ENCLOSURE 2

BWROG-08071

Comment Summary Table and SE Markup

Non-Proprietary Version

IMPORTANT NOTICE

This is a non-proprietary version of Enclosure 1 to BWROG-08071, which has the proprietary information removed. Portions of Enclosure 1 that have been removed are indicated by an open and closed bracket as shown here [[ ]].

Location	Comment
Section 1.0, Section 3.1, Section 3.4.1.2, Section 4.0 Item 3, and Section 5.0	The cover letter to the LTR submittal specifically requested that certain methods described in the LTR be considered as shared elements. Following is the paragraph from the cover letter. "This report documents an Exclusion Region boundary shape function called the Modified Shape Function, which is an alternative to the previously approved Generic Shape Function. The Modified Shape Function is a shared element that may also be applied to the Option III Long Term Solution. In addition, the sensitivity studies included in the subject report (May 2007) support other Long Term Solutions Options that use the ODYSY methodology in the determination of various boundary regions. In the future, these other Long Term Solutions may reference this report as providing supporting studies." This was also stated in the Preface, Section 1.3 and Table 1-1. The general limitation of the LTR to 1-D and II plants is certainly true. However, it was requested that the shared elements be approved for application to the other options. The following passages in the draft SE restrict the application of the LTR to Option I-D and II plants only: Page 1 Lines 28 and 33 Page 2 Line 36 Page 7 Lines 25-26 and Lines 34-35 Page 20 Lines 2-3 Page 21 Line 21-22
Section 3.1.2	Clarified differences between Option 1-D and II. Also, change word usage from low to local. Add "in" before "the absence"
Section 3.3.1 and Section 4.0 Item 1	The statements regarding the SOLOMON online monitor should be generalized to require an online monitor of equivalent capability. There are non-SOLOMON online monitors currently used in plants and there may be monitors of a different vintage, capability and name in the future. The use of a stability monitor is unique to Option I-D plants and provides an additional defense-in-depth feature, along with the Buffer Region. A stability monitor that may not be based on ODYSY still provides the same defense-in-depth feature.
Section 3.3.3	Page 6 Line 33 Change word usage from operating to oscillation.
Section 3.4.1.3.1	Delete core-wide. The statement is generally correct about stability calculations.

Location	Comment
Section 3.4.1.4 and Section 4.0 Item 5	Similar to the provisions in the in-process TRACG Supplement 3 and Gamma Thermometer SEs, there are certain changes in the ODYSY LTR that are to be allowed under 50.59 provisions. It is desirable to make the wording similar in each SE. From GT LTR Draft SE >>>Following are 2 limitations, one not allowing changes and one allowing changes. Modifications to the adaption technique in the PANAC11 based GT-CMS described in NEDE-33197P are considered by the NRC staff to constitute a departure from a method of evaluation in the safety analysis and may not be used for licensing calculations without prior NRC review and approval. Changes in the numerical methods to improve code convergence would not be considered by the NRC staff to constitute a departure from a method of evaluation in the safety analysis (i.e. may be used in licensing calculations without prior NRC review and approval). Making similar modifications to the ODYSY 1D SE Section 4.0 Item 5 5. Any changes to the basic models that form the basis for the ODYSY05 methodology **are considered by the NRC staff to constitute a departure from a method of evaluation in the analysis and** will require specific NRC review and approval before being applied to licensing analyses. Changes to the code resulting in deviations of **less than** 0.05 ~~or greater~~ in the decay ratio relative to the results in Reference 1 **would not be considered by the NRC staff to constitute a departure from a method of evaluation in the safety analysis and such changes may be used in licensing calculations without prior NRC review and approval.**~~will require NRC review and approval before being applied to licensing analysis.~~ (Section 3.4.1.4) Similar changes in Section 3.4.1.4
Section 3.4.1.5	Typographical error. Change is to its.
Section 3.4.1.6	It is suggested that the ODYSY Core Wide vs. Regional capability statements in Section 3.4.1.6 be modified to clarify the capability relative to the approval status. While ODYSY does have the capability to predict regional mode oscillation decay ratios, this capability has not been qualified and therefore not approved for the current application to Option I-D and II plants. ODYSY calculations that predict the core wide and hot channel decay ratios and used in conjunction with the stability criterion map are sufficient to assess stability margins for both Option I-D plants in which core wide mode oscillations are dominant, and for Option II plants in which either core-wide or regional mode oscillations may be dominant.

Location	Comment
Section 3.4.1.6	There is a SER discussion on the validity of the frequency domain code and the Staff adds a restriction on the core decay ratio being close to unity. *The NRC staff reviewed the response and found that for small perturbations the linearity assumption of the frequency domain solution is valid and, therefore, decay ratios near or slightly above unity do not invalidate the methodology.* We would like to propose the following wording similar to the wording in RAI-6: *The ODYSY decay ratio calculation method is applicable to decay ratios greater than unity as long as the oscillation magnitudes stay within the linearity assumptions of the methodology.* This flexibility is needed for the core-wide dominance calculation where core decay ratio might be much [[ ]]channel decay ratio above. However, by saying that the core decay ratio is only valid close to unity, our calculation will be invalidated.
Section 3.4.2.1.1	Add ABWR to be consistent with historical record.
Section 3.4.3.1.1	Page 14 Line 30 and 31. Make the statement regarding bundle suppression plural.
Section 3.4.3.1.1 and Section 4.0 Item 7	A hard [[ ]] limit is imposed by Section 4.0 Item 7 of this SE, where it was not in the previous NEDC-32992P-A SE. [[ ]] The statements in the LTR regarding the channel [[ ]] The following wording from Section 5.2 Page 5-2 of the LTR presents the more complete condition for demonstrating core-wide mode oscillations. [[ ]]
Section 3.4.3.1.1	Page 15 Line 13. Insert “for the hot channel” to clarify demonstration. Page 15 Line 18. Insert hot to clarify demonstration.
Section 3.4.3.1.2	Page 15 Line 42. Correct Spelling of judgement to judgment.
Section 3.4.3.2.2	Page 16 Line 47. Suggest removal of superlative highly. Page 18 Line 34. …the core-wide ~~the~~ channel… Delete second the.
Section 6.0	Page 22 Line 26. Correct spelling of Yarksy to Yarsky.

DRAFT SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

LICENSING TOPICAL REPORT NEDE-33213P

"ODYSY APPLICATION FOR STABILITY LICENSING CALCULATIONS INCLUDING

OPTION I-D AND II LONG TERM SOLUTIONS"

BOILING WATER REACTORS OWNERS' GROUP

PROJECT NO. 691

1.0 INTRODUCTION AND BACKGROUND

``````````By letter dated June 5, 2007, the Boiling Water Reactor (BWR) Owners' Group (BWROG) submitted General Electric - Hitachi Nuclear Energy Americas (GEH) licensing topical report (LTR) NEDE-33213P, "ODYSY Application for Stability Licensing Calculations Including Option I-D and II Long Term Solutions," for U.S. Nuclear Regulatory Commission (NRC) staff review (Reference 1). By letters dated March 28 and May 19, 2008, the BWROG supplemented the original submittal with responses to the NRC staff's requests for additional information (RAIs) (References 2 and 3, respectively).

The LTR NEDE-33213P describes a modified methodology for using the ODYSY code (a One Dimensional Dynamic Code for Stability) to perform stability licensing calculations for Option I-D and II long term stability (LTS) solution plants. Specifically, the LTR documents a revised exclusion region (ER) application procedure that: (1) removes the 0.15 decay ratio adder applied to the LTS Options I-D and II (Reference 5) and (2) implements an ER boundary shape function called the Modified Shape Function (MSF), which is an alternative to the previously approved Generic Shape Function (GSF). The BWROG intends to use ODYSY analyses to determine operating ranges for Option I-D and II LTS solution plants where instabilities are highly unlikely to occur, and are therefore prevented using ERs and associated controls.

The NRC staff has previously reviewed and approved the use of ODYSY in licensing analyses for LTS solutions (Reference 4). The LTR NEDE-33213P (Reference 1) supersedes "ODYSY Application for Stability Licensing Calculations," NEDC-32992P-A, July 2001 (Reference 5). Plants referencing LTR NEDC-32992P-A may continue to do so as NEDE-33213P does not invalidate the previously NRC-approved LTR. Therefore, since the NRC staff has previously reviewed the application of ODYSY to Option III and Detect and Suppress Solution – Confirmation Density (DSS-CD) backup stability protection (BSP) analyses the NRC staff has not revisited these reviews as part of the review of the subject LTR**, except for the use of MSF in Option III.**

While the NRC has previously reviewed the ODYSY code and found it applicable to operating BWR designs (Reference 4), the current approval is limited only to those BWRs implementing either Option I-D or II LTS solution**, with the exception of the shared elements (e.g., MSF) with other solutions as specified in the subject LTR**.
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2.0 REGULATORY EVALUATION

The BWROG submitted its application in accordance with the code scaling, assessment, and uncertainty (CSAU) methodology. The NRC staff completed its review of the subject LTR in accordance with the CSAU methodology, consistent with Section 15.0.2, "Review of Transient and Accident Analysis Methods," of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," and in accordance with the following regulations.

The regulation at Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Appendix A, General Design Criterion (GDC) 12, "Suppression of reactor power oscillations," requires that unstable oscillations either be prevented or detected and suppressed before fuel design limits are exceeded. GDC 12 states:

> The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.

GDC 10, "Reactor design," requires that the reactor protection system must be capable of terminating any anticipated transients, including unstable power oscillations, prior to exceeding fuel design limits. GDC 10 states:

> The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

3.0 TECHNICAL EVALUATION

3.1 LTS Solutions

The LTR describes a modified methodology for using the ODYSY code to perform stability licensing calculations for Option I-D and II LTS solution plants. The current application as described in the subject LTR is only applicable to those operating reactors with approved Option I-D or II LTS solutions **with the exception of the shared elements (e.g, MSF) with other solutions as specified in the subject LTR**.

3.1.1 Option I-D: Administratively-Controlled Regional Exclusion with Flow-Biased Average Power Range Monitor (APRM) Neutron Flux SCRAM

The Option I-D LTS solution is based on a hybrid of prevention and detect and suppress features to meet the requirements of GDC 12. Option I-D is applicable to tight orifice BWR designs where the enhanced channel stability effectively precludes regional mode oscillations. The prevention feature of Option I-D is to define an ER. The ER is a portion of the power-to-flow operating map where entry is administratively prohibited. Outside of the ER decay ratio analyses performed with ODYSY demonstrate that thermal hydraulic instability (THI) events are highly unlikely.

In the event that an unplanned event forces the plant into the ER, a flow biased APRM SCRAM detects and suppresses power oscillations prior to breaching the safety limit minimum critical power ratio (SLMCPR). By analysis, the plant demonstrates that the oscillation mode is expected to be core-wide and, therefore, the APRM based SCRAM is effective in detecting the oscillations. Plants that cannot rule out by analysis the possibility of regional power oscillations cannot implement the Option I-D LTS solution.

Generally ODYSY is used to determine points along the ER boundary where the core-wide decay ratio is below a specified acceptance criterion. These points are typically at the edge of the power-to-flow operating map on the natural circulation line (NCL) and the high flow control line (HFCL). A shape function defines the ER based on a functional fit to the two points on the NCL and HFCL.

Option I-D plants are afforded additional conservative margin by implementing a defense-in-depth buffer region around the ER where on-line stability margins are monitored. The buffer region is based on an expansion of the ER by either: (1) 5 percent margin in flow or power, or (2) a point where the decay ratio is determined to be 0.15 lower. The more conservative of the two is used to define the buffer region.

3.1.2 Option II: Quadrant APRM (BWR/2)

The Option II LTS solution is applicable only to BWR/2 designs. The Option II LTS solution is substantially similar to the Option I-D LTS solution except in the detect and suppress feature **and in the absence of a buffer region**. The BWR/2 APRM channels are arranged according to the ~~low~~ **local** power range monitor (LPRM) detectors in each quadrant; hence, the APRM signals are sensitive to potential regional mode oscillations and therefore provide a direct detection function. The APRM initiated SCRAM in the event of a core-wide or regional oscillation occurs early enough following entry into the ER that the oscillations are suppressed prior to breaching the SLMCPR.

3.2 ODYSY Solution Technique

In its application for Option I-D and II LTS licensing calculations, ODYSY analyses are performed at several points along the HFCL and NCL until the points where the core-wide decay ratio is determined to be 0.8. ODYSY is a linearized, small perturbation, frequency domain code based on the ODYN transient analysis code. ODYSY solves a one-dimensional coupled neutronic kinetics equation over several parallel hydraulic channels based on input from an upstream steady-state nuclear design code (PANACEA).

ODYN is a transient reactor analysis code based on a one-dimensional neutronics model and a void-quality correlation fluid model. The application of the ODYN methodology and ODYSY for expanded operating domains was reviewed and approved by the NRC staff. In the NRC staff's safety evaluation (SE) the NRC staff documented concerns with the application of the Findlay-Dix void quality correlation to high void fractions experienced at extended power uprate (EPU) or maximum extended load line limit analysis plus (MELLLA+) conditions.

The ODYSY decay ratio uncertainty of 0.2 was found to adequately bound any potential uncertainties in the stability performance for Option I-D and II plants resulting from power distribution uncertainties relating to the nuclear design methods and void-quality correlation uncertainties (Reference 6).

The ODYN and kinetics models in ODYSY form the basis for determining the forward and feedback transfer functions of excitation to the system on the system response. The product of these two transfer functions is referred to as the open loop transfer function (OLTF) (Reference 5).

In a case where a system is truly unstable, the OLTF is able to propagate the excitation via feedback mechanisms once the initial perturbation is removed. According to the Nyquist theorem, in a frequency domain, the response of the OLTF can be used to determine if a system is unstable by observing if this response passes through or encircles the negative unity point on the real axis (Reference 7).

In essence the OLTF is a characteristic function of the reactor system given its configuration and conditions. As the point of interest is the negative unity point on the real axis, the actual mechanism of the perturbation to the system is moot since the system will self-sustain an excitation at this point. Typically the OLTFs analyzed by the ODYSY code are the flow/pressure drop OLTF for the channel stability analysis and the core power/feedback power OLTF for the core-wide stability.

In many cases the OLTF response for a real reactor system will not pass through the negative unity point for its operating conditions. The decay ratio is then used as a measure of the damping of oscillations for situations where oscillations are not self-excited by the system. The decay ratio is calculated by determining the distance in the frequency domain between the negative unity point on the real axis and the nearest point on the OLTF response locus.

3.3 Modifications to the Approved ODYSY Application

ODYSY has previously been approved for performing licensing calculations for Option I-D and II plants (Reference 4). In the current application three modifications are proposed for the ODYSY methodology.

3.3.1 Decay Ratio Adder

The Option I-D and II ERs are predicted based on ODYSY calculations with a conservative 0.15 decay ratio adder. The 0.15 adder was in place for the previously approved FABLE/BYPASS methodology to account for a consistent bias and retained as an inherent conservatism in the ODYSY methodology. The current application provides additional qualification calculations to support the elimination of the 0.15 adder.

The NRC staff performed a review of the ODYSY uncertainties and biases based on the CSAU methodology as documented in Section 3.4 of this SE. The NRC staff has found that the qualification of ODYSY is sufficient to demonstrate that there is adequate conservatism in the uncertainty analysis and a conservative adder is not required, based on the code's accuracy, to assure adequate stability margin in ER licensing calculations.

A buffer region is included around the **Option I-D** ER where stability is monitored using ~~the ~~**a stability on-line monitor (e.g.,** SOLOMON (Stability On-line ODYSY Monitor) ~~method~~**or an equivalent system)**. The buffer zone is calculated according to points along the HFCL and the NCL where the ODYSY predicted decay ratio is 0.65 (or the acceptance criterion lest 0.15) or at least 5 percent margin is available in power and flow (whichever is more limiting). ~~SOLOMON~~ **The stability on-line monitor has the capability to** monitor~~s~~ the stability margin by evaluating the core and hot channel decay ratios using **real time plant conditions obtained from the plant process computer (e.g., using** 3D MONICORE input and ODYSY **or an equivalent system)** to ensure that the decay ratios are less than the acceptance criteria during operation in the buffer region. **Such a system may also be used to predict the core and hot channel decay ratios prior to planned entry into the buffer region.** The NRC staff finds that the buffer region and stability monitor provide adequate assurance that the requirements of GDC 12 are met without the 0.15 adder on the calculated decay ratio.

3.3.2 Feedwater Temperature Reduction (FWTR)

The second modification to the ODYSY methodology proposed in the current application is to allow for feedwater temperature dependent-ERs. During its review of the ODYSY uncertainties and biases the NRC staff reviewed the sensitivity of the ODYSY code to FWTR.

As documented in Section 3.4.3.2.2 of this SE, the NRC staff reviewed the ability of ODYSY to perform calculations at various feedwater temperatures to verify its applicability at temperatures other than nominal temperature. Based on its review, the NRC staff finds that ODYSY can reliably predict the core-wide and the channel decay ratios for various degrees of FWTR over the range of anticipated conditions for the operating fleet.

3.3.3 Modified Shape Function

The current application also includes a modified shape function. The ER boundary is defined by a boundary on the power-to-flow operating map based on stability analyses performed at points on the NCL and the HFCL. The previously-approved GSF is a function that defines the ER boundary based on these two calculated points. In the current application a slightly less conservative MSF is proposed for Option I-D and II plants.

The BWROG provided a demonstration analysis of the ER boundary calculation using both the GSF and MSF and provided the results in Figure 2-1 of Reference 1. The acceptability of the MSF is based on a demonstration that the MSF bounds a line of constant decay ratio from the NCL to the HFCL. The results in the figure indicate that the [[

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For evaluation conditions assuming a fixed feedwater temperature and Haling power shape, the constant decay ratio line should be linear on the power-to-flow map, this has been demonstrated by the BWROG analyzing subsequent points using ODYSY between the NCL and HFCL. In response to RAI-8 (Reference 2), the BWROG provided additional descriptive details of the analysis conditions along the constant decay ratio line. In particular, the NRC staff verified that the analysis points were extrapolated from both the HFCL and NCL according to conservative analysis inputs. The NRC staff reviewed the response to RAI-8 and found that the [[

]] The NRC staff finds that this approach is acceptable, because it adequately captures the steady-state conditions of the plant at these points in the power-to-flow map.

The slope of the constant decay ratio line will depend on any variation in the feedwater heating, because it is driven by inlet subcooling and the core power peaking. Since the BWROG performs the ER boundary analysis using a Haling power shape the variation in the slope as a result of power peaking is captured by using a bounding analysis (see Section 3.4.3.1.1 of this SE).

The BWROG proposes developing FWTR-dependent ER boundaries. While the MSF is slightly less conservative than the GSF, if specific ER boundaries are determined for various feedwater heats (and hence degree of inlet subcooling) the constant decay ratio line will be linear. The MSF maintains a conservative concave shape for the boundary and thus acceptably bounds the constant decay ratio line.

The NRC staff evaluated the constant decay ratio line and provided the results in Figure 3.3-1 attached to this SE. A linear trend fit demonstrates that the [[ ]] The NRC staff reviewed the analytical conditions for the points along the constant decay ratio line. These conditions were provided to the NRC staff in response to RAI-8. For each point, the NRC staff calculated the ratio of the power-to-flow as well as the product of core power peaking and core power divided by the product of the inlet subcooling and the core mass flow rate. Table 3.3-1 attached to this SE summarizes the conditions. The NRC staff found that the variation in the latter parameter for all state points is [[ ]] The NRC staff expects the decay ratio to be a strong function of the power, flow, peaking, and inlet subcooling. The ODYSY calculations provide reasonable assurance that the constant decay ratio line is essentially linear on the power-to-flow map using the conservative analysis assumptions and this is consistent with the expected trends based on the prevailing phenomena.

The BWROG demonstrated the conservatism of the MSF determined by ODYSY HFCL and NCL constant decay ratio points (0.8). The demonstration analyses were compared to instability events for large BWR cores (a BWR/5 and BWR/6). The predicted ERs were compared to plant data.

In the current application, ODYSY was used to calculate a hypothetical ER for a BWR/5 and a BWR/6, and a transient trace was provided showing the plant trajectory and SCRAM during actual instability events at these plants. The demonstration analyses indicate that there is a substantial margin in both power and flow from the ER boundary to the onset of instability and the point of ~~operating~~ **oscillation** power range monitor (OPRM) SCRAM during these events.

The NRC staff requested additional information regarding these demonstration analyses in RAIs-5(c) and RAI-5(d). The RAI responses (Reference 2) indicate significant margin to the onset of instability is afforded by the ODYSY predicted MSF based ER.

The NRC staff, therefore, finds that there is reasonable assurance that the use of the MSF is acceptable for Options I-D and II when specific FWTR-dependent ER boundaries are determined.

3.4 Code Scaling, Applicability, and Uncertainty Evaluation

The CSAU methodology consists of fourteen steps contained within three elements. The first element includes Steps 1 through 6 and determines the requirements and code capabilities. The scenario modeling requirements are identified and compared against code capabilities to determine the applicability of the code to the specific plant and accident scenario. Code limitations are noted during Element 1.

The second element in the methodology includes Steps 7 through 10 and assesses the capabilities of the code by comparison of calculations against experimental data to determine code accuracy, scale-up capability, and appropriate ranges over which parameter variations must be considered in sensitivity studies.

The third element in the methodology consists of Steps 11 through 14 and individual contributors to uncertainty, such as plant input parameters, state, and sensitivities, are calculated, collected, and combined with biases and uncertainties into a total uncertainty.

3.4.1 Element 1 – Requirements and Code Capability

3.4.1.1 Step 1 – Scenario Selection

The processes and phenomena that can occur during an accident or transient vary considerably depending on the specific event being analyzed. The BWROG has identified THI as the event to which the methodology under review will be applied. Application of the ODYSY methods to other transients, accidents, or licensing analyses has not been considered in this review.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.1.2 Step 2 – Nuclear Power Plant Selection

The NRC staff has previously reviewed the application of ODYSY to BWR/2-6 and the advanced boiling water reactor (ABWR) **(Reference 4)**. The current application, however, is **generally** limited to those BWRs approved to implement either the Option I-D or Option II LTS solution**, with the exception of the shared elements with other solutions as specified in the subject LTR.**. The **Option I-D** ~~and II~~ **LTS solution** ~~so~~ plants have specific design features that limit regional mode oscillatory behavior for high power-to-flow ratios. ~~While the NRC has previously reviewed the ODYSY code and found it applicable to operating BWR designs (Reference 4), the current approval is limited only to those BWRs implementing either Option I-D or II LTS solution.~~

The NRC staff has previously reviewed the application of ODYSY to Option III and Detect and Suppress Solution – Confirmation Density (DSS-CD) backup stability protection (BSP) analyses and has not revisited these reviews as part of the review of the subject LTR**,**~~.~~ **with the exception of the shared elements as specified in the subject LTR.**

In the conduct of its review, the NRC staff evaluated the qualification of ODYSY to perform stability analyses along the HFCL. The NRC staff considered in its technical review of the efficacy of ODYSY to model the conditions of operation along high flow control lines encompassed by the 100 percent rod line as well as the extended load line limit analysis (ELLLA), and maximum ELLLA (MELLLA) expanded operating domains. The NRC staff did not review the applicability of ODYSY to expanded operating domains with higher HFCLs. Application of ODYSY to Option I-D or II plants operating above the MELLLA line will require NRC review.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.1.3 Step 3 – Phenomena Identification and Ranking

The behavior of a nuclear power plant undergoing an accident or transient is not influenced in an equal manner by all phenomena that occur during the event. A determination must be made to establish those phenomena that are important for each event and various phases within an event. Development of a Phenomena Identification and Ranking Table (PIRT) establishes those phases and phenomena that are significant to the progress of the event being evaluated.

The BWROG provided a stability calculation PIRT in Table 3-1 of Reference 1. These phenomena can be divided into two areas, those impacting the core and fuel design and those relating to the model conditions during the analysis. The NRC staff has reviewed the PIRT for completeness. The PIRT identifies those phenomena affecting the feedback mechanisms that drive THI. The phenomena identified by the BWROG provide a complete characterization of: first, those that impact the dynamic feedback between neutronic response, fuel heat flux transient response, pressure response, and fluid condition response; and second, those initial core state parameters that have an impact on the stability margins. The NRC staff finds that the PIRT completely identifies the major feedback phenomena and addresses those analysis parameters that influence the core power shape, power level, flow, and fluid conditions, which are generally used to characterize stability margins. The NRC staff finds that the PIRT is adequate in its scope. The NRC staff reviewed each of the PIRT items in terms of its ranking as documented in the following sections.

3.4.1.3.1 Core and Fuel Design Parameters

In the evaluation of stability performance the key phenomena are related to the accurate modeling of density wave oscillations and neutronic feedback in the case of ~~core-wide~~ stability calculations. The BWROG identified eight basic phenomena ranking as either high or medium for core or channel decay ratio calculations.

3.4.1.3.1.1 Phenomena Affecting Neutronic Feedback

In determining the decay ratio the effects of neutronic feedback on the transfer function are high ranking phenomena for core-wide stability evaluation. The PIRT identifies the [[ ]] The NRC staff agrees that these capture the predominant reactivity feedback mechanisms for BWRs and finds this ranking acceptable.

3.4.1.3.1.2 Phenomena Affecting Thermal Hydraulic Phase Lags

In analyzing density wave oscillations it is essential to capture accurately any phase lags between feedback mechanisms and the ultimate impact on fluid conditions. These phase lags describe the time lag between initial fluid condition perturbation response and the feedback response to that initial change. The BWROG identified the key phenomena in assessing these phase lags, particularly: [[

]] The NRC staff finds that these phenomena were appropriately identified and ranked and therefore finds their inclusion in the PIRT acceptable.

[[ ]] For stability evaluation to determine the exclusion zone the important phenomena for modeling density wave oscillations must include those affecting the phase lag for fluid response, which is heavily dependent on the transient heat transfer from the fuel pellet to the fluid and therefore gas gap conductance plays a much more important role. The fuel rod surface heat transfer is required for calculating the fluid response, but some uncertainty in this parameter will have a larger effect on the cladding surface temperature than dynamic fluid response, and therefore, will have a smaller impact on the overall stability assessment for calculations that demonstrate margin to instability. However, should ODYSY be considered for evaluation of reactor THI events leading to critical power, then the PIRT ranking for the [[ ]] must be reevaluated. Additionally, since the current application involves performing ODYSY calculations at conditions such as to determine conservative boundaries to prevent unstable conditions leading to critical power conditions, the PIRT does not need to include those phenomena related to transient heat transfer for dryout or post dryout consideration. The NRC staff, therefore, finds that the PIRT adequately addresses those transient thermal hydraulic and heat transfer phenomena to capture the effect of phase lag and is therefore acceptable.

3.4.1.3.1.3 Phenomena Affecting Flow Conditions

In the modeling of density wave oscillations, it is important to predict the dynamic distribution of the core flow, particularly in response to changing dynamic core power distribution, as well as in the prediction of the limiting channels for channel stability evaluation. The BWROG identified the [[ ]] therefore, the NRC staff finds that this portion of the PIRT is acceptable.

3.4.1.3.1.4 Phenomena Affecting Heat Deposition in the Fluid

The BWROG's PIRT identifies direct moderator heating as a [[ ]] The direct moderator heating affects the bypass void fraction which may have an impact on calculated set points for stability protection when the void fraction is large, as described in Reference 6. However, the direct moderator heating also affects the phase lag to a certain extent as some portion of a neutronic power response to a perturbation will result in a certain fraction of energy that is essentially instantly deposited in the coolant as opposed to that transient power that is later deposited in the coolant through rod heat flux. Therefore, this particular phenomenon also impacts the phase lag between neutronic power response and the change in fluid thermal properties. Therefore, the NRC staff agrees with its inclusion in the PIRT, furthermore, based on the relatively small fraction of core power that is deposited as direct moderator heat, the NRC staff concurs with [[ ]]

3.4.1.3.2 Evaluation Conditions

The evaluation condition phenomena refer to those initial conditions whose modeling has a significant impact on the accurate and acceptable modeling of density wave oscillations.

3.4.1.3.2.1 Phenomena Affecting Coolant Flow Loop

The BWROG identified several [[ ]] Therefore, the NRC staff finds this portion of the PIRT acceptable.

3.4.1.3.2.2 Phenomena Affecting Inlet Coolant Conditions

The evaluation conditions regarding the thermal properties of the fluid [[ ]] Therefore, the NRC staff finds this portion of the PIRT to be acceptable.

3.4.1.3.2.3 Phenomena Affecting the Core Power Distribution

The initial core power distribution is a key parameter in the stability analysis as it directly affects the neutron importance distribution, and hence local response to perturbations as well as impacting the initial void distribution. The BWROG identified those evaluation condition phenomena that affect the core power distribution, [[ ]] The NRC staff finds that the list is sufficiently complete to capture the important phenomena. The BWROG [[ ]] the NRC staff agrees with such a distinction based on the differences in the analysis procedures for these two instability modes.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.1.4 Step 4 – Frozen Code Version Selection

The version of a code, or codes, reviewed for acceptance must be “frozen” to insure that after an evaluation has been completed, changes to the code do not impact the conclusions and that changes occur in an auditable and traceable manner. The BWROG has specified that the ODYSY05 code, which is internally controlled through the engineering computer program (ECP) review process, is used for stability licensing calculations.

In RAI-2, the NRC staff requested verification that ODYSY05 has been controlled under the Level 2 process for ECPs. The response to RAI-2 (Reference 2) confirms that ODYSY has been maintained under the Level 2 process since NRC approval.

The NRC staff understands that changes may be made to the code for various reasons without having a fundamental impact on the code’s execution of the basic methodology. Section 2.7 of Reference 1 specifies those code changes that ~~constitute a change~~ **are considered by the NRC staff to constitute a departure from a method of evaluation in the analysis and** ~~requiring~~ **require** NRC review, namely:

- Changes to the models as described in References 8 and 9.
- Changes that result in [[ ]] relative to the values quoted in Reference 1.

Changes to the code resulting in deviations of [[ ]] **relative to the results in Reference 1 would not be considered by the NRC staff to constitute a departure from a method of evaluation in the safety analysis and such changes may be used in licensing calculations without prior NRC review and approval.** The NRC staff finds that these code change criteria are sufficient to ensure that the methodology and accuracy of the code are adequately preserved if code changes are implemented.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.1.5 Step 5 – Provision of Complete Code Documentation

The NRC staff has previously audited the ODYSY code documentation during the review of Reference 5. The current application does not involve a change to the base ODYSY code relative to the previously reviewed and approved method, but does require a CSAU evaluation in order to determine the acceptability of removing a conservative adder and adapting the process by which ODYSY calculational results are used in licensing evaluations. Therefore the NRC staff does not require additional information regarding the code documentation to complete ~~is~~ **its** review in accordance with SRP Section 15.0.2, other than those items requested in RAI-2, including the limitations specified in the user manual, as provided in Reference 2.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.1.6 Step 6 – Determination of Code Applicability

The stability licensing evaluations and proposed methodology in the subject LTR are based on the determination of those core power, flow, and FWTR conditions that result in core-wide decay ratios equal to the acceptance criterion. ODYSY has previously been reviewed by the NRC staff and found acceptable for the calculation of channel and core-wide decay ratios (Reference 4).

While ODYSY does ~~not~~ have the capability to predict regional mode oscillation decay ratios, **this capability has not been qualified and therefore not approved for the current application to Option I-D and II plants. ODYSY calculations that predict the core wide and hot channel decay ratios and used in conjunction with the stability criterion map are sufficient to assess stability margins for both Option I-D plants in which core wide mode oscillations are dominant, and for Option II plants in which either core-wide or regional mode oscillations may be dominant.**~~but for the current application to Option I-D and II plants the dominant instability mode is the core-wide mode. ODYSY calculations that predict the hot channel decay ratio provide a basis for demonstrating that the dominant mode is core-wide, and therefore, the~~ **The** current method**, which relies on the stability criteria map,** does not require the direct calculation of the regional mode oscillation decay ratio. Furthermore, the Option II plants include direct detection and suppression capabilities for regional mode oscillations based on the quadrant APRM design and do not require explicit modeling of the regional mode oscillations. The NRC staff, therefore, finds that the capabilities of ODYSY are sufficient for the stability licensing evaluations.

Furthermore, ODYSY is a frequency domain code. Frequency domain codes typically do not produce reliable numerical results for decay ratios for unstable reactor conditions (i.e., decay ratios much higher than unity). In response to RAI-5(a), the BWROG provided additional details of the applicability of the ODYSY code to scenarios where the decay ratio is above unity (Reference 2). The NRC staff reviewed the response and found that for small perturbations the linearity assumption of the frequency domain solution is valid and, therefore, **the ODYSY decay ratio calculation method is applicable to decay ratios greater than unity as long as the oscillation magnitudes stay within the linearity assumptions of the methodology**~~decay ratios near or slightly above unity do not invalidate the methodology~~. However, the current methodology is based on determining those core conditions where the reactor decay ratio is 0.8, therefore, showing margin to the onset of THI. Therefore, ODYSY is being applied within the capabilities of its solution technique and within the application range established by its qualification database.

The NRC staff therefore finds that the ODYSY code is applicable to the proposed stability licensing calculations proposed in the subject LTR.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.2 Element 2 – Assessment and Ranging of Parameters

3.4.2.1 Step 7 – Establish Assessment Matrix

3.4.2.1.1 ODYSY Qualification

The qualification basis for ODYSY is extensive. The NRC staff has previously reviewed and approved ODYSY for application to BWR/2-6 **and ABWR,** including operation for expanded operating domains including EPU conditions. The qualification database is summarized in Table 3.4-1 attached to this SE. The Vermont Yankee Nuclear Power Station (VYNPS) tests and ODYSY calculational results are shown in the attached Table 3.4-2. The VYNPS tests are particularly relevant to the subject review as VYNPS is an Option I-D plant.

The VYNPS tests verify the uncertainty assessment and accuracy of ODYSY to predict stability margins for Option I-D plants up to the threshold of instability.

Based on the inclusion of a wide variety of plant data, including full scale plant data for core-wide oscillations and oscillations that exceed decay ratios of unity, the NRC staff finds that the qualification basis for ODYSY is acceptable for the determination of modeling uncertainties and biases.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.2.2 Step 8 – Nuclear Power Plant Nodalization Definition

The nodalization in ODYSY for the proposed application remains unchanged since ODYSY was previously approved for stability analysis. The channels are modeled with 24 axial nodes. This is consistent with the nuclear design model and provides sufficient axial resolution to capture the nuclear coupling between the nodes and allows for sufficiently accurate modeling of the variation in thermal hydraulic properties of the fluid axially to model density wave phenomena (Reference 5). Therefore, the NRC staff finds that the axial nodalization remains acceptable for the current application.

The core may be modeled with 19 radial channel groupings. In general, an accurate core stability model should include sufficient radial nodalization such that:

- No single channel group accounts for more than 20 percent of the total core thermal power generation. If a single channel group represents more than 20 percent of the total power there is not sufficient resolution to characterize the radial power shape.

- The core model must include at least three channel groups for each bundle type that contributes significantly to the core power. This general requirement ensures that bundle design differences in terms of mechanical design (spacers, orifices, and part length rods) are resolved sufficiently in order to capture these effects on the radial power distribution.

- The model must include a hot-channel to model the highest power bundle for each significant bundle type in the core. Typically the hot channel decay ratio will be a strong function of the mechanical design of the bundle and the axial power shape. The individual modeling of the hot channel for each bundle type allows for the accurate determination of the limiting hot channel decay ratio.

The ODYSY code allows for a sufficiently large number of radial channel groups to accommodate these requirements. Therefore, the NRC staff finds that the radial nodalization capabilities of ODYSY are acceptable. In response to RAI-9 (Reference 2), the BWROG provided descriptive details of the ODYSY radial nodalization standard production procedure and verified that the nodalization is consistent with general practices.

However, for reactors with mixed fuel vendor core designs it is possible to have a large number of bundle types and ODYSY may not have sufficient radial channel groups to meet the radial nodalization requirements. This scenario would only occur for particular, and unusual, circumstances where as many as six bundle types are included in the core. Though this scenario would be rare, for these cases a plant- and cycle-specific evaluation must be performed to determine the adequacy of ODYSY for performing licensing evaluations.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.2.3 Step 9 – Definition of Code and Experimental Accuracy

The simulation of plant tests and instability events in Step 7 using an appropriate nodalization in Step 8 provides a means to quantify the accuracy of the ODYSY code. The accuracy is assessed by determining the bias and uncertainty in the ODYSY prediction of the figure of merit, which is the decay ratio in this case. The BWROG has provided qualification of the ODYSY code to calculate the decay ratio for several full-scale integral effects tests and events. The determination of the code uncertainty and bias is described in Step 13.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.2.4 Step 10 – Determination of Effects of Scale

The qualification basis for ODYSY is based on full scale plant events and tests, therefore, no consideration in regards to the effects of scale is required.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.3 Element 3 Sensitivity and Uncertainty Analysis

3.4.3.1 Step 11 – Determination of the Effect of Reactor Input Parameters and State

The purpose of this step is to determine the effect that variations in the plant operating parameters have on the uncertainty analysis. Plant process parameters characterize the state of operation and are controllable by the plant operators to a certain degree. In the current application, the ODYSY uncertainty analysis is not being updated. However, the CSAU analysis must consider the effects of these plant parameters on the phenomena identified in the PIRT to determine if the conservative adder to account for feedwater temperature changes can be removed without a detriment to plant safety.

The NRC staff has reviewed the PIRT and found it to be acceptable. The primary parameters affected by changes in feedwater temperature are related to the core power distribution and core inlet subcooling.

3.4.3.1.1 Haling Depletion Applicability and Validation

The ODYSY calculations are performed based on a PANACEA state point. A PANACEA wrap-up file is generated for particular points during exposure and at particular power and flow conditions. For stability solution licensing calculations, the PANACEA wrap-ups are calculated according to a Haling depletion. Using the Haling module, PANACEA calculates the cycle exposure such that the end of cycle (EOC) reactor power shape matches nodal cycle exposure distribution. In general, a Haling depletion results in the minimum axial power peaking and slightly overestimates the cycle energy.

While reactor control strategies (both conventional and control cell) preclude actual Haling exposure, generally the Haling shape at the EOC is a reasonably bounding power shape to perform stability evaluations. In general, bottom-peaked power shapes are limiting from a channel stability standpoint. The Option I-D plants have tight inlet orificing and consequently are more susceptible to the core-wide oscillation mode than channel oscillations or regional mode oscillations.

The BWROG provided an assessment of the Haling assumption relative to core follow data collected over eight cycles at four Option I-D plants. Generally, the Haling EOC power shape results in bounding core-wide decay ratio predictions. [[

]]

The NRC staff has reviewed the Haling validation data in Appendix A of Reference 1. The validation cases considered a wide variety of control strategies including one cycle with ~~a~~ suppressed bundle**s**. Generally, the EOC Haling power shape is bounding of the power shapes experienced during the actual cycle exposure. The EOC Haling shape flattens the axial power shape relative to the actual operating shapes. This has the effect of shifting the axial power profile into the higher void regions of the core, thereby increasing the adjoint in regions where the nodal void reactivity feedback is relatively strong. Under the EOC Haling conditions, the core can be reasonably expected to experience a stronger negative void reactivity feedback coefficient than experienced over the course of cycle exposure as a result. The NRC staff agrees that it is reasonable to use the EOC Haling shape as a bounding power shape in developing the ER boundary and that the proposed process is therefore acceptable.

In RAI-4, the NRC staff requested that the BWROG calculate the core average void reactivity coefficient at the EOC using a PANACEA inlet enthalpy perturbation for the Haling and actual exposure histories in Appendix A and compare them. The results of the comparison were provided in Reference 2. The comparisons indicated that the dynamic void reactivity coefficient predicted using the Haling depletion was either equal to or more negative than the nominal depletion value. A more negative void reactivity coefficient results in a greater susceptibility to THI, and thereby confirms the conservatism of the Haling depletion assumption.

The NRC staff has found that the cases considered cover a wide range of operating plant conditions and demonstrate that the Haling exposure calculation is a conservatism in the analysis methodology.

However, the channel decay ratio is not driven by the strong void feedback and channel instabilities are predominantly a function of thermal hydraulic phenomena. For Option I-D plants, the licensing procedures require a **maximum hot channel decay ratio** demonstration that **shows that** regional mode oscillations are highly unlikely based on a [[

]] In order to perform this demonstration**,** the Haling power shape **for the hot channel** is not used. The channel decay ratio is most limiting when the axial power shape is shifted towards the bottom of the core, thus, reducing the boiling boundary and increasing the ratio of two-phase to single-phase pressure drop. Therefore, when determining the channel decay ratio a hot channel axial power shape overlay is required.

Option II plants include quadrant based APRM instrumentation and, therefore, include a direct detection of regional mode instability, therefore a maximum **hot** channel decay ratio demonstration is not required for these plants.

3.4.3.1.2 FWTR ER Demonstration

The BWROG proposes to perform ER boundary calculations that explicitly account for variations in the feedwater temperature. The BWROG has performed analyses using ODYSY to demonstrate the analysis process.

The BWROG provided demonstration analyses for several plants where FWTR-specific ERs were calculated using ODYSY. The NRC staff found that the lower boundary of the ER on the NCL was not particularly sensitive to the FWTR. The NRC staff requested additional information in RAI-3. The NRC staff review of the response is documented in Section 3.4.3.2.2 of this SE.

In RAI-1, the NRC staff requested an analysis of the core outlet average void fraction and hot channel void fraction for the ER boundary points on the NCL using PANACEA (which employs an identical void quality correlation to ODYN). The results of the analyses were presented in Reference 2. The maximum outlet void fraction for the hot channel was calculated to be [[ ]] on the HFCL and [[ ]] on the NCL. The maximum outlet void fractions are within the qualification of the Findlay-Dix void quality correlation. The core average quantities are substantially lower, and even the hot channel outlet void fractions are calculated to be appreciably lower than [[ ]]

The NRC staff has reviewed these demonstration analyses and found that the variation of the ER with changes in the feedwater temperature is consistent with the NRC staff's engineering judgement (see Section 3.4.3.2.2 of this SE). The NRC staff agrees that calculating the ER boundary based on actual plant conditions results in a more accurate representation of the core, and is a more direct means for accounting for the effects of inlet subcooling. Therefore, the NRC staff finds that the proposed method for developing FWTR-dependent ER boundaries using ODYSY is acceptable.

The NRC staff has reviewed the qualification of the ODYSY method against full-scale plant data and found that the ODYSY code provides accurate calculation of the decay ratio without indication of bias. The NRC staff also notes several conservatisms that are included in the methodology. The BWROG provided a summary of the analysis conditions in response to

RAI-5(g). The BWROG describes the analysis procedure in greater detail in response to RAI-11. The NRC staff reviewed these responses and found the key analysis conservatisms to include:

- For FWTR-specific analyses the balance-of-plant (BOP) feedback is included by analyzing the decay ratio for equilibrium steady-state conditions of feedwater and inlet subcooling. Operational conditions resulting in the plant maneuvering near the exclusion zone from higher power may occur, however, the BOP response is significantly lagged. Therefore, during the short-term operation near the ER, the plant experiences conditions that are more stable than the analysis conditions prior to reaching an equilibrium state.
- PANACEA Haling depletions are performed for the thermal hydraulic conditions of the analysis state-point to determine the radial and axial power distributions. The Haling depletion was shown to result in conservative core nuclear characteristics.

- The most limiting exposure point is explicitly determined according to the analysis procedure. The power/flow points along the NCL and HFCL for the most limiting exposure point and are applied with the MSF to determine the ER. The ER is then applied throughout the entire cycle operation.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.3.2 Step 12 – Performance of Nuclear Power Plant Sensitivity Calculations

3.4.3.2.1 Axial Power Shape

The BWROG has provided a study of the effect of axial power shape on the predicted decay ratio. This analysis was evaluated by the NRC staff as described in Section 3.4.3.1.1 of this SE to determine the applicability of the Haling depletion power shape input in the analysis. The study, however, also provides a basis for demonstrating the code sensitivity to the axial power shape. The NRC staff found that the prediction of the core decay ratio based on the various power shapes demonstrates a strong dependence of the code-predicted core decay ratio on the predicted core average void reactivity feedback, which is expected. Therefore, the NRC staff finds that the demonstration studies provide an adequate basis to demonstrate that the code sensitivity to the axial power shape is consistent with the expected trend in stability margin with void coefficient.

3.4.3.2.2 Core Inlet Subcooling

As a result of environmental and other conditions the feedwater temperature will experience small variations during normal operations. To address the sensitivity of the decay ratio of the inlet subcooling the NRC staff requested in RAI-7 that the BWROG perform a sensitivity analysis for feedwater temperature variations on the same order as normal operational fluctuations. The results of the study indicate that the normal variation in feedwater temperature is sufficiently small that its effect on the analytical results is negligible.

The BWROG provided demonstration analyses to illustrate the ER boundary calculation based on various FWTRs. The NRC staff found that the ER boundary along the HFCL is ~~highly~~ sensitive to the FWTR. The demonstration calculations also provide the effects of FWTR on channel decay ratio. The NRC staff reviewed these trends in the ER boundary and channel decay ratio based on various analysis feedwater temperatures.

In response to RAI-5(e), the BWROG compared the sensitivity of ODYSY to TRACG calculated decay ratios to feedwater temperature. Time domain TRACG analyses indicated a sensitivity of approximately [[ ]] The response states for the standard production technique that ODYSY indicates a similar degree of sensitivity, or a change of [[ ]] Based on comparisons to the sophisticated TRACG time domain code, the NRC staff finds that the sensitivity of the core decay ratio predicted by ODYSY is expected.

The channel decay ratio decreases with increasing FWTR. As the inlet subcooling is increased the boiling boundary will rise and decrease the ratio of two-phase to single-phase pressure drop in the channel, which has a stabilizing effect. The NRC staff finds that ODYSY predicts this trend as shown in the attached Figure 3.4-1 for all plants except Plant C. In general, the channel decay ratio is highly sensitive to the ratio of single-phase to two-phase pressure drop. Channel stability is evaluated with a fixed hot channel overlay power shape. Hypothetically, the single channel will oscillate in flow while power is being driven by neighboring stable bundles. Therefore, neutron kinetics are ignored in this analysis. A FWTR results in increased inlet subcooling and resultant increase in the boiling boundary height. The NRC staff expects monotonic decrease in channel decay ratio with increasing FWTR. The NRC staff understands that Option I-D analyses are performed only to demonstrate channel decay ratios are less than the acceptance criterion of [[ ]] to ensure that regional mode oscillations are highly unlikely. However, the NRC staff requested in RAI-10 that the BWROG explain the physical nature of the results of the Plant C channel decay ratio analyses for the largest FWTR (100 °F).

In response to RAI-10, the BWROG clarifies that the ER is based on the limiting exposure state point for core-wide stability. The channel stability is therefore driven by the hydraulic performance but will also be sensitive to the radial peaking factor at the limiting exposure point for given analysis conditions. The response states that the limiting exposure point for the maximum FWTR occurs at low exposure relative to the other points. The low exposure state point has a larger hot channel radial power peaking factor. Therefore, the increase in channel decay ratio for Plant C is a result of increased radial peaking. The sensitivity presented in attached Figure 3.4-1 demonstrates the overall trend expected by the NRC staff; however, considering that the axial and radial power shapes differ for the FWTR points depending on the limiting exposure point, the results for Plant C are not unexpected since the radial peaking factor does vary.

The radial peaking factor has a first order effect on channel stability. In a supplement to the response to RAI-10, the BWROG provided additional details regarding the hot channel decay ratio calculation for Plant C (Reference 3). The results indicate that the increase in the decay ratio for the maximum FWTR is a result of increased radial peaking at an earlier exposure state point in the analysis. The NRC staff agrees that the Plant C channel decay ratios are significantly smaller than the acceptance criterion of [[ ]] for all exposure state points.

The ER boundary extends with increased FWTR. This is a result of the destabilizing effect of axial power shift towards the core inlet with the increased inlet subcooling. Attached Figures 3.4-2 and 3.4-3 plot the power-to-flow ratio for a constant decay ratio as a function of the FWTR. The plots show that as the feedwater temperature is reduced the required power-to-flow ratio for the reactor to become unstable is reduced.

The core stability performance is more sensitive to the FWTR along the HFCL than along the NCL. As can be seen in attached Figure 3.4-3, [[

]] In RAI-3, the NRC staff requested that the BWROG explain the insensitivity along the NCL. The response to RAI-3 explains that a [[ ]] A single exposure point was considered by the BWROG for one plant. Sensitivity analyses were performed to demonstrate the competing effect.

In general, a FWTR may be stabilizing under particular conditions where the FWTR serves to reduce the core reactivity void coefficient and increase the single-phase to two-phase pressure drop. Along the NCL the core flow is essentially constant; therefore, the effect of the FWTR on the reactor power is the driving phenomenon affecting the instantaneous decay ratio. As reactor power is reduced, the boiling boundary rises in the core and the axial power shifts upward. The upward shift in the reactor power is a stabilizing effect. The FWTR affects both the phase lag between the power and flow as well as affecting the axial power distribution. Generally a FWTR will result in a downward shift in reactor power relative to a nominal FWT at a constant core power, however, for a given core power level a FWTR will reduce core average void fraction. Since void reactivity coefficient becomes less negative with decreasing core average void, a FWTR along the NCL for a fixed core power level may be stabilizing due to reduced void reactivity. In evaluating the ER along the NCL, [[

]] This effect has been demonstrated in the response to RAI-3 (Reference 2) and attached Figure 3.4-3.

The NRC staff finds that the sensitivity of the core and channel decay ratios to changes in the FWT are expected and consistent in magnitude when compared to stability test conditions tabulated in the ODYSY qualification. Therefore, the NRC staff finds that ODYSY can reliably predict the core-wide ~~the~~ channel decay ratios for various FWTRs over the range of anticipated conditions for the operating fleet.

3.4.3.2.3 Core Flow

In response to RAI-5(f), the BWROG provided the results of a sensitivity analysis of the core flow. The sensitivity analysis was performed for a realistic model (Case 3c) from the qualification. The core flow was varied over the core flow uncertainty range as documented in NEDE-32906P-A (Reference 10). The results indicate that the decay ratio is insensitive to variations in core flow as great as [[ ]] percent. Specifically the results show a change in the predicted decay ratio of [[ ]] percent increase in core flow. In the sensitivity analyses the eigenvalue is [[

]] Therefore, the NRC staff finds that the sensitivity analysis indicates a conservative sensitivity as it includes the feedback in the reactor power in addition to changes in the thermal hydraulic response.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

3.4.3.3 Step 13 – Determination of Combined Bias and Uncertainty

The uncertainty in the figure of merit (or the decay ratio) has been assessed for ODYSY based on full-scale plant test data and instability event data. A summary of the qualification database is provided in attached Table 3.4-1. The qualification supports the uncertainty of 0.2 in the decay ratio. The current application does not propose a change in the uncertainty. The NRC staff has reviewed the application of ODYSY to EPU and MELLLA+ conditions and found that the 0.2 uncertainty is adequately conservative to address uncertainties in nuclear and thermal hydraulic parameters for these expanded operating domains (Reference 6), but does not agree with the BWROG that this uncertainty is necessarily [[ ]] standard deviations. The NRC staff, however, finds that the additional uncertainties related to nodal nuclear and thermal hydraulic parameters for EPU or MELLLA+ operating domains will be sufficiently small compared to the 0.2 uncertainty value that there is a reasonable degree of assurance that this uncertainty is at least [[ ]] standard deviations. Since this application does not involve an adjustment to the uncertainty, the NRC staff finds that this value is acceptable and the NRC staff does not account for any potential conservatism in this quantity when evaluating the current application.

Accuracy of the ODYSY code to predict the decay ratio of unstable conditions for a variety of plants with extremely unstable conditions, including those conditions leading to decay ratios greater than one, provides an adequate technical basis to determine that the ODYSY methodology does not result in any bias for decay ratio evaluations less than unity. The conservative 0.15 decay ratio adder in place for the ODYSY methodology was originally included based on a bias in the FABLE/BYPASS methodology. The adder was retained in the ODYSY methodology for conservatism.

The NRC staff finds that the ODYSY qualification does not indicate biases in the core-wide decay ratio based on extensive qualification. The NRC staff has found that the analysis procedure includes several inherent conservatisms, and that ODYSY analyses using actual THI plant data demonstrate conservatism in the MSF determined ER.

Given that the uncertainty is included in the figure of merit (a decay ratio of 0.8) and that the MSF acceptably bounds that region of the power-to-flow map where the calculated decay ratio would exceed 0.8 (see Section 3.3), the uncertainty and bias determination are acceptable and the NRC staff finds that the analyses support the current application methodology.

The NRC staff finds that the BWROG is consistent with this step in the CSAU approach.

4.0 LIMITATIONS AND CONDITIONS

The NRC staff has identified conditions and limitations on the application of the subject LTR for licensing analyses. These conditions and limitations are as follows:

1. A buffer region is established based on points along the HFCL and NCL where the ODYSY calculated decay ratio is 0.65 or 5 percent margin in power or flow is provided (which ever is more conservative). Stability monitoring will be performed in the buffer region using ~~the~~ **a stability on-line monitor**~~SOLOMON methodology~~. (Section 3.3.1)

2. When using the MSF to calculate the ER boundary, the ER boundary must be FWTR-specific. (Section 3.3.3)

3. The NRC staff review and approval of the subject LTR is limited to those plants that are approved to implement the Option I-D and II LTS solutions**, with the exception of the shared elements with other solutions as specified in the subject LTR.**~~.~~ (Section 3.4.1.2)

4. The NRC staff review and approval of the subject LTR is limited to those operating conditions bounded by the MELLLA line on the power/flow map. (Section 3.4.1.2)

5. Any changes to the basic models that form the basis for the ODYSY05 methodology **are considered by the NRC staff to constitute a departure from a method of evaluation in the analysis and** will require specific NRC review and approval before being applied to licensing analyses. [[
]] relative to the results in Reference 1 **would not be considered by the NRC staff to constitute a departure from a method of evaluation in the safety analysis and such changes may be used in licensing calculations without prior NRC review and approval.**~~will require NRC review and approval before being applied to licensing analysis.~~ (Section 3.4.1.4)

6. Restrictions and Limitations 1 through 10 specified for ODYSY input in response to RAI-2 must be met, or justification provided on a plant-specific basis if these are not met (Reference 2). (Section 3.4.1.5) Specifically:
[[
1)

2)
3)
4)
5)
6)
7)
8)
9)
10)
]]

7. The channel decay ratio for Option I-D plants must be calculated and compared to [[

]] (Section 3.4.3.1.1)

8. When determining the channel decay ratio a hot channel axial power shape overlay is required. (Section 3.4.3.1.1)

9. For FWTR-specific analyses the BOP feedback is included by analyzing the decay ratio for equilibrium steady-state conditions of feedwater and inlet subcooling. (Section 3.4.3.1.2)

10. PANACEA Haling depletions are performed to determine the radial and axial power distributions. (Section 3.4.3.1.2)

11. The most limiting exposure point is explicitly determined and used to determine power and flow conditions of the state points on the HFCL and NCL. (Section 3.4.3.1.2)

12. Licensing analyses are performed using a radial nodalization that meets the requirements stated in Section 3.4.2.2.

13. Operation in certain expanded operating domains may require particular provisions to account for methods uncertainties or plant conditions unique to that operating domain. The NRC staff has previously reviewed the application of ODYSY for plants operating in expanded operating domains and requires certain conservative adjustments to plant parameters such as APRM set points. For plants implementing EPU or EPU/MELLLA+, the conditions, limitations, and restrictions regarding the analytical codes and methods as documented in the NRC staff's SE for the most recently approved revision or supplement to NEDC-33173P-A, " Applicability of GE Methods to Expanded Operating Domains," will apply to the methods described in the subject LTR (NEDE-33213P).

5.0 CONCLUSION

The NRC staff has reviewed the subject LTR (Reference 1), which includes the modifications to the ODYSY method for Options I-D and II stability licensing calculations, and finds the methods applicable when exercised in accordance with the conditions and limitations described in Section 4.0 of this SE. The methods as documented in Reference 5 are acceptable for reference to perform those required analyses as documented in Reference 1.

While the NRC has previously reviewed the ODYSY code and found it applicable to operating BWR designs (Reference 4), the current approval is limited only to those BWRs implementing either Option I-D or II LTS solution**, with the exception of the shared elements with other solutions as specified in the subject LTR.** The NRC staff has previously reviewed the application of ODYSY to Option III and DSS-CD BSP analyses and has not revisited these reviews as part of the review of the subject LTR.

When this LTR is referenced in licensing applications, the NRC staff does not intend to repeat our review of the acceptable material described in the subject LTR; our review will ensure that the material presented applies to the specific plant involved. If the NRC's criteria or regulations change so that its conclusions about the acceptability of the nuclear methods or uncertainty analyses are invalidated, the licensee referencing the subject LTR will be expected to revise and resubmit its respective documentation, or submit justification for the continued effective applicability of these methodologies without revision of the respective documentation.

6.0 REFERENCES

1. NEDE-33213P, "ODYSY Application for Stability Licensing Calculations Including Option I-D and II Long Term Solutions," May 2007, submitted via letter dated June 5, 2007. (ADAMS Package Accession No. ML071590196)

2. Letter from Bunt, R. (BWROG) to U.S. Nuclear Regulatory Commission, Responses to Requests for Additional Information (RAIs) Dated February 21, 2008, Regarding the Submittal of BWROG Topical Report (TR) NEDE-33213P, "ODYSY Application for Stability Licensing Calculations Including Option I-D and II Long Term Solutions," dated March 28, 2008. (ADAMS Package Accession No. ML080920324)

3. Letter from Bunt, R. (BWROG) to U.S. Nuclear Regulatory Commission, Response to Request for Additional Information (RAI) From April 23, 2008 Telephone Exchange With Mr. Peter Yarsky (NRC), on RAI-10 Information Regarding Hot Channel Decay Ratio of Plant C Cycle N+1, as Related to Submittal of BWROG LTR NEDE-33213P, "ODYSY

Application for Stability Licensing Calculations Including Option I-D and II Long Term Solutions," dated May 19, 2008. (ADAMS Package Accession No. ML081420020)

4. Letter from Richards, S. (USNRC) to Klapproth, J. (GENE), Review of NEDC-32992P, "ODYSY Application For Stability Licensing Calculations," dated April 20, 2001. (ADAMS Accession No. ML011100200)

5. NEDE-32992P-A, "ODYSY Application for Stability Licensing Calculations," GE Nuclear Energy, July 2001, submitted via letter dated September 13, 2001. (ADAMS Package Accession No. ML012610606)

6. Final Safety Evaluation by the Office of Nuclear Reactor Regulation for LTR NEDC-33173P "Applicability of GE Methods to Expanded Operating Domains," dated January 17, 2008. (ADAMS Package Accession No. ML073340231)

7. Lahey, R., Moody, F., "Thermal Hydraulics of a Boiling Water Nuclear Reactor," American Nuclear Society, 1977.

8. NEDC-32339P-A Supplement 1, "Reactor Stability Long-Term Solution: Enhanced Option I-A, ODYSY Application to EIA," December 1996; Letter from Timothy E. Collins (USNRC), Request for Additional Information for GE Topical Report, NEDC-32339P, Supplement 1 (TAC No. 89222), dated June 1, 1994; and Letter from R.A. Pinelli (GENE), Response to NRC Request for Additional Information for GE Topical report, NEDC-32339P, Supplement 1, dated November 9, 1994.

9. NEDC-32661P, "ODYSY Description and Qualification," October 1996.

10. NEDE-32906P-A, Revision 3, "TRACG Application for Anticipated Operational Occurrences (AOO) Transient Analysis," GE, September 2006. (ADAMS Package Accession No. ML062720163)

Attachment: Proprietary Figures and Tables

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