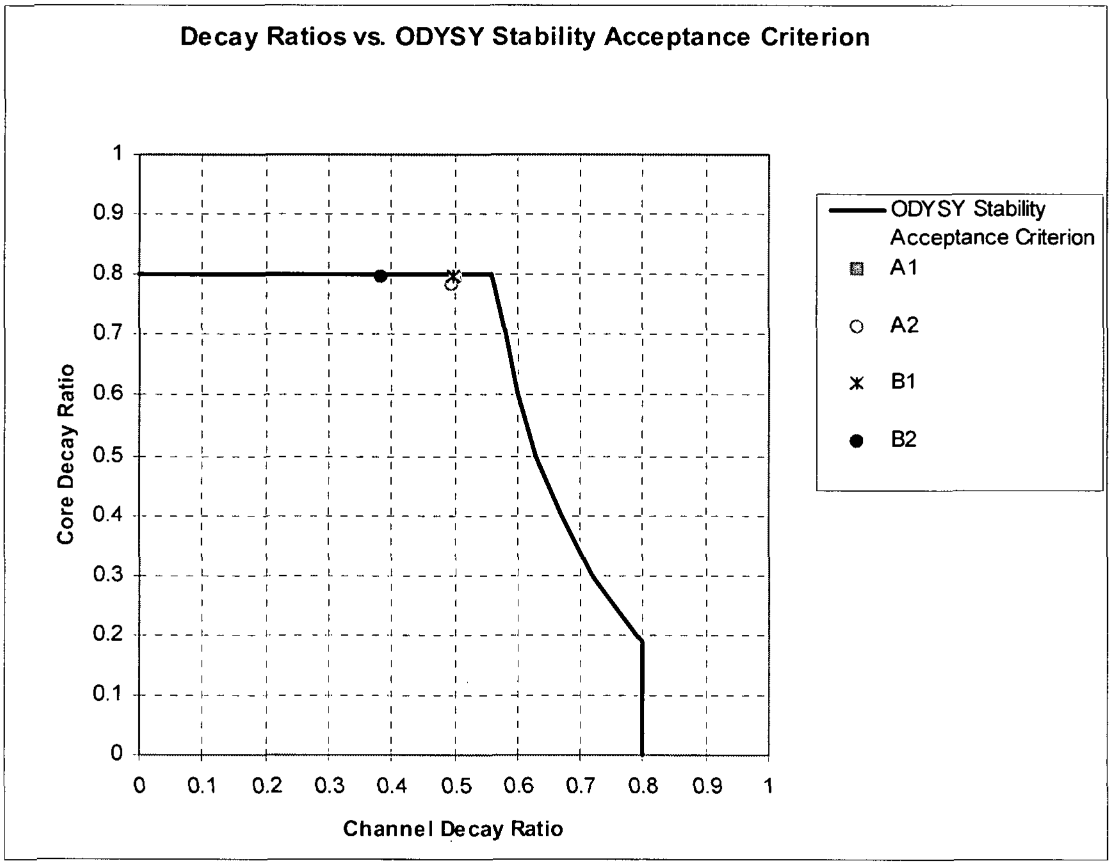

Figure 2
Illustrative Decay Ratio Results versus ODYSY Stability Acceptance Criteria for Nominal Feedwater Temperature Operation

Note - A1, A2 & B1 are clustered.

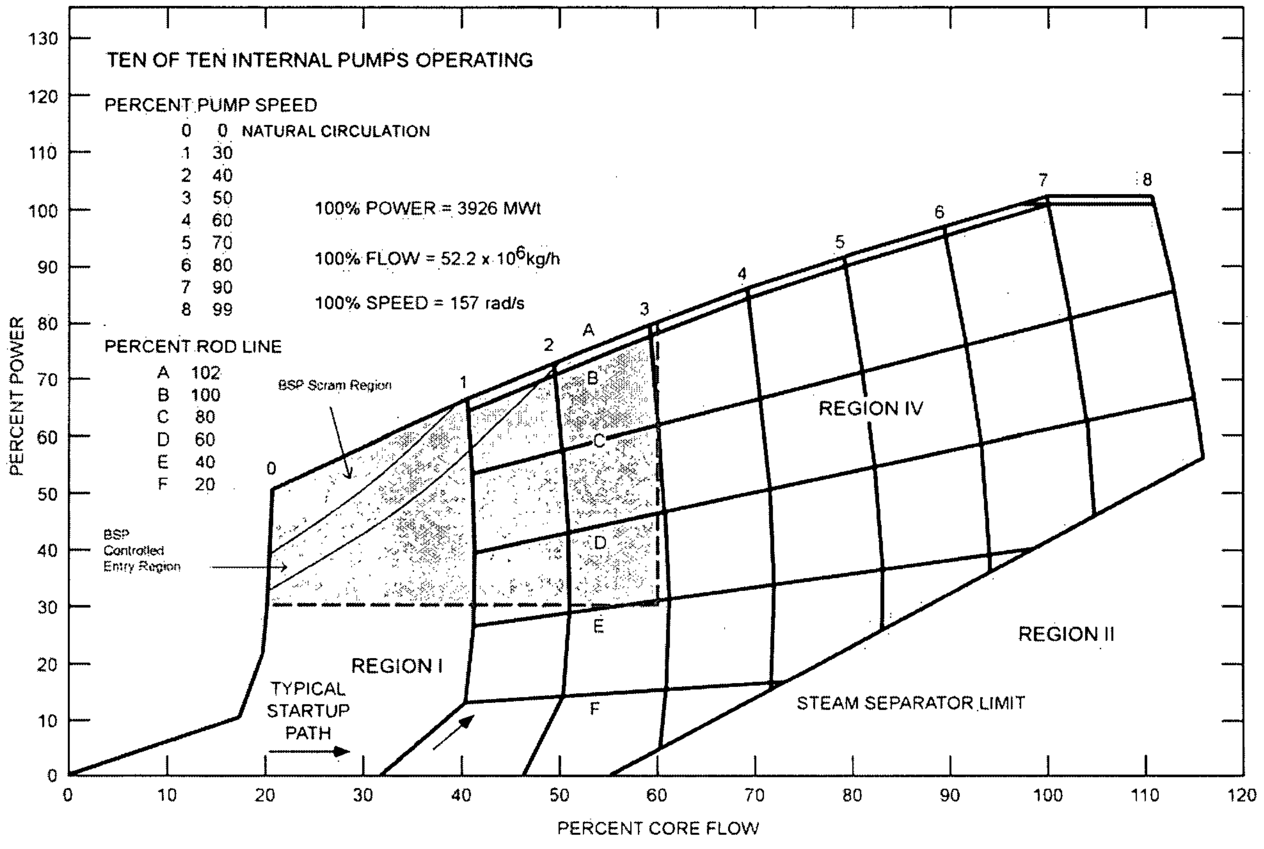

Figure 3 BSP Regions Illustration for Nominal Feedwater Temperature Operation

Appendix A

Justification of Changes to the Generic DCD

Justification for Changes to the Generic DCD

As discussed in this Licensing Topical Report (LTR), this LTR proposes exemptions to generic Technical Specifications (TS) changes to the ABWR DCD. The exemption to generic TS requires NRC approval. This LTR demonstrates that the proposed changes meet the requirements for a design certification amendment per the proposed revision to 10 CFR 52.63(a).

10 CFR 52.63(a)(1)(vi) (as proposed in SECY-06-220) allows for a change to a generic DCD if the change "Contributes to increased standardization of the certification information." As discussed below, the proposed changes to the generic DCD satisfy this criterion.

The proposed changes involve the implementation of the BWROG stability Option III as required by the DCD and are intended to be generic and applicable to all COL applicants that reference the ABWR design certification. The BWROG stability Option III design work was being performed during the ABWR design certification and was not complete at the time of certification. Therefore, this LTR is implementing the BWROG Option III methods that are currently used for operating plants. These have been reviewed and approved by the NRC.

At least one prospective COL applicant (i.e., the COL applicant for South Texas Project Units 3 and 4) intends to implement the proposed departures from the ABWR DCD. Furthermore, it may be expected that other COL applicants will also desire to implement the proposed departures.

Given the generic nature of these proposed changes and the fact that at least one COL applicant intends to make the changes, it would contribute to increased standardization if the NRC were to make a generic change to the DCD to incorporate these proposed changes. Therefore, the proposed changes satisfy the criteria in 10 CFR 52.63(a)(1)(vi).

Appendix B

ABWR Licensing Basis
Hot Channel Oscillation Magnitude (HCOM) Analysis

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 Objective

The objective of this report is to provide the results of the ABWR-specific analysis of the licensing basis Hot Channel Oscillation Magnitude (HCOM) associated with the BWROG Option III stability solution. The results include the impact due to conditioning filter cutoff frequencies of 1.0 Hz and 1.5 Hz and the use of an averaging filter cutoff frequency of 0.167 Hz (OPRM system firmware specification).

The analysis implements the methodology developed by the BWROG Stability Detect & Suppress Methodology Committee and approved by the NRC (Reference 7.1), and is based on the ABWR specific information in Table 1. This HCOM analysis is intended to be used with either the generic fuel Critical Power Ratio (CPR) performance curve (Reference 7.1, Figure 4-13) or a plant specific curve (as applicable)* and the plant specific Initial Critical Power Ratio (Reference 7.1, Sections 4.2 and 4.5.1) to establish a stability detection algorithm amplitude trip setpoint which provides adequate minimum critical power ratio (MCPR) safety limit protection.

2.0 Background

The licensing basis methodology supporting stability long-term solution Option III was developed under the direction of the BWROG Stability Detect & Suppress Methodology Committee and documented in Reference 7.1. This methodology provides a statistically based demonstration that the Option III stability solution will reliably detect and suppress expected stability related power oscillations and provide a high degree of confidence that the MCPR safety limit is not violated as a result of anticipated instabilities. This methodology was reviewed and approved by the NRC as indicated in Reference 7.1.

The Option III stability solution combines closely spaced Local Power Range Monitor (LPRM) detectors into "cells" to effectively detect either core-wide or regional modes of reactor instability. These cells are termed Oscillation Power Range Monitor (OPRM) cells and are configured to provide local area coverage with multiple channels. The OPRM cell signals are analyzed by the Option III detection algorithm to determine when a reactor trip is required.

The Option III detection algorithm consists of "Period", "Amplitude" and "Growth Rate" based components (see References 7.1, 7.2, and 7.3). Of these, only the Period Based Detection Algorithm (PBDA) is used to demonstrate safety limit protection and is the subject of this assessment. The other components provide defense in depth by minimizing the likelihood of fuel failure as a result of an unanticipated instability.

This assessment determines the maximum normalized licensing basis HCOM when a scram is initiated by the stability Option III protection system described in Table 1. This HCOM may

* The generic Delta CPR Over Initial MCPR Versus Oscillation Magnitude (DIVOM) slope provided in Figure 4-13 of Reference 7.1 has been reported to be potentially non-conservative (10CFR Part 21 Notification SC01-02). The use of a plant and cycle specific DIVOM slope is an acceptable alternative to the generic slope.

be directly related to the change in critical power ratio (ΔCPR) for an instability event as described in the approved licensing methodology. The parameter used to measure the HCOM is defined as:

$\Delta = (P - M)/A$

where:

Δ = normalized HCOM,

P = peak hot channel power for a given oscillation cycle,

M = mean of the minimum values of hot channel power occurring just before and after the peak, and

A = average value of hot channel power during the oscillation

The hot channel is defined as the channel that attains the highest normalized oscillation magnitude, (P-M)/A. The maximum HCOM for an OPRM-initiated reactor scram is dependent on a number of factors including:

- LPRM to OPRM assignments
- trip setpoint
- growth rate
- power oscillation response contours
- LPRM failures
- trip overshoot
- RPS trip logic
- delay time for control rod insertion
- cutoff frequency of the two-pole Butterworth filter
- oscillation frequency.

The licensing basis HCOM is determined by a Monte Carlo analysis using a combination of deterministic and statistical inputs as described in Reference 7.1. The licensing basis value for "Δ" is an upper bound (one-sided) statistical limit at a conservatively estimated 95% probability and 95% confidence level.

Table 2 contains the calculated licensing basis HCOM (Δ) values, as a function of amplitude setpoint and conditioning filter cutoff frequency for the Option III configuration defined in

Table 1. These oscillation magnitudes may be used to establish the appropriate PBDA amplitude trip setpoint (i.e., a setpoint which provides adequate MCPR safety limit protection given the existing plant operating limits). The PBDA confirmation count setpoint is related to the PBDA amplitude setpoint based on Table 3-2 of Reference 7.1.

3.0 Approach

A Monte Carlo module has been incorporated into the OPRM code for use in calculating the licensing basis hot channel oscillation magnitude. The OPRM code used in this application (designated OPRM01A) incorporates the approved licensing basis methodology described in Reference 7.1 as well as the plant unique features specified in Table 1. One thousand trials are used to establish the distribution for the hot channel oscillation magnitude. From this distribution, the 39th highest Δ value is selected that corresponds to the single-sided tolerance limit at 95% probability and 95% confidence for 1000 trials.

The OPRM signal passes through a Butterworth 2-pole conditioning filter and a Butterworth 2-pole averaging filter before the Period Based Detection Algorithm (PBDA) is applied. The purpose of the conditioning filter is to remove high frequency noise in order to determine whether or not an instability event has occurred. The averaging filter is used to generate an average signal that is used to generate a normalized signal. Once the number of successive confirmation counts (SCC) has been achieved, the PBDA will send a trip signal if the amplitude of the normalized signal exceeds the amplitude setpoint.

The attenuation of an input signal caused by the 2-pole Butterworth filter is given as follows:

$$\frac{R(\omega)}{A} = \frac{1}{\sqrt{1+\left(\omega/\omega_c\right)^4}}$$

where

$R(\omega)$ = filtered signal with filter frequency ω,

A = amplitude of input signal,

ω = frequency of input signal, and

ω_c = cutoff frequency.

The amount of attenuation and boost depends upon cutoff frequencies used in the conditioning and averaging filters and the signal frequency. The evaluation was performed using two different conditioning filter cutoff frequencies, 1.0 Hz and 1.5 Hz (Reference 7.4), and an averaging filter cutoff frequency of 0.167 Hz.

The OPRM01A analysis determines the response of LPRMs and OPRMs based on licensing basis input (Reference 7.2), ABWR specific inputs on LPRM to OPRM assignments and the detection algorithm amplitude trip setpoint. The requirement for the number of operable

OPRM channels is included in the TS bases. The code and the analysis results have been verified in accordance with GE procedures for safety related applications.

4.0 Analysis Basis

The OPRM01A methodology approved by the NRC and used in this assessment is based on the following assumptions (see Reference 7.1):

- The oscillation mode is always regional. (This is a conservative assumption since the regional mode oscillation is more limiting than the core-wide mode oscillation).

- Consistent with the licensing methodology described in Section 4.3.5.2 of Reference 7.1, this analysis assumed that there are no LPRM failures. (This is a conservative assumption since the OPRM01A methodology is valid for the ABWR 4P-configuration application with actual random LPRM failures up to at least 50%).

- The most responsive OPRM channel is assumed to fail for all trials. (The most responsive channel failure is defined as the failure of the trip channel containing the OPRM cell that would generate the first half trip signal).

- A chi-squared growth rate distribution is used with a mean value of approximately 1.10. The growth rate is uniformly applied to the LPRM, OPRM, and hot channel. It is assumed to remain constant during the portion of the instability that generates the trip signal.

- Six oscillation contours are used to represent the relative power distribution during the oscillation - two at the beginning of cycle, two at the middle of cycle, and two at the end of cycle. It has been demonstrated in Reference 7.1 that the licensing basis HCOM is relatively insensitive to the cycle selected as the basis of contours. The oscillation contours represent the relative power distribution among the LPRMs in the core. Each contour contains the following information for each LPRM: normalized average, harmonic response and phase angle. For each trial in the Monte Carlo process, the contour is randomly selected.

- A chi-squared oscillation period distribution is used with a mean value of approximately two seconds. The period is uniformly applied to the LPRM, OPRM, and hot channel. It is assumed to remain constant during the portion of instability that generates the trip signal.

- The evaluation was performed using two different values for the conditioning filter cutoff frequency, 1.0 Hz and 1.5 Hz, and one value for the averaging filter cutoff frequency, 0.167 Hz.

- Tmin and Tmax are conservatively set at 1.0 and 3.5 seconds, respectively (Reference 7.5).

The following inputs were incorporated in the OPRM01A statistical model for the ABWR analysis based on the input specified in Table 1:

- The LPRM-to-OPRM assignments used in the analysis are shown in Figures 1 through 4.
- The Reactor Protection System (RPS) trip logic is two out of four.
- The delay time until control rod insertion of 1.24 seconds is adequate to disrupt the reactor instability.
- The core size is 872 fuel bundles of GE 14 fuel. There are 52 LPRM strings per OPRM channel.

5.0 Results

The results of the OPRM01A analysis for three different OPRM amplitude trip setpoints using the ABWR specific information provided in Table 1 is shown in Table 2 for the ABWR licensing basis HCOM with filtering effects. The filtering effects include the effect of signal attenuation due to cutoff filtering and the effect of signal boost due to averaging filtering. HCOM values are shown for two different conditioning filter cutoff frequencies, 1.0 Hz and 1.5 Hz.

For any OPRM amplitude trip setpoint between 1.05 and 1.15, a linear interpolation scheme can be used to obtain the corresponding HCOM.

6.0 Minimum Number of Operable OPRM Cells

GE has performed an assessment regarding the minimum number of operable OPRM cells for ABWR Option III stability. Based on 26 (50% failure rate) randomly failed LPRMs out of 52 LPRMs per OPRM channel and the minimum two out of four LPRMs required for an operable OPRM cell, the minimum number of operable OPRM cells is 32 (nominal value) out of 44 OPRM cells for each of the four OPRM channels. This number is calculated based on a statistical simulation and is applicable to the ABWR OPRM 4P configuration (Figures 1 through 4).

7.0 References

7.1 Reactor Stability Detect and Suppress Solutions Licensing Basis Methodology for Reload Applications, NEDO-32465-A, August 1996.

7.2 BWR Owners' Group Long-Term Stability Solutions Licensing Methodology, NEDO-31960-A, November 1995.

7.3 BWR Owners' Group Long-Term Stability Solutions Licensing Methodology, NEDO-31960-A, Supplement 1, November 1995.

7.4 Stability Option III Period Based Detection Algorithm Allowable Settings, Safety Communication SC03-20, October 4, 2003.

7.5 Stability Option III: OPRM Tmin Specification, Safety Communication SC02-21, November 22, 2002.

Table 1. ABWR Information for Stability Option III Application

Information below is used to perform the ABWR specific statistical assessment of the licensing basis hot channel oscillation magnitude [(P-M)/A].

	Description	Value
1.	Fuel Type	GE 14
2.	RPS Trip Logic (1 out of 2 twice) or (2 out of 4)	2 out of 4
3.	Scram Delay Time (msec)	
	a. Response time of OPRM hardware	400 msec
	b. Response time of RPS	90 msec
	c. CRD delay to start of rod motion	200 msec
	d. Time to insert control rods 2 feet into the core at minimum Tech Spec speed	550 msec
	Total Scram Delay (msec) (sum a, b, c, & d)	1240 msec
4.	LPRM-to-OPRM cell assignment scheme from Reference 7.1	4P
5.	Minimum number of LPRMs required for an OPRM cell to be operable (1 or 2)	2

Table 2. Hot Channel Oscillation Magnitude Results

OPRM Amplitude Trip Setpoint (Peak/Average)	Licensing Basis HCOM with 1.0 Hz Cutoff*	Licensing Basis HCOM with 1.5 Hz Cutoff*
1.05	0.171	0.158
1.10	0.334	0.309
1.15	0.490	0.455

* The cutoff frequency of the Butterworth 2-pole conditioning filter.

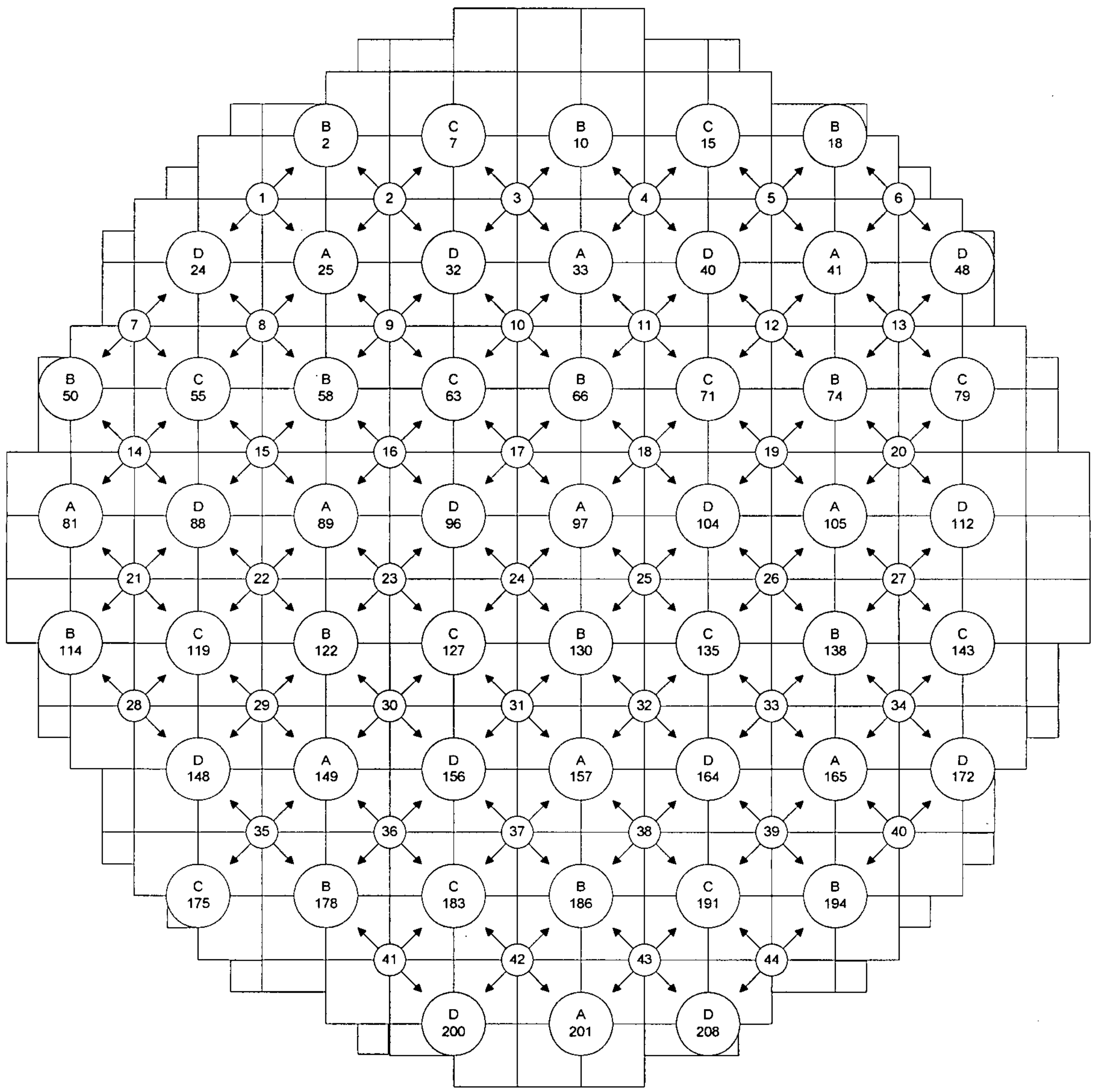

Figure 1. OPRM Assignments (Channel A) for ABWR

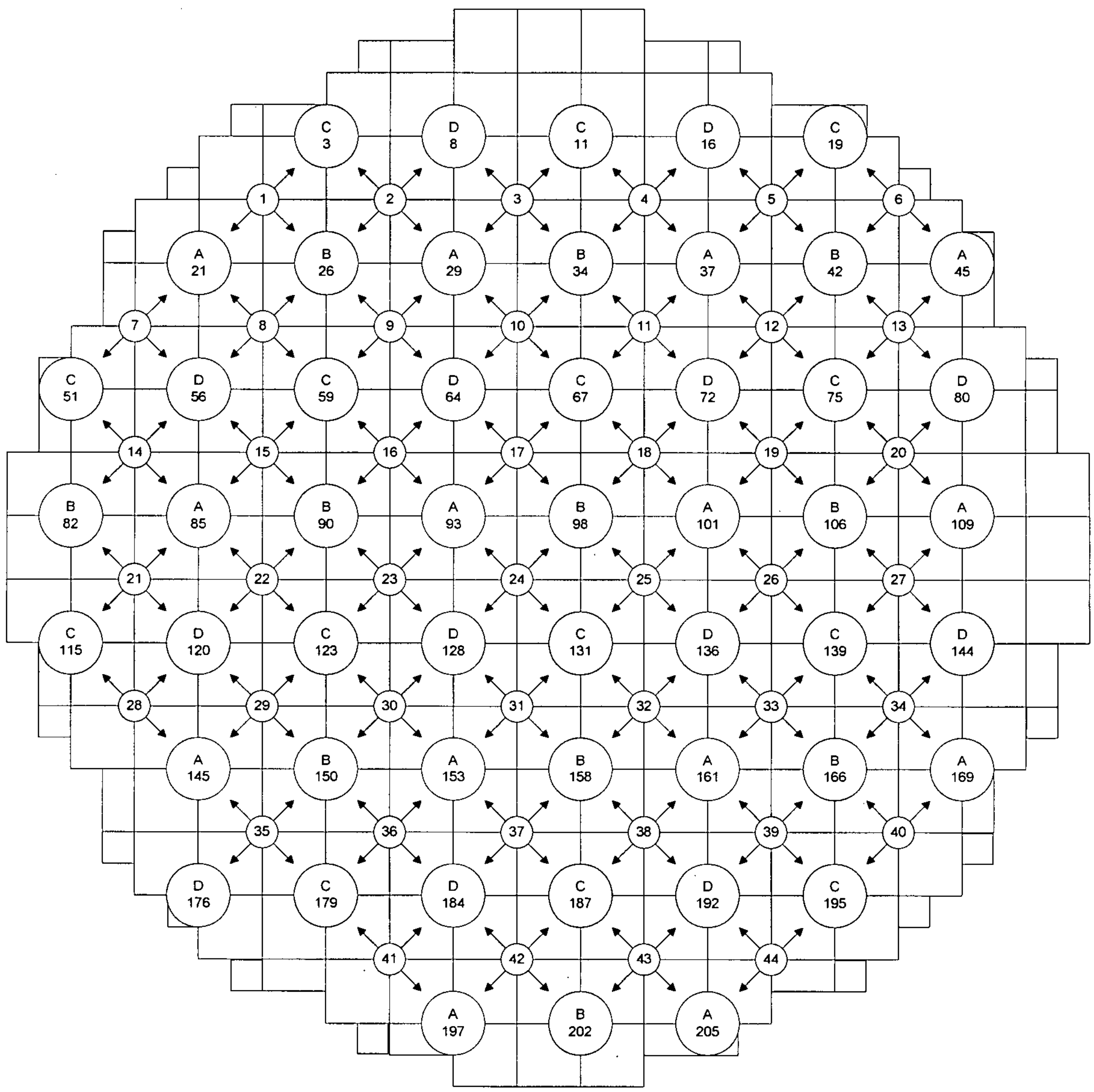

Figure 2. OPRM Assignments (Channel B) for ABWR

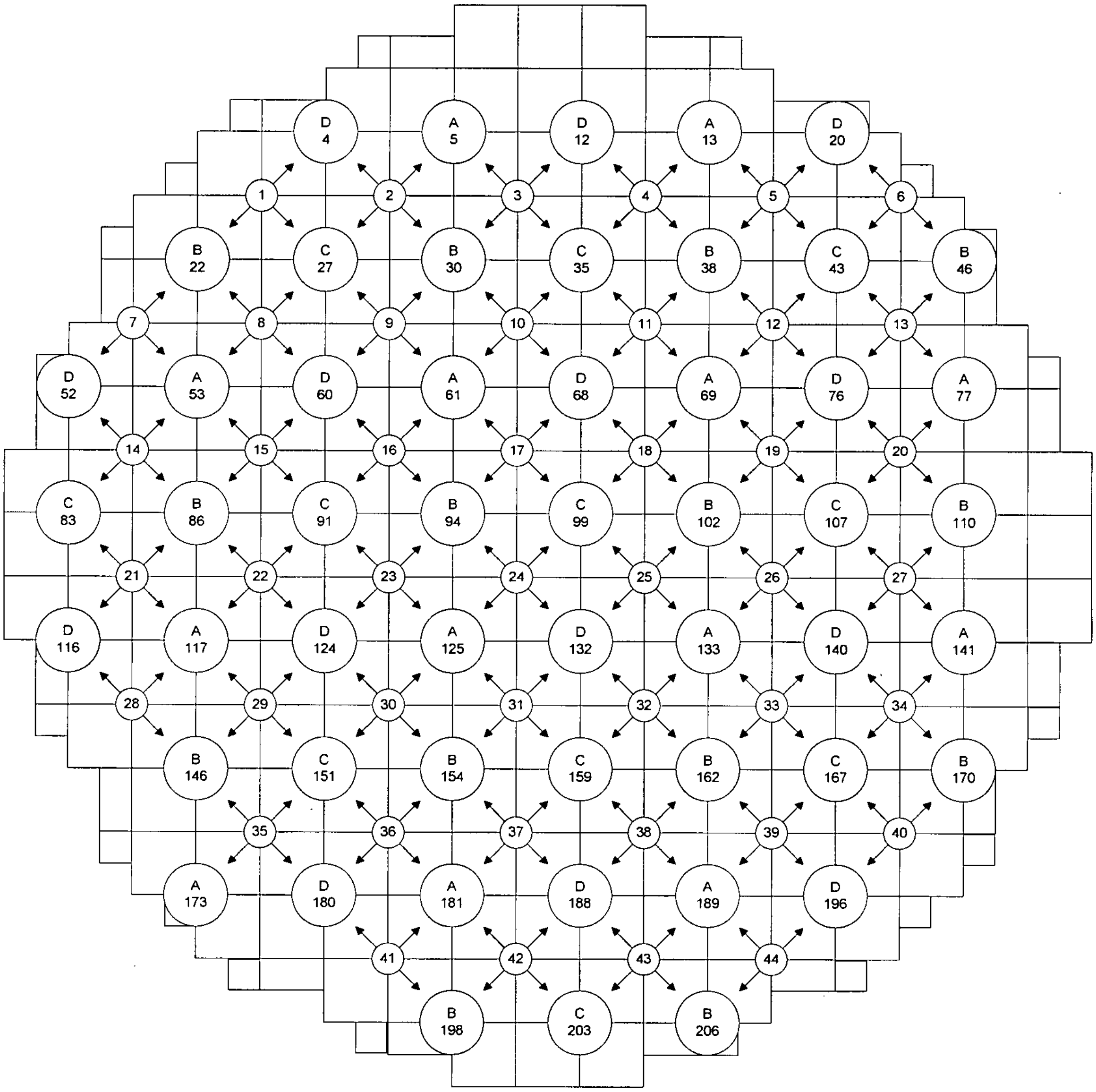

Figure 3. OPRM Assignments (Channel C) for ABWR

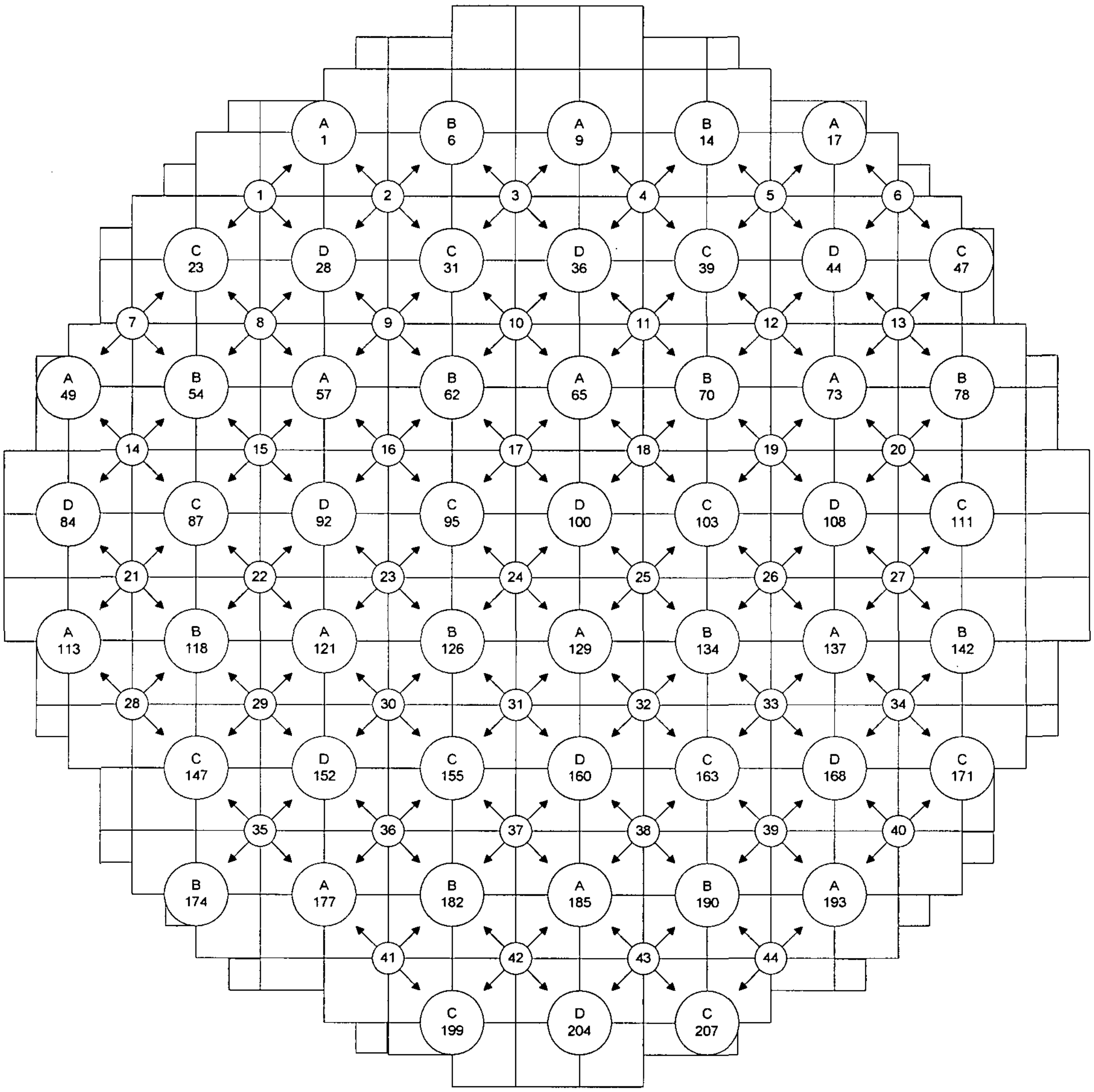

Figure 4. OPRM assignments (Channel D) for ABWR

Appendix C

ABWR DCD Significant Tier 2 Marked Changes

4.4.3.3.2 Other Performance Characteristics

Other performance characteristics shown on the power/flow operating map are:

- **Constant Rod Lines A, B, C, D, E, F**—These lines show the change in flow associated with power change while maintaining constant control rod position.
- **Constant Pump Speed Lines 1, 2, 3, 4, 5, 6, 7, 8**—These lines show the change in flow associated with power changes while maintaining constant RIP speeds.

4.4.3.3.3 Regions of the Power/Flow Map

Region I — This region defines the system operational capability with the reactor internal pumps running at their minimum speed (30%). Power changes, during normal startup and shutdown, will be in this region. The normal operating procedure is to startup along Curve 1 shown in Figure 4.4-1.

Region II — This is the low power area of the operating map where the carryover through steam separators is expected to exceed the acceptable value. Operation within this region is precluded by system interlocks.

Region III — This is the high-power/low-flow area of the operating map in which the system is the least damped. ~~Operation within this region is precluded by SCRRI (Selected Control Rods Run-In).~~

This is also called the Oscillation Power Range Monitor (OPRM) armed region (as shown on the power flow maps). Operation within this region is monitored by the OPRM function of the Neutron Monitoring system.

Region IV — This represents the normal operating zone of the map where power changes can be made, by either control rod movement or by core flow changes, through the change of the pump speeds.

4.4.3.3.4 Design Features for Power/Flow Control

The following limits and design features are employed to maintain pow conditions shown in Figure 4.4-1:

(1) **Minimum Power Limits at Intermediate and High Core Flows** unacceptable separator performance, the recirculation system with an interlock to reduce the RIP speed.

(2) **Pump Minimum Speed Limit:** The reactor internal pumps (R equipped with anti-rotation devices (ARD) which prevent a tripped RIP from rotating backwards. The ARD begins operating at 31.4 rad/s decreasing speed. In order to prevent mechanical wear in the ARD, minimum speed is specified at 31.4 rad/s. However, to provide a stable operation, the minimum pump speed is set at 47.1 rad/s (30% of required).

conditions in the normal operating region (i.e., the intercept of 102% rod line with all operating RIPs at their minimum speeds, assuming only 9 out of 10 RIPs are in operation) are as follows:

- Core Decay Ratio 0.72
- Channel Decay Ratio 0.36

These results are shown in Figure 4.4-3 together with the criteria. From Figure 4.4-3, it is confirmed that the ABWR is stable in the normal operating region.

Furthermore, automatic logics (Figure 4.4-4) which prevent plant operation in the region with the least stability margin is also implemented. This design is similar to Option I-A, one of long-term solutions considered by the BWROG. In addition, in order to meet the stability design requirements specified in the ALWR Utility Requirements Document, Option III, LPRM based Oscillation Power Range Monitor (OPRM), which is also one of the long-term solutions considered by the BWROG, has been implemented in the ABWR design.

As for issues that relate to ATWS stability, they are of no concern to the ABWR design, since the ABWR design has logic to automatically initiate the SLCS, including automatic initiation of feedwater run back. Furthermore, the ABWR EPG will incorporate any changes recommended by the BWROG.

In summary, the ABWR stability design is consistent with th ... gy proposed by the BWROG committee on thermal hydraulic s ... l be stable in the normal operating region.

Subsequent analysis for the ABWR presented in Reference 4.4-17 utilizing the stability analysis procedures documented in References 4.4-18, 4.4-19 and 4.4-20 confirm the stability of the ABWR with implementation of Option III.

4.4.4 Loose-Parts Monitoring System

The Loose-Parts Monitoring System (LPMS) is designed to ... ose metallic parts within the reactor pressure vessel. The LPMS ... e sound that can indicate the presence of loose parts impacti... pressure vessel or its internals. The LPM detection system ca... ts of selected signals. However, the system, by itself, cannot diagn... location of a loose part.

4.4.4.1 Power Generation Design Bases

The LPMS is designed to provide detection and operator warning of loose parts in the RPV to avoid or mitigate damage to or malfunctions of reactor components.

Additional design considerations provide for the inclusion of electronic features to minimize operator interfacing requirements during normal LPMS operation. These

4.4-4 R.C. Marinelli and D.E. Nelson, "Prediction of Pressure Drops During Forced Convection Boiling of Water", ASME Trans., 70, 695-702, 1948.

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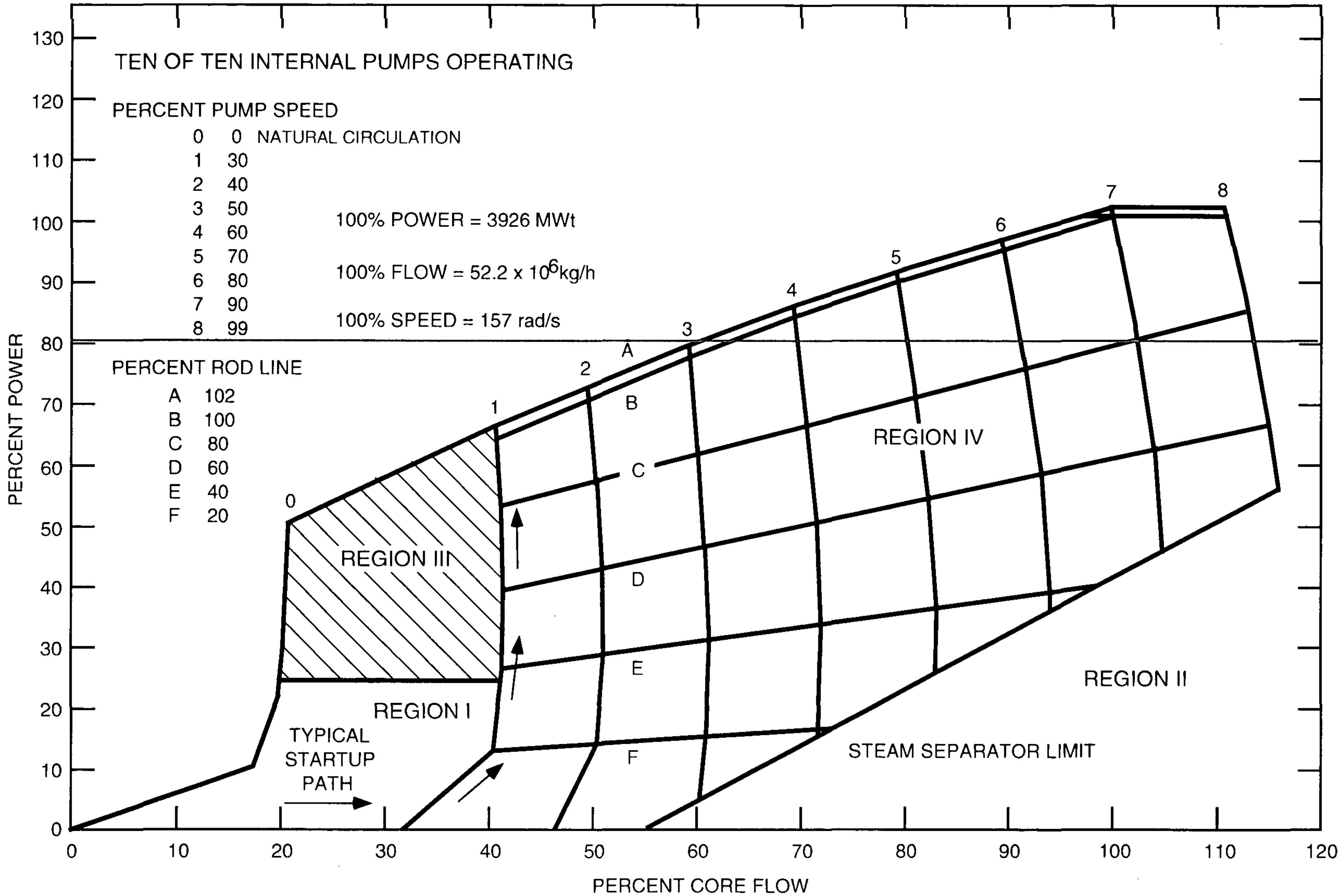


Figure 4.4-1 Power-Flow Operating Map Used for System Response Study

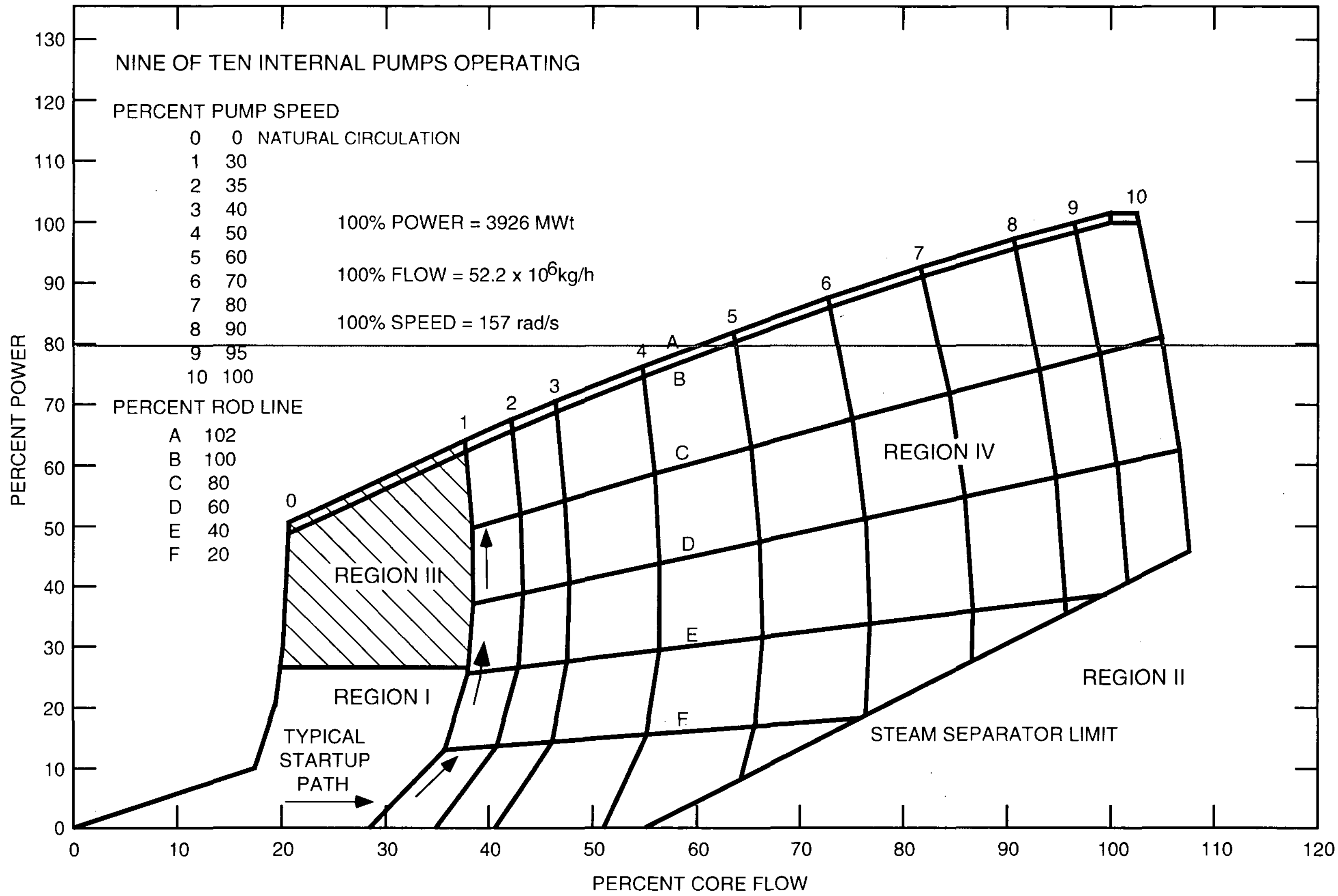


Figure 4.4-2 Power-Flow Operating Map Used for System Response Study (9 RIPs Operation)

Figure 4.4-1 Power-Flow Operating Map Used for System Response Study

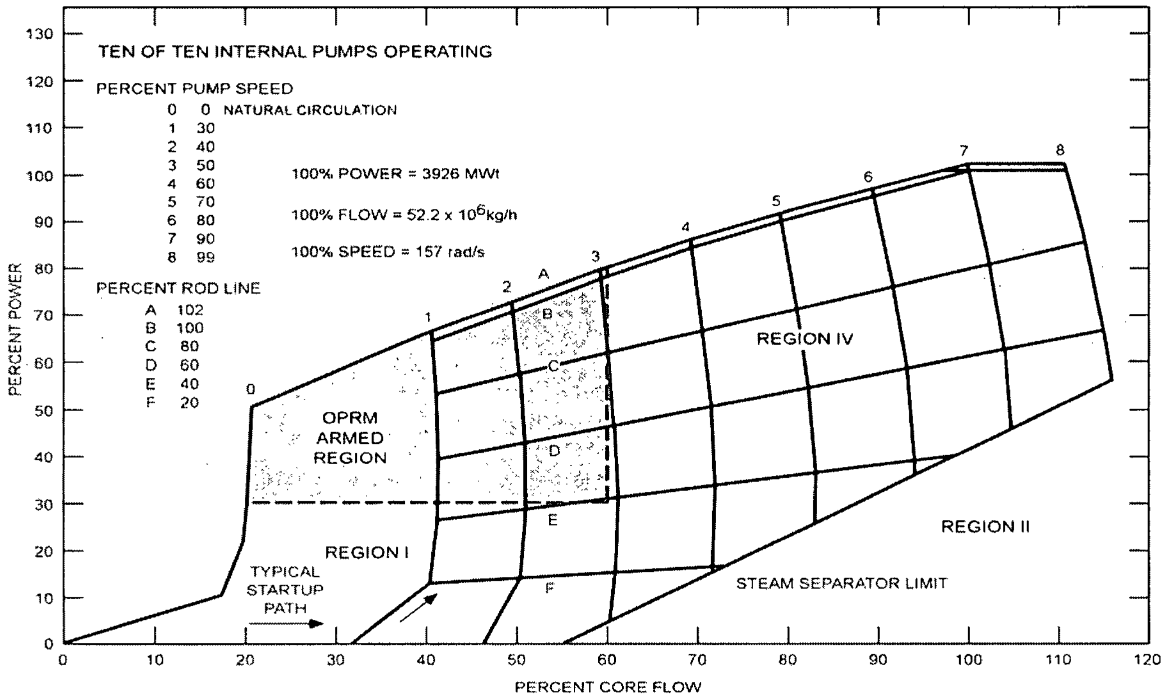
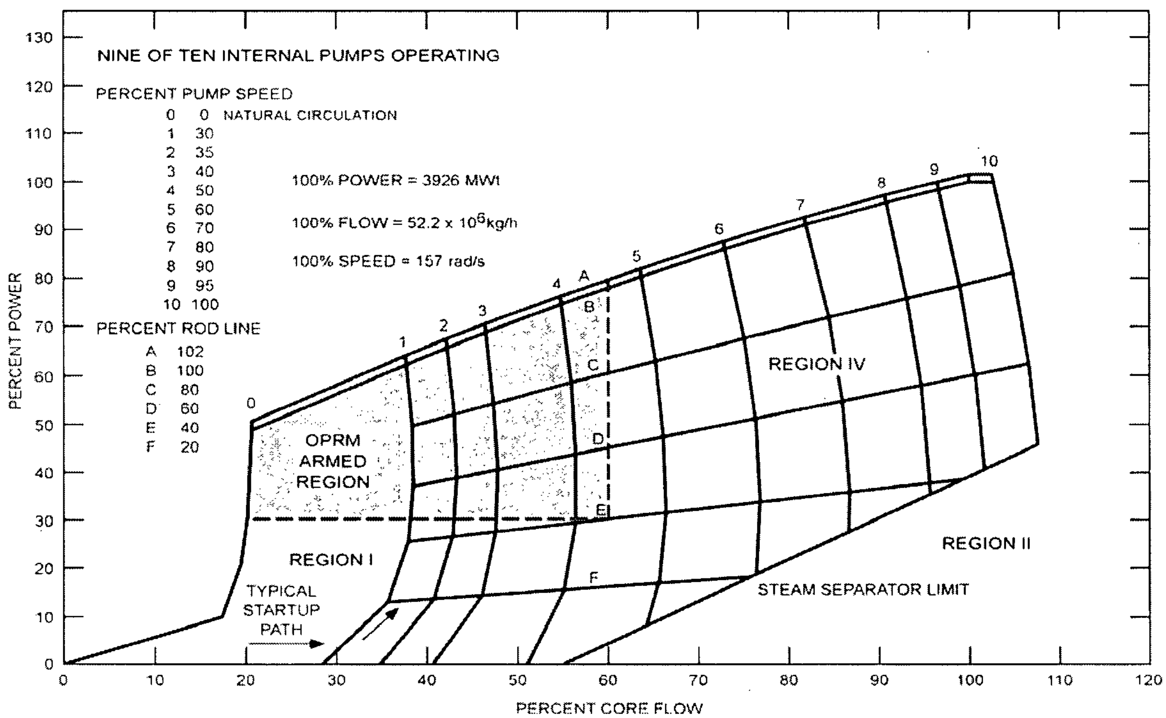


Figure 4.4-2 Power-Flow Operating Map Used for System Response Study (9 RIPs Operating)



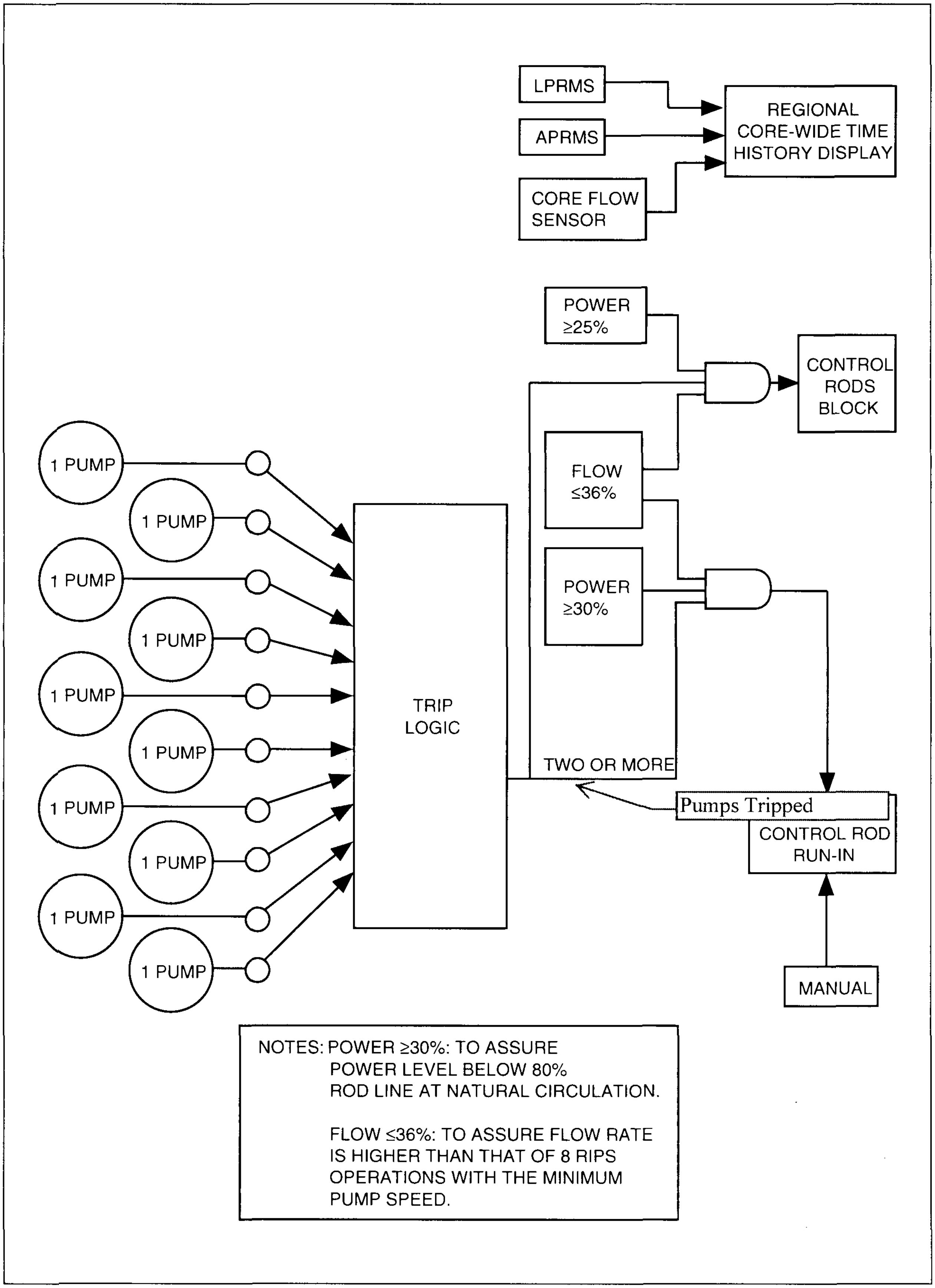


Figure 4.4-4 Stability Controls and Protection Logic

ACTIONS (continued)

CONDITION	REQUIRED ACTION	COMPLETION TIME
D. One or more Functions with four required SENSOR CHANNELS inoperable.	D.1 Place one channel in trip. AND D.2 Restore at least one required channel to OPERABLE status.	Immediately 1 hour
E. Required Action and associated Completion Time of Condition A, B, C or D not met.	E.1 Enter the Condition referenced in Table 3.3.1.1-1 for the Function.	Immediately
F. As required by Required Action E.1 and referenced in Table 3.3.1.1-1.	F.1 Reduce THERMAL POWER to below the level listed in Table 3.3.1.1-1 for the Function.	4 hours
G. As required by Required Action E.1 and referenced in Table 3.3.1.1-1.	G.1 Be in MODE 2.	6 hours
H. As required by Required Action E.1 and referenced in Table 3.3.1.1-1.	H.1 Be in MODE 3.	12 hours
I. As required by Required Action E.1 and referenced in Table 3.3.1.1-1.	I.1 Initiate action to insert all insertable control rods in core cells containing one or more fuel assemblies.	Immediately
J. As required by Required Action E.1 and referenced in Table 3.3.1.1-1.	J.1 Initiate action to place the reactor power/flow relationship outside of the region of applicability shown in Figure 3.3.1.1-1.	Immediately

(continued)

INSERT 1

Table 3.3.1.1-1 (Page 7 of 7)
SSLC Sensor Instrumentation

(a) With any control rod withdrawn from a core cell containing one or more fuel assemblies.

(b) Trip automatically bypassed within each SRNM and not required to be OPERABLE at reactor power levels ≤[0.0001]% RTP.

[1.0] [3.5]

(c) 1. Neutron flux oscillations within any OPRM cell have a period between [1/15] seconds and [3/35] seconds that persists for [10] cycles with a peak to peak amplitude of that is [10]% of point or greater.

2. Neutron flux oscillations within any OPRM cell that have a period between [0.31] and [2.2] seconds become larger than [30]% of point within [3] periods or oscillations with the specified period range that are greater than [10%] of point grow by [30]% of point within [3] cycles.

(d) With any Turbine Stop Valve not fully closed.

(e) When associated features are required to be operable.

(f) During CORE ALTERATIONS or operations with a potential for draining the reactor vessel.

(g) During movement of irradiated fuel assemblies in the secondary containment.

(h) When RSW pumps are required to be OPERABLE or in operation.

BASES

APPLICABLE SAFETY ANALYSIS, LCO, and APPLICABILITY (Continued)

2.f. Oscillation Power Range Monitor

The Oscillation Power Range Monitor (OPRM) Function detects the existence of neutron flux oscillations that could cause violation of the fuel thermal limits. This Function is not assumed in any ABWR safety analysis. However, it is included for redundancy and diversity and to provide confidence that the assumptions used in fuel limits calculations are preserved.

three

The OPRM uses ~~two~~ algorithms to detect flux oscillations. Each algorithm operates on several groups of LPRMs (called OPRM cells). The OPRM cells are selected to provided a representation of the radial neutron flux distribution so that local flux oscillations will be detected. The OPRM logic is as shown in Reference 4.

s

The amplitude/growth rate algorithm measures the amplitude of flux oscillations as a fraction of the average value (i.e % of point). The algorithm is invoked if the peak to average value exceeds a specified amount. The algorithm measures the period of the oscillation to determine if it is within the range expected for thermo-hydraulic core oscillations. If it is, then the cell flux is scanned for three of the measured periods. If the sensed flux increases (growth rate) by a specified amount or becomes larger than a specified amount (amplitude) within this period, then a trip is declared.

The period based algorithm measures the period of successive peaks and minimums in sensed flux. If the period is within the range expected for core thermo-hydraulic oscillations for a specified number of times and the amplitude is greater than a specified value, then a trip is declared.

Only the period based algorithm is credited with providing an oscillation suppression trip before the fuel MCPR safety limit is violated. The amplitude/growth rate algorithms are categorized as defense-in-depth features and are not required to be OPERABLE per the LCO.

There are four divisions of OPRMs, one in each NMS ~~division~~. Each OPRM acquires data from LPRMs distributed ~~throughout~~ the core. Therefore, each OPRM is capable of detecting an oscillation in any core region. ~~Each OPRM sends trip data to all four RPS TLUs via suitable isolators~~.

two-out-of four voter

Insert 2

the RPS TLU in the same division.

The potential for power oscillations in a BWR is restricted to operation conditions with low core flow and relatively high power. In order to reduce the potential for spurious trips due to LPRM noise, the OPRM function is automatically bypassed when the power flow relationship is ~~below the characteristic~~ shown in Figure 3.3.1.1-1.

outside of the region of applicability

(continued)

BASES

APPLICABLE SAFETY ANALYSIS, LCO, and APPLICABILITY (Continued)

2.f. Oscillation Power Range Monitor (continued)

The Allowable Values for the trip and bypass setpoints are based on extensive analysis of BWR core oscillation characteristics.

The OPRM Function is required to be OPERABLE when the power/flow characteristic is as shown in Figure 3.3.1.1-1 since this shows conditions where core oscillations can occur. Four divisions of this function are required to be OPERABLE to ensure that no single failure will preclude a scram from this Function on a valid signal.

, each consisting of an OPERABLE OPRM with 32 out of 44 cells,

2.g. APRM ATWS ADS Permissive

During a postulated ATWS event the Standby Liquid Control (SLC) System injects borated water into the reactor to reduce power level. Operation of any Safety/Relief valves would interfere with proper operation of SLC. Therefore, ADS is inhibited if APRM indicated power level remains above the SLC initiation point. The APRM ATWS ADS Permissive Function is combined with a Reactor Water Level-Low, Level 1.5 signal such that the ADS is inhibited unless both power and level are below their setpoints.

The APRM ATWS ADS Permissive Function is used in the ADS portion of the SSLC. When two of the four APRM channels indicate that power level is less than the Allowable Value then the inhibit is removed and ADS can occur based on the ADS initiation signal data.

Four channels of this Function is required to be OPERABLE in Modes 1 and 2 since these are the MODES where the ATWS functions must be OPERABLE. See the B3.3.1.3, "SLC and FWRB Actuation" for the applicability basis.

The Allowable Value is selected to be consistent with the SRNM ATWS Permissive Allowable Value.

3.a., b. & c. Reactor Vessel Steam Dome Pressure-High

An increase in the RPV pressure during reactor operation compresses the steam voids and results in a positive reactivity insertion. This causes the neutron flux and

(continued)

BASES

ACTIONS (Continued)

E.1 (continued)

channel/division and provides for transfer to the appropriate subsequent Condition.

and

F.1, G.1, H.1 ~~and J.1~~

If the Required Action for Conditions A, B, C, or D are not met within the specified Completion Times, the plant must be placed in a MODE or other specified condition in which the LCO does not apply. The Completion Times are reasonable, based on operating experience, to reach the specified condition from full power conditions in an orderly manner and without challenging plant systems. In addition, the Completion Time of Required Action F.1 is consistent with the Completion Time provided in LCO 3.2.2, "MINIMUM CRITICAL POWER RATIO (MCPR)."

I.1

If the Required Action for Conditions A, B, C, or D are not met within the specified Completion Times, the plant must be placed in a condition in which the LCO does not apply. This is done by immediately initiating action to insert all insertable control rods in core cells containing one or more fuel assemblies. Control rods in core cells containing no fuel assemblies do not affect the reactivity of the core and are, therefore, not required to be inserted. Action must continue until all insertable control rods in core cells containing one or more fuel assemblies are fully inserted.

Insert 3

K.1

This Action applies when the Required Actions and associated Completion Times for Conditions A, B, C, or D are not met for Functions used to isolate specific flow paths.

If the Function is not restored to OPERABLE status or placed in trip within the allowed Completion Time, plant operation may continue if the affected penetration flow path(s) is isolated. Isolating the affected penetration flow path(s) accomplishes the safety action of the inoperable function.

(continued)

BASES

SURVEILLANCE REQUIREMENTS (Continued)

SR 3.3.1.1.14 (continued)

The 18 month frequency is based on the ABWR expected refueling interval and the need to perform this Surveillance under the conditions that apply during a plant outage. The specified high reliability of the devices used in the RPS processing-coupled with operating experience which shows that random failures of instrumentation and embedded processor components that cause serious time degradation, but not channel failure, are infrequent-provides confidence that the specified Frequency is adequate.

REFERENCES

1. DCD Tier 2, Section 6.3.3, "ECCS Performance Evaluation".
2. DCD Tier 2, Chapter 15, "Accident Analysis".
3. DCD Tier 2, Figure 7.2-9, "RPS IED".
4. DCD Tier 2, Figure 7.6-2A, "OPRM Logic".
5. DCD Tier 2, Table 5.2-6, "LDS Control and Isolation Function vs. Monitored Process variables".
6. DCD Tier 2, Section 15.4.1, "Continuous Rod Withdrawal Error-Low Power".
7. DCD Tier 2, Appendix 15E, "ATWS Performance Evaluation".
8. DCD Tier 2, Section 5.2.2, "Overpressure protection".
9. DCD Tier 2, Section 1.1.3.
10. DCD Tier 2, Table 6.2-7.
11. DCD Tier 2, Section 9.2.15.
12. BWROG-94079, "BWR Owner's Group Guidelines for Stability Interim Corrective Actions," June 1994.

(continued)

INSERT 1

OR			
J.2			
		Initiate alternate method to detect and suppress thermal hydraulic instability oscillations.	Immediately

INSERT 2

Each OPRM channel receives identical LPRM signals from the corresponding APRM channel as inputs, and forms a special OPRM cell configuration to monitor the neutron flux behavior of all regions of the core. Each OPRM cell signal represents a combination of four LPRM signals selected from the LPRM strings at the four corners of a four-by four bundle square region and from different LPRM elevations. For locations near the periphery where one corner of the square does not include an LPRM string, the OPRM cells use the inputs from the remaining three LPRM strings. The LPRM signals may be input to more than one OPRM cell within an OPRM channel. The LPRM signals assigned to each cell are summed and averaged to provide an OPRM signal for this cell. There are a total of forty-four (44) cells for each OPRM channel. The overall axial and radial distributions of these LPRMs between the OPRM channels are uniform. A trip in any cell causes a trip of the OPRM channel. Each OPRM channel will send a trip signal to an OPRM 2-out-four voter in its division and each of the other divisions.

INSERT 3

J.1

If the Required Action for Conditions A, B, C, or D are not met within the specified Completion Times for Function 2f channels, the plant must immediately initiate action to place the reactor power/flow relationship outside of the region of applicability shown in Figure 3.3.1.1-1 or the alternate method of detecting and suppressing thermal-hydraulic instability oscillations is required. This alternate method is described in Reference 12. It consists of increased operator awareness and monitoring for neutron flux oscillations when operating in the region where oscillations are possible. If indications of oscillation, as described in Reference 12, are observed by the operator, the operator will take the actions described by procedures, which include initiating a manual scram of the reactor.