Enclosure 1

NEDO-32992

GE Nuclear Energy

175 Curtner Avenue
San Jose, CA 95125

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GE NON-PROPRIETARY INFORMATION

Licensing Topical Report

ODYSY Application for Stability Licensing Calculations

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INFORMATION NOTICE

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

April 20, 2001

MFN 01-016

Mr. James F. Klapproth, Manager
Engineering & Technology
GE Nuclear Energy
175 Curtner Ave
San Jose, CA 95125

SUBJECT: REVIEW OF NEDC-32992P, "ODYSY APPLICATION FOR STABILITY LICENSING CALCULATIONS" (TAC NO. MB0373)

Dear Mr. Klapproth:

By letter dated October 26, 2000, GE Nuclear Energy (GENE) submitted Topical Report NEDC-32992P, "ODYSY Application for Stability Licensing Calculations" and requested approval of ODYSY as a replacement for the GENE FABLE/BYPSS code system for both long-term stability solution and new fuel design stability analysis. The staff has reviewed Topical Report NEDC-32992P for application for BWR stability calculations and concludes that the ODYSY code can be used as a replacement for the FABLE/BYPSS code for calculating core wide and channel decay ratios. The staff's safety evaluation is enclosed.

The staff finds that the subject topical report is acceptable for referencing in licensing applications to the extent specified under the limitations delineated in the report and in the associated NRC safety evaluation. The safety evaluation, which is enclosed, defines the basis for acceptance of the topical report.

The NRC requests that GENE publish an accepted version of the revised Topical Report NEDC-32992 within 3 months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed safety evaluation between the title page and the abstract, and add an "-A" (designating accepted) following the report identification number (i.e., NEDC-32992-A).

If the NRC's criteria or regulations change so that its conclusion in this letter that the topical report is acceptable is invalidated, GENE and/or the applicant referencing the topical report will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the topical report without revision of the respective documentation.

Pursuant to 10 CFR 2.790, we have determined that the enclosed safety evaluation does not contain proprietary information. However, we will delay placing the safety evaluation in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

If you have any questions, please contact Robert Pulsifer, GENE Project Manager, at (301) 415-3016.

Sincerely,

Stuart A. Richards, Director
Project Directorate IV and Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 710

Enclosure: Safety Evaluation

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phenomena. For this application, one of the most important parts of the CSAU method is the Phenomena Identification and Ranking Table (PIRT). This is a table developed by a group of experts of relevant phenomena which have to be modeled to predict decay ratios. These phenomena were then ranked and for the ODYSY code, GENE required that all medium ranked phenomena be modeled in ODYSY. The staff reviewed the PIRT and found it to be complete and its rankings appropriate.

2.2 Plant Demonstration Analyses

In order to demonstrate that ODYSY can be used as a replacement of FABLE/BYPSS for the generation of long-term stability exclusion regions, GENE performed three plant analyses using both FABLE/BYPSS and ODYSY. These calculations showed that as long as ODYSY is used as discussed below in Section 3, it generates results that are generally consistent with FABLE/BYPSS. One notable trend is the performance of ODYSY at the high flow control line. For two plants, FABLE/BYPSS and ODYSY compare well, but for the other one there is a small difference in the predicted exclusion region. Based on discussions with GENE, this difference appears to be caused by the fact that ODYSY predicts new fuel with part length rods better than FABLE/BYPSS.

3.0 <u>STABILITY LICENSING APPLICATION PROCEDURE</u>

The application procedure is as follows:

a. Calculations will be performed on the highest flow control line and the natural circulation line.

b. The calculations are exposure dependent.

c. ODYSY is used with nominal inputs.

d. A 0.15 adder is added to the ODYSY predicted core wide decay ratios.

e. The decay ratios are plotted on the currently approved stability criterion map.

f. Using the currently approved generic shape function, an exclusion region is plotted on the power to flow map.

4.0 <u>NEW FUEL LICENSING</u>

As previously discussed. GENE also proposed to replace FABLE/BYPSS as the code to evaluate the relative stability performance of new fuel using the Amendment 22 to GESTAR-11 process. This process stipulates that new fuel needs to be as or more stable than previous fuel. If this cannot be demonstrated, then it must be shown that the exclusion region on the power/flow map is unchanged. This is judged by comparing the core wide and channel decay ratios. The demonstration analyses previously discussed show that ODYSY is capable of performing these types of assessment and predicts results which agree well with FABLE/BYPSS.

5.0 CONCLUSION

The staff has reviewed the use of ODYSY as a complete replacement of the FABLE/BYPSS code for use in both long-term stability solution applications and new fuel licensing as specified in Amendment 22 to GESTAR-II. This review included an on-site visit to review the design record files documenting the analysis presented in the LTR. This review allowed the staff to evaluate the effectiveness of the application procedure. The use of ODYSY as a replacement for FABLE/BYPSS does not change the methodology of the approved long-term stability solutions.

The staff considers the use of ODYSY as a replacement of FABLE/BYPSS acceptable for all currently approved long-term stability solution FABLE/BYPSS applications and for new fuel licensing. The staff's conclusions are based on the conservative nature of the proposed ODYSY application procedure and the qualification studies which show that ODYSY is acceptable for decay ratio predictions to within the 20 percent core wide and channel decay ration uncertainties that are used in the application procedure. It is, therefore, acceptable that the ODYSY code can be used as a replacement for the FABLE/BYPSS code for calculating core wide and channel decay ratios.

6.0 REFERENCES

1. J. Post and A. Chung, "ODYSY Application for Stability Licensing Calculations," GE Nuclear Energy, October 2000.

2. B. Boyack, et. al., "Quantifying Reactor Safety Margins: Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large Break Loss of Coolant Accident," NUREG/CR-5249, December 1989.

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Date: April 20, 2001

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ABSTRACT

This report discusses the application of ODYSY, the General Electric (GE) proprietary best-estimate frequency domain stability code, to perform licensing basis stability calculations. An appropriate procedure is defined for stability licensing calculation applications for boiling water reactors (BWRs).

ODYSY has been previously approved for stability solution Enhanced Option I-A (E1A) licensing calculations. ODYSY has also been used to perform other stability analyses; however, except for E1A, GE currently performs stability licensing calculations using the NRC-approved FABLE/BYPSS methodology. ODYSY applications offer the benefit of more accurate simulations of BWR events and conditions, as well as compatibility with the PANAC11 3-dimensional core simulator which operates on a newer computational platform.

1.0 INTRODUCTION

1.1 Background

ODYSY is a best-estimate General Electric (GE) proprietary Engineering Computer Program (ECP) which incorporates a linearized, small perturbation, frequency domain model of the reactor core and associated coolant circulation system. The program may be used to predict hydrodynamic stability for both a single channel and a full reactor core. It will predict both core-wide mode coupled thermal-hydraulic and reactor kinetic instabilities and single channel thermal-hydraulic instabilities.

ODYSY is based on the approved ODYN transient model, including an axial one-dimensional (1-D) kinetics model extended to multiple channels [1]. It has axial varying void and Doppler reactivity feedback, and it has flexibility in the fuel rod modeling to accommodate axial variations in fuel bundle geometry. The axial variation capability makes it ideal for evaluating the stability of advanced fuel designs which have axial varying geometry.

Currently, two GE models are approved for stability licensing calculations. FABLE is approved for exclusion region calculations using the procedure defined in Reference 2. This has been applied for licensing calculations for stability long-term solution Option I-D, Option II, and Enhanced Option 1-A (E1A) as defined in References 2 and 3. It has also been used for new fuel licensing compliance with Amendment 22 of GESTAR II [4]. ODYSY has been approved for E1A boundary generation and reload validation analyses [5].

FABLE is based on the REDY transient analysis model. Just as ODYN provided an improvement in the accuracy of transient modeling over REDY, ODYSY provides an improvement in frequency domain modeling over FABLE. The purpose of this application licensing topical report (LTR) is to define an appropriate application procedure for the use of ODYSY for all stability licensing frequency domain calculations.

ODYSY has been extensively qualified for single channel thermal-hydraulic instabilities and for core wide coupled thermal-hydraulic and reactor kinetics instabilities from full-scale BWR plant data. Samples of the full-scale qualification studies are provided in References 5 and 6 (a NRC Request for Additional Information and the associated response are also listed with Reference 5). The Technical Evaluation Report (TER) included with the Safety Evaluation Report (SER) on the E1A ODYSY application report [5] states:

> "A detailed review and formal approval by NRC of ODYSY has not been requested. The use of [the] ODYSY code in this context is intended exclusively as a best-estimate calculation of core-wide and hot-channel decay ratios to be used in boundary- and reload-confirmation procedures associated the [Enhanced] Option I-A implementation. .... A detailed review of [the ODYSY] models was not part of the scope of this review, but from the description provided, the models appear to be adequate for stability calculations."

- The stability acceptance criteria is identical to that used with FABLE and already approved for ODYSY application to E1A (Figure 1-1).
- An extensive review of ODYSY was performed for E1A, including an independent benchmark calculation by the TER author.
- This application report includes comparisons to the previously approved FABLE application procedure results.
- ODYSY is approved for stability monitoring calculations during plant operation as part of the Option I-D stability solution.

1.2 Summary

This document demonstrates the acceptable use of ODYSY analysis results for licensing BWR power plants within the applicable licensing bases. GE has provided information to support *the use of ODYSY as an alternative to previously approved methods of analyzing BWR core and hot-channel decay ratios and demonstrating compliance with licensing limits.* Stability calculations are performed to establish a stability exclusion region on a BWR power/flow operating map which is consistent with the long-term stability solution which has been applied to the BWR being analyzed. Stability calculations are also performed with ODYSY to determine the change in reactor stability performance (i.e., the delta-decay ratio, ΔDR) from a previously approved fuel design or plant configuration. This application report demonstrates that ODYSY analyses can be used as an alternate core and hot-channel decay ratio analysis process for licensing calculations.

GE has considered the requirements of Draft Regulatory Guide DG-1096, Transient and Accident Analysis Methods [7], when compiling this LTR. The Phenomena Identification and Ranking Table (PIRT) is generated and evaluated. In addition, the Code Scaling, Applicability, and Uncertainty (CSAU) analysis is performed. The ODYSY code qualification bases, model accuracy and uncertainty have previously been documented to the NRC in Reference 5. Code scaling is not an issue, since the benchmarks have been to full-scale reactor tests and events. One additional qualification study of an actual plant instability in addition to those reported in Reference 5 is included in this report. The code uncertainty has been factored into the accepted ODYSY stability criterion map, which is the figure of merit for stability exclusion region generation based on core and hot channel decay ratios. This LTR documents that the intended application of ODYSY for stability licensing calculations is within the previously approved applicability and range, and an uncertainty of greater than two standard deviations is incorporated into the stability criterion map.

1.3 Scope of Review

GE requests that the NRC approve ODYSY for use to analyze core and hot-channel decay ratios to demonstrate compliance with stability licensing limits in BWR plants. The scope of application includes those core and hot-channel decay ratio calculations for which the FABLE methodology has been previously approved.

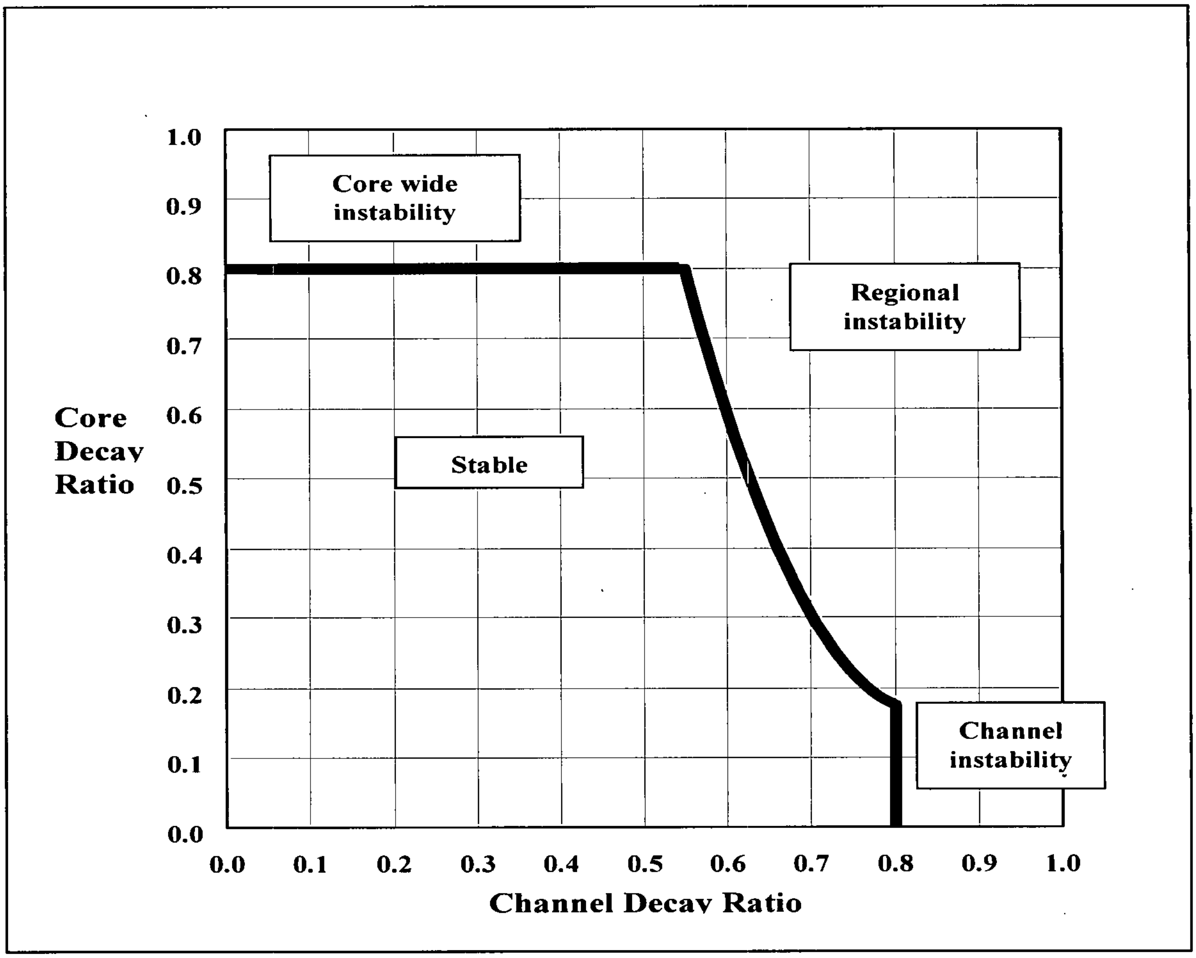

Figure 1-1. Stability Criteria Map

2.0 LICENSING REQUIREMENTS AND SCOPE OF APPLICATION

2.1 10CFR50 Appendix A

The *General Design Criteria (GDC) for Nuclear Power Plants* are stipulated in Appendix A to Part 50 of 10CFR. The stability licensing basis is set forth in GDC-12. This GDC requires assurance that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are either not possible or can be reliably and readily detected and suppressed. Following the March 9, 1988, LaSalle-2 reactor instability event, GE and the BWR Owners' Group (BWROG) developed stability interim corrective actions (ICAs) [8] and stability long-term solutions [2]. The stability solutions are in the general category of prevention solutions ("power oscillations....are not possible") and detect-and-suppress solutions ("power oscillations....can be reliably and readily detected and suppressed"). Some solutions are considered to be combination solutions with both prevention and detect-and-suppress features.

Core and hot channel decay ratio calculations are only required for solutions which include a prevention element. The implemented stability long-term solutions which have prevention features and require decay ratio calculations are E1A, Option I-D, and Option II [2, 3]. NRC approval of licensing methods used for exclusion region analyses implies that the methods are capable of assessing the capacity to prevent a reactor instability consistent with the solution licensing bases "as it relates" to the GDC.

2.2 Instability Prevention Solutions

NRC Bulletin 88-07 Supplement 1, "Power Oscillations in Boiling Water Reactors," [9] endorsed the ICAs and the BWROG program to develop generic long-term solutions. The long-term solutions developed by GE and the BWROG are described in NEDO-31960-A [2]. Long-term solutions I-A and I-D each have an exclusion region as an instability prevention features as described in NEDO-31960-A. The TER on these solutions identified concerns with the I-A solution which led to the development of the E1A solution as documented in NEDO-32339-A, Revision 1 [3]. In addition, at least one plant which implemented Option II has included an exclusion region as part of their solution. Therefore, decay ratio calculations to determine an exclusion region are required for stability licensing calculations for solutions E1A, I-D, and II.

2.3 New Fuel Licensing

Therefore, decay ratio calculations to determine the relative stability performance of a new fuel design or to determine the impact on an exclusion region are required for new fuel licensing.

2.4 Application Procedure

2.4.1 Current FABLE Procedure

The current approved model for decay ratio calculations and exclusion region determination is the FABLE code. The FABLE model includes a point kinetics model, fuel heat transfer model, channel thermal-hydraulic model, and a numerical transfer function to represent the downcomer and recirculation system.

The procedure for decay ratio calculations with FABLE is specified in Section 5.2 of NEDO-31960-A [2]. The procedure specifies:

- The most negative point model nuclear void coefficient is used. Doppler reactivity feedback is not included in the evaluation.
- Standard design values for thermal-hydraulic data is used.
- Spacer friction loss coefficients based on crudded spacers.
- Limiting core average and hot channel axial power shapes is used.
- A minimum of 8 channel groups are used to model the radial power distribution.
- A gap conductance multiplier of 1.6 is applied to the nominal value.

Standard design values are used in the analysis for thermal-hydraulics data. These values are consistent with GE methods for other transient and accident analysis and are necessary to ensure consistency between the various analytical calculations performed for a stability analysis. In addition, the decay ratio adjustment factor defined in Reference 10 is applied to the calculated FABLE decay ratio. Using crudded spacer loss coefficients, applying a multiplication factor on gap conductance, and using the decay ratio adjustment factor are all based on improving the FABLE performance for qualification data and producing an appropriate level of conservatism in the decay ratio result.

The procedure is used to define the exclusion region endpoints on the High Flow Control Line (HFCL) and the Natural Circulation Line (NCL). The Generic Shape Function (GSF) (Section 2.9) is used to define the region boundary between the HFCL and NCL endpoints. The combination of the model, inputs, application procedure, decay ratio adjustment factor, and GSF produces an appropriate stability exclusion region boundary.

2.4.2 Proposed ODYSY Procedure

A procedure is specified for decay ratio calculations with ODYSY which produces an appropriate stability exclusion region boundary. The ODYSY procedure is basically the same as FABLE except for the following:

The procedure, including a comparison to the FABLE procedure, is provided in Section 5.

2.4.3 Advantages of ODYSY Compared to FABLE

ODYSY has many advantages over the use of FABLE for stability licensing analyses. These advantages include:

- Axial geometry variation provides more accurate modeling of advance fuel designs.
- 1-D kinetics model.
- Exposure-dependent calculations provide a more accurate calculation of the core and hot channel decay ratios during an operating cycle.
- An empirical output adjustment to the calculated core and hot-channel decay ratios is not needed.
- ODYSY operates on a computer platform consistent with the updated core simulator model and is capable of interfacing with PANAC11 [11].

2.5 Conformance with CSAU Methodology

The NRC has recently introduced a draft regulatory guide and standard review plan on analytical computer codes, DG-1096 [7]. The draft guideline defines the procedures, methods, and concepts that are acceptable to the NRC staff for the development and assessment of evaluation models used to analyze transient and accident behavior. The draft guide specifically endorses the use of Code Scaling, Applicability, and Uncertainty (CSAU) methodology to document the acceptability of transient and accident analysis methodologies.

The proposed application of ODYSY for BWR stability exclusion region licensing calculations addresses all the elements of the NRC-developed CSAU evaluation methodology [12]. The CSAU report describes a rigorous process for evaluating the total model and plant parameter uncertainty for a nuclear power plant calculation. The rigorous process for applying realistic codes and quantifying the overall model and plant parameter uncertainties represents the best available practice. While the CSAU methodology was developed for application to loss-of-coolant accidents (LOCAs), there are no technical reasons that prevent CSAU methodology from being applied to other analyses such as stability calculations. A statistical process very similar to the CSAU methodology was applied by the NRC in the safety evaluation of the current ODYN based licensing methodology for transient calculations [13]. ODYN is the time domain model which was used to create the frequency domain code ODYSY.

The CSAU methodology consists of 14 steps as documented in Reference 12. These steps are addressed for the current ODYSY application as outlined in Table 2-1.

Table 2-1. Code Scaling, Applicability, and Uncertainty Evaluation

CSAU Step	Description	Addressed In
1	Scenario Specification	Sections 2.8 &4.3
2	Nuclear Power Plant Selection	Section 2.10
3	Phenomena Identification and Ranking	Section 3.0
4	Frozen Code Version Selection	Sections 2.7 & 4.4
5	Code Documentation	References 5 & 6
6	Determination of Code Applicability	Section 4.1
7	Establishment of Assessment Matrix	Section 4.2
8	Nuclear Power Plant Nodalization Definition	Section 4.7
9	Definition of Code and Experimental Accuracy	References 5 & 6
10	Determination of Effect of Scale	Section 4.8
11	Determination of the Effect of Reactor Input Parameters and State	Sections 4.4 & 4.5
12	Performance of Nuclear Power Plant Sensitivity Calculations	Section 4.9 Reference 2
13	Determination of Combined Bias and Uncertainty	References 5 & 6
14	Determination of Total Uncertainty	Section 2.7.2, References 5 & 6

2.6 Implementation Requirements

The implementation of ODYSY into actual stability licensing analysis is contingent on completion of the following implementation requirements:

- Review and approval by the NRC of the application procedure described in Section 5.
- Review and approval by the NRC of the stability Option I-D Exclusion Region for Duane Arnold Energy Center Extended Power Uprate.

A technical design procedure will also be developed for performance of exclusion region analyses with ODYSY.

2.7 Review Requirements For Updates

ODYSY is a controlled computer code under the ECP quality assurance requirements. The code version which has been used for this analysis is ODYSY05. This version of the code is "frozen" under GE ECP requirements in accordance with the CSAU methodology for a "frozen" code.

In order to effectively manage the future viability of ODYSY for stability licensing calculations, GE proposes the following requirements for upgrades to the code to define changes that (1) require NRC review and approval and (2) that will be on a notification basis only.

2.7.1 Updates to ODYSY Code

A code version which involves modifications to the basic models described in References 5 and 6 may <u>not</u> be used for stability licensing calculations without NRC review and approval.

A code version which includes changes in the numerical methods to improve code convergence may be used for stability licensing calculations without NRC review and approval.

A code version which includes features that support automation of code input/output may be used for stability licensing calculations without NRC review and approval.

2.7.2 Updates to ODYSY Model Uncertainties

Since the NRC has explicitly approved the ODYSY stability criteria map [4], the criteria map will not be modified for licensing calculations without NRC review and approval. If new data becomes available with which the specific model uncertainties may be reassessed, the model uncertainty will not be revised for stability licensing calculations without NRC review and approval.

2.8 Evaluation Scenario

The ODYSY calculation is a frequency domain code, hence an "evaluation scenario" is not meaningful, since a time domain transient response can not be calculated in the frequency domain. Rather, evaluation conditions are specified. The ODYSY calculation is performed at specified points on the power/flow map with appropriate core and reactor conditions such as power shapes, core inlet temperature, etc. The conditions are defined in accordance with the proposed application procedure defined in Section 5.

2.9 Generic Shape Function

The ODYSY application procedure defines state points on the HFCL and the NCL which meet the region boundary generation stability criteria. The region boundary is then defined with the Generic Shape Function (GSF). The GSF is a fit to power/flow state points with a constant decay ratio. The GSF has been approved by the NRC as documented in Reference 2:

$$P = P_B \left(\frac{P_A}{P_B} \right)^{\frac{1}{2}\left[\frac{W - W_B}{W_A - W_B} + \left(\frac{W - W_B}{W_A - W_B} \right)^2 \right]} \qquad (2\text{-}1)$$

where

Point A is on the HFCL, Point B is on the NCL,
P = a core thermal power value on the region boundary (% of rated),
W = the core flow rate corresponding to power, P, on the region boundary (% of rated),
P_A = core thermal power at point A (% of rated),
P_B = core thermal power at point B (% of rated),
W_A = core flow rate at point A (% of rated), and
W_B = core flow rate at point B (% of rated).

2.10 Nuclear Power Plant Selection

The included plant types are BWR/2s, BWR/3s, BWR/4s, BWR/5s, BWR/6s, and the Advanced BWR (ABWR). Jet pump, natural circulation, and internal recirculation pump plant designs are included. For the jet pump designs, the recirculation flow control systems include motor-generator designs, flow control valve designs, and variable speed pump designs. Application of the ODYSY kinetics, fuel heat transfer, and channel thermal-hydraulic models are identical for the listed power plant designs. The only major difference is in modeling of the steam separators and circulation system. Since ODYN has been qualified for each of these configurations, and ODYSY is simply the frequency domain transformation of the ODYN model, ODYSY is also applicable to each of these recirculation system.

3.0 PHENOMENA IDENTIFICATION AND RANKING

The critical parameters for stability exclusion region calculations are core and channel decay ratios. The values of the critical parameters are determined by the governing physical phenomena. To delineate the important physical phenomena, it has become customary to develop phenomena identification and ranking tables (PIRTs), which are ranked with respect to their impact on the critical parameters. The most cost efficient, yet sufficient, analysis reduces all candidate phenomena to a manageable set by identifying and ranking the phenomena with respect to their influence on the critical parameters.

The PIRTs represent a consensus of GE expert opinions. PIRTs are developed with only the importance of the phenomena in mind and are independent of whether or not the model is capable of handling the phenomena.

Table 3-1 was developed to identify the phenomena that influence stability calculations. The impact on the core and hot channel decay ratio is indicated for the design parameters and evaluation conditions. The ranking of the phenomena is done on a scale of high importance to low importance or not applicable, as defined by the following categories:

- *High importance (H):* These phenomena have a significant impact on the critical or primary safety parameters.
- *Medium importance (M):* These phenomena have a moderate impact on the critical or primary safety parameters.
- *Low importance (L):* These phenomena have an insignificant impact on the critical or primary safety parameters.
- *Not applicable (N/A):* These phenomena have no impact on the critical or primary safety parameters.

Table 3-1. Phenomena Identification & Ranking Table - Stability Calculations

4.0 APPLICABILITY OF ODYSY TO STABILITY LICENSING CALCULATIONS

The objective of this section is to demonstrate the applicability of ODYSY for the analysis of stability licensing calculations in BWRs. To accomplish this purpose, the capability of the ODYSY models to treat the highly ranked phenomena and the qualification assessment of the ODYSY code for core and hot channel decay ratios are examined in the next two subsections.

4.1 Model Capability

The ODYSY code consists of four main models:

- Reactor kinetics model – neutronic parameters are collapsed from a 3-D PANACEA wrap-up and evaluated in a 1-D kinetics model which includes void and Doppler reactivity feedback.
- Fuel heat transfer model – consists of a 1-D radial conduction model for the fuel rod cladding, gap, and fuel pellet.
- Channel thermal-hydraulics model – consistent with other GE design methods, it has a drift flux correlation including subcooled void modeling.
- Recirculation system model – the upper plenum, steam separators, downcomer, and recirculation system are modeled as hydraulic regions.

Table 4-1. Phenomena & ODYSY Capability Matrix - Stability Calculations

4.2 Qualification Assessment

4.3 Instability Events

There are basically two types of events evaluated for reactor stability:

- Pseudo steady-state (e.g., during a reactor startup) – core flow and reactor power are both being increased. Increasing reactor power at a greater rate than core flow is increased can be destabilizing.
- Transient flow event (e.g., a recirculation pump runback or trip event) – core flow is decreased and power generally follows the flow control line corresponding to the initial condition when the flow transient event occurred. A runback reduces core flow more dramatically than power is reduced and can be destabilizing.

Since ODYSY will not analyze a transient event, these events are evaluated by specifying the appropriate analysis inputs and initial conditions.

4.4 Analysis Inputs

Specific inputs for each condition to be evaluated are specified via internal procedures, which are the primary means used by GE to control application of engineering computer programs (ECPs). The specific code input will be developed in connection with the application LTR and the development of the application specific procedure.

Code inputs can be divided into four broad categories: (1) geometry inputs; (2) model selection inputs; (3) initial condition inputs; and (4) plant parameters. The geometry inputs are used to specify diameter, thickness, length, area, volume, etc. Uncertainties in these parameters were present in the full-scale qualification tests and are adequately addressed in the 0.20 uncertainty which has been applied to the core and channel decay ratio, as shown on the stability criteria map. Model selection inputs are used to select the features of the model that apply for the intended application. Once established, these inputs are fully specified in the procedure for the application and will not be changed. The initial conditions are addressed in Section 4.5 and the plant parameters are addressed in Section 4.6.

4.5 Initial Conditions

Initial conditions are those conditions that define reactor state at which the calculation is to be performed. Initial conditions include the Evaluation Condition parameters listed in Table 4-1, except for the recirculation system definition which is a plant parameter. Two conditions are defined for calculating core and hot channel decay ratios to determine a stability licensing basis exclusion region. The two conditions are:

- Steady-state operation on the NCL. - The associated core average axial power shape is based on a rated power/rated flow Haling depletion at the actual power and NCL flow rate being analyzed. Since the Haling depletion is exposure dependent, this produces an exposure-dependent result for the core decay ratio on the NCL. The initial condition on the NCL is assumed to be Xenon free.

- A flow runback along the HFCL from the full power/minimum flow state point on the power/flow operating map. - The associated core average axial power shape is based on a rated power/minimum flow Haling depletion at the actual power and HFCL flow rate

being analyzed. Since the Haling depletion is exposure dependent, this produces an exposure dependent result for the core decay ratio on the HFCL. The initial condition on the HFCL is assumed to be constant at the initial operating condition.

The associated void coefficient is also dependent on the power/flow state point and exposure being analyzed. This produces an exposure dependent result for the core and hot channel decay ratio at each condition being analyzed.

The initial conditions specified for the condition being analyzed are obtained from verified core simulator (PANACEA) wrap-ups and the verified ISCOR thermal-hydraulic model on the BWR Engineering Data Bank (BWREDB) maintained by GE for ECP evaluations.

4.6 Plant Parameters

Plant parameters are those plant and cycle specific values which are required to describe the plant being evaluated. Plant parameters include design information such as the Core and Fuel Design parameters listed in Table 4-1, as well as Evaluation Condition parameters such as the recirculation system definition. The plant parameters can have a significant impact on the core and hot channel decay ratio calculations. For example, the core inlet orifice size impacts the single-phase (1Φ) pressure drop and the two-phase/single-phase pressure drop ratio (2Φ/1Φ Δp). A plant with a tight core inlet orifice design will have a high 1Φ pressure drop and a low 2Φ/1Φ Δp ratio. This type of design has been shown to have relatively low core and channel decay ratios. An identical plant with a loose core inlet orifice would have a reduced 1Φ pressure drop and a higher 2Φ/1Φ Δp ratio. The loose orifice design has been shown to have relatively larger core and channel decay ratios.

The plant design inputs are obtained from the verified ODYN base deck from the BWREDB for the plant being analyzed and verified core simulator (PANACEA) wrap-ups used in reload licensing analysis.

4.7 Effects of Nodalization

Nodalization has a meaning in a time domain model relative to the finite differences in space associated with the integration scheme used in the model. This meaning does not translate well to a frequency domain code since it does not perform a time based integration.

The comparable nodalization strategy for ODYSY is reflected in the axial power shape, the number of channels used to model the core, and the number of regions used to model the ex-core thermal-hydraulics.

- A 25 node axial power shape and core thermal-hydraulics model are used, consistent with the associated nuclear methods. This gives a very accurate representation of the axial variation in the core as it affects core and hot channel decay ratios which is consistent with the approved transient evaluation model (ODYN).

- Up to nineteen channel groups are used to model the core based on channel geometry and power distribution. This gives a very accurate representation of the radial power distribution for calculating the core decay ratio.

- The ex-core regions (upper plenum, steam separator, downcomer, recirculation system, lower plenum) are modeled separately based on the fundamentally based modeling of each region in ODYN. The recirculation system model includes options for external recirculation pumps with jet pumps, external recirculation pumps without jet pumps, and internal recirculation pumps.

This nodalization strategy has been used in previous qualification studies [5, 6], as well as the supplemental qualification studies in Section 6. This nodalization strategy provides the code accuracy documented in References 5 and 6.

4.8 Effects of Scale

4.9 Sensitivity Analysis

Sensitivity studies have been performed for ODYSY as documented in Appendix E of Reference 2. Additional sensitivity studies are reported in Reference 14. Sensitivity studies include evaluations of Xenon concentration, boiling boundary height, axial flux shape, radial peaking factor, feedwater temperature and cycle exposure. These sensitivities were used when the best-estimate ODYSY application procedure was established for E1A validation studies. The current ODYSY stability application procedure is compared to the proposed ODYSY exclusion region procedure in Section 5.

A sensitivity study has also been performed on the impact of using a Haling exposure or a rodded exposure as it impacts the core average axial power shape (APS). A sample plant with an equilibrium cycle of GE12 fuel (10x10 fuel rod array) was used for the sensitivity study. The stability calculations are based on actual rodded burn core simulator predictions. The Haling exposure cases are first burned to end of cycle, then back-burned to beginning of cycle, then burned to the desired exposure using the Haling power shape. A state point at minimum pump speed along the HFCL is used, which corresponds to 68.7% power and 39.2% core flow for the sample plant used in this sensitivity study. The Haling case hot channel decay ratio calculation uses the hot channel axial power shape overlay specified for the licensing calculation procedure.

Figure 4-1. Haling Core Average Axial Power Shape vs. Exposure

Figure 4-2. Rodded Core Average Axial Power Shape vs. Exposure

Figure 4-3. Core Decay Ratio Comparison: Haling vs. Rodded Burn

Figure 4-4. Channel Decay Ratio Comparison: Haling vs. Rodded Burn

5.0 ODYSY STABILITY LICENSING APPLICATION PROCEDURE

This section of the report defines the proposed ODYSY procedure for stability exclusion region licensing calculations. A model comparison is made to FABLE, since the previously approved application procedure used FABLE. Comparisons are also provided to the FABLE procedure and the ODYSY procedure used for Enhanced Option I-A (E1A) region boundary validation studies.

5.1 Model Comparisons

FABLE and ODYSY both have the same model structure, though ODYSY has substantial modeling improvements as compared to FABLE. FABLE is based on the transient code REDY, while ODYSY is based on the transient code ODYN [1]. The codes provide a Laplace transform of the time domain methods to produce a frequency domain methodology. Both frequency domain codes consist of a reactor kinetics model, channel thermal-hydraulic model, a recirculation (ex-core) hydraulics model, and a fuel heat transfer model. The characteristics of each of these models in FABLE and ODYSY are described in Table 5-1.

The one-dimensional (1-D) kinetics model in ODYSY provides an improvement over the point kinetics model in FABLE. The channel thermal hydraulics in ODYSY uses the more accurate drift flux formulation and models axial varying geometry such as part length fuel and water rods. The ODYSY ex-core hydraulics model considers the specific regions, including upper plenum, steam separator, downcomer, recirculation system and lower plenum as separate hydraulic regions. This is more accurate than the numerical transfer function used to represent the entire ex-core flow path in FABLE. ODYSY has a 1-D radial conduction model for the fuel rod as compared to a lumped parameter model for FABLE. ODYSY can model axial geometry variations present in advanced fuel designs. ODYSY also produces an exposure-dependent calculation, since it includes exposure-dependent inputs such as void coefficient, Doppler coefficient, and core average axial power shape.

5.2 Proposed Application Procedure

The proposed application procedure is designed to produce a conservative estimate of the region on the power/flow map which has the potential for reactor instability. The proposed ODYSY application procedure for licensing basis decay ratio calculations is summarized as follows:

5.3 Comparison to Other Procedures

Table 5-2 provides a comparison of the proposed procedure to the FABLE exclusion region procedure and the E1A ODYSY validation procedure. The procedure addresses the same parameters addressed in NEDO-31960-A [2] for the original FABLE procedure.

5.3.1 Void Coefficient

The actual exposure-dependent void coefficient (in terms of nuclear void coefficient/delayed neutron fraction) is used in the calculation. The void coefficient is based on the actual core and cycle configuration being analyzed. This produces an exposure-dependent decay ratio calculation.

5.3.2 Thermal-Hydraulics Data

Standard design values for thermal-hydraulics data are used in the analysis. These values are consistent with updated GE methodology (Method B from Reference 15) used in current design procedures for transient and accident analysis and are necessary to ensure consistency between the various calculation methodologies.

5.3.3 Axial Power Shape

The core average axial power shapes (APS) are based on a Haling depletion, and are specific to the exposure point being calculated. For calculations on the NCL, the actual off-rated power/flow conditions are used to define the APS. For calculations on the HFCL, the APS from the lowest flow at which rated power can be achieved (often called the ELLLA or MELLLA point) is used since this is in fact the highest rod line on which the plant is licensed to operate.

The hot channel APS is overlayed to produce a conservative hot channel result. The hot channel APS is the same as was used previously in the FABLE procedure [2].

5.3.4 Radial Power Distribution

Up to nineteen (19) channel groups are used to model the radial power distribution. The hot channel option is used for each fuel type present in the core based on the maximum radial power. Channel grouping is adequate to model each of the fuel support casting orifice types (central, intermediate, and peripheral) which are present in the core.

5.3.5 Pellet-Clad Gap Conductance

5.3.6 Other Inputs

Additional inputs required such as plant heat balance data, recirculation loop resistance, separator loss coefficients, reactor component dimensions, fuel physical parameters, and material properties are based on standard design values. The loss coefficients for fuel bundle spacers is different from the previous FABLE application. When FABLE was qualified, the qualification studies used spacer loss coefficients corresponding to crudded spacers to improve the correlation to the qualification data. The ODYSY qualification studies used spacer loss coefficients corresponding to spacers are not crudded. ODYSY (and ODYN) performance and qualification against BWR plant data has been correlated with this bases, and it is essential to carry the same bases through to the ODYSY stability licensing procedure to ensure accurate calculations within the qualification bases.

5.4 Procedure Application to Stability Solutions

The procedure described will be applied to Option I-D exclusion region boundary generation. At least one plant with Option II has included an administratively controlled exclusion region. The procedure for calculation of the Option II exclusion region is identical to the Option I-D procedure.

The E1A Standard Cycle (SC) calculation within the E1A region boundary generation process currently uses the FABLE procedure. ODYSY is used for E1A region boundary validation, but FABLE is used in the E1A SC calculation. The SC is a FABLE calculation of core and hot channel decay ratio for a standard 8x8 fuel and core design for four state points on the NCL and four state points on the HFCL. Using a standard 8x8 design ensures that this calculation produces a result which indicates the relative stability performance of the plant, not the fuel and core design. The actual fuel and core performance is addressed in the E1A Reference Cycle and boundary validation studies which use the E1A ODYSY procedure (Table 5-2). The E1A ODYSY validation procedure will not be changed in the E1A process. The only change to the E1A process will be to use the ODYSY exclusion region procedure for the E1A SC calculation.

5.5 Conservatism of Procedure

Demonstration analysis is provided in Section 7 of this report to illustrate the application of the ODYSY procedure and show that ample conservatism is retained in the ODYSY procedure relative to the previous FABLE procedure.

Table 5-1. Model Comparison: FABLE vs. ODYSY

Modeling	FABLE	ODYSY
Reactor Kinetics	• Point kinetics with no Doppler feedback • Void feedback from flux squared weighting of nodal void reactivity	• 1-D kinetics with void and Doppler feedback • Parameters collapsed from 3-D PANACEA wrap-up
Channel Thermal-Hydraulics	• Mixture equations with subcooled boiling • Bankoff slip correlation	• Drift flux formulation with subcooled voids • Consistent with other GE design methods
Ex-Core Hydraulics	• Numerical transfer function using gain and phase lags based on downcomer and recirculation loop geometry	• Upper plenum, steam separator, downcomer, recirculation system, modeled as hydraulic regions
Fuel Heat Transfer	• Lumped parameter model for cladding, gap, and fuel	• 1-D radial conduction model for cladding, gap, and fuel
Axial Geometry	• Does not model axial geometric variation in advanced fuel designs	• Models axial geometric variation in advanced fuel designs
Core simulator	• Input from PANAC10 or earlier	• Input from PANAC11 or earlier

Table 5-2. Procedure Comparison: FABLE vs. Proposed ODYSY vs. E1A ODYSY

Application	FABLE Exclusion Region Procedure	Proposed ODYSY Exclusion Region Procedure	E1A ODYSY Validation Procedure
Reactivity coefficients	Most negative point model void coefficient in cycle No Doppler coefficient	Exposure-dependent 1-D kinetics model void coefficient Includes Doppler coefficient	Same as proposed ODYSY procedure except based on EOC Haling, not exposure dependent
Thermal-hydraulic data	Standard values consistent with transient analysis methods in use at the time the procedure was developed (ISCOR Method A [15])	Standard values consistent with transient and accident analysis methods currently in use (ISCOR Method B [15])	Same as proposed ODYSY procedure
Core average axial power shape (APS)	On the NCL, use the limiting off-rated APS from EOC full power Haling depletion On the HFCL, use the rated APS from EOC full power Haling depletion	On the NCL, use the exposure dependent off-rated APS from full power Haling depletion On the HFCL, use the exposure dependent off-rated APS from a minimum flow at rated power Haling depletion	Same as the proposed ODYSY procedure except based on EOC Haling, not exposure dependent
Xenon concentration	Constant Xenon at the operating condition	On the NCL, no Xenon On the HFCL, constant Xenon at the initial operating condition	Same as proposed ODYSY procedure
Hot channel APS	Overlay a conservative hot channel APS	Same as FABLE procedure	Same as FABLE procedure
Radial power	8 or more channel groups used to	19 channel groups used to	Same as proposed ODYSY

Application	FABLE Exclusion Region Procedure	Proposed ODYSY Exclusion Region Procedure	E1A ODYSY Validation Procedure
distribution	model core	model core	procedure
Gap conductance	1.6 gap conductance multiplier on core average gap conductance	Use core average gap conductance	Same as proposed ODYSY procedure
Spacer model	Crudded spacer loss coefficients	Clean spacer loss coefficients [1]	Same as proposed ODYSY procedure
Empirical output adjustment	Yes [10]	No	Same as proposed ODYSY procedure
Stability Criteria	As shown in Figure 1-1 (e. g., at core decay ratio = 0.80, the maximum channel decay ratio = 0.56)	Same as FABLE procedure	Same as FABLE procedure

6.0 SUPPLEMENTAL QUALIFICATION STUDIES

6.1 Original Qualification Database

ODYSY was qualified primarily against Vermont Yankee, LaSalle KRB, Cofrentes, and Leibstadt data. ODYSY was also qualified against TRACG predictions of channel instability for LaSalle and Leibstadt. The original qualification database is documented in References 5 and 6. This database resulted in the core and channel decay ratio uncertainty documented in Section 2.7.2.

6.2 Supplemental Qualification Database

A reactor instability event occurred at a non-US BWR/5 on January 24, 1995. ODYSY calculations were performed to determine the core and channel decay ratios when the reactor instability occurred and to determine the effectiveness of proposed actions to allow plant restart without experiencing a reactor instability.

The BWR/5 is designed with a flow control valve (FCV) recirculation system. The instability occurred while preparing for recirculation pump up-shift during a reactor startup in the middle of an operating cycle. The plant was operating at about 36% rated power and 38% rated core, which is near the 66% rod line with normal feedwater temperature for the power/flow operating state. The plant was operating with the FCVs partially open and both recirculation pumps on low speed. The normal procedure is to partially close both FCVs to reduce core flow, shift the recirculation pumps to high speed, and then gradually open the FCVs to increase core flow. In this instance, when the operators closed the FCVs, the plant conditions changed to ~31.8% power, as indicated on the Average Power Range Monitor (APRM) and 32% core flow and a core-wide mode reactor instability developed. There was some uncertainty on the initial power and power level following the flow reduction. Other indications are that power may have been 33.1% of rated when the oscillation began.

As flow was being decreased, the power oscillations grew slowly to an amplitude of ~11% peak-to-peak, as indicated on the APRM. The flow reduction and oscillation growth to reach a limit cycle oscillation took about 4 minutes. After ~1-2 minutes of limit cycle oscillations, the operator increased core flow by opening the FCVs and the oscillation magnitude decreased to ~3% peak-to-peak. A manual scram was initiated ~7 minutes after the flow reduction had been initiated (this plant was not using stability Interim Corrective Actions under the requirements of NRC Bulletin 88-07, Supplement 1 [9] at the time this event occurred).

Table 6-1. Supplemental BWR/5 Instability Event Qualification Studies

Figure 6-1. Supplemental BWR/5 Instability Event Qualification Studies

7.0 DEMONSTRATION ANALYSIS

The analyses provided in this section are a demonstration of the proposed process representative of where the procedure will be applied. Demonstration analysis is provided for Option I-D exclusion region generation and for evaluation of the stability licensing requirements of new fuel licensing. The Option I-D demonstration analysis includes calculations for three plants which compare the exclusion region generated with the FABLE procedure to the exclusion region generated with the proposed ODYSY procedure. The new fuel licensing demonstration analysis compares the FABLE procedure result to the ODYSY procedure result for a previously approved GE fuel design.

As described in Section 5, the FABLE procedure is also used for at least one Option II exclusion region generation and for the E1A SC calculation. The process for calculation of the Option II exclusion region and the E1A SC are identical to the Option I-D process. Therefore, a separate demonstration analysis for Option II and the E1A SC are not necessary. A demonstration analysis for application of the ODYSY procedure to Option II and the E1A SC would not present any new information beyond the stability Option I-D demonstration analysis. The Option I-D demonstration analysis is adequate to demonstrate the effect of the ODYSY procedure compared to the FABLE procedure for application to Option I-D, Option II exclusion region, and E1A Standard Cycle calculations.

7.1 Option I-D Demonstration Analysis

Option I-D has an administratively controlled exclusion region. It also has a buffer zone which is 5% in power and flow outside the exclusion region. The exclusion region is reviewed for applicability each reload, and re-calculated if the reload criteria indicate that the region might change significantly. Sample calculations are presented for three Option I-D plants using the ODYSY exclusion region procedure and compared to the FABLE procedure result.

This indicates that there is a greater variation in the FABLE results on the HFCL than along the NCL. FABLE is less accurate at modeling fuel designs with axially varying geometry than ODYSY. This inaccuracy is more pronounced along the HFCL, since this condition has a higher power and void fraction than the calculations along the NCL. In addition, a decay ratio change produces a bigger impact in flow along the HFCL than the change in power along the NCL. Thus, differences in FABLE and ODYSY results are magnified along the HFCL when plotted on a power/flow map. It is concluded that the improved accuracy in the ODYSY analysis, especially for more advanced fuel

designs, may result in an increase in exclusion region size for some Option I-D plants. Others may decrease in size slightly and others will remain virtually unchanged.

7.1.1 Demonstration Plant #1

Demonstration Plant #1 shows a slightly smaller exclusion region from the ODYSY procedure along the HFCL and a slightly larger exclusion region on the NCL. The exclusion region for demonstration plant #1 is illustrated in Figure 7-1.

Table 7-1. Plant 1 Exclusion Region Endpoints: FABLE vs. ODYSY

7.1.2 Demonstration Plant #2

Demonstration Plant #2 shows an exclusion region generated with the ODYSY procedure which is nearly identical to the FABLE procedure exclusion region. The exclusion region for demonstration plant #2 is illustrated in Figure 7-2.

Table 7-2. Plant 2 Exclusion Region Endpoints: FABLE vs. ODYSY

7.1.3 Demonstration Plant #3

Demonstration Plant #3 shows an exclusion region based on the ODYSY procedure which is larger than the FABLE based exclusion region along the HFCL, but nearly identical to the FABLE based exclusion region on the NCL. The exclusion region for demonstration plant #3 is illustrated in Figure 7-3.

Table 7-3. Plant 3 Exclusion Region Endpoints: FABLE vs. ODYSY

7.2 New Fuel Licensing

Table 7-4. Amendment 22 P8x8R - GE14 Comparison: Decay Ratio Vs. Exposure

Table 7-5. Amendment 22 P8x8R - GE14 Comparison: Limiting Decay Ratio

Table 7-6. Amendment 22 Comparison Loose Orifice Plant: Exclusion Region Endpoints

7.3 Demonstration Analysis Conclusions

The demonstration analysis illustrates application of the ODYSY procedure and shows that ample conservatism is retained in the procedure relative to the previous FABLE application. The improved ODYSY capability to model modern fuel designs with axially varying geometry may result in an increase in the exclusion region size for some plant-specific evaluations.

The demonstration analysis also illustrates that the ODYSY procedure is appropriate for new fuel licensing. The ODYSY calculation is more accurate than FABLE, especially for new fuel designs with axially varying geometry.

Using the ODYSY procedure to determine the exclusion region could support development of an exposure-dependent exclusion region.

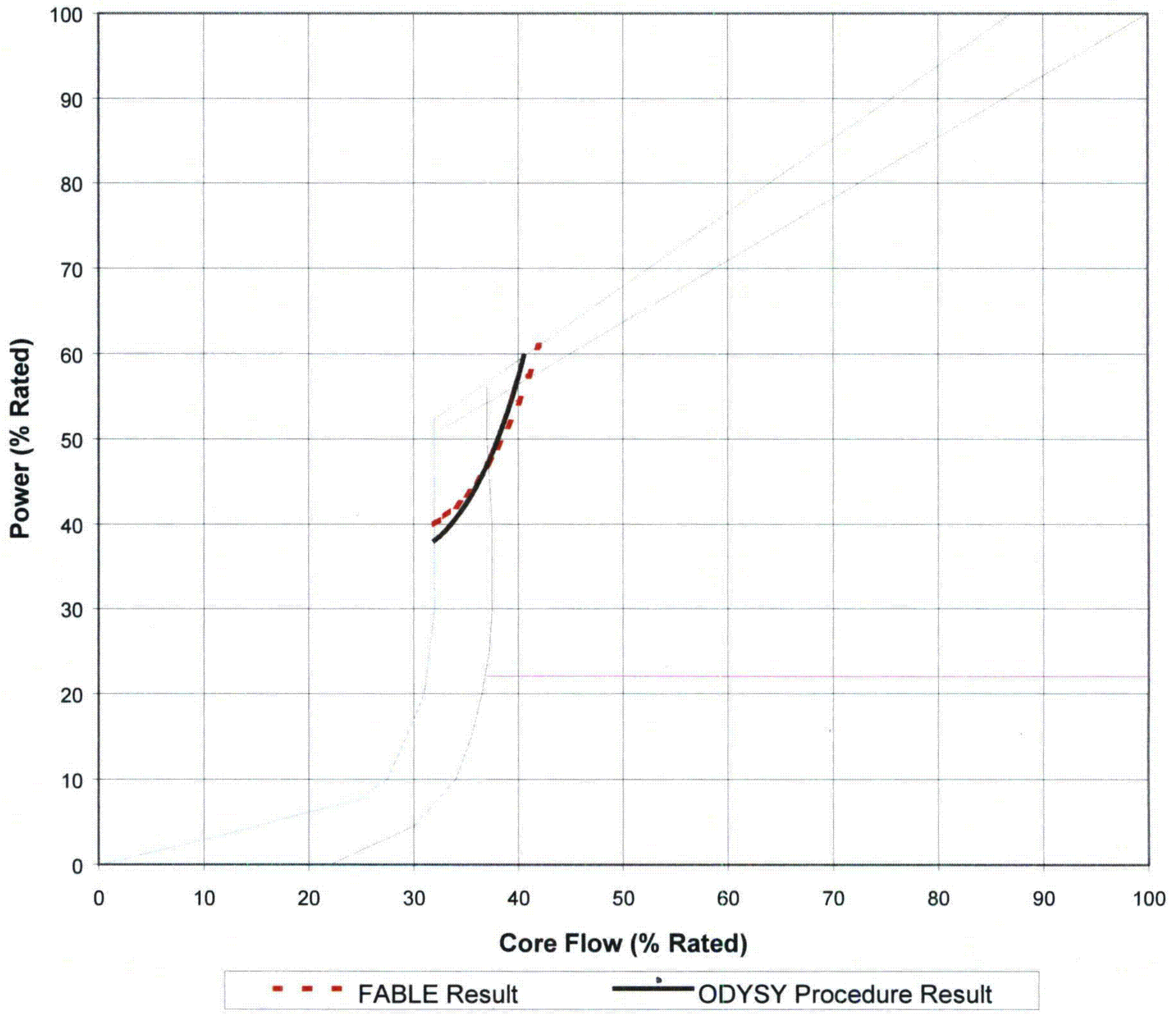

Figure 7-1. Plant 1 Exclusion Region Illustration

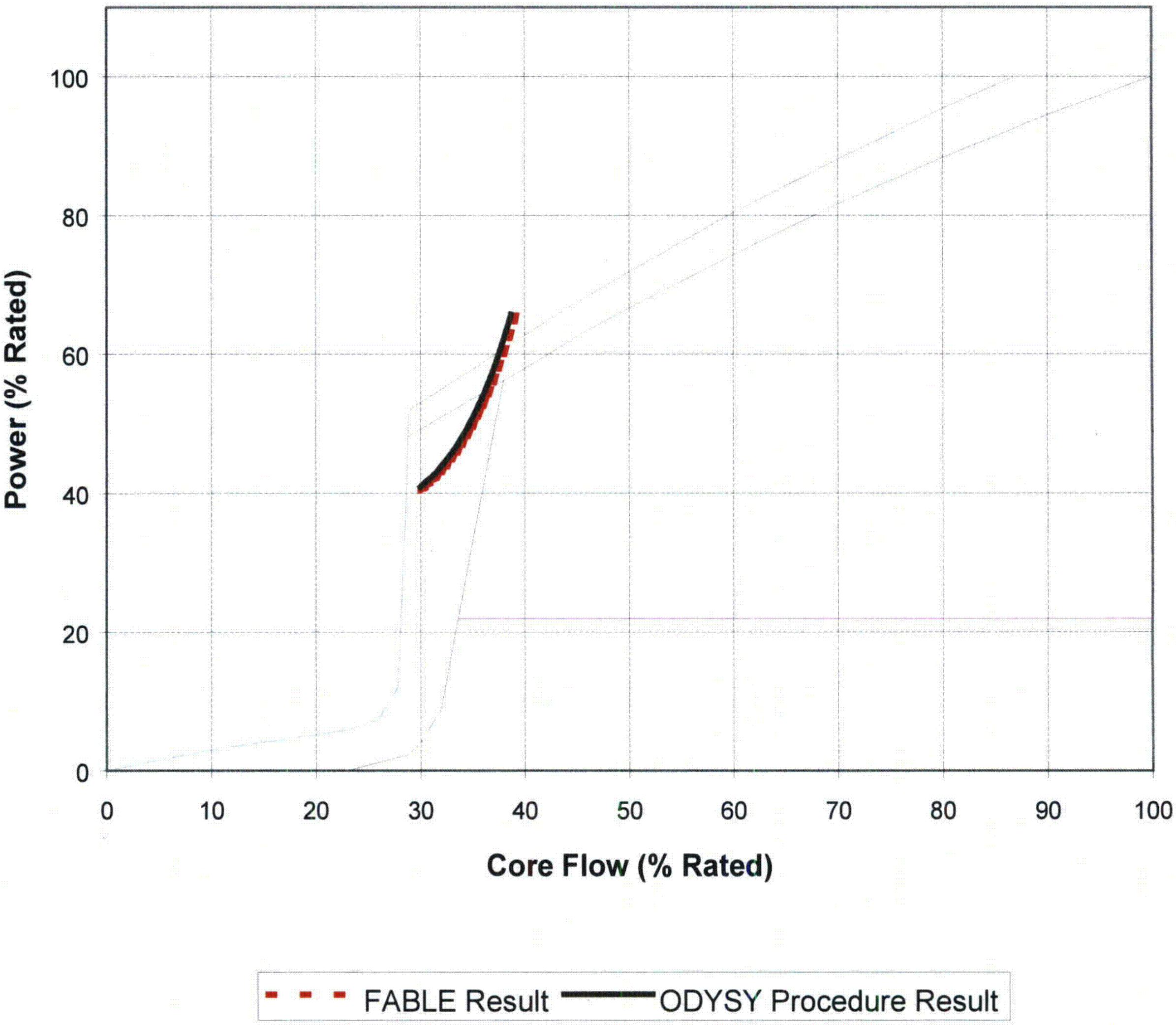

Figure 7-2. Plant 2 Exclusion Region Illustration

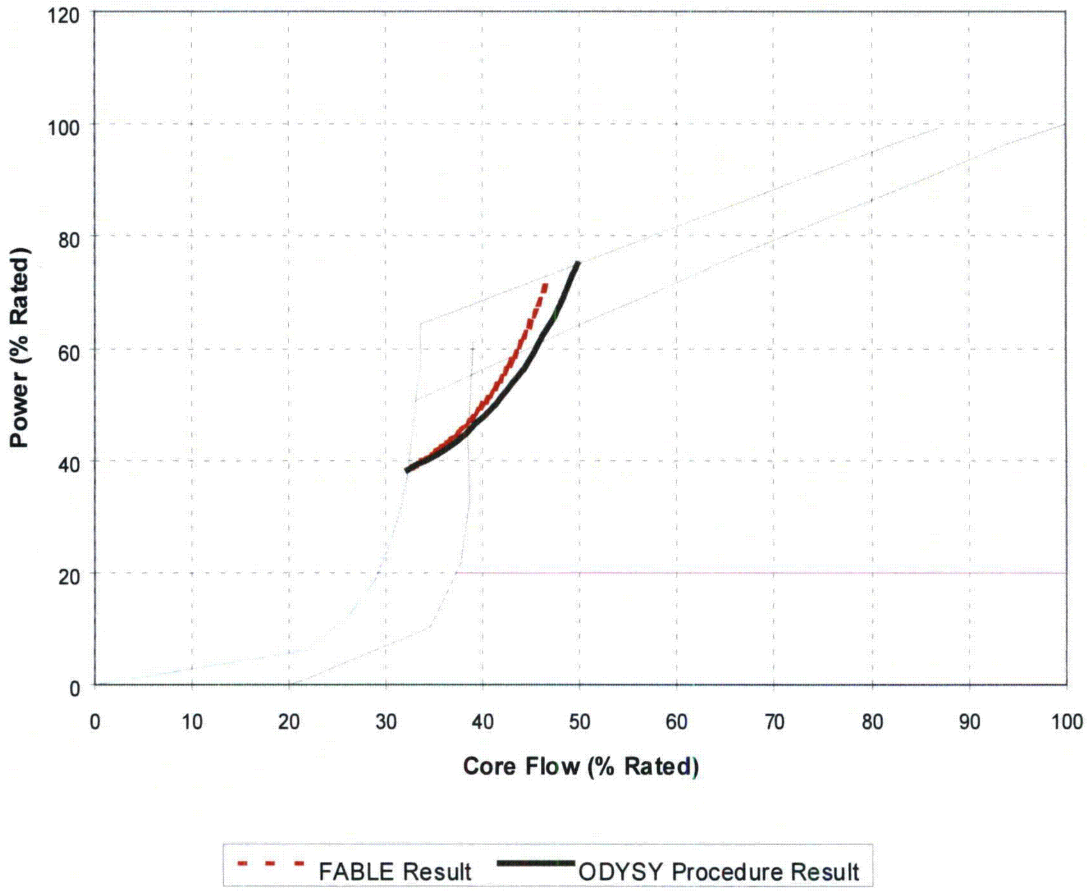

Figure 7-3. Plant 3 Exclusion Region Illustration

Figure 7-4. Amendment 22 Loose Orifice Plant: Core Decay Ratio vs. Exposure

Figure 7-5. Amendment 22 Loose Orifice Plant: Channel Decay Ratio vs. Exposure

Figure 7-6. Amendment 22 Tight Orifice Plant: Core Decay Ratio vs. Exposure

Figure 7-7. Amendment 22 Tight Orifice Plant: Channel Decay Ratio vs. Exposure

Figure 7-8. Amendment 22 Comparison Loose Orifice Plant: Exclusion Region on Power/Flow Map

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