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Licensing Topical Report

BWR Owners' Group Long-Term Stability Solutions Licensing Methodology (Supplement 1)

GE Nuclear Energy

175 Curtner Avenue
San Jose, CA 95125

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Class I
March 1992

Licensing Topical Report

BWR OWNERS' GROUP
LONG-TERM STABILITY SOLUTIONS
LICENSING METHODOLOGY

SUPPLEMENT 1

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

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TABLE OF CONTENTS

	Page
ABSTRACT	
1.0 INTRODUCTION	1-1
2.0 SUMMARY AND CONCLUSIONS	2-1
3.0 DEFINITIONS	3-1
4.0 SOLUTION DESCRIPTIONS AND GENERAL REQUIREMENTS	4-1
4.1 Stability Long-Term Solution Classification	4-1
4.2 Select Rod Insert/Delayed Scram Application to Option I-A	4-2
5.0 REGIONAL EXCLUSION LICENSING METHODOLOGY	5-1
5.1 Stability Criteria	5-1
5.2 Region Boundary Definition Procedure	5-3
5.3 Application of Region Boundary Methodology	5-4
6.0 DETECTION AND SUPPRESSION LICENSING METHODOLOGY	6-1
6.1 Oscillation Detection Algorithm Description	6-1
6.2 Algorithm Parameters	6-6
6.3 Summary of Testing Results	6-15
6.4 Licensing and Design Basis Criteria	6-20
7.0 REFERENCES	7-1
APPENDIX - RESPONSE TO NRC QUESTIONS ON NEDO-31960	A-1

LIST OF TABLES

Table	Title	Page
5-1	FABLE/BYPSS Stability Criteria	5-6
5-2	Hot Channel Axial Power Distributions	5-7
6-1	Algorithm Testing - Steady State and Transient Data	6-24
6-2	Algorithm Testing - Instability Data	6-25
6-3	Sample Algorithm Parameters	6-26
A-1	Comparison of Confirmation and Region Boundary Definition Cases	A-15

LIST OF FIGURES

Figure	Title	Page
5-1	FABLE/BYPSS Stability Criteria	5-8
5-2	Hot Channel Axial Power Shapes - Region Definitions	5-9
5-3	Bias Correction Factors	5-10
6-1	Conditioning Filter - Stable Data	6-27
6-2	Conditioning Filter - Limit Cycle Data	6-28
6-3	Amplitude- and Growth Rate-Based Detection	6-29
6-4	Period-Based Detection	6-30
6-5	Example of Period-Based Detection	6-31
6-6	Algorithm Testing - Recirculation Pump Restart	6-32
6-7	Algorithm Testing - Turbine Control Valve Testing	6-33
6-8	Algorithm Testing - Instability During Control Rod Withdrawal (LPRM 1)	6-34
6-9	Algorithm Testing - Instability During Control Rod Withdrawal (LPRM 2)	6-35
6-10	Algorithm Testing - Constant Growth Rate Instability (Cycle 1)	6-36
6-11	Algorithm Testing - Constant Growth Rate Instability (Cycle 7)	6-37
6-12	Example Setpoint Overshoot Distribution (Second Peak)	6-38
A-1	Comparison of Confirmation and Region Boundary Definition Cases	A-16

ABSTRACT

Compliance with stability licensing criteria set forth in 10CFR50 Appendix A, General Design Criterion (GDC) 12, is achieved by either preventing stability-related neutron flux oscillations or detecting and suppressing the oscillations prior to exceeding specified acceptable fuel design limits. The BWR Owners' Group (BWROG) has developed long-term solutions which incorporate either prevention or detection and suppression features, or use a combination of both features to ensure compliance with GDC-12. Methodologies have been developed to support the licensing of these long-term solutions and were documented in a licensing topical report (Reference 1). Supplemental information is provided to the licensing topical report which covers details on the safety classification of the long-term solutions, use of select rod insert and delayed scram for Option I-A, an enhanced oscillation detection algorithm and responses to NRC questions on the licensing methodologies.

ACRONYMS AND ABBREVIATIONS

A/D	-	Analog-to-Digital
APRM	-	Average Power Range Monitor
ASF	-	Automatic Suppression Function
ATWS	-	Anticipated Transients Without Scram
BWR	-	Boiling Water Reactor
BWROG	-	Boiling Water Reactor Owners' Group
CPR	-	Critical Power Ratio
EOC	-	End of Cycle
GDC	-	General Design Criteria
GE	-	General Electric Company
LBS	-	LPRM-Based System
LPRM	-	Local Power Range Monitor
MCPR	-	Minimum Critical Power Ratio
NMS	-	Neutron Monitoring System
NRC	-	Nuclear Regulatory Commission
OPRM	-	Oscillation Power Range Monitor
RPS	-	Reactor Protection System
SRI	-	Select Rod Insert
3D	-	Three-Dimensional

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

July 12, 1993

L. A. England, Chairman
BWR Owners' Group
Gulf States Utilities
River Bend Station
North Access Rd.
St. Francesville, LA 70775

Dear Mr. England:

SUBJECT: ACCEPTANCE FOR REFERENCING OF TOPICAL REPORTS NEDO-31960 AND NEDO-31960 SUPPLEMENT 1, "BWR OWNERS GROUP LONG-TERM STABILITY SOLUTIONS LICENSING METHODOLOGY" (TAC NO. M75928)

The staff has completed its review of the Topical Reports NEDO-31960 and NEDO-31960 Supplement 1," submitted by the BWR Owners Group (BWROG) by letters dated May 31, 1991 and March 16, 1992. These reports describe and justify the use of several BWROG developed long-term solutions to BWR stability issues and the methodologies developed for evaluating appropriate setpoints and performance criteria for these solutions.

We find the solutions of NEDO-31960 and Supplement 1 to be acceptable for referencing in license applications to the extent specified, and under the limitations delineated in NEDO-31960 and Supplement 1 and the associated NRC technical evaluation. The enclosed safety evaluation defines the basis for acceptance of these topical reports.

We do not intend to repeat our review of the matters found acceptable as described in NEDO-31960 and Supplement 1 when the report appears as a reference in license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to the matters described in the application of NEDO-31960 and Supplement 1.

In accordance with procedures established in NUREG-0390, it is requested that the BWROG publish accepted versions of this topical report, within three months of receipt of this letter. The accepted versions shall include an "A" (designating accepted) following the report identification symbol.

Should our criteria or regulations change so as to invalidate our conclusions concerning the acceptability of the report, the BWROG or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

Ashok C. Thadani, Director
Division of Systems Safety and Analysis

Enclosure:
NEDO-31960 Evaluation

ENCLOSURE

SAFETY EVALUATION REPORT ON "BWR OWNERS' GROUP LONG-TERM STABILITY SOLUTIONS LICENSING METHODOLOGY" NEDO-31960 AND SUPPLEMENT 1

1 INTRODUCTION

The Boiling Water Reactor Owners' Group (BWROG) has submitted to the U.S. Nuclear Regulatory Commission (NRC) the Topical Report NEDO-31960, "Long-Term Stability Solutions Licensing Methodology," (Ref. 1) and Supplement 1 (Ref. 2) for staff review. The long-term solutions described in these reports consist of conceptual designs for automatic protection systems developed by the BWROG with its contractor, General Electric Company (GE), to either prevent stability-related neutron flux oscillations or to detect and suppress any oscillations that may occur. The reports also describe the methodologies that have been developed to establish setpoints and demonstrate the adequacy of the protection systems to prevent violation of the critical power ratio (CPR) safety limits in compliance with General Design Criteria (GDC) 10 and 12 in Appendix A to Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50). The BWROG has requested that the NRC staff review these reports and approve the following:

* The overall regional exclusion and detection and suppression methodology, including the overall treatment of uncertainties.

* The solution concepts and associated licensing approach for each option.

* The application of the methodology to the solution concepts.

* The BWROG/GE position concerning safety classification of new and existing hardware; that is, the safety classification of all existing and interfacing equipment should not change when new or modified stability long-term solution hardware is installed.

The BWROG plans to proceed with the selection of options and specific hardware design based on NRC's approval of the proposed concepts and associated methodologies.

2 EVALUATION

The solution options proposed by the BWROG in NEDO-31960 are:

I <u>Exclusion Region</u> A region in the high-power/low-flow area of the power/flow map outside of which instabilities are very unlikely is calculated for each representative BWR type using well-defined procedures. If the reactor is operated within this exclusion region, an automatic protective action is initiated to exit the region. This action is based exclusively on power and flow measurements; the presence of oscillations is not required for its initiation. Four solutions for the Type I option have been proposed by the BWROG, although not all have been completely developed:

I-A Immediate protective action is taken when entering the exclusion region. This action can be either a scram or a select rod insert (SRI).

I-B Same as I-A, but the protective action when entering the exclusion region can be bypassed if a stability monitor is operational and detecting sufficiently stable conditions (e.g., a decay ratio less than 0.6).

I-C Protective action is taken if the following two conditions both exist: (1) the reactor is operating inside the exclusion region and (2) an average power range monitor (APRM) oscillation (of small magnitude) is detected.

I-D A few small-core plants with tight inlet orifices have a reduced likelihood of out-of-phase instabilities. For these plants, the existing unfiltered, flow-biased APRM scram provides sufficient protection. In addition, administrative controls are proposed to maintain the reactor outside the exclusion region.

II <u>Quadrant-Based APRM Scram</u> In a BWR/2, the quadrant-based APRM is capable of detecting both in-phase and out-of-phase oscillations with sufficient sensitivity to initiate automatic protective action to suppress the oscillations before safety margins are compromised.

III <u>LPRM-Based Detect and Suppress</u>. Local power range monitor (LPRM) signals or combinations of a small number of LPRMs are analyzed on line by using three diverse algorithms. If any of the algorithms detect an instability, automatic protective action is taken to suppress the oscillations before safety margins are compromised. Two options have been proposed by the BWROG: Option III and Option III-A. The main difference between the two is in the hardware implementation. Option III requires a new Class 1E computerized system. For Option III-A, newly designed digital replacements of the existing APRM amplifier cards will be used and a smaller number of LPRM detectors in a revised configuration will be required. Conceptually, the algorithms are similar in both solutions.

The NRC contractor, Oak Ridge National Laboratory (ORNL), assisted the staff in reviewing the topical reports. ORNL has provided a technical evaluation report (TER) that is included as Attachment 1. The TER describes the results of the staff's review of the functional performance criteria for the proposed protection systems and of the assumptions, principles, and models inherent in the methodologies used to define protection system stability boundaries and setpoints. The staff's evaluation of hardware safety classification follows.

At a meeting on March 26, 1992, with the NRC staff, the BWROG proposed that for the long-term stability solution options relying on "APRM flow biased scram" recirculation drive flow signals, the use of existing hardware be allowed in the new protection system. The recirculation flow drive system, although highly reliable, is not designed to Class 1E standards. The staff, therefore, requested additional information on plant-specific arrangements of the existing recirculation drive flow instrument channels, channel integrity and independence, the failure rate data for each component in the flow channels, and the failure indication alarms. The response, which the BWROG transmitted with a July 17, 1992, letter (Ref. 3) provides the results of a survey among 9 licensees for 12 operating plants. In general, redundant flow channels exist in these arrangements. The failure history of the channel components (from eight BWR units covering 84 reactor-years) shows the failures to be random and the failure rate to be insignificant. For failure indication, the output signal from a flow channel is compared to the output signal from another flow unit. The comparator activates an alarm when two flow signals differ more than the specified tolerance. Alarms also are activated when the comparator fails high or low. Isolators are provided between flow units and between the comparator and the APRM circuitry and the alarm circuitry. However, the survey results indicate that many operating plants do not meet the configuration in BWROG

Viewgraph 3/26-7, "Drive Flow Signal Path," which was shown at the meeting on March 26, 1992.

The staff will review the hardware design details on a plant-specific basis. In general, it finds the proposed concept to be acceptable, but may require modifications for some plants.

3 CONCLUSIONS

The staff has reviewed the licensing basis for long-term solutions to BWR stability proposed by the BWROG and adopts the recommendations described in the attached TER. The regulatory positions with respect to the specific approvals requested by the BWROG are summarized below:

(1) Methodology

The exclusion region calculation methodology described in NEDO-31960 and its Supplement 1 is acceptable for defining the Option I-A exclusion region and the Options III and III-A exclusion boundaries outside of which the detect and suppress action may be deactivated. The overall treatment of uncertainties is acceptable for the selection of initial conditions and for the selection of oscillation contours and the treatment of failed LPRM sensors for Options III and III-A. The methodology is acceptable for evaluating the protection provided by the Option II quadrant-based APRM scram. Specific procedures for application of the methodology consistent with documentation and calculations submitted for this review should be developed and documented by BWROG.

(2) Solution Concepts

(a) Options I-B and I-C have not been developed in detail by the BWROG and, therefore, will not be considered acceptable as long-term solutions until fully developed by the BWROG and reviewed and approved by the staff. Option I-D is still under review and its acceptability as a long-term solution depends, to a large degree, on the details of calculations that are not yet available. Attachment 1 identifies some concerns about the Option I-D reliance on predictive calculations to conclude that the out-of-phase mode of oscillation will be avoided. To address these concerns and to provide reasonable assurance that out-of-phase oscillations will be avoided by I-D plants, it may be necessary to incorporate strict operational controls on axial and radial power distribution and to enhance the capability to recognize operating conditions that are approaching instability by other means such as on-line stability monitoring. Core stability sensitivities are illustrated by experience with the instability event on August 15, 1992, at Washington Nuclear Power Unit 2, in which oscillations developed outside of the stability exclusion regions because of a combination of fuel, core design and control rod patterns which resulted in conditions unfavorable to core stability, and conditions that an NRC inspection team concluded to be vulnerable to out-of-phase instability (Ref. 5). The staff will evaluate the acceptability of Option I-D when the calculations for the lead plant are submitted. If the lead plant analyses are acceptable, the staff will evaluate detailed calculations for all plants that may propose Option I-D (e.g. Duane Arnold, Vermont Yankee, Monticello, and FitzPatrick). If individual plant analyses are inconclusive because of large uncertainties involving assumed operating conditions, the quality of administrative controls and available core monitoring to reduce instability vulnerabilities will be considered in evaluating the Option 1-D acceptability for a specific plant.

(b) The implementation of Option I-A is an acceptable long-term solution for any type of BWR, subject to the following conditions:

(i) Specific reload confirmation procedures should be developed so that for every reload, the licensee can either confirm the applicability of old exclusion region settings or set a new exclusion region boundary.

(ii) The exclusion boundary setpoints for this option should be sufficiently bounding to avoid changes on a cycle-by-cycle basis. Major setpoint changes should be expected only if the fuel design changes significantly.

(iii) When establishing reactor trip setpoints for the power/flow exclusion region scram, operational restrictions on other parameters important to stability (e.g., radial and axial power distribution during low flow power maneuvering) that are consistent with the assumptions of the exclusion boundary analyses should be addressed, including the need for technical specifications, and factored into the setpoint evaluation.

(iv) Select rod insert (SRI) may be used in conjunction with Option I-A, but a full scram should occur if the reactor does not exit the region within a reasonable period of time (about a few seconds).

(c) Option II is an acceptable long-term solution for implementation in BWR/2s, which have quadrant-based APRM scrams. For implementing Option II, plant-specific analyses should show that the quadrant-based APRM scram provides sufficient protection against out-of-phase instability modes to avoid the violation of CPR safety limits.

(d) Options III and III-A are acceptable long-term solutions for implementation in any type of BWR, subject to the following conditions:

(i) All three algorithms described in NEDO-31960 and Supplement 1 should be used in Option III or III-A. These three algorithms are high LPRM oscillation amplitude, high-low detection algorithm, and period-based algorithm.

(ii) The validity of the scram setpoints selected should be demonstrated by analyses. These analyses may be performed for a generic representative plant when applicable, but should include an uncertainty treatment that accounts for the number of failed sensors permitted by the technical specifications of the plant's applicant.

(iii) Implementation of Option III or III-A will require that the selected bypass region outside of which the detect and suppress action is deactivated be defined in the technical specifications.

(iv) If the algorithms detect oscillations, an automatic protective action should be initiated. This action may be a full scram or an SRI. If an SRI is implemented with Option III or III-A, a backup full scram must take effect if the oscillations do not disappear in a reasonable period of time or if they reappear before control rod positions and operating conditions have been adjusted in accordance with appropriate procedural requirements to permit reset of the SRI protective action.

(v) The LPRM groupings defined in NEDO-31960 to provide input to the Option III or III-A algorithms are acceptable for the intended oscillation-detection function. These LPRM groupings are the oscillation power range monitor for Option III or the octant-based arrangements for Option III-A. The requirements for a minimum operable number of LPRM detectors set forth in NEDO-31960 are acceptable.

(e) Options I and II do not protect the fuel against single-channel instability, and the protection provided by Options III and III-A for single-channel instability is not highly reliable. When implementing the long term solution, a procedure to review the thermal hydraulic stability of lead use assemblies (LUA) in a core reload should be established. The review should ensure that inclusion of the LUA as proposed in the core reload is very unlikely to result in single-channel instability.

(3) Safety Classification

As a minimum, the recirculation drive flow channel should comply with the requirements of the Electrical and Electronics Engineers, Standard 279 (Ref. 4), which include the single-failure criterion, component quality, channel independence, and the capability for test and calibration. Isolation devices are required to be qualified for their application. No credible failure at the output of an isolation device should prevent the associated protection system channel from meeting the minimum performance requirements specified in the design bases. The plant-specific submittal should include the specification documentation for the isolation device. In addition, because Solution I-A involves an automatic reactor scram function, any modification to the reactor protection system trip function requires a submittal to the NRC proposing a change in the technical specifications. The plant-specific technical specification change should include limiting conditions for operation, action statements, allowable out-of-service times, surveillance tests, and test frequency commensurate with the importance to safety of the system. The detailed technical specification requirements should be addressed generically during review of the detailed hardware design.

4 REFERENCES

1. NEDO-31960, "BWR Owners' Group,Long-Term Stability Solutions Licensing Methodology," May 1991.

2. NEDO-31960, Supplement 1, "BWR Owners' Group Long-Term Stability Solutions Licensing Methodology," March 1992.

3. Letter from C. L. Tully (BWROG) to A. C. Thadani (NRC), "Response to RAI on Stability Report NEDO-31960," dated June 5, 1992," July 17, 1992.

4. Institute of Electrical and Electronics Engineers, Standard 279, "Criteria for Protection Systems for Nuclear Power Generating Stations."

5. Letter from J. B. Martin, NRC, to A. L. Oxsen, Washington Public Power Supply System, "NRC Augmented Inspection of Washington Nuclear Project, Unit 2", September 29, 1992.

ORNL/NRC/LTR-92/15

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SUMMARY

This report documents the main conclusions and recommendations derived from our review of the Boiling Water Reactor Owners' Group (BWROG) long-term solutions of the stability issue as described in NEDO-31960 and its Supplement-1 (references 1 and 2). Overall, this review is very positive. Our main conclusion is that all three of the proposed solution types (I, II, and III) are technically sound and, in our opinion, any of them will solve the stability issue if properly applied.

Although not specifically related to the stability issue, the fact that implementation of a new reactor protection function will most probably result in an increased number of challenges to the reactor protection system may lead to a new safety problem unless the number of unnecessary challenges is minimized by design. It is recognized that the normal function of these solutions is to provide an automatic protection action (i.e., a scram or a runback) if either oscillations are detected or the exclusion region is entered; however, the implementation of this function must be performed carefully in order to minimize the number of unnecessary actuations while maintaining a very high probability to perform the intended safety function.

Detailed recommendations, including some qualifiers and reservations, are specified in the main text of this report. A condensed summary of these recommendations follows:

1. Approve the overall licensing methodology described in NEDO-31960 and its Supplement 1 for Solutions I-A, II, and III. This methodology includes the treatment of uncertainties and the selection of initial conditions and calculation parameters. The approval should be conditioned to assure plant-specific consistency with the axial (2.0) and the radial (end-of-cycle Haling) peaking factors assumed for the core power distribution calculation parameters.

2. Do not approve Solution concepts I-B and I-C because of its lack of detailed development and/or interest by the BWROG.

3. Do not approve Solution concept I-D at this time until the final evaluations that NRC has requested have been performed. This recommendation does not imply a rejection of Solution I-D; the approval of Solution I-D depends on the details of calculations that have not yet been performed by the BWROG.

4. A select rod insert (SRI) is an acceptable automatic protection action for any of the approved solutions (I-A, II, or III) as long as a full scram takes effect if either the oscillations do not disappear or the reactor does not exit the exclusion region within a reasonable period of time (a few seconds). The exclusion region must be examined prior to each plant operating cycle to assure consistency with the axial and radial power peaking distribution assumed in the exclusion region boundary calculations.

5. The BWROG must establish a criteria to limit radial and axial peaking factors during startup operations to those values considered for the analyses of the exclusion region.

The main technical issue of significant relevance that still remains to be solved is the reload-dependent confirmatory analyses required to assert the applicability of the previous-cycle safety settings and, in particular, the applicability of "old" exclusion regions to new types of fuel and loading patterns. The BWROG is aware of this problem and is currently developing a methodology

for these cycle-dependent confirmations that is based on a "response surface" approach. The goal is that these confirmatory calculations should be expected to be positive most of the time; major setpoint changes should only be expected following significant fuel design changes. The documentation of this reload-confirmation methodology is expected in Supplement 2 to NEDO-31960 that should be published in the spring of 1993. Supplement 2 will also contain a correlation to estimate the loss of critical-power-ratio margin as a function of the power oscillation amplitude. This correlation is necessary to confirm the setpoints required for Solution III as well as the nonprotected region for Solution I-D.

BACKGROUND

Following the March 1988 instability event in the LaSalle BWR, the BWROG initiated a task to investigate actions that industry should take to resolve the BWR stability issue as an operational concern. Through analysis,[3] the BWROG found that the current plant protection system, that is based on a scram on high average power range monitor (APRM) signal, may not provide enough protection against out-of-phase modes of instability; thus, the BWROG decided that a new automatic instability suppression function was required as a long-term solution and that this function should have a rapid and automatic response which does not rely on operator action.

The BWROG does not plan to solve the stability problem on a "generic" basis, but it has proposed three different options instead. It will be up to the individual licensees to choose which solution will be implemented in their reactor. The options currently being considered by the BWROG are:

I Exclusion Region. A region outside which instabilities are very unlikely is calculated for each representative plant type using well-defined procedures. If the reactor is operated inside this exclusion region, an automatic protective action is initiated to exit the region. This action is based exclusively on power and flow measurements, and the presence of oscillations is not required for its initiation. Four concepts of type I have been proposed by the BWROG:

I-A Immediate protection action (either scram or SRI) upon entrance to the exclusion region.

I-B Same as I-A, but the exclusion region can be bypassed if a stability monitor is operational and detecting sufficiently stable conditions (for instance, decay ratio less than 0.6)

I-C Protection action is taken if two conditions are satisfied: (1) the reactor is operating inside the exclusion region (defined similarly as in Solution I-A), AND (2) an APRM oscillation (of small amplitude) is detected.

I-D Some small-core plants with tight inlet orifices have a reduced likelihood of out-of-phase instabilities. For these plants, it is claimed that the existing flow-biased high APRM scram provides sufficient protection. In addition, administrative controls are proposed to maintain the reactor outside the exclusion region.

II Quadrant-Based APRM Scram. In a BWR/2. the quadrant-based average-power-range monitor is capable of detecting both in-phase and out-of-phase oscillations with sufficient sensitivity to initiate automatic protective action to suppress the oscillations before safety margins are compromised.

III LPRM-Based Detect and Suppress. Local power range monitor (LPRM) signals or combinations of a small number of LPRMs are analyzed on-line by using three diverse algorithms. If any of the algorithms detects an instability, automatic protective action is taken to suppress the oscillations before safety margins are compromised. Two different options have been considered by the BWROG: Solution Concept III, and Solution Concept III-A. The main differences between the two is in the hardware implementation: Solution III requires a new Class 1E computerized system, and Solution III-A may use newly designed digital replacements of the APRM amplifier cards that will require a smaller number of LPRM detectors. Conceptually, the algorithms are (or may be) similar in both solutions.

CONCLUSIONS AND RECOMMENDATIONS

Positive conclusions

1. Overall, the BWROG has done an excellent job of addressing the stability issue in operating reactors. The BWROG has recognized that a problem exists, and they have attempted to solve it in a technically competent manner instead of performing analyses that would defend inaction.

2. The three proposed solution types (I, II, and III) are technically sound and, in our opinion, any of them will solve permanently the issue if properly applied.

3. The solutions can be implemented in existing reactors in a relatively straightforward manner without compromising their intended function.

4. The analyses techniques proposed by the BWROG in their licensing methodology appear to be sufficient to verify the effectiveness of these solutions in the lead plants.

5. The proposed BWROG procedures to generate input data for exclusion region calculations appear to be sufficiently conservative enough. Even though these procedures do not call for absolutely bounding values for all parameters, the conservatism is derived from the fact that reasonably bounding values are used for all parameters at the same time. In the real world, forcing one parameter towards its bounding limit is incompatible with having other parameters at their limit. The conservative nature of these procedures is verified through the use of transient confirmatory analyses under expected operating conditions, which include startup, pump runbacks, and loss feedwater conditions.

6. The application of Solution II to Oyster Creek has shown that the quadrant-based APRM scram provides sufficient protection for either in-phase or out-of-phase oscillations in a BWR/2.

7. The three proposed algorithms for Solution III appear to be able to detect oscillations in a manner reliably enough that automatic suppression action can be taken by the protection system. The good detection sensitivity of the period-based algorithm allows for fairly tight scram setpoints; therefore, this solution does not need to rely heavily on difficult calculations to show sufficient safety margin under a wide range of conditions and fuel types.

8. The arguments presented in NEDO 31960 about the expected oscillation modes are convincing, although they are not absolutely bounding in the case of the single-channel oscillation. We agree that the most likely oscillation modes will be either in-phase (or corewide) or out-of-phase (or regional). Higher order regional modes are not likely, because of their increased eigenvalue separation. We however have some minor reservations with respect to the single-channel type of instability (see reservation 10 in the next section and recommendation 12).

Reservations

1. Even though there are only three general types of solutions (Solutions I. II. and III). at least seven possible implementations (Solutions I-A. I-B. I-C. I-D. II. III. and III-A) have been proposed at one time or another. A more general type of solution that would apply to all reactors would have been preferable.

2. Some solutions (especially Solution I-A, regional exclusion with scram upon entry to the region) will most probably be implemented with margins as tight as possible to avoid unnecessary scrams. This approach might result in cycle-dependent implementations that would require new safety-system setpoints based on cycle-specific data for each reload. This is not a desirable feature in a long-term solution.

3. Solution I-B (exclusion region with bypass based on stability monitor) has not been developed in detail. and it appears to have been abandoned by the BWROG. If solution I-B were still under consideration. we would have reservations with respect to the ability of stability monitors to measure the decay ratio of the out-of-phase instability mode with sufficient accuracy to allow a bypass of the exclusion region scram. For example. in the Ringahls-1 tests.[4] the measured decay ratio was about 0.7 at 70% power and an instability was observed at 72.5% power. This event clearly casts a shadow on the viability of Solution I-B as an option.

4. Solution I-C (delta APRM flux scram) has not been developed in detail by the BWROG. If some licensee would want to pursue this option. we would have to look in more detail at the scram setpoint. The methodology used to estimate this setpoint should be similar to the one used for Solution III. including uncertainties and failed LPRM signals.

5. Solution I-D (small cores with tight inlet orifices) relies too strongly on decay ratio calculations that predict that the oscillation mode is very likely to be corewide. In this solution. the flow-biased scram does not appear to give significant protection against out-of-phase instabilities should they occur. Although these calculations will be documented in Supplement 2 of NEDO 31960 (due spring 1993). it is expected that there will be an area

within the exclusion region where the flow-biased scram does not provide protection for out-of-phase oscillations.

6. We have some concerns about the methodology to estimate the stability of the out-of-phase (or regional) mode of oscillation. The BWROG proposes to use an acceptance region defined in a two-dimensional plane with the FABLE-calculated corewide and hot-channel decay ratios as coordinates (see Fig. 5-1 of reference 2, NEDO-31960/S1). The applicability of this acceptance region to determine whether a reactor condition is likely to oscillate in-phase or out-of-phase may impact the approval of Solution I-D. The two main concerns that we have about the methodology that defines core-channel decay ratio acceptance criteria are:

   6.1 Core-channel decay ratio acceptance criteria were developed by using test data and other calculations. In all these benchmark cases, the actual radial and axial power shapes were used with FABLE to estimate the core and hot-channel decay ratio. The BWROG, however, proposes to distinguish between in-phase and out-of-phase oscillation modes based on this acceptance criteria but using the conservatively defined "procedure" power shapes as inputs instead of the best estimate shapes. Although we agree that the procedure power shapes result in a conservative exclusion region, they may bias the results towards the in-phase mode of oscillation by using nonconsistent axial power shapes (flat for corewide and extremely bottom peaked for the hot channel). In summary, the data base used to develop the acceptance criteria do not envelop the conditions for the intended use (i.e., cannot distinguish accurately between in-phase and out-of-phase modes).

   6.2 The out-of-phase mode of instability is a function of how strong the flow feedback is, and that is represented qualitatively by the channel decay ratio in the acceptance criteria. However, the out-of-phase mode is also a function of the eigenvalue separation between the fundamental and first azimuthal neutronic modes. The eigenvalue separation is not included in the acceptance criteria, which represent only "typical" loading patterns and core sizes. It is conceivable that other loading patterns might result in different acceptance criteria.

7. Reducing the number of false positives (i.e. scrams when it was not required) for Solution III (LPRM-based detect and suppress) is crucial for the solution to work; however, the BWROG may take this false-scram avoidance to such an extreme that the solution will not work. Minor problems with electronic noise, controllers out of tune, or many other unknown parameters may result in failure to scram when required, if this solution is not carefully designed. This is the reason we recommend (as proposed by the BWROG) that several diverse algorithms be implemented simultaneously for Solution III.

8. Solutions III, I-C, and I-D depend partly on a correlation that relates the change in critical power ratio (CPR) caused by a neutron power oscillation. It is not clear that such a correlation exists or how many independent parameters it must contain. The BWROG has been working towards developing this correlation and is trying to define it in a conservative manner. BWROG expects to complete this correlation development in February 1993. The correlation documentation will be included in the Supplement 2 to NEDO-31690 that is expected in the spring of 1993.

9. The applicability of the delta-CPR correlation (see paragraph 8 above) to new fuels or fuels from different vendors is not clear. This point is being addressed by the BWROG, and a formal position is expected in Supplement 2 to NEDO 31960.

10. Reactor operators have a large degree of freedom to chose control rod patterns and power distributions during startup at low powers. Some of these "achievable" power distributions may result in instabilities outside the exclusion region, even if the reload confirmation procedures were successful. Criteria must be set by the BWROG to assure the operator that the reactor is within the limits where the Solution I exclusion region is applicable.

11. Under normal conditions, single-channel instabilities are not probable, because these conditions are likely to induce an out-of-phase instability before the single-channel instability develops. This argument, however, is based on the fact that many channels of the same type are loaded, and therefore, if one channel is close to instability, many channels will also be unstable and are likely to produce a global out-of-phase oscillation. This is not the case, however, with lead use assemblies (LUAs), where perhaps only one channel of that type is loaded. If this LUA had stability characteristics quite different from those of the rest of the core, a single-channel instability in the LUA could be possible. For this reason, we are recommending that the thermohydraulic stability of all LUAs be determined (see recommendation 13).

Recommendations

1. Approve the overall exclusion region calculation methodology as described in NEDO-31960 and its Supplement 1. The results of these exclusion region calculations may be used as part of the implementation of Solutions I and III.

2. Approve the overall treatment of uncertainties described in NEDO-31960 as it applies to the selection of initial conditions for exclusion region calculations and its confirmatory runs.

3. Pending review of the specific reload confirmation procedures that should be outlined in a second supplement to NEDO-31960, approve Solution Concept I-A for implementation in any BWR line with the following design objectives:

    3.1 Specific reload confirmation procedures must be developed so that for every reload, the licensee can either (1) confirm the applicability of old exclusion region settings, or (2) set a new exclusion region boundary.

    3.2 Favor implementations of Solution I-A that are not expected to change the exclusion boundary setpoints on a cycle-by-cycle basis. Confirmatory calculations should be expected to be positive most of the time: major setpoint changes should only be expected following significant fuel design changes.

    3.3 Select rod insert (SRI) may be used in conjunction with Solution I-A, but a full scram must take effect if the reactor does not exit the region within a reasonable period of time (of the order of a few seconds).

4. Do not approve Solution Concept I-B at this time. Solution I-B has not been developed in detail by the BWROG. If a licensee chose to implement Solution I-B, they would have to resolve the question of whether a noise-based stability monitor can provide adequate protection against instabilities in the out-of-phase mode.

5. Do not approve Solution Concept I-C at this time. Solution I-C has not been developed in detail by the BWROG.

6. Do not approve Solution Concept I-D at this time until lead plant confirmation analyses are performed, documented, and reviewed. It is expected that Supplement 2 to NEDO 31960 (due spring 1993) will contain confirmation analyses for the Duane Arnold plant that will allow a detailed review and a final decision on the acceptability of Solution Concept I-D. This recommendation does not imply a rejection of Solution I-D; the approval of Solution I-D depends on the details of calculations that have not yet been performed by the BWROG.

7. Approve Solution Concept II for implementation in BWRs with quadrant APRM scram (i.e. in any BWR/2). Oyster Creek has already submitted technical specification changes that implement this solution (see Ref. 5).

8. Approve Solution Concept III for implementation in any BWR line with the following design objectives:

   8.1 To avoid unexpected problems, several diverse algorithms must be used to detect oscillations. Automatic protection action must initiate if either of the algorithms detects oscillations (i.e., the algorithm outputs are connected by a logical OR, not a logical AND).

   8.2 The three algorithms described in NEDO-31960 and its supplement may be used in Solution III. These three algorithms are (1) high LPRM oscillation amplitude, (2) high-low detection algorithm, and (3) period-based algorithm. Preferably, all three algorithms should be used.

   8.3 The licensees that implement these algorithms must demonstrate by analyses the validity of the scram setpoints selected. These analyses may be performed on a representative-plant basis when applicable but must include an uncertainty treatment that takes into account the number of failed sensors permitted by technical specifications.

   8.4 The scram setpoints should be selected such that at least one of the algorithms has a large probability of detecting the oscillation and initiating protective action to prevent violation of any fuel safety criterion.

   8.5 If the algorithms detect oscillations, an automatic protection action must be initiated. This action may be a full scram or an SRI. If an SRI were to be implemented with Solution Concept III, a full scram must take effect if either (1) the oscillations do not disappear in a reasonable period of time, or (2) the reactor remains inside the exclusion region as defined by the general regional exclusion methodology of Solution I-A.

9. The LPRM groupings defined in NEDO 31960 to provide input to the Solution III algorithms appear appropriate for the intended oscillation-detection function. These LPRM groupings are: the oscillation power range monitor (OPRM) for Solution III or the octant-based arrangements for Solution III-A. The minimum requirements for operable number of LPRM detectors set in NEDO 31960 appear appropriate.

10. Approve the overall treatment of uncertainties described in NEDO-31960 as it applies to the selection of oscillation contours and failed LPRMs for Detect and Suppress Concepts (Solution III).

11. Implementation of Solution III will require the documentation of the selection of the bypass region outside which the detect and suppress action is deactivated.

12. The BWROG must establish a criteria to limit the actual radial and axial peaking factors during startup operations to those values considered for the analyses of the exclusion region. This criteria must be based on parameters or information readily available to the operator in the control room. Defining this criteria must be part of the reload confirmation analyses.

13. Establish a procedure to review the thermohydraulic stability of lead use assemblies (LUA). Solutions I and II do not protect the reactor in the case of a single-channel instability, and the protection for Solution III is limited. These instabilities are not likely if many bundles of one type are loaded in the core, but they could be possible if the wrong type of LUA were to be loaded. Thermohydraulic stability analyses must be required during LUA review if Solutions I or II are used.

REFERENCES

1. General Electric Company, *BWR Owners' Group Long-Term Stability Solutions Licensing Methodology*, NEDO-31960, May 1991.

2. General Electric Company, *BWR Owners' Group Long-Term Stability Solutions Licensing Methodology*, NEDO-31960 Supplement 1, March 1992.

3. General Electric Company, *Fuel Thermal Margin During Core Thermal Hydraulic Oscillations in a Boiling Water Reactor*, NEDO-31708, June 1989

4. B-G Bergdahl and R. Oguma, "BWR Stability Investigation in Ringhals-1 Measurement Data from October 26, 1989," *Proceedings of The International Workshop on Boiling Water Reactor Stability, Holtsville, N.Y., 17—19 October 1990*, pp 142—159, OECD/NEA/CSNI Report No 178, October 1990.

5. Oyster Creek Nuclear Generating Station, *Technical Specification Change Request No. 191*, Docket No. 50-219, October 9, 1991.

APPENDIX A

LAPUR AUDIT CALCULATIONS OF Solution I EXCLUSION REGION CALCULATIONS

AUDIT CALCULATIONS

A series of audit calculations were performed with the LAPUR code to verify the results presented by the BWROG that were based on FABLE/BYPSS calculations. All relevant input data used in the FABLE/BYPSS was made available for this review, and we set up LAPUR input decks that were representative of the conditions modeled by FABLE. The main result of these calculations is presented in Table A.1 and Figs A.1 and A.2. We observe that the maximum difference between LAPUR- and FABLE-calculated decay ratios is 0.09. This can be considered as excellent agreement and representative of the differences in modeling of both codes.

This type of code-to-code benchmark is not as good as a code-to-data benchmark, but it assures that gross modeling errors or systematic errors in the preparation of the input decks have not occurred. Furthermore, it ensures that "data fudging" is not taking place to obtain desired results, because all the data has to be made available and is evaluated for expected value ranges.

Both codes, LAPUR and FABLE, have been benchmarked against data from actual stability tests with satisfactory results. In general, it is recognized that this type of frequency-domain codes has an accuracy better than 20%. Thus, if a decay ratio of 0.8 or smaller is calculated, it is highly probable that stable reactor operation will result. Decay ratios larger than 0.8 result in smaller probabilities of stable operation. Note, however, that large errors are possible if the proper data are not used as input to the code. The 20% error quoted above is for detailed test benchmarks where extreme care is taken to reproduce the exact axial and radial power shapes, core pressure drops, and reactivity coefficients; calculations using approximate descriptions of the core operating condition are likely to result in larger errors.

The axial power shapes assumed in the BWROG analysis are: (1) fairly uniform (end-of-cycle Haling) shape to calculate the corewide decay ratio, and (2) strongly bottom peaked (2.0 peaking at node 3/24) to calculate the hot-channel thermohydraulic decay ratio. It is well known that the high-power channels (maybe 25% of the total number of channels) have the most influence in the stability of the reactor. This is due to the fact that the adjoint flux and density reactivity coefficients are higher in the high-power channels. Furthermore, hot channels tend to have bottom-peaked power shapes, that may be more unstable. To test the validity of the uniform power shape assumption, we ran two cases to determine corewide stability boundary: (1) with all channels having the same Haling power shape and (2) with a graded axial power shape, so that the hot channels have a bottom-peaked shape (2.0 at node 3/24), but the core average is the same as in case (1). The chosen power shapes are drawn in Figs. A.3 and A.4 for a BWR/3 and BWR/5 respectively. The out-of-phase and hot-channel decay ratio calculations were based on the graded power shapes of Figs. A.3 and A.4. The out-of-phase decay ratio was calculated by LAPUR assuming an eigenvalue separation of \$1.00 between fundamental and first harmonic neutronic modes. This \$1.00 value is a representative, but not bounding value of the eigenvalue separation. These results show that the uniform (Haling) power shape is more conservative at lower flows, but the use of bottom peaked graded shapes results in higher decay ratios at higher flows.

Reload Confirmation Procedures

The main technical issue of significant relevance that still remains to be solved is the reload-dependent confirmatory analyses required to assert the applicability of the previous-cycle safety settings and, in particular, the applicability of "old" exclusion regions to new types of fuel and loading patterns. The BWROG is aware of this problem and is currently developing a methodology for these cycle-dependent confirmations that is based on a "response surface" approach. The goal is that these confirmatory calculations should be expected to be positive most of the time; major setpoint changes should only be expected following significant fuel design changes. The documentation of this reload-confirmation methodology is expected in Supplement 2 to NEDO-31960 that should be published in the spring of 1993.

Of particular concern is how the reload procedures will be used to evaluate startup power distributions. For example, the root cause of a recent instability event in a BWR/5 has been determined to be the extreme radial (1.92) and axial (up to 1.87) peaking factors during the startup. This extreme power distribution was apparently not covered by the standard exclusion region calculations, which assumed a more mild radial power peaking factor. Nevertheless, the operator was allowed to have that extreme distribution without violating any thermal limits.

Figure A.5 shows a comparison of the equilibrium-cycle exclusion region for the Perry reactor (a BWR/6) and the exclusion region that results if the actual axial and power shapes from the recent BWR/5 event are used. As it can be observed, the standard BWR/6 exclusion region from NEDO-31960 is not as conservative as the actual region. Therefore, we have recommended that the BWROG must establish a criteria to limit the actual radial and axial peaking factors during startup operations to those values considered for the analyses of the exclusion region. This criteria must be based on parameters or information readily available to the operator in the control room.

Table A.1. LAPUR-FABLE/BYPSS benchmark/audit calculations

Reactor type	Power (%)	Flow (%)	Corewide decay ratio		Hot-channel decay ratio	
			FABLE	LAPUR	FABLE	LAPUR
BWR/3	42	30	0.77	0.68	0.34	0.28
	52	45	0.46	0.47	0.19	0.17
	71	45	0.65	0.64	0.35	0.38
	84	60	0.45	0.41	0.21	0.28
BWR/5	42	30	0.65	0.73	0.50	0.50
	52	45	0.39	0.37	0.34	0.32
	71	45	0.56	0.50	0.55	0.62
	84	60	0.30	0.32	0.31	0.39

Table A.2. Typical LAPUR5X input deck for a BWR/3

```
LAPUR5X :: BWROG I BWR3 71/45
  1
988.8, 502.3, 1782.9, 44.01E6, 0.101, 0.035, 0.80, 1.0
  2
7, 24, 0, 1, 0, 0, 0, 1, 0
  3
5, 25, 25, 25, 25, 25
  4
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 30.48
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 30.48
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 30.48
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 30.48
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
      15.875, 15.875, 15.875, 30.48
  5
      0.27, 0.86, 1.02, 1.06, 1.08, 1.09, 1.10,
      1.11, 1.14, 1.15, 1.16, 1.16, 1.17, 1.17,
      1.17, 1.16, 1.15, 1.14, 1.11, 1.06, 0.98,
      0.85, 0.58, 0.27, 0.00
      0.92, 1.64, 2.00, 1.88, 1.70, 1.53, 1.37,
      1.25, 1.15, 1.07, 1.00, 0.95, 0.90, 0.86,
      0.81, 0.78, 0.74, 0.70, 0.66, 0.60, 0.53,
      0.44, 0.33, 0.19, 0.00
      0.20, 1.20, 1.40, 1.60, 1.51, 1.40, 1.30,
      1.22, 1.15, 1.09, 1.04, 1.00, 0.97, 0.94,
      0.90, 0.87, 0.84, 0.81, 0.78, 0.73, 0.67,
      0.59, 0.48, 0.33, 0.00
      0.20, 1.00, 1.10, 1.30, 1.29, 1.24, 1.19,
      1.14, 1.11, 1.08, 1.05, 1.03, 1.00, 0.99,
      0.96, 0.95, 0.93, 0.91, 0.89, 0.85, 0.81,
      0.75, 0.67, 0.54, 0.00
      0.03, 0.13, 0.12, 0.13, 0.32, 0.55, 0.77
      0.96, 1.15, 1.29, 1.41, 1.49, 1.57, 1.63
      1.70, 1.72, 1.74, 1.75, 1.72, 1.67, 1.54
      1.29, 0.69, 0.02, 0.00
  7
7,   1,    1,    1,    1,    1,    1,    1
  9
7,  127.2,  127.0,  98.6,  129.3,  97.4,  127.3,  25.0
 10
7,  36.8,  36.8,  36.8,  36.8,  36.8,  36.8,  229.0
 11
7, -0.280, -0.280, -0.280, -0.280, -0.280, -0.280, -0.280
 13
7,   0.,   0.,   0.,   0.,   0.,   0.,   0.
 14
7,   81,   87,   73,  106,   91,  202,   84
 15
7,   60,   60,   60,   62,   60,   62,   62
 16
7,   1,    1,    1,    2,    1,    2,    2
 17
    2, 411.48, 411.48
 18
    2, 231.24, 238.96
 19
    2, 97.97, 101.15
 20
    2, 97.97, 101.15
 21
    2,  1.33,  1.34
 22
```

```
      2,   0.1,   0.1
 23
      2,   0.1,   0.1
 24
      2,   1.3,   1.3
 25
      2,  0.125,  0.125
 26
7,   1,    1,    1,    2,    1,    2,    2
 27
      2,  10.44,  10.33
 28
      2, 1.0439, 1.0414
 29
      2, 0.5581, 0.5581
 30
      2, 0.0373, 0.0373
 31
      2, 0.0813, 0.0813
 32
      2, 0.2675, 0.2347
 33
      2, 0.0114, 0.0114
 34
7,   1,    1,    1,    1,    1,    1,    1
 35
      1,    1
 36
          411.48
 37
            1.40
 53
 1.E-3, 1.E-3, 1.E-3, 2.E-5, 1.E-3, 1.E-9, 1.E-2, 5.E-8
 54
      1, 12
 0
```

Table A.3. Typical LAPUR5W input deck for a BWR/3

```
 7, 1, 1
2
      81,    87,    73,   106,    91,   202,    84
3
      411 -48
4
      0.2,  0.3
5
 1   6
6
            1
7
  6, 0.185E-3, 1.226E-3, 1.096E-3, 2.210E-3, 0.647E-3, 0.236E-3
8
  6,  0.0124,   0.0305,   0.1110,   0.3010,   1.1300,   3.0000
9
            1
10
    1      0.0
11
            1
12
    1    -4 E-5
17
      -2.5E-03
18
    1       7
19
           1.,    1.,    1.,    1.,    1.,    1.,    1
20
          1.2,   1.0,   0.8,   0.6,   0.4,   0.2,   0.0
21
        -5.64,   5.66,   14.06, 18.84,  20.51,  20.98,  21.44
22
   12,  0.20, 0.30, 0.40, 0.43, 0.46, 0.50, 0.53
      0.56, 0.60, 0.63, 0.66, 0.70
23
 0  1  1  1  1  1  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0
24
 1  1  1  1  1  1  1  1  1
28
     1.
29
     5     0.0     0.5    -1.0    -1.5    -2.0
30
     0
0
```

Table A.4. Typical LAPUR5X input deck for a BWR/5

```
LAPUR5X :. BWROG I BWR5 71/45
  1
988.8, 505.7, 2359., 48.7E6, 0.095, 0.035, 0.80, 1.0
  2
7, 24, 0, 1, 0, 0, 0, 1, 0
  3
5, 25, 25, 25, 25, 25
  4
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875,  30.48
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875,  30.48
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875,  30.48
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875,  30.48
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15.875
        15.875, 15.875, 15.875, 15.875, 15.875, 15.875, 15 875
        15 875, 15.875, 15.875, 15.875, 15.875, 15.875, 15 875
        15.875, 15.875, 15.875,  30.48
  5
        0.319 , 0.9116, 1.1074, 1.1675, 1.1771, 1.1688, 1 1563
        1.1448, 1.1338, 1.1236, 1.1168, 1.1144, 1.115 , 1.1168
        1.1176, 1.1162, 1.1104, 1.0959, 1.0671, 1.0159, 0.9304
        0.7936, 0.6085, 0.2713, 0.0
        0.9200, 1.6400, 2.0000, 1.8800, 1.7000, 1.5300, 1.3700
        1.2500, 1.1500, 1.0700, 1.0000, 0.9500, 0.9000, 0.8600
        0.8100, 0.7800, 0.7400, 0 7000, 0.6600, 0.6000, 0 5300
        0 4400, 0.3300, 0.1900, 0.00
        0.6243, 1.4709, 1.6902, 1.6185, 1.5084, 1.4012, 1.2969
        1 2163, 1.1473, 1 0909, 1.0404, 1.0037, 0.9664, 0.9361
        0.8977, 0.8743, 0.8427, 0.8105, 0.7778, 0.7276, 0.6671
        0.5856, 0.4788, 0.3253, 0.0
        0.6279, 1.2755, 1.3809, 1.3471, 1.2940, 1.2406, 1.1870
        1.1442, 1.1067, 1.0752, 1.0465, 1.0253, 1.0033, 0.9852
        0.9619, 0.9475, 0.9278, 0.9074, 0.8863, 0.8531, 0.8118
        0.7536, 0.6716, 0.5385, 0.0
        0.1017, 0.6170, 0.7994, 0.9319, 1.0072, 1.0526, 1.0894
        1.1146, 1.1341, 1.145 , 1.1640, 1.1795, 1.1998, 1.2183
        1.2395, 1.2494, 1.2567, 1.2508, 1.2230, 1.1694, 1.0680
        0 8977, 0.6653, 0.2213, 0.0
  7
7,   2,    3,    4,    5,    5,    5,    5
  9
7, 121.11, 121.60, 121.72, 122.39, 121.26, 121.96,  32.94
 10
7,  27.7,  27.7,  27.7,  27.7,  27.7,  27.7,  193.0
 11
7, -0.280, -0.280, -0.280, -0.280, -0.280, -0.280, -0.280
 13
7,   0.,   0.,   0.,   0.,   0.,   0.,   0.
 14
7,   83,   87,  100,  110,  122,  170,   92
 15
7,   62,   62,   62,   62,   62,   62,   62
 16
7,   1,    1,    1,    1,    1,    1,    1
 17
     1   411.48
 18
     1   238.96
 19
     1   101.15
 20
     1   101.15
 21
     1     1.34
 22
```

```
     1      0.1
23
     1      0.1
24
     1      1.3
25
     1    0.125
26
7,   1,     1,     1,     1,     1,     1,     1
27
     1    10.33
28
     1   1.0414
29
     1   0.5581
30
     1   0.0373
31
     1   0.0813
32
     1   0.2256
33
     1   0.0114
34
7,   1,     1,     1,     1,     1,     1,     1
35
     1        1
36
         411.48
37
           1.40
53
  1.E-3   1.E-3   1.E-3   2.E-5   1.E-3   1.E-9   1.E-2   5.E-8
54
     1       25
56
 11  12  13   0
 0
```

Table A.5. Typical LAPUR5W input deck for a BWR/5

```
LAPURSW .. BWROG I BWR5 71/45
 1
  7, 1, 1
 2
        83,    87,   100,   110,   122,   170,    92
 3
        411.48
 4
        0.2,  0.3
 5
  1   6
 6
              1
 7
    6, 0.185E 3, 1.226E 3, 1.096E-3, 2.210E-3, 0.647E-3, 0.236E 3
 8
    6,  0 0124,  0.0305,  0.1110,  0.3010,  1.1300,  3 0000
 9
              1
10
     1      0 0
11
              1
12
     1    4.E 5
17
         -2 5E 03
18
     1        7
19
             1,     1,     1,     1,     1,     1,     1
20
          1 2,   1.0,   0.8,   0 6,   0.4,   0.2,   0.0
21
          6 05,  3.63,  11.81, 17 19,  19.84,  20 78,  21.70
22
    12,  0.20, 0.30, 0 40, 0 43, 0 46, 0.50, 0 53
        0.56, 0.60, 0.63, 0.66, 0.70
23
  0   1   1   1   1   1   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0
```

```
24
 1   1   1   1   1   1   1   1   1
28
   1
29
   5    0.0    0 5    1.0    -1.5    -2.0
30
   0
0
```

Table A.6. LAPUR calculations for a typical BWR/3
(DR = decay ratio, NF = natural frequency of oscillation)

Flow (Mlb/h)	Power (MW)	Corewide*		Out-of-phase		Hot-channel		Corewide**	
		DR	NF (Hz)	DR	NF (Hz)	DR	NF (Hz)	DR	NF (Hz)
10	800			0.93	0.31	0.80	0.27	1.13	0.31
20	800	0.82	0.26	0.36	0.34	0.32	0.29	0.64	0.34
20	1000			0.65	0.38	0.48	0.34	0.85	0.38
20	1200			0.95	0.41	0.67	0.37	1.07	0.41
29.4	1060	0.68	0.32	0.28	0.41	0.28	0.36	0.50	0.42
29.4	1200	0.79	0.34						
29.4	1500			0.79	0.50	0.55	0.45	0.86	0.50
44	1306	0.47	0.37	0.14	0.48	0.17	0.42	0.29	0.48
44	1783	0.64	0.44	0.45	0.59	0.38	0.54	0.51	0.58
44	2000	0.69	0.43	0.66	0.62	0.49	0.57	0.64	0.61
44	2500	0.85	0.51	1.05	0.67	0.84	0.62	0.98	0.66
50	2500			0.82	0.70	0.59	0.65	0.73	0.70
50	2600			0.85	0.70	0.66	0.66	0.80	0.70
50	3000	0.79	0.57						
58.7	2109	0.41	0.50	0.22	0.68	0.28	0.66	0.27	0.66
58.7	3000			0.64	0.84	0.50	0.77	0.51	0.81
58.7	3200			0.82	0.85	0.59	0.79	0.62	0.84

* Using average axial power shape for all channels.
** Using graded power shapes of Fig. A.3.

Table A.7. LAPUR calculations for a typical BWR/5
(DR = decay ratio, NF = natural frequency of oscillation)

Flow (Mlb/h)	Power (MW)	Corewide*		Out-of-phase		Hot-channel		Corewide**	
		DR	NF (Hz)	DR	NF (Hz)	DR	NF (Hz)	DR	NF (Hz)
10	500	0.76	0.17	0.52	0.22	0.74	0.20	0.75	0.22
10	600	1.06	0.18	0.74	0.24			0.96	0.24
20	800	0.76	0.24	0.49	0.31	0.40	0.27	0.65	0.31
20	1000	0.96	0.27	0.84	0.35	0.63	0.31	0.93	0.34
32.5	1396	0.73	0.35	0.68	0.46	0.50	0.42	0.72	0.45
32.5	1500	0.78	0.36	0.83	0.47	0.57	0.43	0.82	0.46
32.5	1600	0.83	0.38						
48.7	2200			0.72	0.63	0.53	0.59	0.57	0.61
48.7	2360	0.50	0.49	0.87	0.65	0.62	0.60	0.69	0.63
48.7	2500	0.55	0.50	0.99	0.66	0.70	0.62	0.80	0.64
48.7	3000	0.71	0.55						
48.7	3500	0.94	0.60						
55	2500			0.68	0.69	0.51	0.65	0.49	0.67
55	2700			0.84	0.71	0.61	0.67	0.62	0.69
55	3000	0.50	0.57	1.07	0.75	0.78	0.70	0.84	0.72
55	4000	0.82	0.66						
65	2791	0.32	0.58	0.32	0.78	0.39	0.75	0.23	0.74

* Using average axial power shape for all channels.
** Using graded power shapes of Fig. A.3.

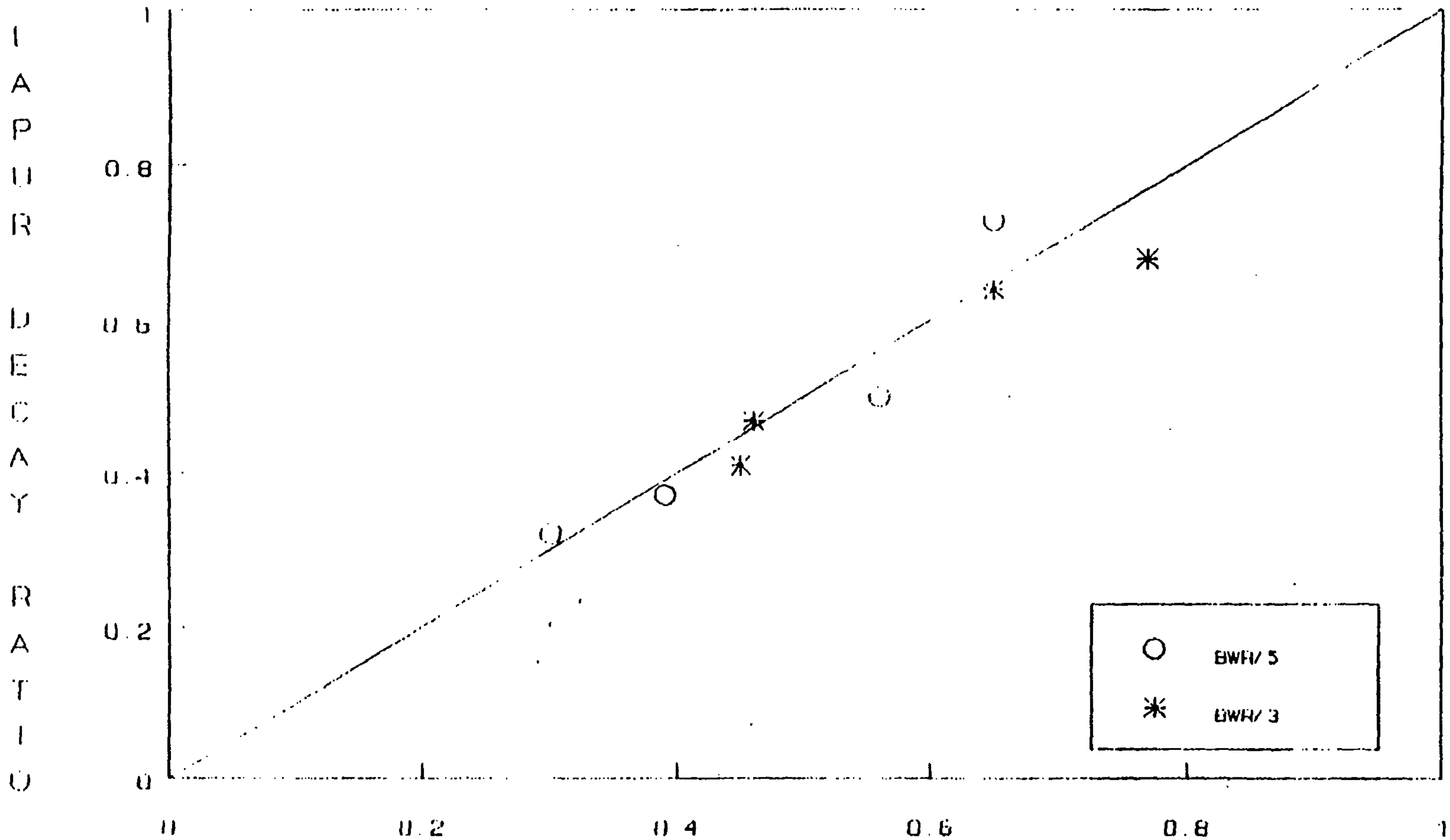

Figure A.1. Comparison between corewide decay ratios calculated by LAPUR and FABLE.

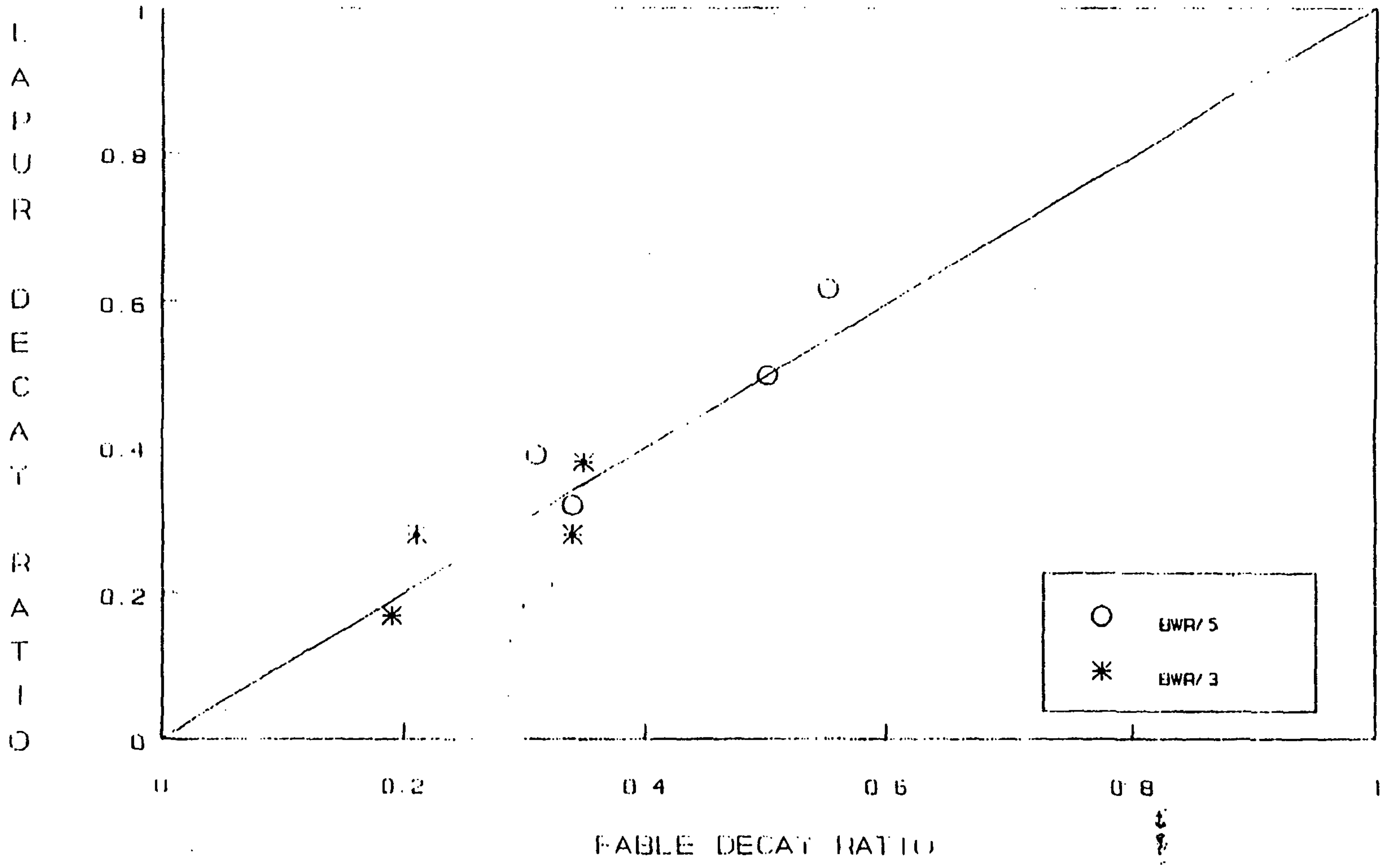

Figure A.2. Comparison between hot-channel decay ratios calculated by LAPUR and FABLE.

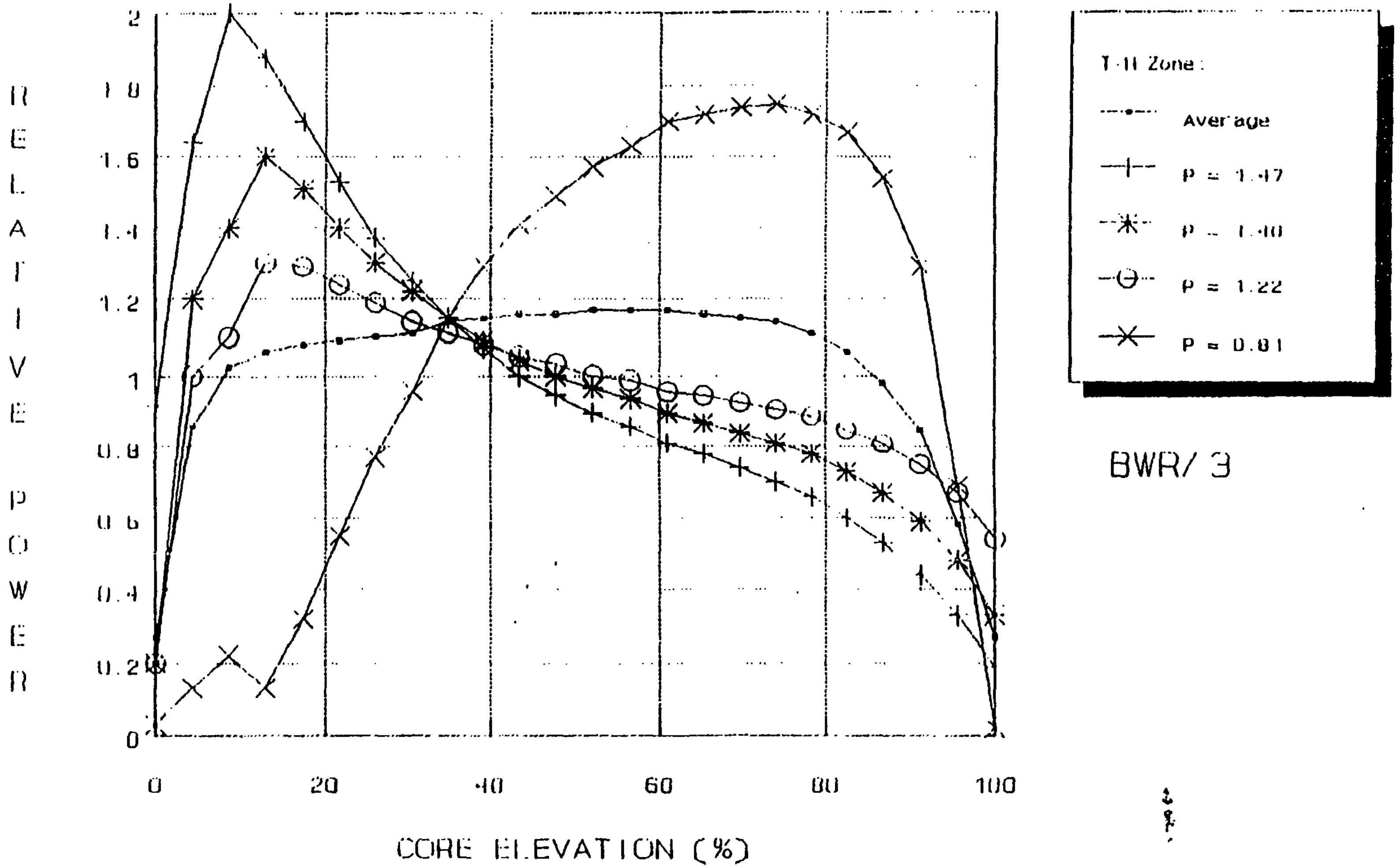

Figure A.3. Power shapes used for hot-channel and out-of-phase mode calculations in a typical BWR/3.

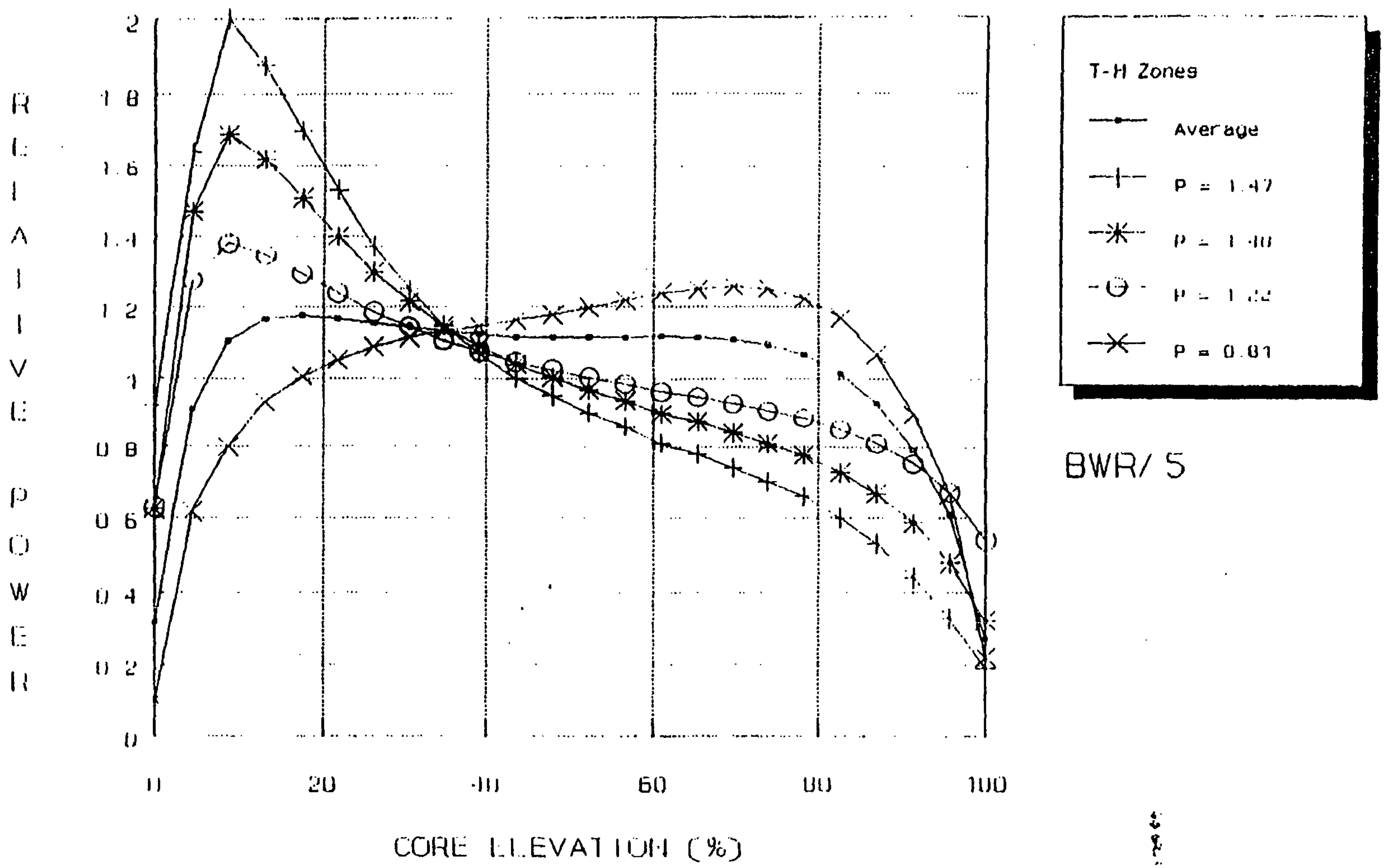

Figure A.4. Power shapes used for hot-channel and out-of-phase mode calculations in a typical BWR/5.

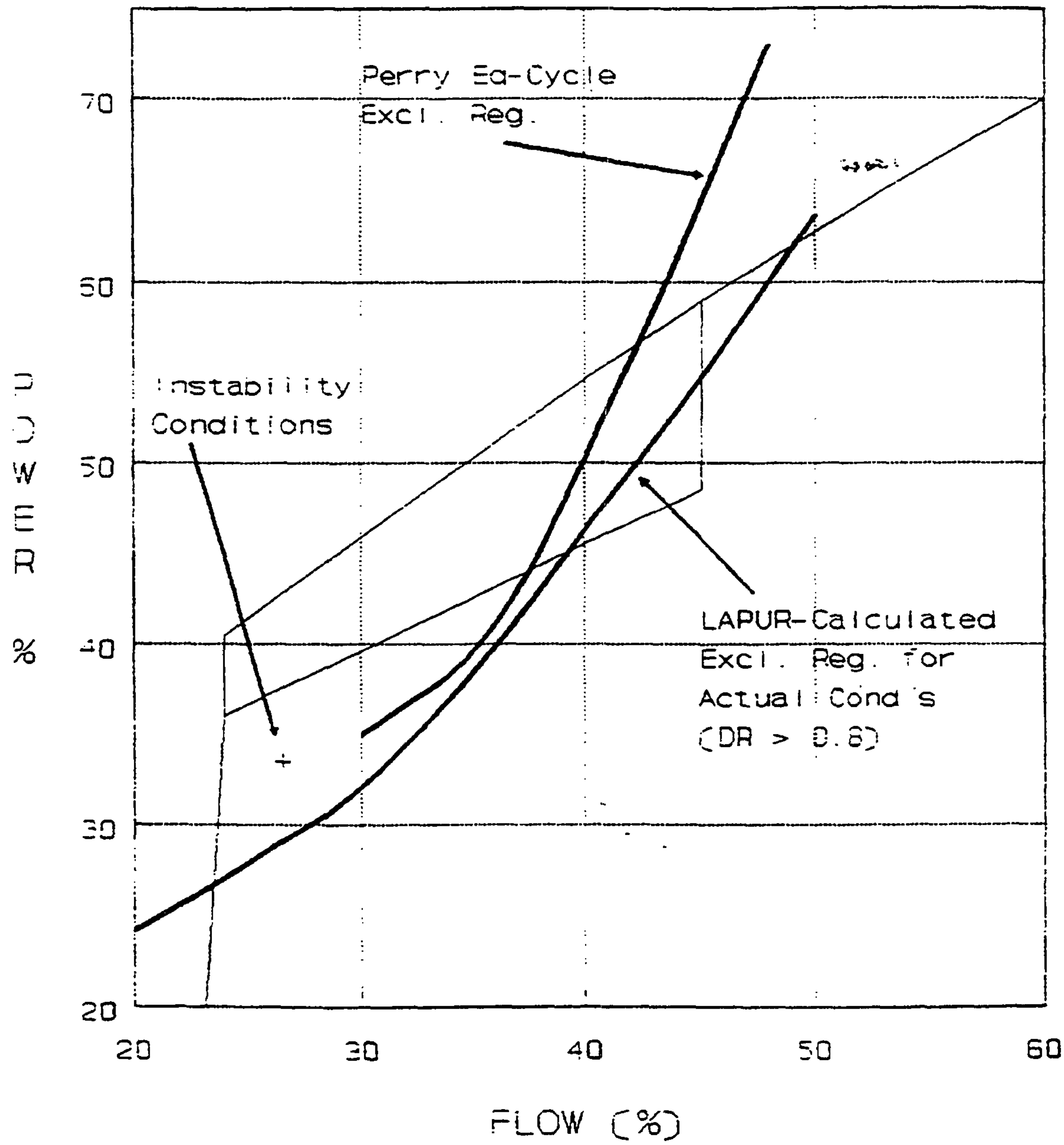

Figure A.5. Comparison between equilibrium-cycle exclusion region and the exclusion region for the specific operating conditions of a BWR/5 instability event.

APPENDIX B
Solution I-D REQUIREMENTS

This section defines a minimum set of items that will have to be provided to complete our review of Solution I-D. These items should be provided for the initial Solution I-D lead plant (Duane Arnold).

1. Describe how the exclusion region for administrative control actions will be calculated and defined.

2. Describe in detail the proposed administrative control actions if the reactor enters the exclusion region.

3. Describe any hardware or administrative control rod block functions that will be associated with the exclusion region. Specifically, describe how these functions are calculated and defined and what type of automated or operator action is required.

4. Describe in detail the information that the operator relies on to provide these administrative controls. In particular, describe how the information is presented to the operator and its "safety classification" (i.e. Class 1-E or not). Explain why this safety classification is adequate.

5. Describe what indications the operator would have in the control room if a power oscillation (either in-phase or out-of-phase) were to develop. Describe the operator actions required under these circumstances.

6. Provide analyses showing the area inside the exclusion region where the flow-biased scram does not provide protection for out-of-phase instabilities. These calculations determine the nonprotection line, which is defined as the line in the power-flow map below which the flow-biased scram does not provide automatic protection. Two lines must be defined:

   6.1 The nonprotection line at the 95% probability level with the initial CPR at technical specification limits.

   6.2 The nonprotection line at the 50% probability level with the expected initial CPR.

7. Provide reasonably bounding analyses showing that oscillations in the out-of-phase mode are highly unlikely in Solution I-D plants operating below the 50%-level nonprotection line. These calculations must be performed along the 50%-level nonprotection line and include at least the following cases:

   7.1 Calculations of core and hot-channel decay ratios using the standard BWROG procedures for exclusion region calculations (NEDO 31960). These calculations must show that the core decay ratio is significantly larger than the hot-channel decay ratio so that the predicted mode of oscillation for these conditions is in-phase. Provide documentation of the radial power distribution (in particular the hot-channel peaking factor) used in these calculations, and justify why the chosen peaking factors are conservative.

7.2 Calculations of core and hot-channel decay ratios using conservatively defined bottom-peaked power shapes that are more representative of startup conditions than the standard BWROG procedure. These calculations must include axial and radial power shapes representative of (1) normal startup and (2) operation with failed feedwater heaters. Document the actual power shapes used and justify their conservatism.

LAPUR CALCULATIONS RELATED TO Solution I-D

A series of calculations have been performed with the LAPUR code to confirm the validity of the BWROG claim that small cores with tight inlet orifices are not likely to have out-of-phase instabilities. The results of our analyses show that indeed (as claimed by the BWROG) small cores and tight inlet orifices are beneficial for the out-of-phase mode. However, this benefit does not appear to be sufficient to completely discard the possibility of out-of-phase instabilities in these types of reactors; therefore, we have requested that the BWROG perform the calculations described in the preceding section. Table B.1 shows some of the results of these analyses.

Effect of tight inlet orifice

For the calculations presented in Table B.1, we prepared a representative LAPUR input deck (shown in Table B.2) with a single thermohydraulic region and calculated the corewide and out-of-phase decay ratios as a function of the inlet restriction coefficient to simulate the differences between Solution I-D plants and others. In plants where solution I-D is applicable, the inlet restriction coefficient is of the order of 35 to 40 velocity heads, while other plants have values of the order of 25 to 30 velocity heads; for example, Duane Arnold (the proposed lead plant for Solution I-D) has an inlet orifice diameter of 2.09 inches, compared to 2.43 inches for LaSalle. We have to note that the conditions (especially the axial power shape) chosen for these analyses are not representative of normal operation, but they are achievable and not necessarily bounding; these conditions were chosen because they tend to excite the out-of-phase mode more than the corewide. Two main conclusions can be drawn from the results in Table B.1:

(1) The smaller inlet orifice by itself does not preclude the possibility of out-of-phase instabilities. For example, at 35 velocity heads, the out-of-phase mode is predicted to be unstable (decay ratio greater than 0.8) even at large eigenvalue separations of \$1.5.

(2) The smaller orifice by itself does not guarantee that the corewide mode will dominate and become unstable before the out-of-phase mode does. For example, at 35 velocity heads, the out-of-phase decay ratio is 0.90 at \$1.0 subcritical, while the corewide decay ratio is only 0.84.

In summary, even though smaller (tight) inlet orifices are beneficial and tend to stabilize the out-of-phase mode, increasing the orifice coefficient by about 10 velocity heads reduces the out-of-phase decay ratio by only 10% to 20% depending on the actual circumstances. Therefore, tight inlet orifice plants are less likely to have out-of-phase instabilities, but given that it only results in a 10% to 20% reduction, this effect by itself is not sufficient to preclude out-of-phase instabilities.

Effect of smaller cores

Smaller cores affect the stability of the out-of-phase mode by increasing the neutron leakage on the core periphery. Larger leakage rates tend to increase the eigenvalue separation between the fundamental and first azimuthal harmonic; the larger the separation, the more stable the out-of-phase mode (see Table B.1 for an example). Our evaluation analyses using the LAPUR code indicate that the net effect of reducing the core size in half is to reduce the out-of-phase decay ratio by 10% to 15%. This evaluation assumes constant loading patterns and fuel types; positive or negative changes of larger magnitude can be achieved by altering the loading patterns or fuel type. Therefore, we conclude that the net effect of the small core size by itself (although beneficial) is not sufficient to preclude out-of-phase instabilities in Solution I-D plants.

In first approximation (assuming a homogenous, cylindrical core), the eigenvalue separation of the first azimuthal mode, ρ_s, is given by

$$\rho_s = \frac{D \Delta B^2}{\nu \Sigma_f} \qquad \text{(B-1)}$$

where D is the diffusion coefficient, $\nu\Sigma_f$ is the fission cross section, and ΔB^2 is the difference in geometric buckling between the fundamental and the first azimuthal modes.

The geometric buckling in a cylinder is approximately proportional to the inverse of the radius square and, therefore, is somehow inversely proportional to the number of bundles in the core. Consequently, if core A has half the number of bundles as core B, core A should have approximately twice the eigenvalue separation of core B. From Table B.1, we observe that doubling the eigenvalue separation results in a reduction of decay ratio of the order of 10% to 15%.

The eigenvalue separation, however, depends on many more parameters than just the core size. For instance, super low leakage loading patterns (SL^{3}P) have very low leakage and result in significantly lower eigenvalue separation than in a core the same size with a conventional loading pattern. Another parameter that affects the eigenvalue separation is the fission cross section [see Eq. (B-1)]; therefore, fuels with high enrichment (to allow for longer refueling cycles) should result in smaller eigenvalue separation that can negate the advantages of the small core.

In summary, the core size is an important parameter that affects the eigenvalue separation, but it is not the only one. It is, thus, hard to justify what the eigenvalue separation of a Solution I-D really is.

Operating experience

An additional argument against Solution I-D is the fact that Swedish reactors [for example, Ringahls-1 (see Reference 5)] have experienced out-of-phase instabilities. Swedish BWRs have very tight inlet orifices and have relatively small cores (for instance, Ringahls-1 has only 648 fuel bundles).

Table B.1. LAPUR-calculated decay ratios as a function of inlet orifice size

		Inlet restriction coefficient (velocity heads)					
		25 vh	30 vh	35 vh	40 vh	45 vh	50 vh
Average-channel decay ratio		0.62	0.57	0.52	0.48	0.44	0.41
Corewide mode decay ratio		0.86	0.85	0.84	0.83	0.82	0.81
Out-of-phase mode decay ratio, if eigenvalue separation is	$\rho = -\$0.5$	1.08	1.02	0.96	0.92	0.87	0.83
	$\rho = -\$1.0$	1.06	0.97	0.90	0.83	0.77	0.71
	$\rho = -\$1.5$	1.01	0.90	0.81	0.73	0.66	0.61

Table B.2. LAPUR5X input for Solution I-D analyses

```
LAPUR5X Test case for BWORG Sol I D
  1
977.0, 490.0, 1000.0, 20.E6, 0.0, 0.0, 0.63, 1.0
  2
1, 24, 0, 1, 0, 0, 0, 1, 0
  3
1, 25
  4
        15.24,  15.24,  15.24,  15.24,  15.24,  15.24,  15.24
        15.24,  15.24,  15.24,  15.24,  15.24,  15.24,  15.24
        15.24,  15.24,  15.24,  15.24,  15.24,  15.24,  15.24
        15.24,  15.24,  15.24,  45.53
  5
        0.95,  1.60,  1.80,  1.70,  1.55,  1.45,  1.30
        1.20,  1.15,  1.10,  1.00,  0.95,  0.92,  0.90
        0.86,  0.83,  0.80,  0.78,  0.72,  0.67,  0.62
        0.50,  0.40,  0.20,  0.00
  7
1,    1
  9
1,   764
 10
1,  30.0
 11
1, -0.280
 13
1,    0.
 14
1,   764
 15
1,    62
 16
1,     1
 17
        1   411.29
 18
        1   238.96
 19
        1   102.09
 20
        1   102.09
 21
        1     1.36
 22
        1     0.1
 23
        1     0.1
 24
        1     1.3
 25
        1     0.125
 26
1,      1
 27
        1    10.42
 28
        1    1.0400
 29
        1    0.5586
 30
        1    0.0373
 31
        1    0.0813
 32
        1    0.1356
 33
        1    0.0114
 34
1,      1
 35
        1        1
 36
             411.29
 37
               1.40
 53
```

```
 1.E-3   1.E-3   1.E-3   2.E-5   1.E-3   1.E-9   1.E-2   5.E-8
54
   1     25
0
```

Table B.3. LAPUR5W input for Solution I-D analyses

```
LAPUR5W Test Case for BWROG Sol I D
1
 1, 1, 1
2
     764
3
     411.29
4
     0.40, -1.5
5
 1   6
6
          1
7
   6   1.95E-4   1.10E-3   9.67E-4   2.09E-3   6.58E-4   1.34E-4
8
   6   0.0127   0.0317   0.0115   0.0331   1.40   3.87
9
          1
10
   1   0.0
11
          1
12
   1   3.29E-5
17
   -2.64 E-03
18
   1     7
19
          1     1     1     1     1     1     1
20
         1.2   1.0   0.8   0.6   0.4   0.2   0.0
21
          -2.662   8.006   18.751   23.450   26.545   27.381   27.805
22
7, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4
23
 0  1  1  1  1  1  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0
24
 1  1  1  1  1  1  1  1  1
28
    1.
29
3, -0.5, -1.0, -1.5
30
    0
 0
```

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1.0 INTRODUCTION

A licensing topical report [1] was submitted to the NRC in May 1991 describing the analytical methodologies developed for the BWROG to resolve the thermal-hydraulic stability issue. Solution concepts using this methodology were also submitted for NRC review and acceptance. Since introducing a new protection system can have a significant impact on plant operation, it was the purpose of the licensing topical report to establish the basis for an understanding between the NRC and the BWR Owners' Group on acceptable analytical methodology and solution concepts. Since the submittal of Reference 1, additional work has been performed for the BWROG and questions have been received from the NRC [2] on the licensing topical report. This supplement provides a summary of the recent BWROG efforts and also provides responses to the NRC questions.

Significant work has been initiated on defining the performance requirements for the hardware solutions. This has led to the need to better define the specific requirements for the hardware, relative to safety classification. In addition, the use of select rod insert (SRI) followed by a delayed scram signal for Option I-A is discussed. These topics represent issues that are the result of the increased emphasis on the details of the system design.

As described in Reference 1, two algorithm concepts have been combined into a single oscillation detection algorithm that makes use of three different characteristics of instabilities to provide a robust detection algorithm. The purpose of the oscillation detection algorithm is to provide a reliable trip function that will result in wide margin to specified acceptable fuel design limits. The algorithm must also be capable of detecting a wide range of instabilities and discriminating between these instabilities and expected neutron flux transients that do not require trip initiation. Details of the oscillation detection algorithm and examples of how the algorithm will be applied are presented herein, along with responses to NRC questions on the licensing topical report.

2.0 SUMMARY AND CONCLUSIONS

Stability licensing methodology and long-term solution concepts have been developed by GE[1] in support of the BWROG Stability Program. The methodologies and solution concepts consider both the prevention and the detection and suppression approaches and provide the basis for protection system designs which are applicable to all BWRs in the U.S.. Supplemental information has been generated which provides additional information on the solution concepts, methodology, and the oscillation detection algorithm. In addition, responses to NRC questions on the licensing topical report have been developed and are included in the Appendix to this report.

The long-term solution concepts which provide for an automatic suppression function represent the introduction of a new reactor trip function that must interface with existing equipment. Based on the definitions provided in the regulations, the stability solutions have been classified as protection systems and are not considered to be "safety-related" (Class 1E). However, since the industry codes and standards are primarily directed toward safety-related requirements, the new hardware and software will be specified as Class 1E for design and procurement. Existing equipment and the necessary plant interfaces will be classified and evaluated against the criteria for protection systems.

SRI has been considered for the automatic suppression function for several of the options. It is also being proposed that SRI be used in conjunction with a delayed full core scram. SRI would provide the initial mitigation function (e.g., reduce power following an entry into the exclusion region), and the scram would only occur if the SRI did not complete the required action (i.e., the exclusion region was not exited). The scram delay time chosen would be small (e.g., 10 seconds) compared to the time required for the reactor to reach conditions that could result in an instability. This provides the required protection against the onset of instabilities while simplifying the SRI design and implementation requirements, providing for potential scram avoidance and significantly reducing the potential for unnecessary scrams.

An objective of the detection and suppression systems has been to provide automatic mitigation of instabilities such that they do not become limiting transient events. This requires the ability to detect instabilities at relatively low oscillation magnitudes. The oscillation detection algorithm has been designed to take advantage of the three dominant characteristics of an instability: (1) period, (2) growth rate, and (3) magnitude. By using these characteristics in the algorithm, it is possible to provide detection of instabilities at low magnitudes and also to avoid tripping on spurious signals. Testing using recorded plant data and simulated data has demonstrated the ability of the oscillation detection algorithm to meet these objectives.

3.0 DEFINITIONS

3.1 OSCILLATION PERIOD

For the purposes of the oscillation detection algorithm, the oscillation period is defined as the time interval between two successive peaks or minima of an evaluated signal.

3.2 OSCILLATION PEAK

For the purposes of the oscillation detection algorithm, a peak is assumed to occur in the oscillation anytime the slope of the evaluated signal changes from positive (or zero) to negative.

3.3 OSCILLATION MINIMUM

For the purposes of the oscillation detection algorithm, a minimum is assumed to occur in the oscillation anytime the slope of the evaluated signal changes from negative (or zero) to positive.

3.4 SETPOINT OVERSHOOT

During an oscillation, as the evaluated signal increases past the trip setpoint, an automatic suppression function is initiated. Depending on the timing of the suppression function, the oscillation magnitude may continue to the peak of the cycle and may even reach the peak of the next cycle. The maximum amplitude that the oscillating signal reaches before mitigation occurs is the setpoint overshoot.

4.0 SOLUTION DESCRIPTIONS AND GENERAL REQUIREMENTS

Section 4 of Reference 1 provides descriptions and general requirements for the solution concepts. Appendix A of Reference 1 provides additional information on each of the solution concepts. Additional work has been performed in defining the safety classification and potential use of select rod insertion for the solution options and is summarized in the following sections.

4.1 STABILITY LONG-TERM SOLUTION CLASSIFICATION

GDC 20 from 10CFR50, Appendix A, requires that protection systems "... be designed ... to initiate automatically the operation of appropriate systems ... to assure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences ...". By this definition, the stability long-term solutions can be classified as protection systems. The primary fuel design limit that is being protected during potential instabilities is the Minimum Critical Power Ratio (MCPR) Safety Limit. In addition, the long-term solutions are not required to assure the integrity of the reactor coolant pressure boundary, the capability to shut down the reactor and maintain it in a safe shutdown condition, or the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures. Therefore, it can be concluded that the long-term solutions are not required to be classified as "safety-related" (or Class 1E).

When designing systems, the applicable requirements are identified to ensure that the system will function under the required conditions. In current regulations, a clear distinction does not exist between "protection systems" and "safety-related". GDCs 21 through 24 provide general requirements for the design of protection systems, and IEEE-279 is specifically identified for the design of protection systems. However, most industry codes and standards are directed toward the design of "safety-related" systems. IEEE-279 places requirements on equipment design which are more restrictive than commercial grade equipment but does not require that the design satisfy all "safety-related" requirements.

To satisfy the necessary requirements for the long-term solutions, the new hardware and software designs will be specified as Class 1E for the design and procurement activities. This will simplify the process of identifying the necessary requirements and will also provide for a highly reliable protection system. Existing systems and interfaces will be classified and evaluated against the appropriate IEEE-279 requirements. An example of an interface that would not be required to meet the Class 1E requirements would be the drive flow signals currently used in the Neutron Monitoring System (NMS). These signals provide inputs necessary to define exclusion region boundaries in several of the solution concepts.

4.2 SELECT ROD INSERT/DELAYED SCRAM APPLICATION TO OPTION I-A

Option I-A (Appendix A of Reference 1) provides for automatic regional exclusion to prevent the reactor from operating under conditions which could result in an instability. The region is defined to provide assurance that an instability will not occur outside the exclusion region. If a change in core power or core flow occurs such that the exclusion region is entered, the Option I-A design will automatically initiate an automatic suppression function (ASF) to reduce core thermal power such that the region is exited. This ASF can be either a full core scram or SRI in which only a selected number of control rods scram. For the SRI function, the control rods would be selected to ensure that the power is reduced such that the region is exited. This will require periodic review of the plant's flow control line and control rod pattern to ensure that a sufficient number and distribution of control rods have been selected.

An alternative application of the SRI function has been defined in which the SRI will be combined with a delayed scram. As discussed above, SRI will be automatically initiated upon entry into the exclusion region. However, if after a short time (e.g., approximately 10 seconds) the region has not been exited, an automatic reactor scram will be initiated. The reactor scram provides the necessary prevention of oscillations as required by GDC-12. The timer is selected to be less than the time required for reactor conditions to be established which could result in oscillations which could potentially exceed the MCPR Safety Limit.

This combination of SRI and delayed reactor scram satisfies the necessary requirements for the exclusion region options. The automatic reactor scram is a highly reliable ASF that is already an integral part of the reactor protection system. The SRI function can be used to prevent unnecessary trips by initially reducing the reactor core thermal power to a point below the exclusion region. The use of the delayed scram ensures that, should the SRI function not insert a sufficient number of control rods to exit the region, the region will be exited before reactor conditions can be established which could result in oscillations. This combination results in a system that satisfies the necessary protection function while simplifying the design and implementation of the SRI function.

5.0 REGIONAL EXCLUSION LICENSING METHODOLOGY

The methodology for defining power/flow regions where instabilities can occur is documented in Section 5 of Reference 1. The boundary of this exclusion region is established through the use of an analysis procedure and stability criteria which are demonstrated to be conservative relative to known instability events. Additional information is provided concerning the origin of the stability criteria, details of the procedure power shapes, and the effects of the bias correction factor.

5.1 STABILITY CRITERIA

In Section 5.1 of Reference 1, the development of stability acceptance criteria based on the calculated core and channel hydrodynamic decay ratios is discussed. These criteria are based on FABLE/BYPSS qualification to test data (used to estimate the calculational uncertainty in core and channel decay ratios), Caorso and Leibstadt regional oscillation test data, and estimated regional decay ratio calculations with a separate frequency domain code (ODYSY, Reference 3). The latter considerations were used to estimate the potential conditions under which regional oscillations might occur. The stability criteria are shown in Figure 5-1 and the core and channel decay ratios that define the criteria are provided in Table 5-1.

To estimate the regional decay ratio, ODYSY was used with the addition of a power feedback transfer function for individual channel hydrodynamic calculations. The channel hydraulics for this model are based on the GE one-dimensional transient model, ODYN (Reference 4). The one-dimensional conservation equations of mass and energy are linearized and the Laplace transform taken, such that small-perturbation techniques can be used. Perturbations in local flow variables (such as liquid and vapor velocities, void fraction) are then used in the momentum equation to calculate pressure drop perturbations. This form of the model is capable of calculating the standard channel hydrodynamic decay ratio.

For a regional oscillation, changes in neutron flux occur through coupling with the void reactivity in a harmonic mode of the neutron flux. This feedback term is not included with single channel models, since the heat flux is assumed to remain constant. The void reactivity feedback can be simulated by modeling the neutronics, specifically the harmonic modes. However, the feedback can also be estimated using results from the GE 3D BWR Simulator (Reference 5), which predicts the change in neutron flux for a given change in moderator density. The neutron flux change is a direct result of changes in the local moderator density, for the case of localized perturbations. For regional oscillations, this is a good assumption, since the fundamental mode is not significantly perturbed. Details of the calculation of the power feedback term and how it is incorporated into the channel decay ratio calculation are contained in Section A.3.3.2 of Reference 1.

The regional feedback model was compared to stability data for several known regional oscillations. For Caorso Cycle 2 stability tests, tests at KRB-B, and initial cycle testing at Leibstadt, the above procedure was followed to estimate the power feedback term for the hot and average channels. In all cases, the pure channel hydrodynamic decay ratios (no power feedback) for the hot channels were less than 1.0. When the power feedback term was included, the hot channels were predicted to have "regional" decay ratios greater than 1.0 for conditions of known regional oscillations. Also, the average channels were predicted to have "regional" decay ratios close to 1.0 ($\geq$ 0.9). In general, the channel decay ratios increased by approximately 0.3 when the power feedback term was included. Additional sensitivity studies were performed to determine the sensitivity of the results to conditions of varying core decay ratios.

As the core decay ratio increased, the change in channel decay ratio was observed to increase when the power feedback term was included. Also, as the channel decay ratio increased, the relative change in individual channel decay ratio increased. This is expected, since the channels with higher decay ratios are more responsive and have a larger change in moderator density during an oscillation. For a constant power feedback coefficient, this would result in more feedback to the hydraulics with a resulting increase in decay ratio.

For the three cores analyzed (Caorso, KRB-B, and Leibstadt), the number of fuel bundles were 560, 748 and 648, respectively. These represent relatively large cores which have low eigenvalue separation for the first-order azimuthal harmonic modes, which were the observed modes for the test conditions. Since a bounding curve was chosen to represent the stability criteria and the three plants have relatively low eigenvalue separation, the resulting stability criteria are applicable to the current range of core sizes, and are expected to be conservative for small diameter cores. These core sizes have only been used in the development of the stability criteria and do not imply, in any way, the actual oscillation mode for a specific plant. The oscillation mode is determined by the physical characteristics of the plant, including the fuel design and the fuel inlet orificing.

5.2 REGION BOUNDARY DEFINITION PROCEDURE

Section 5.2.3 of Reference 1 defines the axial power shapes used in the core and channel decay ratio calculations. The following sections provide more detail concerning the definition of these power distributions.

5.2.1 Hot Channel Decay Ratio Calculations

The hot channel decay ratio is calculated for each specified condition and an axial power distribution is assumed that is independent of the core and fuel design. The original determination and bases for these power shapes were discussed in Section 5.2.3 of Reference 1. The hot channel axial power shape is based only on the power/flow conditions that are being analyzed. Depending on the analyzed power/flow conditions, one of three power shapes is used for the hot channel. The power/flow operating domain is divided into three sections: (1) natural circulation operation, (2) forced circulation operation that is representative of startup conditions (assumed to be less than 60% of rated core flow), and (3) high power operation (assumed to be greater than or equal to 60% of rated core flow). The three regions are shown in Figure 5-2 (designated as Natural Circulation, Startup, and High Power). The hot channel axial power distributions associated with the three regions defined in Figure 5-2 are specified in Table 5-2.

5.2.2 Core Decay Ratio

For calculation of the core decay ratio, the fuel assemblies are grouped into hydraulic channel groups, where assemblies in the same channel group are assumed to have the same radial and axial peaking factors. In general, one channel group is assigned to represent the highest powered fuel assembly for each fuel type (hot channels), and one channel group is assumed to represent the peripheral fuel assemblies (peripheral channel group). The remaining fuel assemblies are distributed among several channel groups according to their radial peaking factors (average channel groups). The specification for the hot channel axial power distribution is described in Section 5.2.1.

For each of the average channel groups and the peripheral channel group, the axial power distribution is assumed to be the same and is the calculated core average end-of-cycle (EOC) Haling axial power distribution. For all conditions other than natural circulation, the core average EOC Haling axial power distribution at rated power/flow conditions is used. For evaluations at natural circulation, the EOC Haling exposure distribution is used to calculate the core average axial power distribution at natural circulation and the rated rod line. These axial power distributions are based on calculations of specific core and fuel designs and are calculated for each specific representative plant in a plant group. Reference 1 contains several examples of calculated EOC Haling axial power distributions.

5.3 APPLICATION OF REGION BOUNDARY METHODOLOGY

Sections 5.3 and A.3.3.1 of Reference 1 document the application of the region boundary definition procedure defined in Section 5.2 of Reference 1. Exclusion regions were defined for the Perry BWR/6 plant for Cycle 2 and a representative equilibrium cycle, and also for the Duane Arnold BWR/4 plant for Cycle 10. Each of these examples has applied a FABLE/BYPSS bias correction factor (Section 5.1 of Reference 1) to account for the observed bias between FABLE/BYPSS calculations and measured plant data. The bias is a function of power, flow, power-to-flow ratio, and power density and, therefore, varies for each core condition analyzed. The bias correction factors applied to the FABLE/BYPSS calculated core decay ratios for the conditions used to generate the three exclusion regions are shown in Figure 5-3. For each of the three plants/cycles, a second exclusion region was calculated using FABLE/BYPSS decay ratios without the bias correction factor. For these three plants/cycles, the upper boundary of the exclusion region increased along the maximum rod line by an average of 1.6% flow. The lower boundary along the natural circulation flow line decreased by an average of 2.9% in power. The impact of the bias correction factor on the exclusion region is dependent on the power/flow conditions analyzed and also on the relationship between the core and channel decay ratios and the stability criteria of Figure 5-1.

Table 5-1
FABLE/BYPSS STABILITY CRITERIA

Channel Decay Ratio	Core Decay Ratio
0.00	0.80
0.56	0.80
0.58	0.70
0.61	0.60
0.63	0.50
0.67	0.40
0.72	0.30
0.79	0.20
0.80	0.19
0.80	0.00

Table 5-2
HOT CHANNEL AXIAL POWER DISTRIBUTION

Axial Node	Natural Circulation[1]	Startup[2]	High Power[3]
1 (Bottom)	0.95	0.92	1.05
2	1.58	1.64	1.43
3	1.80	2.00	1.50
4	1.71	1.88	1.40
5	1.57	1.70	1.28
6	1.43	1.53	1.19
7	1.30	1.37	1.14
8	1.20	1.25	1.12
9	1.12	1.15	1.10
10	1.06	1.07	1.10
11	1.00	1.00	1.10
12	0.96	0.95	1.09
13	0.93	0.90	1.08
14	0.90	0.86	1.04
15	0.86	0.81	1.00
16	0.84	0.78	0.95
17	0.81	0.74	0.91
18	0.78	0.70	0.87
19	0.74	0.66	0.81
20	0.67	0.60	0.76
21	0.62	0.53	0.69
22	0.53	0.44	0.61
23	0.41	0.33	0.49
24 (Top)	0.23	0.19	0.29

1 Used for natural circulation conditions.

2 Used for forced circulation startup type conditions with core flow less than 60% of rated core flow.

3 Used for high power conditions where core flow is greater than or equal to 60% of rated core flow.

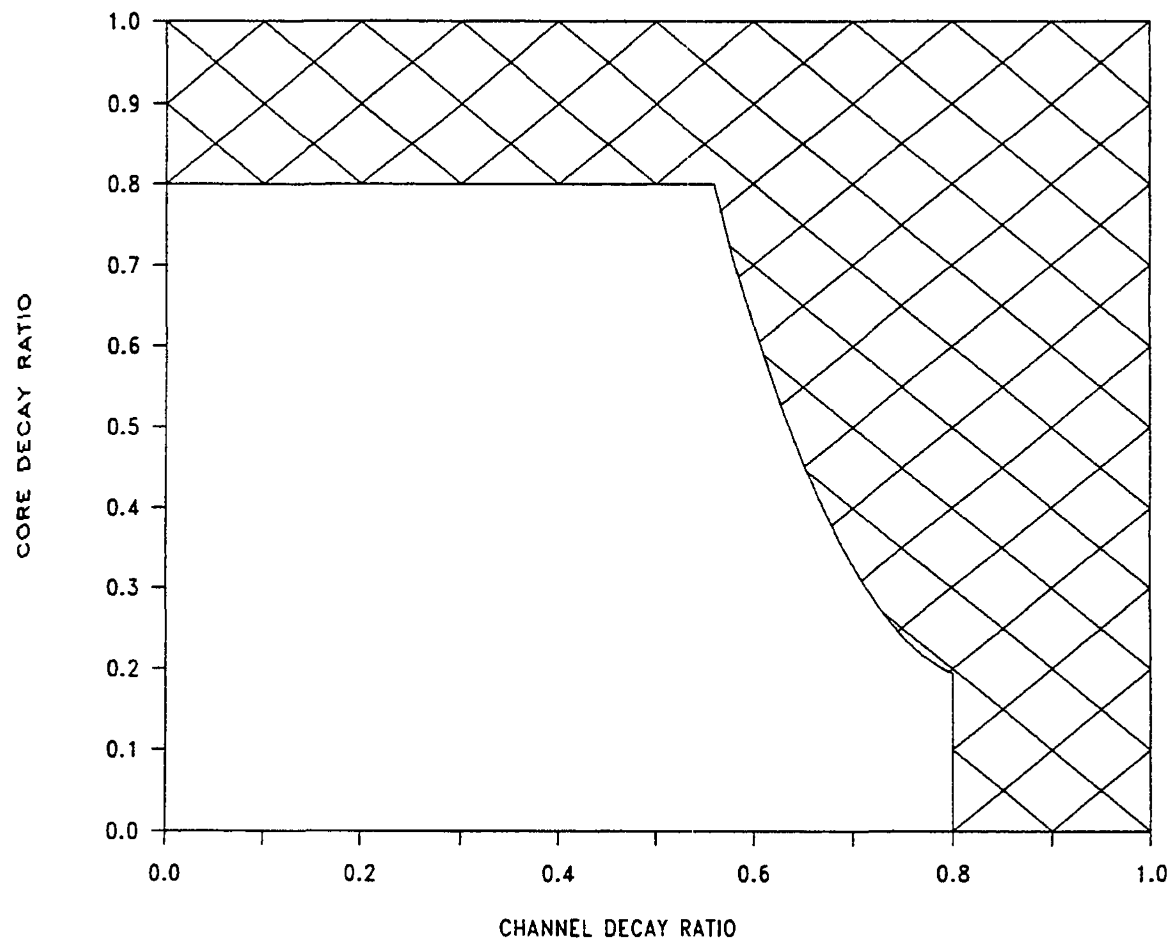


Figure 5-1. FABLE/BYPSS Stability Criteria

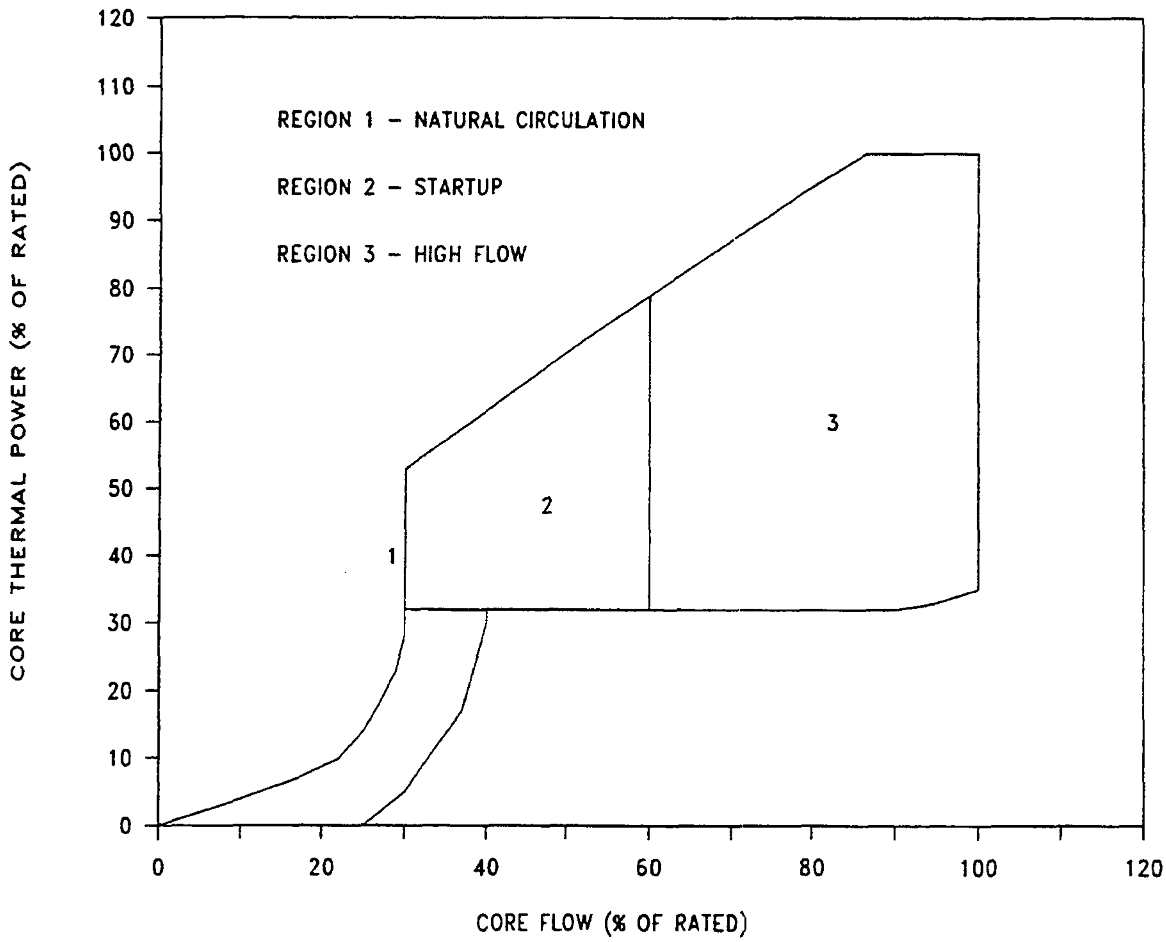


Figure 5-2. Hot Channel Axial Power Shapes - Region Definitions

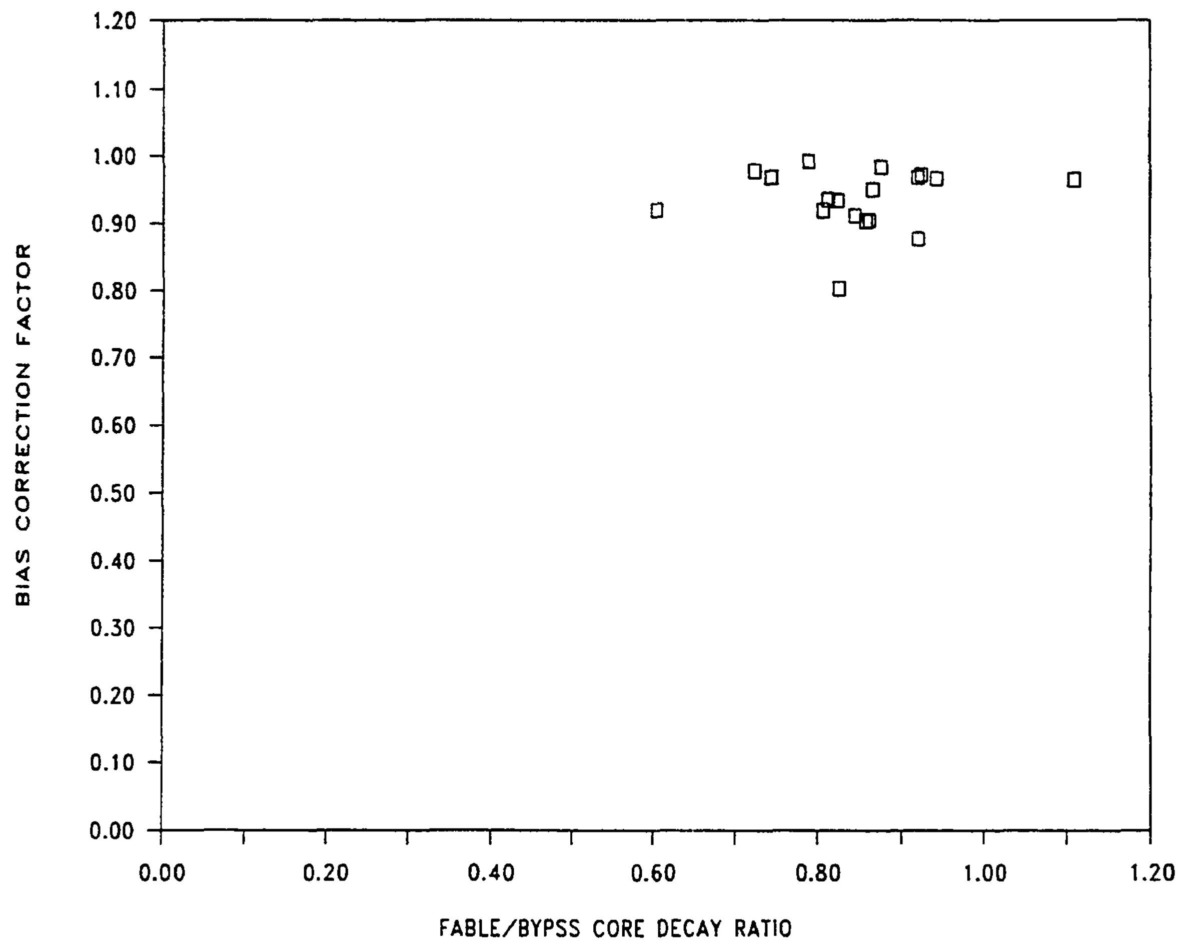


Figure 5-3. Bias Correction Factors

6.0 DETECTION AND SUPPRESSION LICENSING METHODOLOGY

The methodology for evaluating the response of detection and suppression systems is documented in Section 6 of Reference 1. Appendix B of Reference 1 describes several oscillation detection algorithms that have been designed to recognize the presence of instabilities while discriminating against normally occurring neutron flux transients. The overall objective of the oscillation detection algorithm is to reliably detect expected instabilities at a low magnitude such that mitigation can occur well before the MCPR Safety Limit is exceeded. Based on analysis of margin to the MCPR Safety Limit and testing of the various algorithms against recorded plant data and simulated signals, a combined oscillation detection algorithm has been developed that uses the characteristics of both algorithms described in Appendix B of Reference 1. This allows the trip setpoints to be set near an oscillation magnitude of 10% above its average value, thereby providing margin to the MCPR Safety Limit while still providing appropriate trip avoidance by requiring a high level of confirmation prior to trip. Additional information is provided concerning the detection algorithms.

6.1 OSCILLATION DETECTION ALGORITHM DESCRIPTION

Stability-related neutron flux oscillations in a BWR exhibit known characteristics (e.g., a dominant frequency in the range of 0.3 to 0.7 Hz) that are used in the design of the trip algorithm. As the stability threshold is crossed, oscillations begin to grow to a limit cycle (constant oscillation magnitude). The rate of growth of the oscillations is determined by the reactor conditions, how rapidly the condition is entered, and also by the presence of perturbations in the system. In general, the approach to a limit cycle in the magnitude range of interest (prior to trip) is relatively gradual. These characteristics allow an algorithm to be designed that is capable of discriminating between stability-related neutron flux oscillations and other expected neutron flux variations.

The oscillation detection algorithm is based on the detection of the three characteristics described above: (1) periodic behavior which results in peaks and minima occurring at approximately fixed intervals, (2) growth rate which results in an overall increase in magnitude from peak to peak, and (3) absolute magnitude. Use of all three characteristics provides an oscillation detection algorithm that is robust and able to detect a wide range of known instabilities and simulated instabilities, while avoiding spurious trips during expected neutron flux transients.

The oscillation detection algorithm is based on the evaluation of LPRM signals, either individually or in small groups or cells as discussed in Reference 1. The input signal is first filtered (referred to as the "conditioning" filter) to remove noise components with frequencies above the range of interest (i.e., greater than 0.7 Hz). Typically, this is accomplished with a filter with a corner frequency of 1.5 to 2.5 Hz. The effect of applying a filter with a 1.5 Hz corner frequency to a signal with a decay ratio of approximately 0.6 is shown in Figure 6-1. Figure 6-2 shows the effect of applying the same filter to a signal that is near limit cycle conditions. These filters are effective in removing the higher frequency components, while introducing very little attenuation and delay to the desired signal.

The conditioned signal is then filtered (referred to as the "averaging" filter) to produce a time-averaged value. This time-averaged value is used to produce a normalized signal by dividing the conditioned signal by the time-averaged value. This results in signals that typically are close to 1.0, and the variation is representative of the fractional change from their average value (e.g., a signal of 1.10 is 10% above its average value). This also allows the determination of oscillatory behavior about an average value which is the basis for several aspects of the algorithm. The normalized signal is referred to as the "relative signal value".

6.1.1 Amplitude-Based Portion

The amplitude-based portion of the oscillation detection algorithm is described in detail in Section B.1 of Reference 1. The relative signal value is continuously compared to a threshold setpoint, S_1 (Figure 6-3), to determine if the signal value is greater than expected noise levels. If the relative signal value exceeds S_1, then the algorithm begins to look for oscillatory behavior that is within the expected range of frequencies. If the signal is oscillating, then an analogous threshold setpoint that is below the average value of 1.0 (S_2) should be reached by the signal within one-half of an oscillation period. The oscillation detection algorithm evaluates the relative signal value to determine if this occurs in the expected time frame. If the signal goes below S_2 in the expected time, then the algorithm begins to look for the next half of the oscillation period which will result in a peak. If the relative signal value then exceeds the trip setpoint (S_{max}) in the next half-period, a trip is generated for the respective channel.

This portion of the oscillation detection algorithm is referred to as the amplitude-based portion, since it relies primarily on the amplitude characteristics of the oscillation while using a relatively simple measure of the oscillation frequency as a means of confirmation. If at any time during the evaluation a setpoint is not exceeded in the expected time frame, the algorithm is reset and it begins to look for the signal to exceed S_1. It is possible for successive cycles to exceed S_1 and still not result in an amplitude trip if the absolute oscillation magnitude remains below S_{max}.

6.1.2 Growth Rate-Based Portion

The growth rate-based portion of the oscillation detection algorithm follows the same logic as the amplitude-based portion, except that a trip is initiated if the relative signal value exceeds S_3, after exceeding S_1 and S_2 in the expected time frames. The growth rate setpoint, S_3 (Figure 6-3), is based on the peak (P_1) from the previous cycle which exceeded S_1, and is set such that if the signal exhibits a growth rate (analogous to decay ratio, used when the signal magnitude is growing instead of decaying) of DR_3, a trip will occur. S_3 is defined as:

$$S_3 = (P_1 - 1.0) * DR_3 + 1.0 \qquad (6\text{-}1)$$

As with the amplitude-based portion of the algorithm, the growth rate-based portion rate uses a simple measure of the oscillation frequency as confirmation that an instability is occurring.

6.1.3 Period-Based Portion

The period-based portion of the oscillation detection algorithm is described in detail in Section B.2 of Reference 1. Instead of first looking at the relative signal value amplitude, the period-based portion of the oscillation detection algorithm examines the signal to determine the time between successive peaks and successive minima (T1 through T10 in Figure 6-4). For an oscillatory signal, these times represent an estimate of the oscillation period. Since the oscillation period of BWR density-wave instabilities is well known and relatively constant (based on a frequency range of 0.3 to 0.7 Hz), the algorithm only accepts periods that are within the expected range. The first period detected within the expected range is defined as the base period, T_0 (T1 in Figure 6-4). The next period calculated (either based on two successive peaks or minima, depending on whether the base period was from two successive minima or peaks) is then compared to the base period to determine if oscillatory behavior is present. As shown in Figure 6-4, the next period, T2, is within 0.05 seconds of the base period.

Based on evaluation of plant data, it has been found that, as the decay ratio of the input signal increases, the likelihood that the next period will be equal to the base period also increases. In the limit, for an input signal with a decay ratio of 1.0, each successive period is equal to the base period. To detect instabilities at threshold levels, successive periods are compared to determine if they are within a small tolerance, $\pm\epsilon$. This tolerance is typically on the order of several times the signal sample interval. If the current period is equal to the base period, within the tolerance, then this is considered to be a confirmation, and N is incremented by one, where N is the successive confirmation count (shown in Figure 6-4 by periods T1 and T2). To smooth out the effects of a finite sampling interval, a new base period is then calculated that is equal to the average of the consecutively confirmed periods (for T1 and T2 in Figure 6-4, the new base period is 1.625 seconds). The process then continues as the next period is compared to the new base period. Successive confirmations result in an increase in N, the number of confirmations. A large number of successive confirmations is direct evidence that the reactor is approaching an instability.

If any of the current periods are not within the specified tolerance, the confirmation count is reset to zero, and the current period is tested to determine if it should be considered a new base period (i.e., is it within the expected frequency range). In Figure 6-4, period T3 is not close to the base period and the confirmation count is reset. T3 and T4 are also outside the expected period range and are not counted as base periods. The process then continues with the determination of the next period. In Figure 6-4, T5 is selected as a new base period and periods T6 and T7 are close enough to result in two consecutive confirmations. However, period T8 is outside the allowed tolerance and the logic is reset again.

An example of measured plant data in which an instability occurred after about eight minutes is shown in Figure 6-5. An autocorrelation decay ratio is also shown in the figure to illustrate the approach to the instability. The oscillation magnitude is represented by the relative signal value with an average value of 1.0. To illustrate the period-based portion of the oscillation detection algorithm, the number of successive confirmations has also been included in the figure, and has been divided by 10 to allow convenient scaling for the figure.

For the first few minutes of the event shown in Figure 6-5, the signal is relatively stable (decay ratio ≈ 0.5 to 0.8), with a low oscillation magnitude (between 0.97 and 1.03). During the portion of the data when the decay ratio is less than 0.7, there are only a few occasions where the confirmation count is equal to one or two, which is indicative of stable operation. This behavior can be explained by observing the local peaks and minima that are superimposed on the approximately 2.0 second period (Figure 6-1). These local peaks and minima produce small periods that are outside the range of expected frequencies and therefore will not result in confirmations. It is this behavior that allows the period-based portion of the algorithm to discriminate between normally occurring neutron flux noise and an instability. During this portion of the data, the amplitude- and growth rate-based portions of the algorithm would indicate that the signal magnitude is not above the expected threshold value (S_1).

Between five and eight minutes, the signal begins to show an increase in decay ratio (control rods were being withdrawn at low core flow), ultimately resulting in an instability and a limit cycle oscillation with a magnitude near 1.20. As the decay ratio increases, the number of successive confirmations increases (Figure 6-5). At approximately five to six minutes, the number of confirmations increases and goes off scale, indicating successive confirmations during the time when the oscillation is fully developed. Several times during the next few minutes, the confirmation count is reset and then again increases and goes off scale. At approximately 11 minutes into the event, control rods are reinserted and the plant is stabilized. At this point, the confirmation count is reset to zero and the subsequent stable behavior is characterized by six or less successive confirmations. As shown in Figure 6-5, the behavior of the period confirmations closely tracks the approach to an instability and is thus a good indicator of an instability.

Once a sufficient number of successive confirmations ($\geq N_p$) has been detected to indicate a high probability of an instability, channel trip is initiated if the oscillation magnitude exceeds the period-based trip setpoint, S_p. For the period-based portion of the oscillation detection algorithm, the primary characteristic is the oscillation period, and the oscillation magnitude is used as a confirmation that an instability is occurring with a magnitude above the normal noise level.

6.2 ALGORITHM PARAMETERS

The previous sections and Reference 1 have defined various parameters that form a part of the oscillation detection algorithm. Significant testing has been performed to determine the appropriate range of each parameter.

However, final values will be dependent on the full application of the detection and suppression licensing methodology to actual trip systems and core and fuel designs. A complete list of these parameters, including a discussion of their effect on the performance of the oscillation detection algorithm, follows:

Amplitude- and Growth Rate-Based Parameters

S_1 = threshold setpoint
S_2 = minimum threshold setpoint
DR_3 = growth rate factor
S_{max} = maximum amplitude trip setpoint
T_1 = time window for detection of signal going below S_2 (sec)
T_2 = time window for detection of signal exceeding S_3 or S_{max} (sec)

Period-Based Parameters

TMIN = minimum oscillation period (sec)
TMAX = maximum oscillation period (sec)
$\pm\epsilon$ = period tolerance (sec)
N_p = confirmation count trip setpoint
S_p = period-based amplitude trip setpoint

Other Parameters

f_c = corner frequency for conditioning filter (Hz)
P_c = order of conditioning filter (number of poles)
T_a = time constant for averaging filter (sec)
P_a = order of averaging filter (number of poles)
t_s = sample interval (sec)

(1) Threshold Setpoint (S_1)

The threshold setpoint (S_1) is used in the amplitude- and growth rate-based portion of the oscillation detection algorithm to screen out normally occurring neutron flux noise. This noise is of a magnitude and characteristic that does not impact MCPR. As the threshold setpoint is reduced, the algorithm begins to evaluate more flux variations, and in the limit, with S_1 set below the normally occurring noise level, the amplitude-based portion of the algorithm simply becomes a detection of a single flux spike. Since this is not an objective of the algorithm, the threshold setpoint is always set at some level above the expected noise level. As the threshold setpoint is increased, the time at which the algorithm begins to detect an instability is delayed. This may ultimately result in a relatively large setpoint overshoot (setpoint overshoot is the oscillation signal's maximum amplitude prior to mitigation, in relation to the actual trip setpoint). Therefore, the threshold setpoint must not be set so high that significant overshoot occurs.

To account for the variation of noise level among product lines and the expected increase in noise level during single recirculation loop operation, typical values of S_1 are in the range of 1.10 to 1.20.

(2) Minimum Threshold Setpoint (S_2)

The minimum threshold setpoint is the analogous setpoint to S_1 for the portion of the oscillation that occurs below the average value. It has been observed from test data and from simulations that the neutron flux oscillations do not show a symmetrical pattern about the average value. Since the minimum threshold setpoint is only being used as a confirmation that an instability is occurring, it is conservatively set at a point nearer the average than S_1. Typical values of S_2 are in the range of 0.85 to 0.95.

(3) Growth Rate Factor (DR_3)

The growth rate factor (DR_3) is used to determine the trip setpoint (S_3), which is included in the oscillation detection algorithm to detect rapidly growing oscillations before they reach the maximum amplitude trip setpoint (S_{max}). For fast growing oscillations, the possibility of a large setpoint overshoot is greater, since the change in signal amplitude from one cycle to the next is larger. This may result in one cycle just missing S_{max}, with the next cycle significantly overshooting the maximum setpoint. S_3 is therefore calculated based on the previous oscillation peak, such that if the signal is growing with a growth rate greater than DR_3, trip will occur in the next oscillation cycle. This can result in a trip before S_{max} is reached, thereby reducing the final maximum amplitude that the oscillation reaches. The growth rate trip setpoint is also effective in avoiding spurious trips, since it requires two successive oscillation peaks greater than S_1, with the appropriate timing and with an increasing magnitude.

The growth rate is defined as the fractional increase in oscillation magnitude from cycle to cycle, measured from its average value. Since the relative signal value that is being evaluated by the oscillation algorithm has been normalized to 1.0, the growth rate can be defined as:

$$\text{Growth rate} = (P_{i+1} - 1.0)/(P_i - 1.0) \qquad (6\text{-}2)$$

where P_i = ith oscillation peak.

If the ith oscillation peak is known, the next oscillation peak that would occur, given a growth rate of DR_3, can be predicted by rearranging Equation 6-2 to yield:

$$P_{i+1} = (P_i - 1.0) * DR_3 + 1.0. \qquad (6\text{-}3)$$

This is the same expression as in Equation 6-1 and is used to define S_3, which is the growth rate-based trip setpoint.

The selection of DR_3 is dependent on the choices of S_1 and S_{max}. As an example, for S_1 equal to 1.10, and DR_3 equal to 1.30, if a signal just reaches S_1 in an oscillation cycle, the growth rate trip setpoint for the next cycle will be:

$$S_3 = (1.10 - 1.00) * 1.30 + 1.00 = 1.13.$$

Additionally, the upper limit on DR_3 is governed by the choice of S_{max}. If DR_3 is chosen to be too high, the growth rate trip setpoint (S_3) could always result in being higher than S_{max}, thereby never resulting in a trip. This results in the upper limit of DR_3 being:

$$DR_3 \text{ (max)} = (S_{max} - 1.0)/(S_1 - 1.0). \qquad (6\text{-}4)$$

Typical values for DR_3 are in the range of 1.30 to 1.60.

(4) Maximum Amplitude Trip Setpoint (S_{max})

S_{max} is chosen to limit the maximum amplitude that an oscillation can reach, but relies on a very simple confirmation that a true oscillation exists (i.e., S_1 and S_2). Therefore, the magnitude must be chosen to be above the magnitude of normally occurring neutron flux transients that would not otherwise cause a neutron flux trip. Based on experience from plant operation, these types of neutron flux variations are typically limited to values less than 1.20. Typical values for S_{max} are in the range of 1.30 to 1.50.

(5) Time Window for Minimum Threshold (T_1)

Once S_1 has been exceeded, if the input signal has a characteristic oscillation, it is expected that the signal will decrease and go below the minimum threshold setpoint (S_2) in approximately one-half of a cycle.

If the signal value goes below S2 before or after this time, it is indication that the signal variation is not the result of an instability. Since the expected oscillation frequencies range from 0.3 to 0.7 Hz, the expected half-periods range from 0.7 to 1.7 seconds. To provide some margin in the determination of the minimum threshold, the minimum threshold time window is expected to be in the range of 0.3 to 2.5 seconds. The lower and upper values represent the time window after S1 is exceeded, during which the algorithm will begin to look for the signal to go below S2.

(6) **Time Window for Trip Setpoint (T_2)**

Once S_1 has been exceeded and the signal has gone below S_2 in the appropriate time window, the algorithm begins to search for the signal to exceed either S_3 or S_{max}, within the right time window indicative of the expected oscillation frequencies. Since the time from a minimum to a peak is the same as the basis for T_1, the trip setpoint time window (T_2) is set with the same range (0.3 to 2.5 seconds).

(7) **Minimum Oscillation Period (TMIN)**

For the period-based portion of the oscillation detection algorithm, each period is tested against the expected range of oscillation periods. If the period is outside the expected range, a confirmation will not occur and a base period will not be established. In general, the frequency is expected to range from 0.3 to 0.7 Hz, which results in oscillation periods of 1.4 to 3.3 seconds. Typical values for TMIN (the minimum oscillation period) are in the range of 1.0 to 1.4 seconds.

(8) **Maximum Oscillation Period (TMAX)**

The upper range of expected oscillation periods is defined as TMAX. Typical values for TMAX are in the range of 3.0 to 3.5 seconds.

(9) **Period Tolerance ($\pm\epsilon$)**

The period tolerance ($\pm\epsilon$) is used in the period-based portion of the oscillation detection algorithm to determine if two successive periods are close enough to be considered an indication of an instability. It is known, based on measured plant data, that as an instability is approached, the difference between successive periods decreases, and in the limit, each successive period has the same value (within the resolution of the sampling interval). A large tolerance will indicate that confirmations are occurring even when successive periods show rather large variations. A small tolerance will only give a large number of successive confirmations when a distinct oscillation has developed.

At a minimum, the period tolerance cannot be set less than the sample interval, since this is the minimum period resolution possible, unless interpolation is used to predict the actual peaks and minima. Testing has shown that a period tolerance of approximately ±5% of the oscillation period provides a reasonable screen against unnecessary confirmations while providing early detection of an approaching instability. Typical values of the period tolerance are in the range of ±0.050 to ±0.200 seconds.

(10) **Confirmation Count Trip Setpoint (N_p)**

For each successive period that is within $\pm\epsilon$ of the current base period, a confirmation occurs. The confirmation count (N) only increases when successive periods result in confirmations. Whenever any period does not satisfy the period tolerance criterion, the confirmation count is reset to zero. The period confirmation trip setpoint (N_p) is defined as the number of successive period confirmations that must occur before a trip can be initiated. For the trip to be initiated, the relative signal value must also be above a specified setpoint (S_p).

The objective of the period-based portion of the oscillation detection algorithm is to provide a low trip setpoint based on high confidence that an oscillation is occurring. Testing with actual recorded plant data shows that a large number of confirmations occur prior to the oscillation magnitude significantly exceeding normal noise levels. Testing also shows that, during stable operation at low decay ratios, the number of successive confirmations rarely exceeds five. The number of successive confirmations is also dependent on the period tolerance and on the conditioning filter parameters. Typical values for the confirmation count trip setpoint are in the range of 10 to 15 successive confirmations.

(11) Period-Based Amplitude Trip Setpoint - (S_p)

Once the number of successive confirmations exceeds the trip setpoint (N_p), the final confirmation that an instability is occurring is the magnitude of the oscillation. The period-based amplitude trip setpoint must be set higher than normally occurring noise levels but low enough to satisfy the objective of providing margin to the MCPR Safety Limit. Based on testing with available plant data and simulations of instabilities, with a trip setpoint in the range of 1.10 to 1.15, these objectives can be satisfied. Tripping in this range ensures that the oscillation magnitude increase from cycle to cycle is relatively small, thus reducing the setpoint overshoot.

(12) Conditioning Filter Corner Frequency (f_c)

The conditioning filter is used to filter frequency components in the input signal that are higher than the desired frequency range and which could interfere with the algorithm's ability to determine if an instability is occurring. Based on the known frequency range of interest (0.3 to 0.7 Hz), conditioning filters are typically selected with a corner frequency in the range of 1.0 to 5.0 Hz.

(13) **Conditioning Filter Order (P_c)**

The order or number of poles used in the conditioning filter determines how rapidly the gain falls off beyond the corner frequency.

When combined with the corner frequency, the desired filtering effect can be controlled. Most testing has demonstrated that a two-pole filter is sufficient for the objective of the filter. The effect of any signal filtering must also be considered in the determination of the trip setpoints and final maximum amplitudes, since the filters will introduce some time delay and attenuation of the input signals.

(14) **Averaging Filter Time Constant (T_a)**

The averaging filter is used to provide a normalization of the input signal such that the average signal value is 1.0. This simplifies the choice of trip setpoints, since they are expressed as relative values instead of absolutes. This is necessary because of the variation in LPRM signal levels from detector to detector and plant to plant. The choice of the filter time constant is somewhat arbitrary but has been chosen to represent the fuel thermal time constant, since this is known to provide a good approximation of the average signal during oscillations. Therefore, a typical range of filter time constants is from 5.0 to 7.0 seconds.

(15) **Averaging Filter Order (P_a)**

The order or number of poles for the averaging filter has been typically chosen as two, which provides adequate results based on testing of actual plant data and simulated instabilities. As discussed above, any final choice of filtering parameters must be factored into the determination of trip setpoints, since the filters can introduce delays and attenuation of the input signals.

(16) Sample Interval (t_s)

The oscillation detection systems will rely on the analog-to-digital (A/D) converters to process the input signal voltage and convert the input to a digital value. The rate at which the LPRM signals are sampled is important in determining the ability of the algorithm to recognize instabilities. Sufficient resolution of an oscillation cycle is needed to determine its periodicity and magnitude. For the range of expected oscillation periods, typical values of the sample interval are in the range of 0.050 to 0.100 seconds.

6.3 SUMMARY OF TESTING RESULTS

To demonstrate the effectiveness of the various portions of the algorithm and to determine the optimum range of algorithm parameters, a significant amount of testing has been performed using recorded plant data and simulated neutron flux signals. The plant data have been chosen to represent a wide range of plant types, operating conditions, expected neutron flux transients, and actual instabilities. The simulated data (Section 6.3.2.2 of Reference 1) has been generated to represent conditions that have been observed in plants and also to provide extrapolation to conditions not observed in actual plant operating experience (e.g., very high oscillation growth rates).

The testing has been separated into three categories: (1) steady-state and transient data, (2) instability data, and (3) simulated data. The steady-state and transient data are used to demonstrate that the algorithm will appropriately discriminate against conditions that are not required to result in a tripped condition and that can be expected to occur at a plant. The instability data are used to demonstrate that the algorithm will adequately detect an instability and provide a trip signal at a specified setpoint. This evaluation will be used to demonstrate that the algorithm is capable of detecting an instability at a condition close to its onset, thereby resulting in a final maximum amplitude that is close to the trip setpoint (i.e., very small setpoint overshoot). The simulated data are used to extrapolate the instability data and provide a quantitative estimate of the setpoint overshoot distribution (Section 6.4).

6.3.1 Steady-State and Transient Data

Table 6-1 summarizes the steady-state and transient test data that have been evaluated with the oscillation detection algorithm. For all of the transient data recorded, several minutes of steady-state data before and after the transient were also recorded and evaluated. For each condition, from 6 to 12 LPRMs were evaluated, including all four axial levels (A, B, C, and D). In general, a standard set of algorithm parameters was chosen to test all of the data. Sensitivity studies were then performed for selected sets of data that were identified from the initial testing as providing the most challenging signals. Sensitivities were performed for the sample interval, filter parameters, period tolerance, and all major setpoints. Acceptable ranges of parameters were then defined based on their margin to scram avoidance for the steady state and transient data.

Examples of how the oscillation detection algorithm responds during two transients are illustrated in Figures 6-6 and 6-7. The algorithm parameters used for the specific examples in these figures are shown in Table 6-3. These are not intended to be final parameters, but have been chosen to illustrate the algorithm response for the various examples.

In Figure 6-6, LPRM data are evaluated for a single recirculation pump restart transient. This transient has been chosen because it is known to result in substantial neutron flux increases and is typically performed in the low flow region of the operating domain, near conditions at which an instability could occur. The response of a single LPRM is shown in Figure 6-6, with the relative signal value plotted. This relative signal value represents the conditioned signal that has been normalized to the time-averaged value. Therefore, the average value is 1.0. Also shown in the figure is the number of consecutive confirmations, which has been scaled by a factor of 10 for convenience. The pump restart occurs at approximately 200 seconds into the data, and can be recognized by the two neutron flux spikes which reach magnitudes of approximately 1.30 and 1.15, respectively. Clearly, both of these neutron flux spikes exceed the threshold setpoint and the first spike reaches the maximum amplitude trip setpoint of 1.30. However, for the amplitude- and growth rate-based portions of the algorithm, the peaks do not occur with the expected timing and the second peak does not exceed the trip setpoints. Therefore, the amplitude- and growth rate-based portions of the algorithm do not initiate a trip. The period-based portion of the algorithm is also not affected by the pump restart and shows only a very few confirmations for the 10 minutes of data. This same basic behavior was also observed on other LPRMs for which data was recorded.

In Figure 6-7, the LPRM response is from a series of turbine control valve tests which result in a pressure perturbation to the core. These pressure perturbations cause a change in moderator density, which leads to neutron flux variations. These step type changes are introduced during normal turbine control valve testing that is required by technical specifications and are therefore an expected neutron flux response that the algorithm must be capable of avoiding. For each of the neutron flux transients that occurs in the eight minutes of data, the peaks do not exceed the threshold setpoint (S_1) and, therefore, the amplitude- and growth rate-based portions of the algorithm do not initiate a trip. The period-based portion of the algorithm shows only a few confirmations during the eight minutes of data. These responses are typical of the recorded LPRMs and also of the algorithm response to stable data.

These figures show sample responses of the algorithm to recorded plant data that should not result in a trip. Sensitivity studies have been performed to evaluate the effect of variations in the algorithm parameter values on the number of successive confirmations and the sensitivity to the threshold setpoints. In general, a wide range of values for the algorithm parameters can be chosen which satisfy the goal to avoid unnecessary trips, primarily because of the basic design of the algorithm and the need for confirmation prior to trip.

6.3.2 Instability Data

The second phase of the data testing involved evaluations of actual recorded plant instabilities. These included instabilities that resulted from control rod withdrawal, core flow reduction and feedwater temperature reductions. Table 6-2 summarizes the instability data that were used to evaluate the algorithm response. The algorithm parameters defined in Table 6-3 are also used for these examples.

During Cycle 1 startup testing at a BWR/6 plant, extensive stability tests were performed to define the expected region of instability. These tests were initiated after two earlier startup tests had resulted in instabilities. These two instabilities are shown in Figures 6-8 through 6-10. In Figure 6-8, the recorded data begins during control rod withdrawals with the plant very close to an instability. The plotted parameters are the same as in the previous plots with the addition of an autocorrelation decay ratio. For the entire 10 minutes of data, the oscillation amplitude does not exceed the threshold setpoint of 1.10 and, therefore, the amplitude- and growth rate-based portions of the algorithm do not initiate a trip. In the first 50 seconds of data, it can be seen that the period-based portion of the algorithm detects an instability as indicated by the very high successive confirmation count that begins at approximately 30 seconds and continues for more than 100 seconds without interruption (actually goes off the scale). However, during this time frame, the oscillation magnitude is still relatively low such that the period-based amplitude trip setpoint (S_p=1.10) is not exceeded and a trip does not occur.

For the next several hundred seconds, control rods are moved in the vicinity of this LPRM, as evidenced by the abrupt increases and decreases in the relative signal value. These movements temporarily result in a decrease in the decay ratio of the LPRM, although significant confirmations continue to occur. At approximately 450 seconds, the number of successive confirmations again continues to increase without interruption for the remaining 200 seconds of recorded data. This occurs even though adjacent control rods are moved. For this LPRM being monitored, a trip still does not occur because the signal magnitude does not exceed the period-based amplitude trip setpoint (S_p). However, the algorithm is providing significant indication that an instability is occurring, thereby giving the operator early warning, well before any significant reduction in MCPR.

Unlike the steady-state and transient data, LPRMs throughout the core can behave quite differently during a regional instability. In particular, LPRMs near the oscillation line of symmetry exhibit behavior that is influenced by both sides of the oscillation and therefore do not show the natural frequency but, rather, a double frequency. Also, the oscillation magnitude varies from LPRM to LPRM based on the location of the LPRM relative to the peak of the harmonic flux distribution.

This effect is illustrated in Figure 6-9, which shows the response of a second LPRM during the same instability as in Figure 6-8. This second LPRM shows a similar response except that the effect of control rod withdrawals is not evident. From the beginning of the recorded data, the second LPRM shows successive confirmations that are not interrupted for nearly 300 seconds. During this time, the magnitude also increases above the period-based amplitude trip setpoint of 1.10, and a trip would occur based on the evaluation of this LPRM at approximately 150 seconds. During this same interval, the amplitude- and growth rate-based threshold setpoint of 1.10 is exceeded. However, the growth rate is small compared to the trip setpoint, and the maximum amplitude does not exceed 1.30; therefore, these portions do not initiate a trip.

Testing at the same BWR/6 plant during Cycles 1 and 7 resulted in oscillations with a relatively constant growth rate. The algorithm response during these events is shown in Figures 6-10 and 6-11. Both of the instabilities shown were the result of control rod withdrawals at low flow conditions. During the approach to the instability, a significant number of successive confirmations occurs. During these periods before the oscillation establishes a constant growth rate, the oscillation magnitude remains below 1.10 and therefore no trips occur. For both events, once the oscillations begin to establish a constant growth rate, the successive confirmations continue without interruption and a trip would occur the first time the signal exceeds the trip setpoint of 1.10. For the amplitude-based portion of the algorithm, a trip occurs the first time the signal exceeds 1.30. For both of these events, the growth rate was less than DR_3 and therefore a growth rate-based trip did not occur.

6.3.3 Summary of Algorithm Performance

The testing with available plant data has demonstrated that the oscillation detection algorithm is capable of meeting the desired objectives. For the steady-state and transient data examined, the algorithm readily discriminates between the normally occurring neutron flux variations and instabilities. Considerable flexibility is available in the choice of algorithm parameter values to ensure that the algorithm will provide a similar response when used at various BWRs. For the instability events evaluated, the oscillation detection algorithm was demonstrated to have the ability to detect the oscillations at very low magnitudes such that the confirmation count setpoint was exceeded before the oscillation magnitude reached the period-based amplitude trip setpoint. This results in the period-based portion of the algorithm providing a trip signal when the oscillation magnitude is close to the trip setpoint. During this portion of the instability, the oscillation magnitude increase from cycle to cycle is relatively small and the setpoint overshoot is also small. This results in satisfying the objective of maintaining margin to the MCPR Safety Limit.

6.4 LICENSING AND DESIGN BASIS CRITERIA

The overall licensing basis for detection and suppression systems is unchanged from that described in Reference 1. However, with the use of the oscillation detection algorithm, some clarifications are needed to ensure a consistent interpretation of the licensing basis. The following licensing basis criterion is provided for those systems which use the oscillation detection algorithm described in the previous sections:

> The oscillation detection algorithm, in conjunction with the associated detection system, shall be designed to initiate an automatic suppression function to ensure that specified acceptable fuel design limits are not exceeded as the result of any anticipated stability-related neutron flux oscillation.

The licensing basis criterion is provided for compliance with the requirements of GDC-12 and will be demonstrated by applying the methodology defined in Section 6 of Reference 1. "Anticipated stability-related neutron flux oscillations" are those instabilities that result from normal operating conditions, including conditions resulting from anticipated operational occurrences. This category of events is equivalent to the standard terminology for the analysis of events of moderate frequency. This definition of anticipated stability-related neutron flux oscillations is based on operating experience and the basic theoretical understanding of BWR instabilities.

The following design basis criterion is provided to ensure the robust performance of detection and suppression systems:

> The oscillation detection algorithm, in conjunction with the associated detection system, should be designed to initiate an automatic suppression function to limit the size of hypothetical stability-related neutron flux oscillations to a reasonable level.

The design basis criterion is inherently satisfied by the use of several oscillation characteristics (period, growth rate, and amplitude) when determining whether a trip should occur. As such, the design basis criterion is satisfied without the need to evaluate performance relative to fuel design limits.

6.4.1 Application of Oscillation Methodology

To demonstrate that the oscillation detection algorithm satisfies the licensing basis criterion, the oscillation methodology documented in Section 6 of Reference 1 must be applied. This methodology is used to calculate the change in Critical Power Ratio (CPR) due to the anticipated instability events. The objective of the detection and suppression systems is to provide mitigation such that an instability does not have to be considered in the evaluation of limiting events. This is accomplished by demonstrating a wide margin to the MCPR Safety Limit. This objective is intended to simplify the application of the stability methodology to future core and fuel designs.

The application of the oscillation methodology requires the determination of the setpoint overshoot distribution to describe the final maximum amplitude of the oscillation prior to suppression. The setpoint overshoot distribution describes the final maximum amplitude of the oscillation prior to mitigation. The setpoint overshoot distribution is a function of the oscillation detection algorithm parameter values, the assumed oscillation scenarios, and the time required for mitigation to occur. Based on the available instability data, the oscillation detection algorithm has been demonstrated to be capable of initiating a trip signal when the oscillation magnitude is close to the trip setpoint. This would result in very little setpoint overshoot. To quantify the setpoint overshoot distribution, point model simulated scenarios are used to represent a range of expected instability characteristics. The simulated scenarios model the effects of normally occurring neutron flux noise and of oscillations with varying growth rates (Section 6.3.2.2 of Reference 1).

For the application of the oscillation methodology, a set of generated scenarios is evaluated against a specific trip system algorithm and corresponding setpoints to determine the distribution of the signal overshoot. An example distribution of setpoint overshoot for the algorithm parameters described in Table 6-3 is shown in Figure 6-12. The overshoot distribution corresponds to the distribution of "second peaks" as defined in Figure 6-22 of Reference 1. The "second peak" is conservatively chosen for BWR/3-5 plants, since the Technical Specification scram times are slow enough to potentially allow a second peak to occur before mitigation. The scenarios that were evaluated by the oscillation detection algorithm have growth rates ranging from 1.05 to 1.60, with a majority of the scenarios having growth rates near 1.30. Each of the scenarios was generated using a different random noise characteristic (simulated by using different random number seeds) and also included the modeling of up to eight LPRMs for each scenario. Multiple LPRMs are modeled for each scenario, since the detection systems can be tripped by a single LPRM or group of LPRMs, depending on the respective channel design. As shown in Figure 6-12, the oscillation detection algorithm is capable of providing a trip initiation when the signal is close to the trip setpoint.

6.4.2 Example of Monte Carlo Analysis

To demonstrate the effectiveness of the oscillation detection algorithm, the overshoot distribution defined by Figure 6-12 was applied to a BWR/4 reactor operating with a full power MCPR limit of 1.25. When the oscillation detection algorithm as defined in Section 6.1 of this supplement using the parameters of Table 6-3 is used, the mean value of the final MCPR is 1.484, with a lower 95/95 value of 1.35. This can be compared to similar examples in Reference 1 which only used the amplitude- and growth rate-based portions of the oscillation detection algorithm. This demonstrates the ability of the oscillation detection algorithm to provide wide margin to the MCPR Safety Limit.

Table 6-1
ALGORITHM TESTING - STEADY-STATE AND TRANSIENT DATA

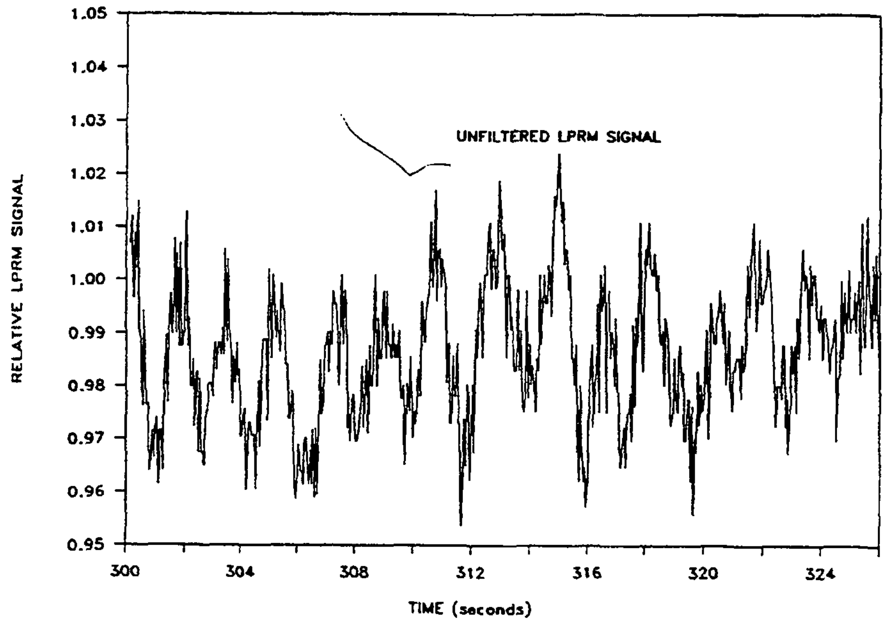
Plant Type	Cycle	Operating Conditions
BWR/4	1	Single Recirculation Pump Trip
		Two Recirculation Pump Trip
		Recirculation flow step changes
		Turbine Stop Valve Testing
		Pressure Regulator Testing
		Turbine Control Valve Testing
		Single Recirculation Pump Restart
		Feedwater Flow step changes
BWR/5	3	Control Rod Moves
		Single-Loop Operation
BWR/6	1	Steady State
	7	Steady State

Table 6-2
ALGORITHM TESTING - INSTABILITY DATA

Plant Type	Cycle	Operating Conditions
BWR/6	1	Control Rod Withdrawal
		Control Rod Withdrawal
		Core Flow Decrease
		Feedwater Temperature Reduction
	7	Control Rod Withdrawal
		Control Rod Withdrawal
		Control Rod Withdrawal
BWR/4	2	Control Rod Withdrawal
Internal Pump Plant	-	Core Flow Decrease

Table 6-3
SAMPLE ALGORITHM PARAMETERS

Parameter	Value
Amplitude- and Growth Rate-Based Parameters	
S_1	1.10
S_2	0.92
DR_3	1.30
S_{max}	1.30
T_1	0.310 to 2.20 sec
T_2	0.310 to 2.20 sec
Period-Based Parameters	
TMIN	1.00 sec
TMAX	3.50 sec
$\pm\epsilon$	0.15 sec
N_p	10
S_p	1.10
Other Parameters	
f_c	1.50 Hz
P_c	2
T_a	6.00 sec
P_a	2
t_s	0.050 sec



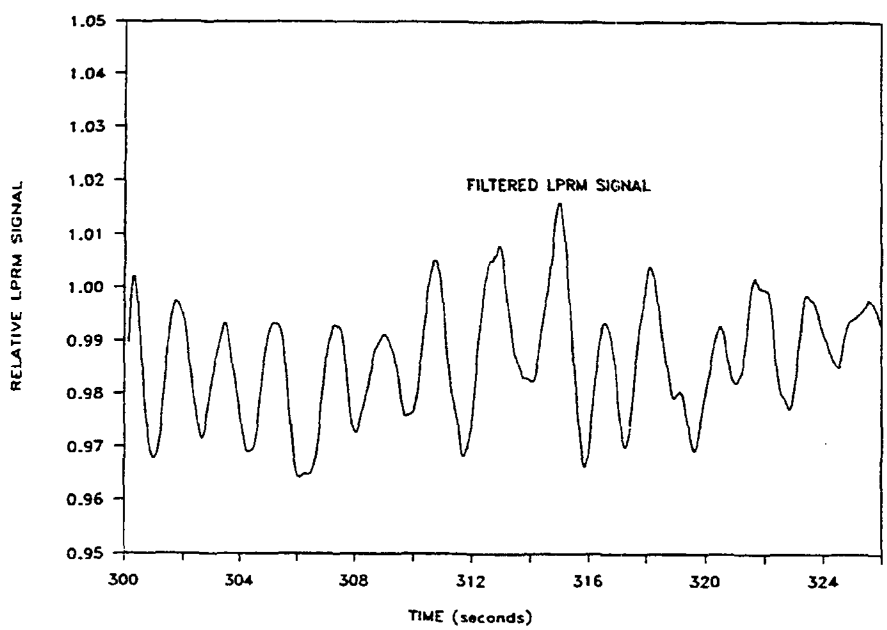
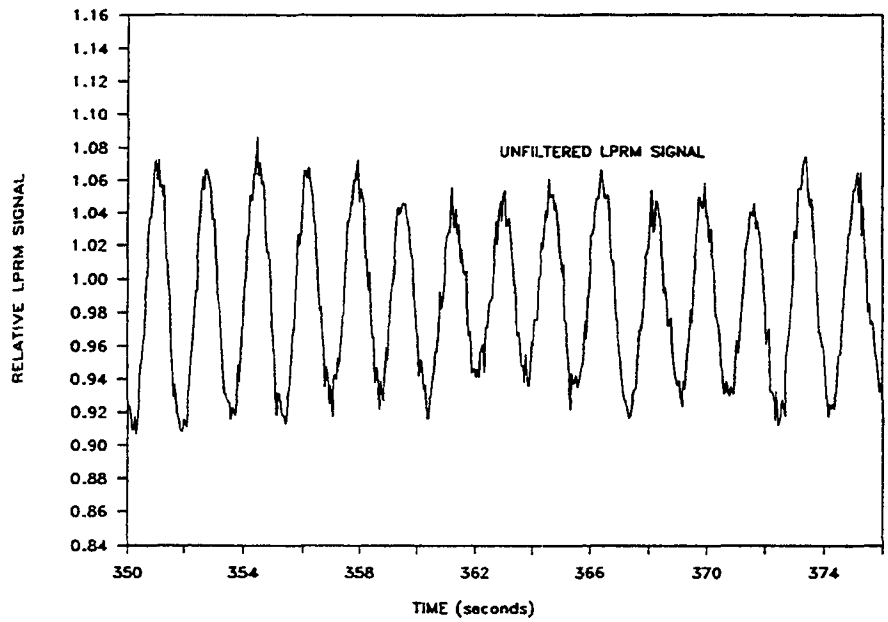


Figure 6-1. Conditioning Filter - Stable Data



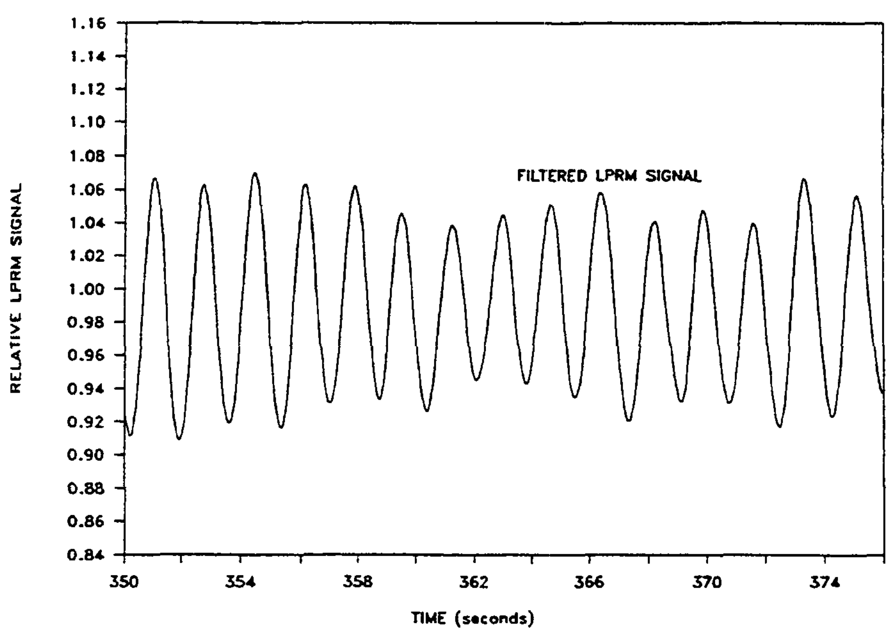


Figure 6-2. Conditioning Filter - Limit Cycle Data

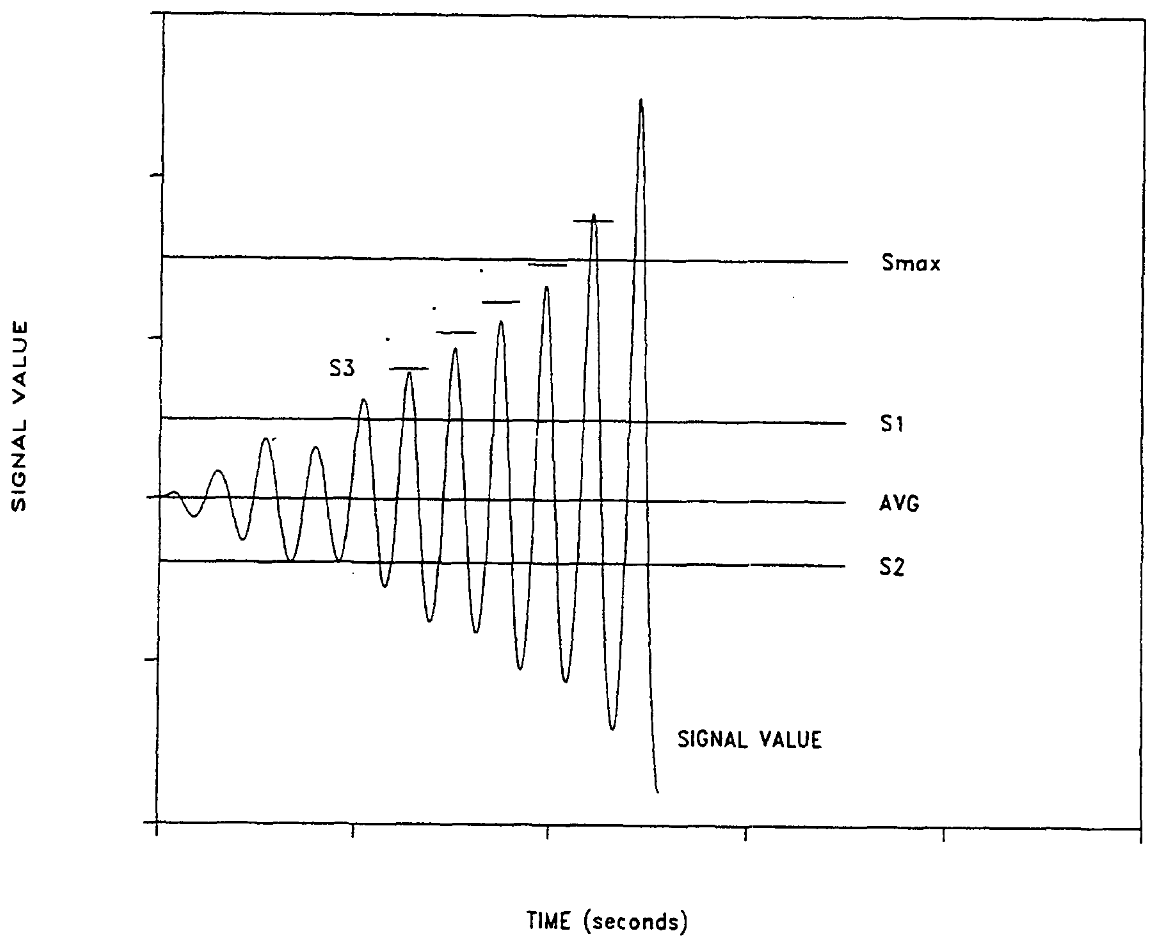


Figure 6-3. Amplitude- and Growth Rate-Based Detection

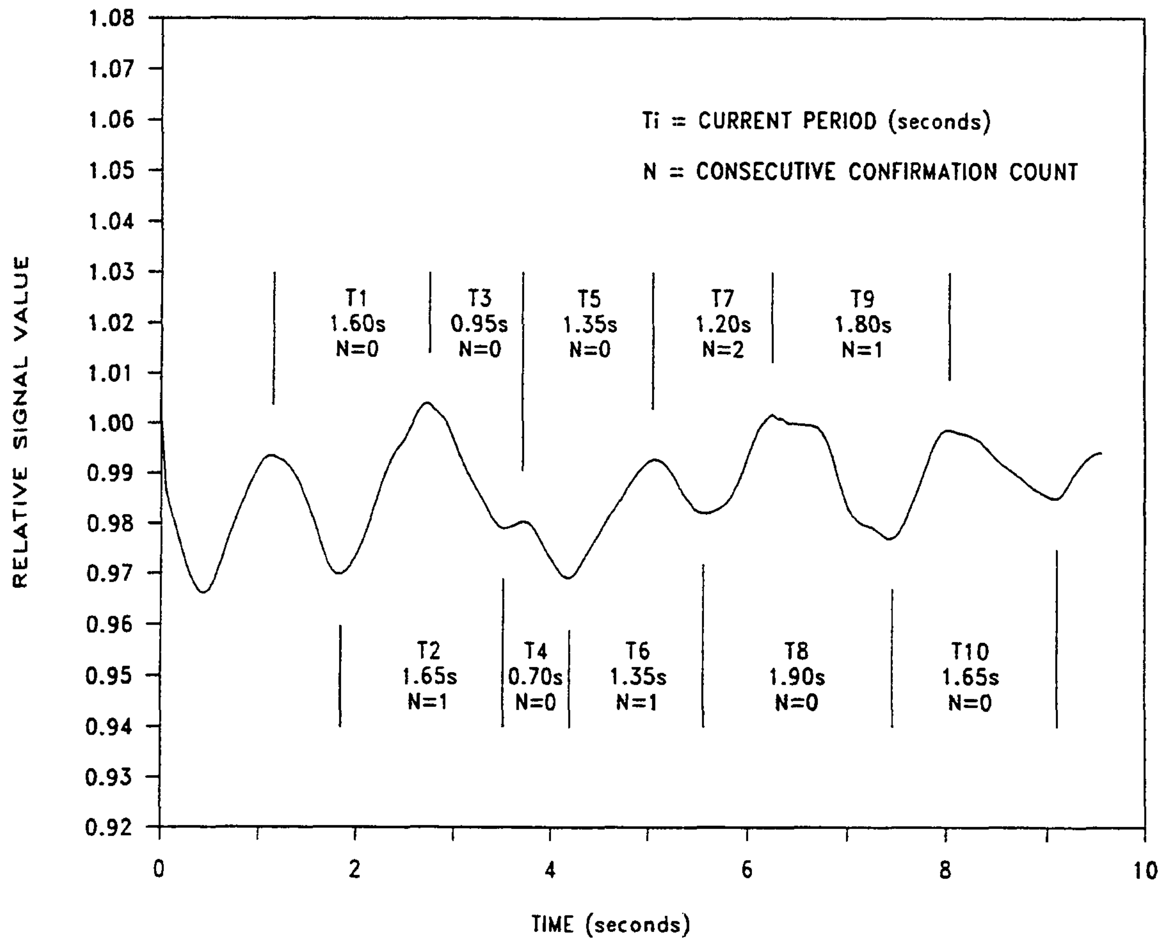


Figure 6-4. Period-Based Detection

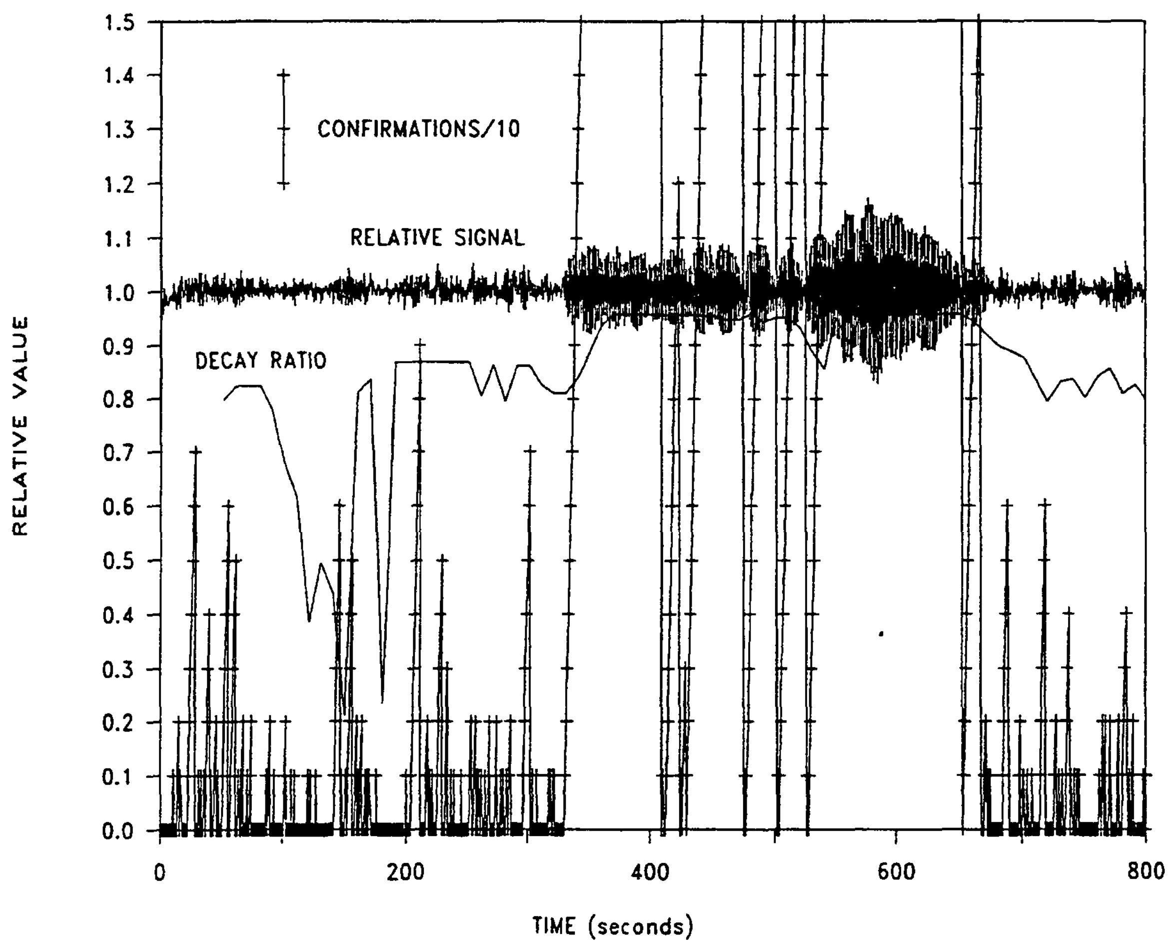


Figure 6-5. Example of Period-Based Detection

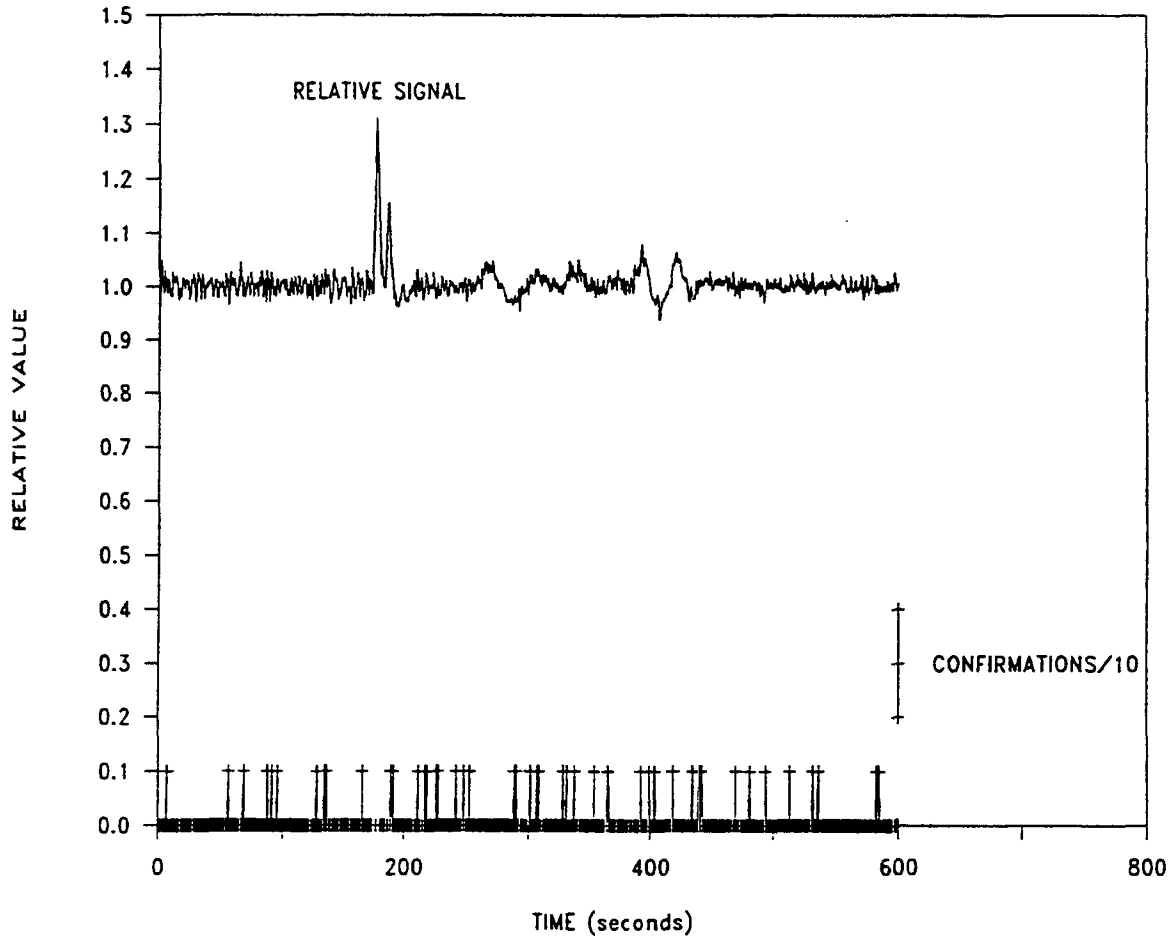


Figure 6-6. Algorithm Testing - Recirculation Pump Restart

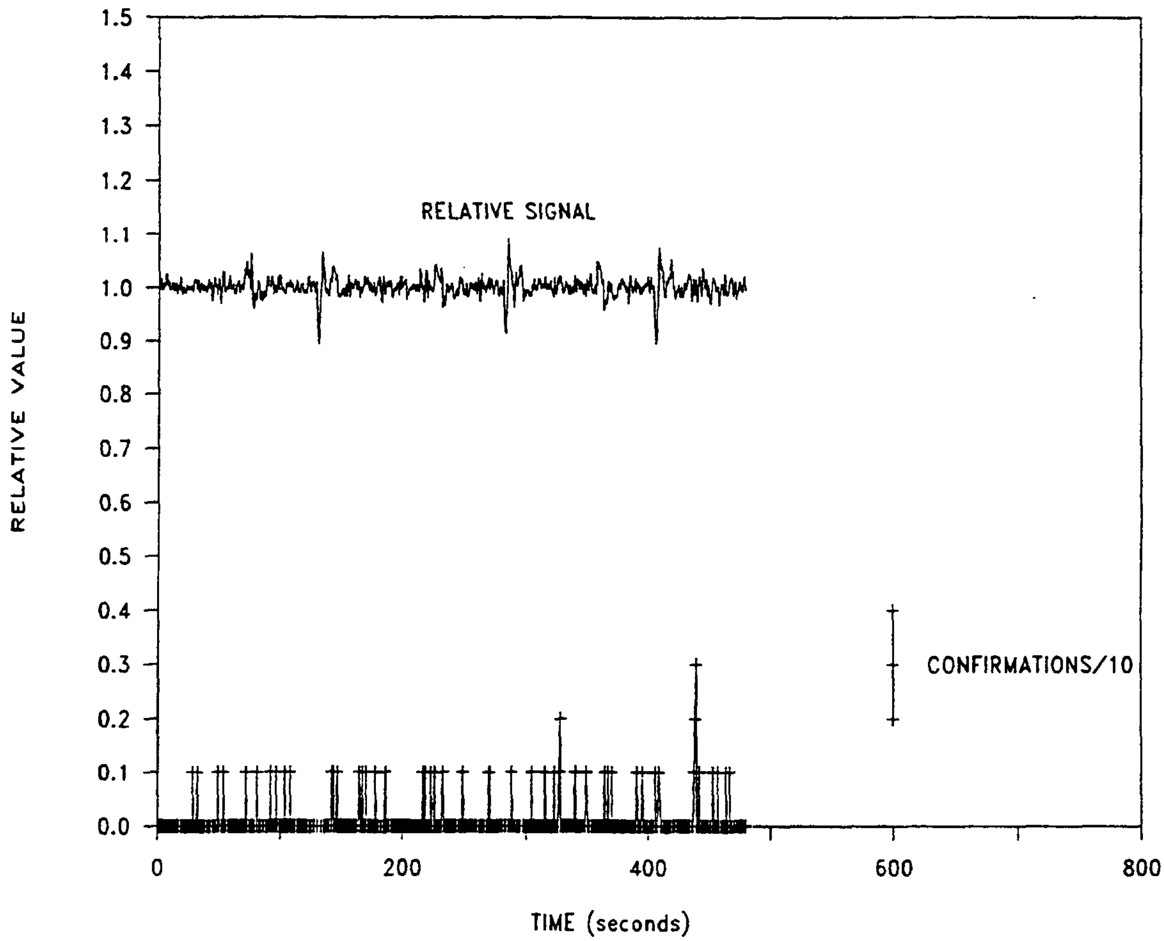


Figure 6-7. Algorithm Testing - Turbine Control Valve Testing

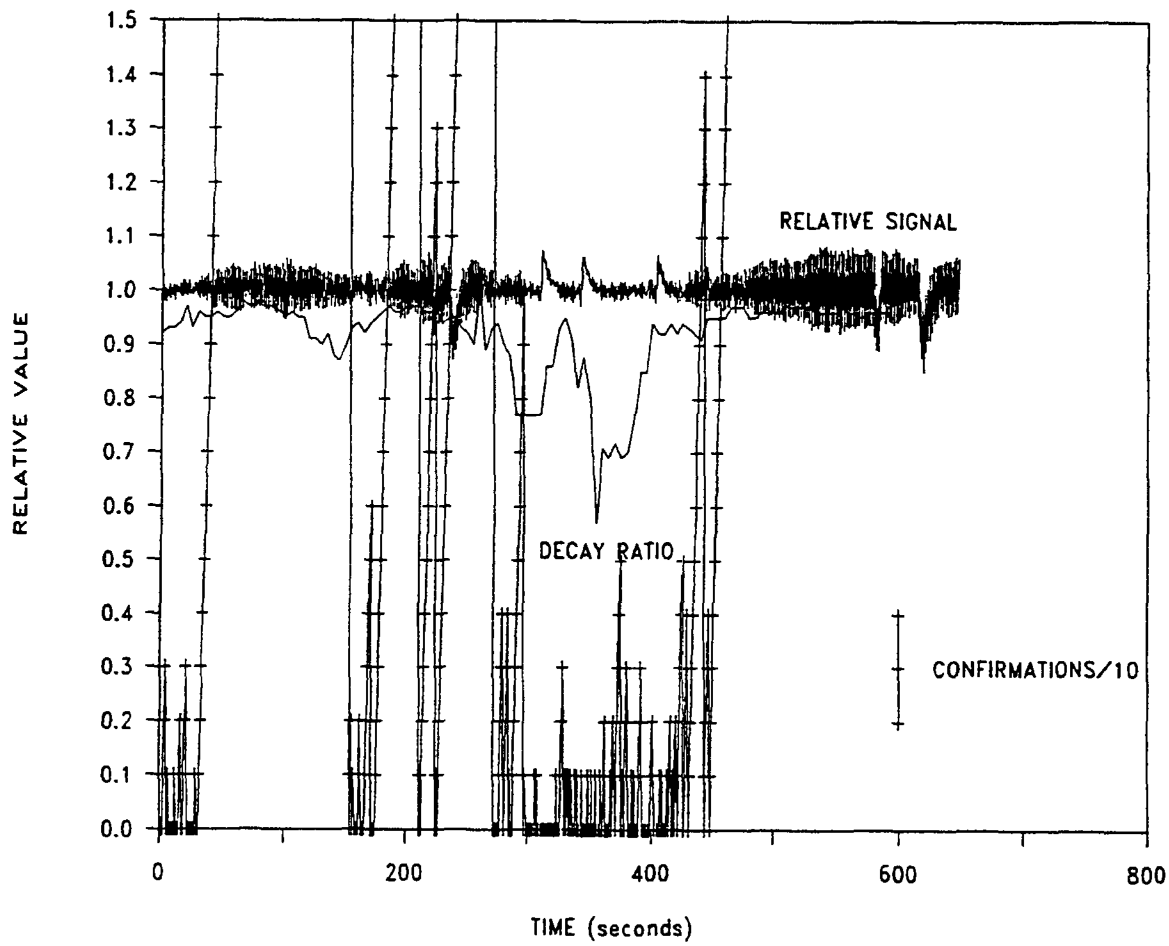


Figure 6-8. Algorithm Testing - Instability During Control Rod Withdrawal (LPRM 1)

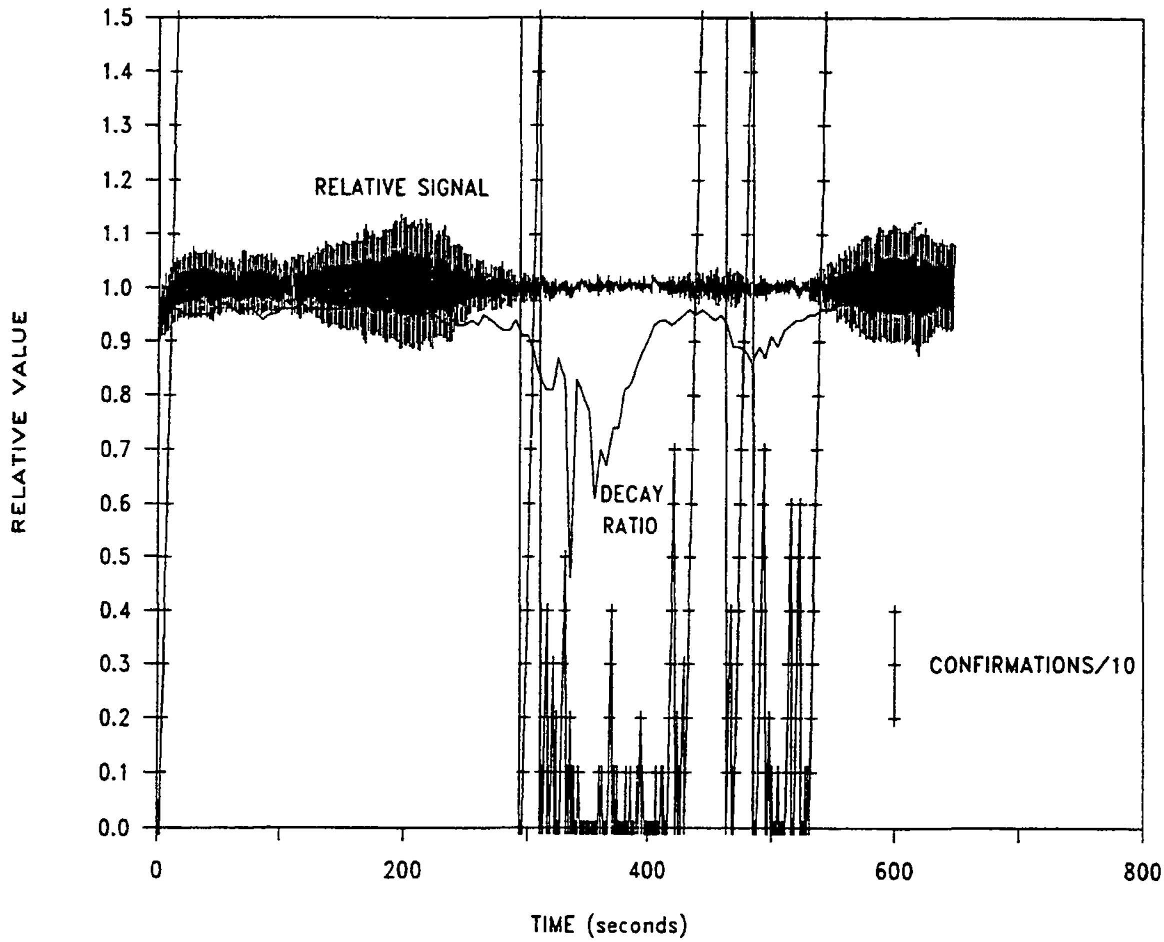


Figure 6-9. Algorithm Testing - Instability During Control Rod Withdrawal (LPRM 2)

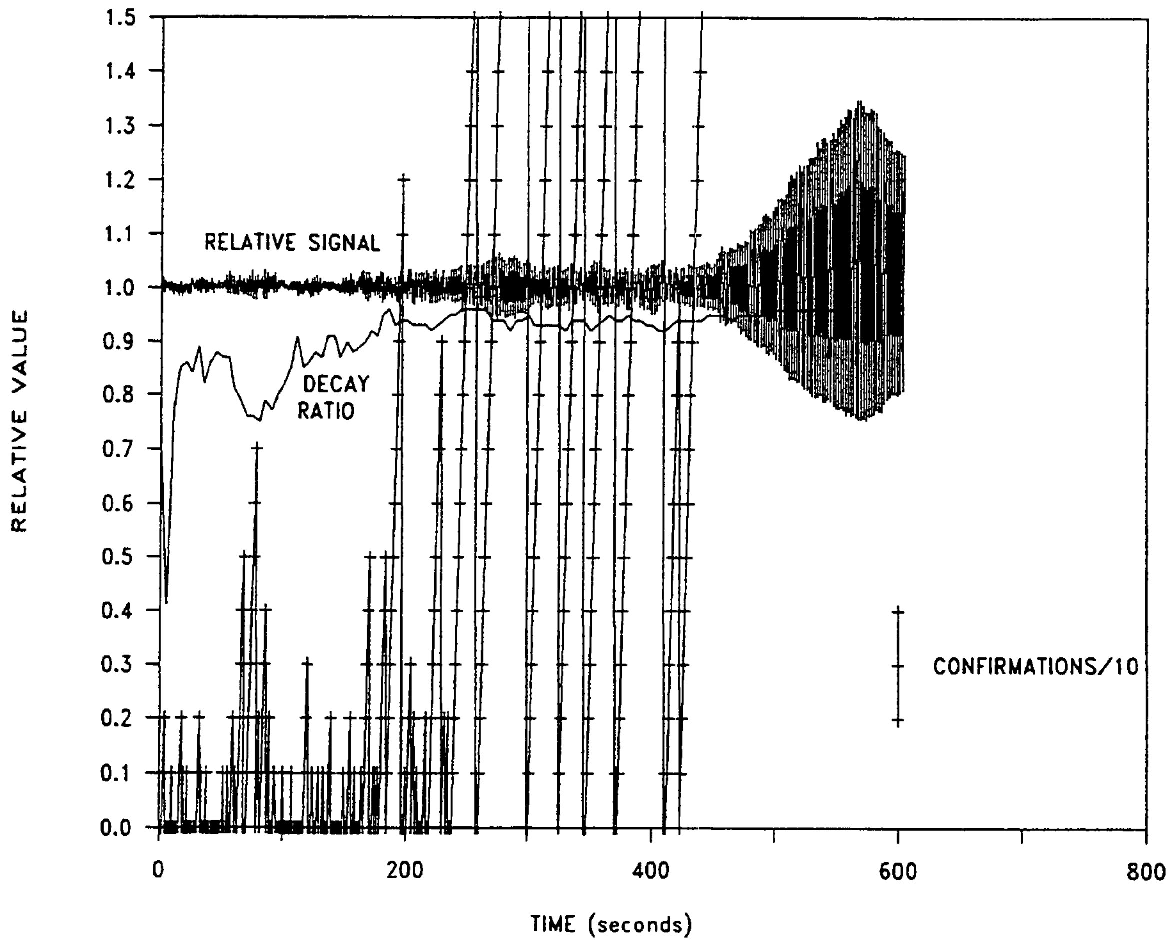


Figure 6-10. Algorithm Testing - Constant Growth Rate Instability (Cycle 1)

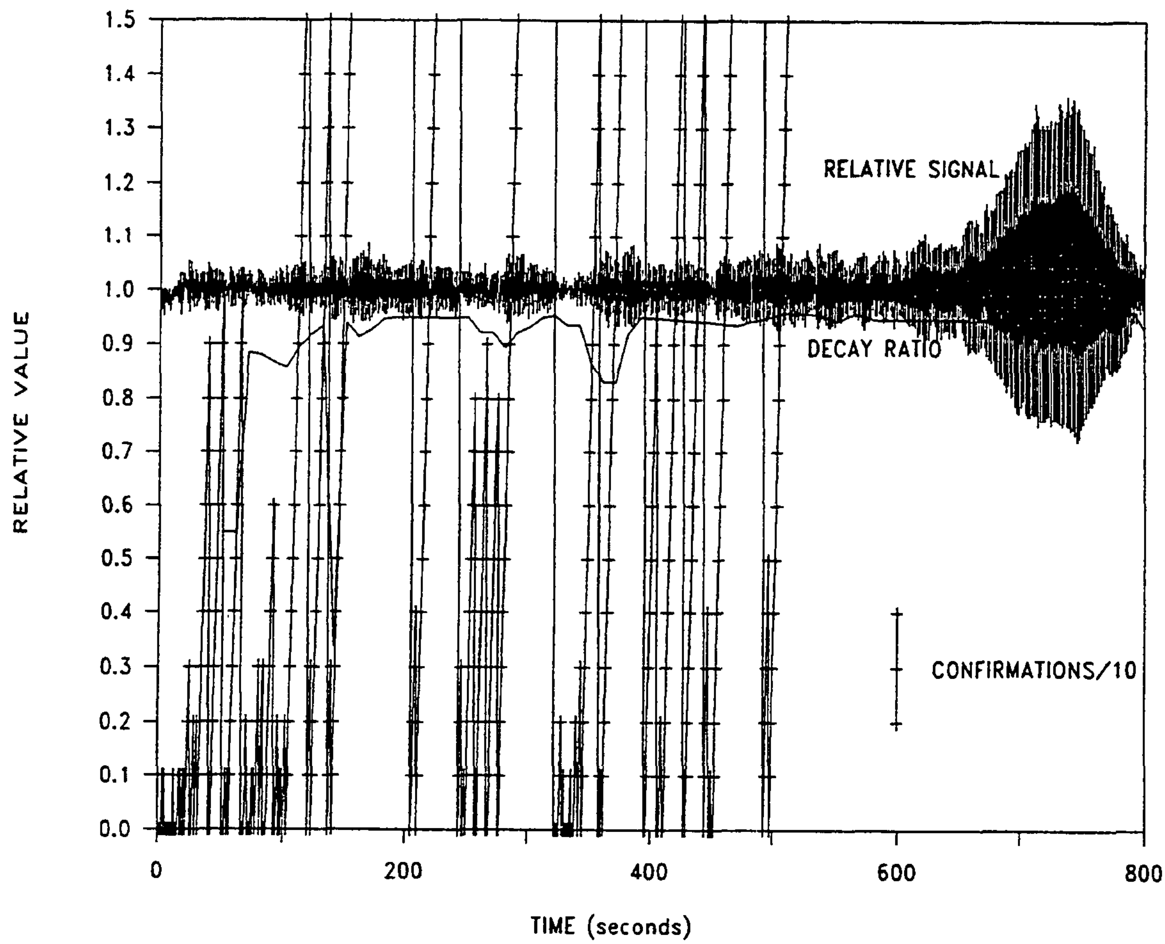


Figure 6-11. Algorithm Testing - Constant Growth Rate Instability (Cycle 7)

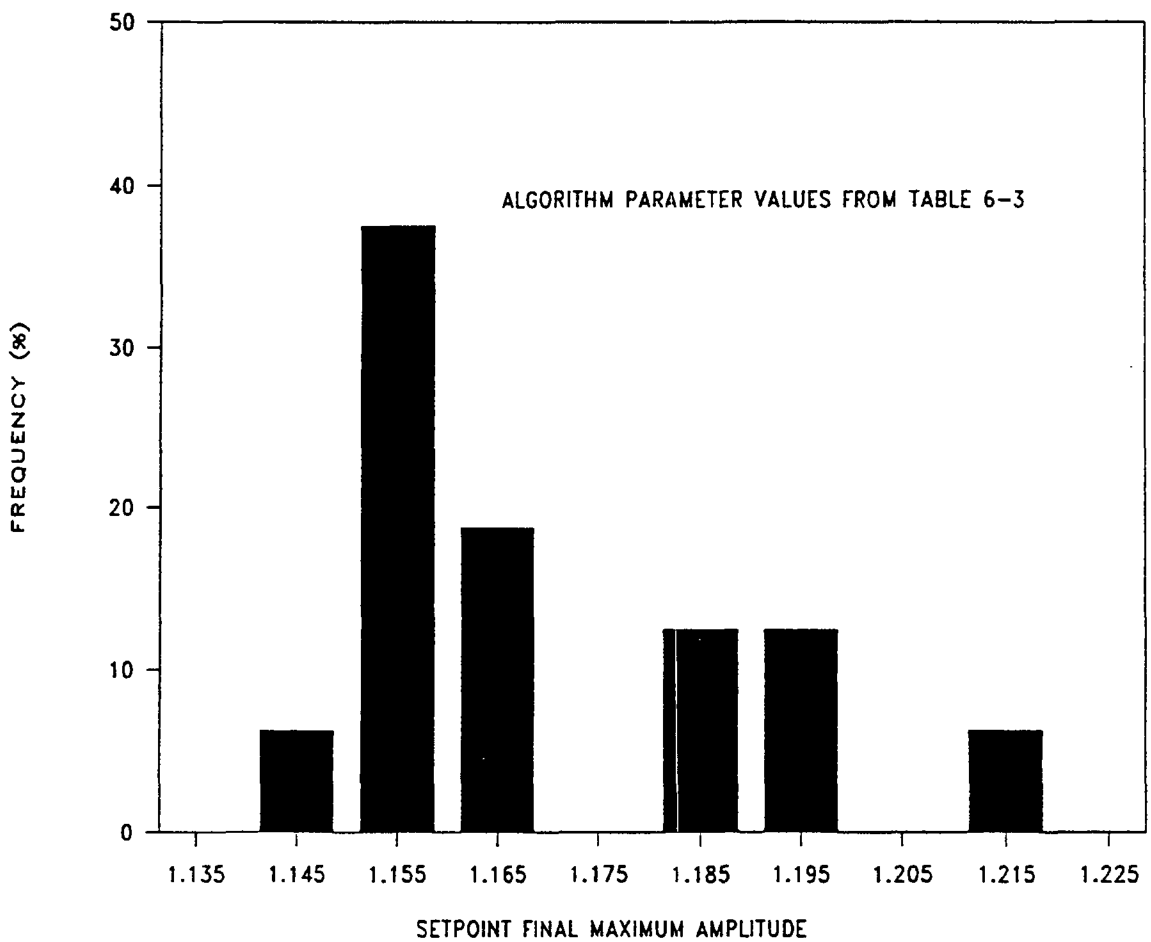


Figure 6-12. Example Setpoint Overshoot Distribution

7.0 REFERENCES

1. NEDO-31960, "BWR Owners' Group Long-Term Stability Solutions Methodology," May 1991.

2. Letter, A.C. Thadani (NRC) to R.D. Binz (BWROG), "Request for Additional Information on Stability Report NEDO-31960," September 5, 1991.

3. L. E. Fennern, et. al, "ODYSY: A Computer Program to Predict Stability of Boiling Water Reactors," Trans. Am. Nucl. Soc., 45, pps. 727-728 (1983).

4. NEDO-24154-A, "Qualification of the One-Dimensional Core Transient Model for BWRs," February 1986.

5. NEDO-30130-A, "Steady-State Nuclear Methods," April 1985.

APPENDIX A
RESPONSE TO NRC QUESTIONS ON NEDO-31960

Reference 2 provided NRC questions concerning the Reference 1 licensing topical report which describes the stability licensing methodology. The questions from Reference 2 have been included in this appendix along with responses. Where appropriate, information related to the questions has been included in the body of this supplement. Some of the responses to the questions are dependent on work which is still in progress and, therefore, these questions have not been completely addressed. In particular, the details of the plant- and cycle-specific application of the generic exclusion region boundaries, and the development of the fuel thermal response during an instability using TRAC-G, have not been completed. Details on these subjects and responses to those questions which have not been addressed in this supplement will be provided in the future.

1. GENERAL QUESTIONS

"1.1 FABLE/BYPSS Bias Correction Factor is Undocumented

In Section 5.1, "Stability Criteria," there is a reference of a bias correction factor that is applied to the results of FABLE/BYPSS. The correction factor has not been documented nor reviewed by NRC. At a minimum, a paragraph is needed describing this correction factor in detail and especially its impact on the stability boundary calculations."

Response

The bias correction factor was developed to account for the conservative bias exhibited by FABLE/BYPSS when compared to plant stability data. The bias was determined to be a function of the core thermal power, core flow, power-to-flow ratio, and core power density. A function was developed which includes each of these parameters, and the coefficients of the function were determined to minimize the error between the calculated decay ratio and the experimental decay ratio. A detailed description of the proprietary bias correction factor will be provided to the NRC for their review. The specific impact of the bias correction factor on the stability boundary calculations has been discussed in Section 5.3.

"1.2 Core Channel Decay Ratio Acceptance Map is Based on Unqualified, Unnamed Code

In Section 5.1, "Stability Criteria," a summary description of the acceptance criterion for stability calculations is described. This acceptance criterion is based on Figure 5-4 of NEDO-31960, which is a map of core and channel decay ratio where stability boundaries are defined for in-phase and out-of-phase instabilities. This map was developed with the aid of an unnamed "separate frequency domain code" following a procedure that is vaguely described in the document. The map of Figure 5-4 is the basis for all decay ratio calculations used for Solution I and for Solution III bypass settings. Thus, given its relevance to these results, the qualification of the code used and the procedure followed to define Figure 5-4 deserves more detailed description so that it can be reviewed properly.

In particular, describe which plant conditions were used in the validation, specifically answer whether the eigenvalue separation used for this qualification was bounding for expected operating plants. The curved part of the map should in theory be a function of the eigenvalue separation of the first subcritical mode; thus, specify whether a sufficiently reactive mode is used in the definition of the map of Figure 5-4."

Response

The stability criteria shown in Figure 5-4 of Reference 1 (Figure 5-1 of this supplement), and further defined in Table 5-1 of this supplement to Reference 1, were developed based on a combination of post-test evaluations of instability events, theoretical considerations of regional oscillations, and the above-mentioned frequency domain calculations. Section 5.1 of this supplement provides additional details concerning the frequency domain code and the procedure used to estimate regional decay ratios using the code. Section 5.1 also discusses the conditions which were used in developing the stability criteria and concludes that the curved part of the map is representative of a sufficiently reactive harmonic mode.

"1.3 Core-Channel Decay Ratio Acceptance Map Should be Defined Uniquely

Most of the results of these documents are based on decay ratio calculations that are compared to Figure 5-4. It would be convenient and easier to validate future calculations if Figure 5-4 were expressed in a unique mathematical form instead of in graphical form as it is now. A table of values for the curved part of the figure or a polynomial fit would uniquely define it and make acceptance of calculated decay ratio values an easier task."

Response

A table of values for the stability criteria has been included in this supplement as Table 5-1.

"1.4 Many Axial Power Shapes Are Used for Decay Ratio Calculations

In Section 5.2.3, "Axial Power Shapes," there is a confusing discussion of which axial power shapes are used where. Words like "relatively high power," "bottom peaked power shape" and "less peaked power shape" are used to vaguely express the procedures. Supply in a graphical form (for instance power-flow map) the operating regions where each axial power shape is used and to which decay ratio (i.e., channel or core) they apply.

Supply also the actual numerical values used as axial power shapes or the detailed specifications to calculate them for each plant group."

Response

Sections 5.2.1 and 5.2.2 have been included in this supplement to clarify the use of axial power distributions for core and channel decay ratio calculations. Figure 5-2 has been included which defines the regions in which the various axial power distributions are applied for hot channel decay ratio calculations. Table 5-2 has been included which provides numerical values for the axial power shapes used in the hot channel decay ratio calculations.

"1.5 **Measurement Uncertainties May Result in "Fuzzy" Exclusion Regions**

The difficulty of estimating thermal power and flow on line is well known, especially at low flows. For example, in a recent European instability event, the operators had unknowingly in effect entered the Exclusion Region B of Bulletin 88-07 because of these uncertainties. In many cases it is hard to know whether the exclusion region refers to the real thermal power and flow (determined through sophisticated off-line analyses) or to the actual power and flow measurements available to the operator in the control room.

Provide an explanation of how measurement uncertainties are treated in exclusion region definitions. Provide a definition of the power and flows to be used by the operator to determine whether the reactor is within the administratively controlled exclusion region."

Response

The calculated region boundaries are considered analytical limits and, as such, do not include any conservatism to account for uncertainties in the measurement of core thermal power and core flow. Measurement uncertainties must be included in the determination of plant-specific setpoints. Individual utilities apply setpoint methodologies to determine these setpoints. The specific setpoint for any given plant is a function of the analytical limit, the instruments and associated procedures involved in the measurement of the process variables, and the chosen setpoint methodology. It is expected that uncertainties on the order of several percent in both power and flow will result from the application of such procedures.

2. QUESTIONS RELATED TO CYCLE-SPECIFIC CONFIRMATION ANALYSES

"2.1 A Representative Void Coefficient for one Plant is Used for all Plants in the Group

Since a void coefficient for a "representative" plant in each group is used, without any safety margins, the Solution I calculations will be hard to extrapolate to other plants. In particular, new fuels or loading patterns may alter the void coefficient slightly in the non-conservative direction. This issue is addressed in several parts of the report, for instance in Section 5.2.1, but never in detail. Explain in detail what is the procedure if Plant X in the future finds that this estimated void coefficient is for instance 5% higher than the one used for its exclusion region calculation. Is the BWROG planning to have cycle-dependent exclusion region?"

Response

As discussed in Section 5.5.1 of Reference 1, it is the intent of the procedure for plant- and cycle-specific application of generic region boundaries to allow the determination of the necessary change in region boundary to ensure comparable margin to the stability criteria. Sensitivity studies will be performed to evaluate the change in decay ratio as a result of the change in void coefficient relative to the base value. For a given change in decay ratio, the resultant change in the region boundary will also be determined. In this way, the effects of cycle-to-cycle variations in void coefficient can be translated into a cycle-to-cycle change in the exclusion region. A utility can choose to initially license a conservative exclusion region to account for these potential changes such that cycle-dependent changes are not necessary or rely on a cycle-dependent calculation if more operating margin is desired.

"2.2 Applicability of Generic Exclusion Region to New Fuel Designs

BWROG proposes to judge new fuels based mainly on its effect of the channel and core decay ratios. However, it appears from Section 5.5.1 that they proposed to perform these analyses using the standard procedures defined in Section 5.1. These procedures use standard (i.e., fixed) axial power shapes for the channel decay ratio. Experience in European reactors has shown that fuel design can have a significant effect on axial power shapes. For instance, a European instability event was mainly attributed to the gadolinium distribution used in the particular core to take better advantage of excessive linear heat rate margins. If this fuel were analyzed following the proposed procedures, the channel decay ratio would be unchanged from the fuel with the standard gadolinium distribution, and no adverse effect on stability would be detected. Thus, explain how changes in axial and radial power distribution will be taken into account when judging new fuels against stability criteria."

Response

Extreme departures from accepted core and fuel design practices cannot be anticipated nor included in the procedure. It is the intent of the procedure for plant- and cycle-specific application of the generic region boundaries to define those parameters which a core and fuel design must satisfy to remain within the bounds of the generic procedure and exclusion region. Checks will be provided to flag such extreme design changes as discussed in the question. Alternatively, it will always be the option of a fuel vendor/utility to perform a plant- and cycle-specific analysis.

3. QUESTIONS RELATED TO SOLUTION I-A

"3.1 Are Region Boundary Confirmation Calculations Conservative Enough?

Section 5.4 describes the exclusion region boundary confirmation analyses. All these calculations are based on expected normal operation conditions; however, experience with European instability events has shown that reactors can be operated (within tech specs) well outside the expected operating conditions, for instance a fast startup with very low feedwater temperature. Indeed, in one of the European instability events in a BWR/6, the power-flow point fell just inside the equilibrium cycle Perry boundary and clearly outside the boundary calculated for Cycle-2 (based on control room measurements).

Even using the expected operating conditions for this transients, many of the calculations result in core-channel decay ratio values that fall quite close to the acceptance boundary (for instance, core decay ratios of 0.75), it is conceivable, then, that more conservative calculations would not confirm the calculated boundary. Explain why the selected transients are considered to be conservative enough. Supply a list of the transients used for these confirmation analyses."

Response

The procedure defined in Section 5 of Reference 1 has been developed to provide a conservative exclusion region. Any individual input (such as the axial power distribution) is not necessarily depicted as conservative, but, instead, the overall procedure and accompanying stability criteria are proposed as a means of defining a conservative exclusion region. The ability of the procedure and criteria to satisfy this goal is evidenced by the example exclusion regions that have been calculated and documented in Reference 1. These represent variations in the exclusion region as a result of expected variations in core and fuel designs. The appropriateness of the procedure and criteria are also evidenced by the location of all instability events that have occurred to

Response to 3.1 (continued)

date relative to the exclusion region boundaries that have been defined for similar plants. In particular, the European event described in the question did, in fact, fall inside the analytical exclusion region calculated for Perry for both Cycle 2 and the equilibrium cycle, even based on the use of control room measurements. Appropriate consideration of measurement uncertainty is a separate issue and is addressed in Question 1.5. Additional calculations have been performed to specifically define an exclusion region for the BWR/6 plant mentioned in the question and, again, the procedure produced an exclusion region that bounded the actual instability event.

"3.2 What are the Power and Flow Measurement Uncertainties?

Solution I exclusion boundary implementation should be based on a measured power and flow as seen in real time at the control room. These two variables are known to be fairly inaccurate specially at low flows. How are those inaccuracies taken into account when defining the exclusion region?

For example, in one of the European BWR/6 instability events, the operator was, according to its instrumentation, well outside Region B as defined by Bulletin 88-07 when an instability was observed. Later analyses showed that the actual power and flow were such that the reactor was probably inside Region B. Solution I type implementation must clearly define in real time whether the reactor is inside or outside the exclusion region and take action accordingly. More refined, non-real-time calculations of operating conditions are of no value for Solution I implementation."

Response

The response to Question 1.5 discussed the application of measurement uncertainties in the determination of plant-specific setpoints.

"3.3 Applicability of Generic Exclusion Boundary to Other Plants in the Group

Section 5.5 deals with the application of generic region boundaries for plant and cycle specific conditions. This is the hardest technical point of Solution I, and the BWROG has done overall a good job at addressing it. The details of the implementation, however, are vague and not well defined yet. It is important that these procedures be well defined and reviewed so that they do not result in extremely overconservative exclusion boundaries on one side, or cycle-dependent boundaries on the other if nominal conditions are used for most parameters.

The example shown for the Perry plant highlights the problem: when one compares the Cycle-2 exclusion region with that of the equilibrium cycle, the differences are quite large (the area of the operating map excluded is almost doubled). It is hard to justify that an unknown cycle (say Cycle 13) will not result in even larger regions. Thus, these procedures must be defined more accurately and in detail."

Response

The exclusion region boundary for Perry increased from Cycle 2 to the equilibrium cycle by 1.2% in core flow along the upper rod line and was decreased by 2.1% in core thermal power at natural circulation. These represent relatively small changes in the overall region boundary. The above concerns about the potential variability of the exclusion region are, however, shared by the BWROG, and the detailed procedures will be adequately addressed in the future.

4. QUESTIONS RELATED TO SOLUTION I-D

"4.1 The Use of Standard BWROG Procedures to Define Oscillation Modes May Not be Conservative

The BWROG procedure for Solution-I-type exclusion region calculations tends to be conservative by using a different axial power shape for core and channel decay ratio estimates. These power shapes are selected so that the current BWROG procedures tend to overestimate both the core and the channel decay ratios and, thus, result in a larger exclusion region (i.e., conservative). The procedure, however, uses a very flat axial power shape that is more representative of full power operation than natural circulation conditions where instabilities are likely, and this power shape tends to overestimate the core decay ratio at the actual conditions. The procedure axial power shape for the hot channel, on the other side, is somehow representative of expected conditions at low flow in the hot channel; thus, it does not overestimate by much the channel decay ratio at low flows. Consequently, using the standard procedure may not result in accurate predictions of oscillation mode. The 'acceptance curve' (see Figure 5-4 of NEDO-31960 for example) in the core-channel decay ratio map was developed using the actual axial power shapes for several conditions. During the development of that curve, it was observed that all out-of-phase instability mode cases fell within the right side of the map, and the in-phase cases fell to the left. This seems to agree with the underlying physics of the instability modes; however, it is only applicable if the actual power shapes are used, not some conservative estimates.

Describe why the standard BWROG procedure is applicable for this case, or show that for the affected plants the core and channel decay ratios fall within the expected (i.e., in-phase mode) range using the actual expected axial power shapes in the appropriate regions."

Response

Since this is a methodology question, the Perry results in Reference 1 may be used to show that more realistic assumptions about the axial power

Response to 4.1 (continued)

distributions do not move the decay ratios toward the regional mode oscillation criterion of Figure 5-1. This is shown in Table A-1 and Figure A-1. A comparison of core and channel decay ratios for procedural and confirmation analysis points with similar power/flow conditions is shown in Table A-1. The procedural analysis points are from Tables 5-2 and 5-3 of Reference 1. The confirmation analysis points are from Table 5-4 of Reference 1. The confirmation analysis is based on using power distributions that are predicted to occur during plant operation. The core and channel decay ratios for the results in Table A-1 are plotted in Figure A-1, with lines connecting those analysis points with similar power/flow assumptions. From Figure A-1, it can be seen that the effect of more realistic power distribution assumptions is to move the resulting decay ratios further away from the region where regional mode oscillations are deemed probable.

Table A-1
COMPARISON OF CONFIRMATION AND REGION BOUNDARY DEFINITION CASES

Point *	Power (%)	Flow (%)	Decay Ratios Hot Channel	Decay Ratios Core
1	75.4	50.0	0.52	0.56
B1	74.5	50.0	0.35	0.25
B2	74.8	50.0	0.38	0.55
7	75.4	50.0	0.49	0.74
B3	75.3	50.0	0.32	0.37
B4	75.1	50.0	0.39	0.59
8	72.9	47.0	0.55	0.82
C5	72.0	48.0	0.35	0.70
10	58.3	45.0	0.42	0.76
C7	59.0	43.5	0.32	0.74

* Refers to indexing used in Tables 5-2, 5-3, and 5-4 of Reference 1. Numerical points are for Region Boundary Definition cases. Alphanumeric points are for confirmation cases.

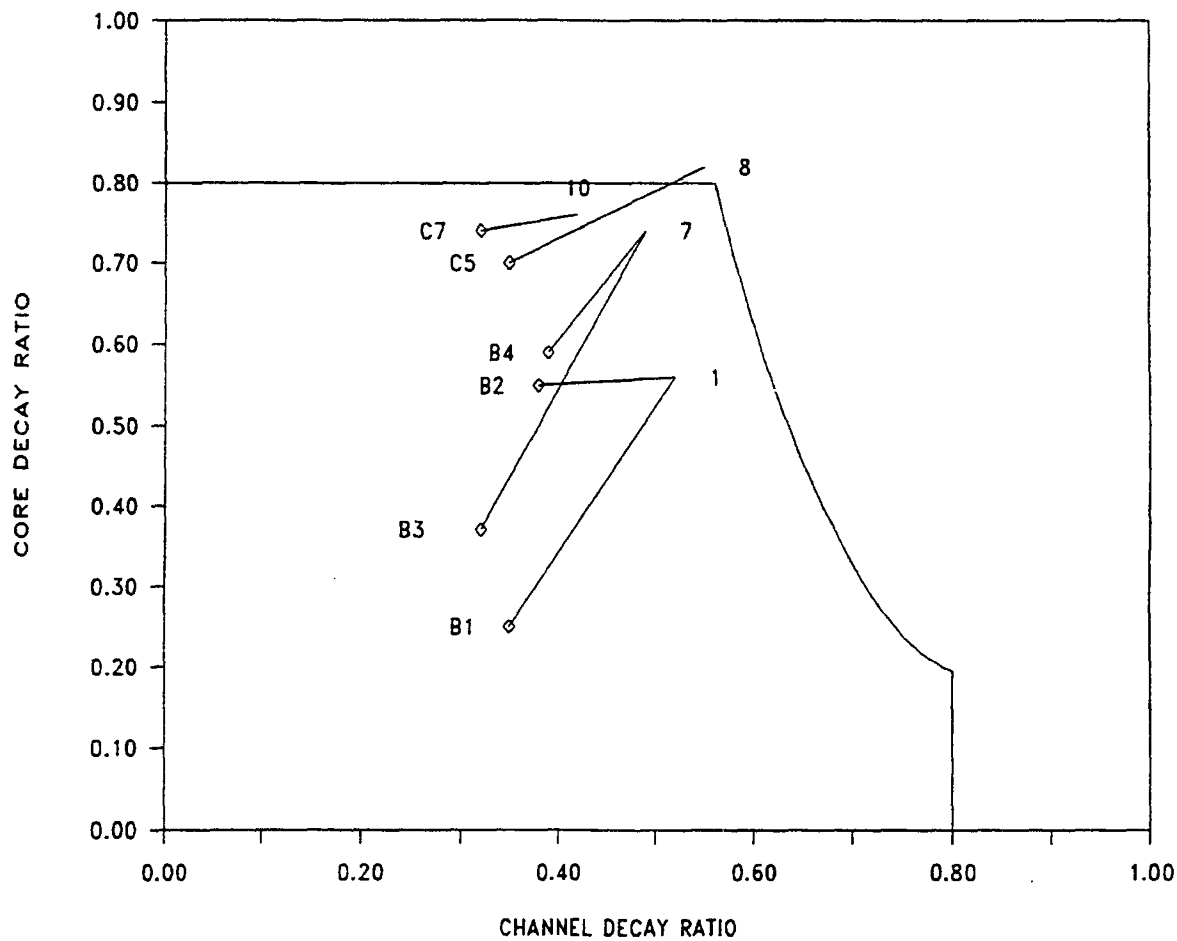


Figure A-1. Comparison of Confirmation and Region Boundary Definition Cases

"4.2 How Does Fuel from Other Vendors Affect Solution I-D Status for a Plant?

In the data presented to NRC so far, only standard GE 8 by 8 fuel has been used.

Provide comments on how does the BWROG plan to address fuel from different vendors."

Response

Fuel designs from different vendors will be addressed in the procedures for plant- and cycle-specific application of the generic region boundaries.

"4.3 Can Operational Transient/Malfunctions Increase the Power Peakings and Invalidate Solution I-D Assumptions?

In a recent European event, the instability was driven by a low feedwater heating caused by valve misalignments and a fast restart following a short shutdown. In addition, the fast restart following the shutdown increased the axial power peaking due to Xenon effects. This event shows that operational transients and/or malfunctions can affect the power shapes and the assumptions used for the calculations. In particular Solution I-D is very sensitive to the assumptions made in the analysis. In effect, out-of-phase instabilities are unlikely in this type of reactors only if the axial power peaking is within reasonable bounds. If very large power peakings were possible, out-of-phase instabilities would result.

Provide comments on why the axial power shapes selected are conservative under all expected operational transients or malfunctions."

Response

In response to Question 3.1, the appropriateness of the region boundary procedure was discussed with the conclusion that the procedure adequately bounds expected operating conditions. This was demonstrated by comparing the generated exclusion regions to actual plant instabilities which cover a wide range of operating conditions and operational transients. The response to Question 4.1 also addressed the use of the procedure power shapes in determining the expected oscillation mode and also concluded that the procedure power shapes provide appropriate results. The question of unexpected axial power shapes is at the very center of the Option I-D philosophy, in that extreme conditions would be required for an Option I-D plant to experience regional oscillations; therefore, this is not an expected mode and does not require compliance to the MCPR Safety Limit under conservative assumptions (e.g., 95/95 probability/confidence). To further demonstrate the appropriateness of the procedural power shapes, a power distribution with an extreme axial peaking factor (2.545 at node 3) was evaluated. This axial power

Response to 4.3 (continued)

distribution was obtained assuming low power, high control rod density condition with lower than expected feedwater heating, and was conservatively applied at 52% power/30% flow for Duane Arnold Cycle 10 (see Table A-2 of Reference 1, Point 10). The most likely power distribution at 52% power/30% flow is based on initial operation at rated power, which will result in a much less bottom-peaked distribution than that analyzed. The resulting channel decay ratio was 0.45, compared to 0.39 when the region boundary procedure is used. Even under these extreme conditions, the oscillation mode is determined to be the core-wide mode based on the criteria in Figure 5-1. This analysis further demonstrates the appropriateness of the region boundary procedure.

"4.4 Would There be any Fuel Damage if an Out-of-Phase Instability Occurred in a I-D Plant?

The basis for Solution I-D is that out-of-phase instabilities are unlikely, but not impossible. Yet it is not clear from this report what are the consequences if the unlikely would occur. In Solution I-D, credit is taken by the fact that these plants have flow-biased scrams; however, the benefits of this scram are not quantified.

Provide the region in the power-to-flow map where the flow-biased scram provides protection against fuel damage without operator intervention. Provide an estimate of the maximum APRM (Average Power Range Monitors) oscillation amplitude that could be expected without fuel damage.

Are the LPRM (Local Power Range Monitors) High-Low Alarms sufficient indication of out-of-phase instabilities to avoid fuel damage if the operator responds within reasonable times?"

Response

When the final fuel thermal performance evaluations have been performed with TRAC-G, the fuel thermal margin calculations for the Option I-D plants will be performed. As part of this analysis, a region in the power-to-flow map where the APRM flow-biased neutron flux scram does not provide protection of the MCPR Safety Limit will be defined. This region will then be plotted against the stability criteria to demonstrate the margin to the occurrence of regional oscillations within this "unprotected" region. APRM oscillation magnitudes and margin to the MCPR Safety Limit as a function of LPRM response will also be determined.

5. QUESTIONS RELATED TO SOLUTION II

"5.1 What is the Status of Solution II?

Provide a status report of Solution II efforts and a closure plan."

Response

The Solution II option is being pursued by Oyster Creek and Nine Mile Point 1 because of their unique APRM design. The associated utilities (GPU Nuclear and Niagara Mohawk) are therefore responsible for their specific status and closure plan.

6. QUESTIONS RELATED TO SOLUTION III

"6.1 Delta CPR Correlation

Overall, the approach followed by BWROG on Solution III is excellent and thoroughly developed. The key technical point for its application, however, is the delta CPR correlation described in part in Section 6.2.3. This correlation is not fully developed yet and would require some thorough review. An example is shown in Figure 6-11, but comes without qualification or much explanation. Our acceptance of Solution III in principle does not imply a de facto acceptance of Figure 6-11 as the delta-CPR correlation to be used for all cases. More documentation has to be provided for this correlation to be accepted."

Response

The CPR versus oscillation magnitude correlation results shown in Figure 6-11 were provided only as an example based on preliminary calculations with the TRAC-G code and are considered to be representative of the final values. Detailed calculations of the CPR response during oscillations are currently underway for a range of fuel types and plant conditions. These analyses will be used to develop the final CPR versus oscillation magnitude correlation. Documentation of the development of the CPR correlation will be provided in the future.

"6.2 Solution III Includes and Undefined Bypass Setpoint

The Solution III type scrams will be bypassed at high flows (Section A.4.1.5). The report does not specify how this bypass flow level will be determined."

Response

The Option III/III-A trip bypass setpoint has been initially defined as operation at greater than 60% of rated core flow or less than 30% of rated core thermal power. The exclusion region calculations documented in Reference 1 confirm that these setpoints provide adequate conservatism for all affected plants. Historical operating experience has also demonstrated that these are acceptable setpoints. The setpoints have been chosen to minimize the need for future review.

"6.3 Out-of-Phase Instabilities May Confuse Solution III Detection Algorithms

During out-of-phase instability events, some LPRM detectors, specially at the D level, have shown the double frequency characteristic of APRM response (i.e., 1 Hz instead of 0.5 Hz). This double frequency may confuse the detection algorithms if a very tight oscillation frequency range is imposed. Allowing for an oscillation range of 0.3 to 1.2 Hz would probably eliminate this concern, especially in Solution III-A, which is only based on a period detection. Explain why the selected frequency range is deemed to be appropriate."

Response

LPRMs which exhibit the double frequency characteristic are either situated along the oscillation axis of symmetry or are located in the top of the core (typically the D levels near the line of symmetry). LPRMs in these locations generally show much smaller oscillation magnitudes than those located at the peaks of the harmonic flux distributions and therefore would not be expected to provide trip signals. In the analysis of trip systems, no credit is taken for these LPRMs and, therefore, it does not matter whether the signal confuses the detection algorithm for these LPRMs. Expanding the frequency range to include these double frequencies would not result in more reliable trip systems but would instead increase the chances of inadvertent trips due to neutron flux variations outside the expected natural frequency. Therefore, the expected frequency range is acceptable for the intended application. It should be noted that Option III-A will use the same oscillation detection algorithm as Option III.

"6.4 Numerical Peak Finding May Degrade Period Based Solution III Performance

Finding a peak in a sampled noisy signal numerically is quite a difficult task. This should be especially so at LPRM level C and D where higher frequencies are often more dominant than the characteristic 0.5 Hz. High order low pass filtering may improve the situation, but it will add a delay and would reduce the true amplitude of a limit cycle should it occur. Any such filtering should be considered while evaluating the setpoints.

Explain in detail the filtering process and peak detection algorithm to be used in Solution III-A."

Response

Section 6.1 of this supplement describes the filtering that is used to eliminate unwanted noise characteristics. In general, two-pole Butterworth digital filters with corner frequencies between 1.5 and 5.0 Hz have been used to perform this filtering. Figures 6-1 and 6-2 show the effect of the filtering on stable and limit cycle data from actual plant measurements. These filter characteristics have been used on a wide variety of recorded plant data as discussed in Section 6.3. The oscillation peaks and minima are determined by looking for a change in slope of the signal from sample to sample. This is most important in the period-based portion of the detection algorithm.

The effects of the filters are explicitly accounted for in the setpoint analysis by keeping track of the unfiltered signal value. The time of trip is determined by the filtered signal, whereas the final maximum amplitude that the signal reaches is based on the unfiltered signal. This final maximum amplitude is used in the determination of the setpoint overshoot distribution and therefore accounts for the filtering effect on signal magnitude. The time of trip accounts for the filter delay and is used in determining whether the first or second peak following trip initiation should be used.

"6.5 Failed LPRM Strings May Degrade Solution III-A Performance

The requirement of having a minimum of only two LPRM strings per scram channel is not very strict, and it may result in unacceptably low setpoints for perverse failure cases. Describe the proposed analyses to demonstrate that this minimum number of active LPRM signals is sufficient to detect instabilities."

Response

The requirement of having a minimum of only two LPRM strings per scram channel operable for Option III-A is intended as a minimum operability requirement. The only failure assumption that is required for this case is the standard single failure of an RPS channel. For Option III-A, standard analyses using the procedure outlined in Section 6.3.2 of Reference 1 will be performed, except that credit will only be taken for the minimum allowed number of operable LPRMs. This analysis will be used to define the minimum operability requirements and any necessary reductions in trip setpoint to allow for the degraded condition. Analyses with all LPRMs assumed operable and with standard assumptions for random LPRM failures will also be performed to determine the normal trip system setpoints.

"6.6 Period Based Solution III Algorithm May Result in Numerous False Alarms

LPRM signals are fairly periodic even at low decay ratios; thus too many false alarms may be expected if the period based Solution III algorithm is designed with significant conservatism. To reduce this false alarm, the designers will probably reduce the tolerances in the algorithm fact that will increase the probability of missing a real instability event. A serious study with real plant data must be performed to justify that the reduction of false alarms has not resulted in an unacceptably high probability of failing to recognize a real event."

Response

The testing of the oscillation detection algorithm is described in Section 6.3 of this supplement and has demonstrated that the algorithm, using a wide range of algorithm parameter values, is capable of detecting instabilities while avoiding unnecessary trips.