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GE Proprietary Information

MFN 05-052
June 2, 2005

Project 717

U.S Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

Attention: Amy E. Cubbage, ESBWR Project Manager
New, Research and Test Reactors Program

Subject: **GE Responses to NRC Request for Additional Information Related to NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis"**

In the Reference 1 letter, the NRC indicated that additional information was necessary to continue its review of the subject topical report. This request for additional information (RAI) covered the areas of additional calculations, additional data from existing calculations and additional ESBWR design information. GE's responses to RAIs 1 through 3 are provided in Enclosure 2. Responses to RAIs 4 through 8 were provided in the Reference 2 letter.

Enclosure 2 contains GE proprietary information as defined by 10 CFR 2.390. Non-proprietary information also is included in order to form a complete package. GE customarily maintains this information in confidence and withholds it from public disclosure. A non-proprietary version of Enclosure 2 is provided in Enclosure 1.

The affidavit contained in Enclosure 3 identifies that the information contained in Enclosure 2 has been handled and classified as proprietary to GE. GE hereby requests that the information of Enclosure 2 be withheld from public disclosure in accordance with the provisions of 10 CFR 2.390 and 9.17.

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If you have any questions about the information provided here, please contact Bharat Shiralkar at (408) 925-6889 (bharat.shiralkar@ge.com) or myself.

Sincerely,

George Stramback
Manager, Regulatory Services

References:

1. MFN 05-008, Letter from U. S. Nuclear Regulatory Commission to Robert E. Gamble, *Request for Additional Information Letter No. 1 Related to NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis,"* February 3, 2005

2. MFN 05-014, Letter from Robert E. Gamble (GE) to U. S. Nuclear Regulatory Commission, *GE Response to NRC Request for Additional Information Related to NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis,"* February 22, 2005

Enclosures:

1. MFN 05-052 – NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis" GE Responses to RAIs 1 through 3 – Non Proprietary
2. MFN 05-052 – NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis" GE Responses to RAIs 1 through 3 – GE Proprietary Information
3. Affidavit, George B. Stramback, dated June 2, 2005

cc:	WD Beckner	USNRC (w/o enclosures)
	LA Dudes	USNRC (w/o enclosures)
	MB Fields	USNRC (with enclosures)
	RE Gamble	GE/San Jose (with enclosures)
	BS Shiralkar	GE/San Jose (with enclosures)
	eDRF 0000-0040-5914	

ENCLOSURE 3

MFN 05-052

Affidavit

General Electric Company

AFFIDAVIT

I, George B. Stramback, state as follows:

(1) I am Manager, Regulatory Services, General Electric Company ("GE") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in Enclosure 2 of GE letter MFN 05-052, George B. Stramback to Amy E. Cubbage (NRC), *GE Responses to NRC Request for Additional Information Related to NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis,"* dated June 2, 2005. The proprietary information is contained in Enclosure 2, *NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis" GE Responses to RAIs 1 through 3.* GE proprietary information is identified by a dark red font with double underlines inside double square brackets. Figures and large equation objects are identified with double square brackets before and after the object. In each case, the superscript notation{3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner, GE relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.790(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a., and (4)b, above.

(5) To address 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GE, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GE, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within GE is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GE are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains the results of analytical models, methods and processes, including computer codes, which GE has developed, and applied to perform stability evaluations using the TRACG code for the BWR. GE has developed this TRACG code for over fifteen years, at a total cost in excess of three million dollars.

The development of the evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GE.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GE would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GE of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 2nd day of June 2005

George B. Stramback
General Electric Company

ENCLOSURE 1

MFN 05-052

NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis"
GE Responses to RAIs 1 through 3

Responses to Requests for Additional Information (RAIs)
NEDE-33083P, Supplement 1 "TRACG Application for ESBWR Stability Calculation"

Requests for Additional Calculations:

RAI 1. Startup with Neutronic Feedback

The TRACG ESBWR startup simulations provided in NEDE-33083P, Supplement 1, do not include neutronic feedback. Even though core void generation occurs late in the transients analyzed (when the pressure is significant), the calculations shown are not conclusive because the void feedback could conceivably result in large power oscillations when coupled to operator actions to maintain the reactor at power.

Please provide a TRACG simulation of ESBWR startup that includes the neutronic feedback. Use the limiting heat up rate. Describe in detail the control model used to simulate operator actions to maintain the reactor at power during the startup transient.

RAI-1. Response

A TRACG simulation of ESBWR startup with the neutronic feedback was performed using the limiting heat up rate. In this analysis, the 269 control rods are divided into 10 groups. The grouping of these control rods and the withdrawal sequence during the startup are similar to those used for operating plants. Results of this simulation have demonstrated that at the limiting heat up rate, no difficulties and no large power oscillations were encountered during the start up transient.

This TRACG calculation was performed with the activation of the 3D kinetics model. The calculation was initiated at the end of the de-aeration period with the steam dome pressure at 0.52 bar and RPV water at 82 C, similar to those calculations documented in NEDE-33083P, Supplement 1. The water level was maintained near the top of the separators. The MSIVs were closed to isolate the RPV. Initially, all control rods are in fully inserted position.

The 269 control rods in ESBWR are divided into 10 groups and the rod group positions are shown in Figure 1-1. Rod Group # 10 represents the control rods for the 25 control cells. The grouping of control rods and the withdrawal sequence during the startup are similar to those used for operating plants. The withdrawal speeds for each of these groups during the transient are specified as TRACG input to simulate the operator actions to maintain the reactor at power during the startup transient. These rod groups are slowly withdrawn to maintain the total reactivity close to 0.0 and the total power level is maintained at around [[ ]]MW until the RPV pressure reaches [[ ]] Subsequently, the MSIVs are opened and the power level is increased in steps (by means of additional rod withdrawals) to achieve rated pressure at [[ ]]

Figure 1-2 shows the withdrawal fraction for all control rods. Groups 1, 2 and 3 are fully withdrawn in 720 seconds. With these 3 groups at fully withdrawn position, the control rod withdrawal fraction is 0.37, i.e., 67% of all rods are in fully inserted position. At this time, the total reactor reactivity (Figure 1-3) becomes greater than 0.0 (critical). Groups 4 and the next several groups are withdrawn with slower speed to avoid rapid change in total reactivity and reactor power.

Figure 1-4 shows the total reactor power. For the first 1500 seconds, the total reactor power consists mainly of decay heat (~20 MW). [[

]] The total reactivity varies around 0.0 and the total power variation around 85 MW is the result of the continuous withdrawal of the control rods. The power is controlled below 150 MW, until the MSIVs are opened. No significant core void is calculated until the MSIVs are opened at 12900 seconds, when the temperature and pressure are near the operating conditions. The heatup rate for this case is 53 C/hour, which is slightly below the maximum allowed rate considering thermal stress of 55 C/hour. Figure 1-5 shows the steam dome pressure response for this case. The RPV pressurizes to 6.3 MPa in 3.6 hours (12900 seconds) and the MSIVs are opened. With the MSIV open the power is limited by BOP systems not by heatup rate. The control rods are withdrawn further to step up the power and to reach the rated pressure at 4.4 hours. At this time, Rod Groups 1 to 7 are fully withdrawn and Group 8 is 50% withdrawn. Groups 9 and 10 (25 control cell rods) are in fully inserted position. The control rod withdrawal fraction is 0.73.

Figure 1-6 shows the core inlet subcooling as a function of time. The local inlet subcooling drops from an initial value around [[ ]]as the system pressurizes to 6.3 MPa. The core flow transient response is shown in Figure 1-7. There are two periods with small flow noise: around 2000 s corresponding to the step increase in power (Figure 1-4) and around 4500 seconds corresponding to some void initiation at the top of separators (Figure 1-8). Steady void fraction is established at the top of the separators after 9000 s. There are no fluctuations in the neutron flux during these periods. The flow result is similar to the case with no reactor kinetics modeled.

Figure 1-9 shows core void in the highest power bundles. Vapor generation begins at the top of the high power bundles at 4500 s. At this time the pressure is about 5 bar. Voids propagate to cell 30 at about 11000 s, by which time the system pressure is above 30 bar. Figure 1-10 depicts the exit flows in the high power bundle. This trace follows the core average flow response shown in Figure 1-7. Figure 1-11 shows the exit flows in the peripheral bundles. The peripheral bundles are in upflow throughout the transient.

Margins to thermal limits (CPR) were calculated for this startup case. The thermal margin for the high power bundles is shown in Figure 1-12. Large margins are maintained throughout. Figure 1-13 is the corresponding plot for the peripheral bundles. Again, large margins are maintained throughout the transient.

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Figure 1-1 ESBWR Control Rod Groups for Startup Simulation

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Figure 1-2 Withdrawal Fraction for all Control Rods

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Figure 1-3 Total Reactivity

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Figure 1-4 Reactor Power

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Figure 1-5 Steam Dome Pressure

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Figure 1-6 Core Inlet Subcooling

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Figure 1-7 Core Inlet flow

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Figure 1-8 Separator Void Fraction

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Figure 1-9 Hot Bundle Void Fraction

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Figure 1-10 Hot Bundle Exit Flow

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Figure 1-11 Peripheral Bundle Exit Flow

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Figure 1-12 Hot Bundle CPR

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Figure 1-13 Peripheral Bundle CPR

RAI 2. ODYSY Calculation

Provide a frequency domain ODYSY calculation for ESBWR beginning of cycle (BOC) conditions. Provide a comparison between the channel, core-wide, and out-of-phase decay ratios calculated by ODYSY and TRACG.

RAI 2 Response:

ODYSY is a GE frequency domain code that has been approved by the NRC for channel and core wide stability evaluations [1]. The NRC has not reviewed the application of ODYSY for out-of-phase stability calculations. Background on this application is provided below.

GE is not seeking approval for the ODYSY code for ESBWR stability analysis. Calculations were performed with ODYSY specifically to respond to the RAI for channel, core wide and out-of-phase regional decay ratios.

ODYSY Model Outline:

ODYSY defines an open loop transfer function of the reactor, which can be used to evaluate stability characteristics. The major components are defined using first-principles governing equations. A small perturbation from steady-state is assumed and the effect on each component model is evaluated by linearizing the governing equations. A Laplace Transform of each perturbation response is performed and transfer functions are constructed to relate model output to perturbations in the input variables. Once the open loop transfer function is assembled, its frequency response is calculated. The frequency response is used to determine the decay ratio of the system at those conditions.

The major components of the reactor core model are the neutronics model, fuel heat transfer model, and thermal-hydraulic model. Multiple parallel channels are allowed by the model. A one-dimensional axial neutronics model is employed. The recirculation loop external to the core models the thermal-hydraulics in the upper plenum, separators, downcomer and lower plenum. The steam lines and control systems are not modeled as part of the stability evaluation but are accounted for in the system initial conditions.

For the out-of-phase mode decay ratios, a point kinetics solution is employed and the open loop transfer function and decay ratio is calculated for each harmonic mode with its associated subcriticality. The decay ratio calculated for the fundamental mode with zero subcriticality corresponds to the core-wide mode. This method follows the approach first proposed by March-Leuba [2]. The core-wide decay ratios obtained with the 1-D and point kinetics models are compared and serve to support the weighting of the neutronic parameters in the point kinetics model.

Neutron Kinetics for Regional Oscillations - Higher Harmonic Modes

The regional mode of instability excites a higher order mode of the neutronics equations. The higher harmonic modes are subcritical at steady-state operating conditions. However, under certain conditions, these modes can be excited because of the transient core thermal hydraulics. To evaluate regional stability, the reactor transfer functions are calculated for the harmonic modes as well as for the fundamental mode. This section discusses the form of the neutronic equation to be solved for the harmonic modes of the neutronics.

The one-group space-time dependent neutron kinetics equation can be written as:

$$\frac{1}{v^*}\frac{\partial\phi(r,t)}{\partial t} = (F(r,t) - L(r,t))\phi(r,t) - \sum_{n=1}^{N}\frac{\partial C_n(r,t)}{\partial t} \quad . \tag{2-1}$$

$$\frac{\partial C_n(r,t)}{\partial t} = \beta_n F(r,t)\phi(r,t) - \lambda_n C_n(r,t)$$

where L(r,t) is the destruction operator and F(r,t) is the production operator.

$$F = \frac{\Sigma_1}{\Sigma}\cdot\frac{K\Sigma}{\mu_o} \tag{2-2}$$

$$F - L = \frac{\Sigma_1}{\Sigma}\left(\frac{K_\infty\Sigma}{\mu_o} - DB^2 - \Sigma\right)$$

The destruction and production operators are time dependent because of void and Doppler feedback effects. These operators are denoted as a sum of a time-independent steady-state part and a time-varying transient part as follows:

$$L(r,t) = L_0(r) + \delta L(r,t) \tag{2-3}$$

$$F(r,t) = F_0(r) + \delta F(r,t)$$

The neutron flux $\phi(r,t)$ and delayed neutron precursor density $C_n(r,t)$ can be expanded into infinite series of harmonic modal components:

$$\phi(r,t) = n_0\phi_0(r) + \sum_{m=1}^{\infty} n_m(t)\phi_m(r) \tag{2-4}$$

$$C_n(r,t) = \frac{c_{n,0}\phi_0(r)}{v^*} + \sum_{m=1}^{\infty} \frac{c_{n,m}(t)\phi_m(r)}{v^*}$$

where $n_m(t)$ and $c_{n,m}(t)$ are time-dependent expansion coefficients of the different flux density modes ϕ_m. n_0 and $c_{n,0}$ are the amplitudes of the steady-state neutron flux and neutron precursor concentration, respectively.

The lower order spatial harmonics can be approximated by the static λ-modes [3].

$$L_0(r)\phi_m(r) = \frac{1}{\lambda_m} F_0(r)\phi_0(r) \tag{2-5}$$

where λ_m is the mth lambda mode eigenvalue. The subcritical reactivity associated with the mth harmonic mode is defined as:

$$\Delta\rho_m = \text{eigenvalue separation} = \frac{1}{\lambda_m} - \frac{1}{\lambda_0}$$

where λ_0 is the largest (fundamental) eigenvalue.

The eigen functions are orthogonal, such that:

$$< \phi_m^+, F_0\phi_j >= \int_{Core} \phi_m^+(r)F_0(r)\phi_j(r)dr = V_1\delta_{mj} \tag{2-6}$$

$$< \phi_m^+, \frac{\phi_j}{v^*} >= \int_{Core} \phi_m^+(r)\frac{\phi_j(r)}{v^*}dr = V_2\delta_{mj} \tag{2-7}$$

where ϕ^+ is the adjoint neutron flux, V_1 and V_2 are normalizing factors and δ_{mj} is the Kronecker delta.

Substituting Equations (2-3) and (2-4) into Equations (2-1), multiplying by the adjoint flux and integrating over the reactor core yields the modal point kinetics equations. The orthogonality relationships Equations (2-6) and (2-7) have been used in this process.

$$\frac{dn_m(t)}{dt} = -\frac{\Delta\rho_m + \beta}{\Lambda_m} n_m(t) + \sum_{n=1}^{N} \lambda_n c_{n,m}(t) + \frac{\rho_{m0}(t)}{\Lambda_m} n_0 + \sum_{j=1}^{\infty} \frac{\rho_{mj}(t)}{\Lambda_m} n_j(t) \tag{2-8}$$

$$\frac{dc_{n,m}(t)}{dt} = \frac{\beta_{ni}}{\Lambda_m} n_m(t) - \lambda_n c_{n,m}(t)$$

where the intermodal reactivity, $\rho_{mj}(t)$, and Λ_m are defined as:

$$\rho_{mj}(t) = \frac{<\phi_m^+, (\delta F - \delta L)(r,t)\phi_j>}{<\phi_m^+, F_0\phi_m>} \tag{2-9}$$

$$\Lambda_m = \frac{<\phi_m^+, \frac{\phi_m}{v^*}>}{<\phi_m^+, F_0\phi_m>} \tag{2-10}$$

The last term in Equation (2-8) for the neutron density contains a summation of an infinite number of nonlinear terms coupling the mth order harmonic with all other harmonics. In the linear approximation, this cross product is neglected.

For regional oscillations, we are concerned with the first azimuthal harmonic mode; if we set m=1, the inter-modal reactivity and subcritical reactivity become:

$$\rho_{10}(t) = \frac{<\phi_1^+, (\delta F - \delta L)(r,t)\phi_0>}{<\phi_1^+, F_0\phi_1>} \tag{2-11}$$

$$\Delta\rho_1 = \text{eigenvalue separation} = \frac{1}{\lambda_1} - \frac{1}{\lambda_0} \tag{2-12}$$

For one-group diffusion theory, the neutron flux is self-adjoint. Thus, $\phi_1^+(r) = \phi_1(r)$, and the reactivity is weighted by the product of the fundamental mode flux and the first harmonic mode flux normalized by the square of the first harmonic mode flux.

Application to ODYSY

By linearizing, Laplace transforming and combining Equations (2-8), we get the neutronics transfer function as:

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(2-13)

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Here ρ_{10} represents the weighted inter-modal reactivity for the first azimuthal mode given by Equation 2-11, and $\Delta\rho_1$ is the eigenvalue separation between the fundamental and first harmonic modes, given by Equation 2-12.

Channel Grouping and Data Averaging

Stability analysis with ODYSY is performed by dividing the core into a number of thermal-hydraulic channel 'groups'. This grouping of fuel channels is based on similarities in thermal-hydraulic characteristics, as well as their location in the core and the relative power level. (ESBWR has only GE14 fuel). In particular, for the analysis of harmonic modes, the product of the fundamental mode neutron flux and the harmonic mode neutron flux is used to differentiate channel groups. A typical regional stability analysis may employ up to 19 channel groups. Sensitivity studies on channel grouping have been performed, which show that 19 groups are sufficient to characterize BWR cores. A special option in PANACEA calculates the higher mode flux solutions and provides the harmonic flux distribution and eigenvalue separation.

In order to use Equation (2-13) for the neutronics transfer function, it is necessary to compute the core integrated values ρ_{10} and Λ_1 from Equations (2-11) and (2-10).

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(2-14)

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ODYSY Results

As requested, ODYSY analysis was performed at BOC for a core power of 4500 MWt. The same PANACEA wrapup file as used for the TRACG analysis was used as the basis for the nuclear parameters for the core wide stability analysis. The initial conditions used for the analysis are shown in Table 2-1. The grouping of the channels by power level is shown in Figure 2-1 for core wide analysis and in Figure 2-2 for regional mode analysis.

The open loop transfer function between channel flow and pressure drop for channel stability is shown in Figure 2-3. The margin to stability is evaluated from the shortest distance from (-1, 0j) to the OLTF locus. The channel decay ratio was calculated to be [[

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Because the channel ratio is very low, the precision in its determination is low and the agreement is acceptable.

The open loop transfer function for core-wide stability is shown in Figure 2-4. This model uses the standard 1-D neutronics model in ODYSY based on radial weighting of nuclear data from PANACEA. The transfer function represents the response in feedback power to a perturbation in core power. The core decay ratio obtained from this transfer function is [[

]] The agreement is good.

The regional stability analysis employs a point kinetics model. The capability to perform rigorous weighting of the PANACEA neutronic parameters through a data processing code is not available, so an approximate approach has been used as discussed in the previous section. [[

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Results for the OLTF for the first harmonic are shown in Figure 2-7. [[

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The values calculated by TRACG for the regional mode are a decay ratio of [[

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The TRACG and ODYSY results for channel, core and regional stability are compared in Table 2-2.

Sensitivity Studies

There is a substantial difference between the corrected and uncorrected void coefficient for the point kinetics application. As a sensitivity study, the regional stability calculation was repeated with the uncorrected fit. The results are shown in Figure 2-8. The decay ratio increased to [[ ]]. These results are closer to the TRACG results. In any case, the TRACG results bound the uncertainty in the ODYSY void coefficient.

Sensitivity studies were also made to explore the reason for the low channel decay ratios. The channel grouping corresponding to the regional mode analysis was used for the study. The key parameter here is the ratio of single-phase to two-phase pressure drop. The ESBWR channel has a higher ratio (0.50) relative to standard BWR fuel because of the shorter overall length and a proportionately longer region above the part length rods. This ratio was progressively decreased by increasing the spacer and upper tieplate losses. Figure 2-9 shows the results for the channel decay ratio. The single-phase to two-phase pressure drop ratio was decreased all the way to 0.23, which produced a channel decay ratio of [[ ]]. The regional decay ratio was also evaluated as the pressure distribution was changed. There was a corresponding increase in the regional decay ratio, driven by the dominant channels. As the single-phase to two-phase pressure drop ratio was decreased all the way to 0.23, the regional decay ratio increased to [[ ]] (Figure 2-10). These trends indicate that the low channel decay ratio is tied to the high single-phase to two-phase pressure drop ratio for the ESBWR bundles, which in turn leads to a low regional decay ratio.

Table 2-1 : Initial Conditions for ODYSY Analysis

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Table 2-2 : Comparison of ODYSY and TRACG Results
Core Power = 4500 MWt; Peak Channel Power = 5.10 to 5.13 MW; BOC

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Figure 2-1: ODYSY Channel grouping for Core Wide Analysis

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Figure 2-2: ODYSY Channel Grouping for Regional Stability Analysis

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Figure 2-3 Channel Transfer Function

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Figure 2-4 Core Transfer Function

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Figure 2-5 Comparison of 1D and Point Kinetics Results

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Figure 2-6 Original and Corrected Fits for Void Reactivity

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Figure 2-7 Transfer Function for First Harmonic Mode

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Figure 2-8 Harmonic Mode Sensitivity to Void Coefficient

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Figure: 2-9 Sensitivity of Channel Decay Ratio to Pressure Distribution

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Figure 2-10: Sensitivity of Regional Decay Ratio to Pressure Distribution

References:

1. J. S. Post and A. K. Chung, "ODYSY Application for Stability Licensing Calculations", NEDC-32992P-A, July 2001.

2. J. March-Leuba and E.D. Blakeman, "A Mechanism for Out-of-Phase Power Instabilities in Boiling Water Reactors", Nucl. Sci. Eng., 107, p. 173 , 1991.

3. K. Hashimoto, "Linear Modal Analysis of Out-of-Phase Instability in Boiling Water Reactor Cores", Ann. Nucl. Energy, 30, No.12, pp.789-797, 1993.

RAI 3. TRACG Calculation of Instability Threshold

Perform a series of TRACG steady-state calculations at BOC conditions with increasing powers until unstable power oscillations develop to demonstrate the power-margin to instability.

RAI 3 Response:

Starting with the rated core design at 4500 MWt at BOC conditions, control rods were withdrawn to increase the core power level. The inserted rods were pulled out uniformly in steps to increase the core power to 5000, 5200 and 5400 MWt. The last power level is higher than the thermal scram point. At each power level, a steady state was established. Channel and core wide stability was evaluated at each state by observing the response to a perturbation from the steady state. These calculations were made using the same process followed for the calculations shown in the Licensing Topical Report. [[ ]] Regional stability evaluations were made at 5200 MWt to see if the regional stability threshold would be reached at a lower power level. The regional decay ratio was found to be well below 1.0 at this power level.

The details of the calculations are provided below. The results of the calculations are summarized in Table 3-2.

The initial conditions for the three elevated power levels are shown in Table 3-1. The corresponding axial power shapes for the average and peak power bundle are shown in Figures 3-1 to 3-3. Stability analysis was performed at the higher power levels using the same techniques employed in the report NEDE-33083 Supplement 1. Channel decay ratio were evaluated by perturbing instantaneously the velocities in the inlet single-phase region of the bundle. Core decay ratios were evaluated by perturbing the steamline pressure and observing the core power response. For regional stability, channels on either side of the axis of symmetry of the harmonic flux shape were perturbed in opposite directions and the channel power responses were evaluated.

The channel stability results are shown in Figures 3-4 through 3-6. The decay ratio increased from [[ ]]

The core wide power responses to pressure perturbations are shown in Figures 3-7 through 3-9. The core decay ratio was of the order of [[ ]]

For the regional analysis, calculations were made at 5200 MW to see of instability in the regional mode would occur at a lower power than for the core wide mode. The harmonic flux shape for the core at 5200 MW is shown in Figure 3-10. The products of the fundamental and harmonic flux shapes are shown in Figure 3-11. Based on these, the channel grouping shown in Figure 3-12 was developed. This is slightly different from the

one used at 4500 MW in the report because of differences in the rod pattern harmonic flux shape. Regional stability was then evaluated by perturbing the inlet velocities to the channel groups in opposite directions on the two sides of the line of harmonic symmetry. Figure 3-13 shows the power response for two channel groups on opposite sides of the line of symmetry, confirming the regional mode of the perturbation. Figure 3-14 shows the response of several channel groups on the same side of the line of symmetry. The maximum decay ratio is [[ ]].

Table 3-1: Initial Conditions at Higher Power Levels

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Table 3-2: Stability Results at Higher Powers

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Figure 3-1 Axial Power Profiles for Average and Peak Bundles at 5000 MW

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Figure 3-2 Axial Power Profiles for Average and Peak Bundles at 5200 MW

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Figure 3-3 Axial Power Profiles for Average and Peak Bundles at 5400 MW

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Figure 3-4 Channel Flow Response to Inlet Velocity Perturbation (5000 MW)

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Figure 3-5 Channel Flow Response to Inlet Velocity Perturbation (5200 MW)

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Figure 3-6 Channel Flow Response to Inlet Velocity Perturbation (5400 MW)

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Figure 3-7 Core Power Response to Pressure Perturbation (5000 MW)

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Figure 3-8 Core Power Response to Pressure Perturbation (5200 MW)

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Figure 3-9 Core Power Response to Pressure Perturbation (5400 MW)

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Figure 3-10 First Harmonic Flux Shape at 5200 MW

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Figure 3-11 Product of the Fundamental and First Harmonics (5200MW)

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Figure 3-12 Channel Grouping for Regional Analysis at 5200 MW

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Figure 3-13 Channel Power Response –Channels on Opposite Sides of Line of Symmetry

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Figure 3-14 Channel Power Response – Channels on Same Side of Line of Symmetry

ENCLOSURE 2

MFN 05-052

NEDE-33083P, Supplement 1, "TRACG Application for ESBWR Stability Analysis" GE Responses to RAIs 1 through 3

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