ENCLOSURE 2

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DSS-CD TRACG Application
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LICENSING TOPICAL REPORT

DSS-CD TRACG APPLICATION

Lev A. Klebanov

Juswald Vedovi

David G. Vreeland

Jun J. Yang

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EXECUTIVE SUMMARY

Several different stability long-term solution options have been developed for boiling water reactors (BWRs). The Detect and Suppress Solution – Confirmation Density (DSS-CD) is a long-term solution that consists of hardware and software for the automatic detection and suppression of stability related power oscillations.

DSS-CD uses an enhanced detection algorithm, the Confirmation Density Algorithm (CDA), which reliably detects the inception of power oscillations and generates an early power suppression trip signal prior to any significant oscillation amplitude growth and Minimum Critical Power Ratio (MCPR) degradation. The TRACG code is used to confirm the MCPR margin during reasonably limiting instability event simulations for DSS-CD applications. Licensing topical report (LTR) NEDC-33075P (Reference 1) provides the DSS-CD generic licensing basis for GEH BWR/3-6 product lines, and describes a standard procedure for plant-specific confirmations of reload designs and other design changes that may affect the DSS-CD generic licensing basis.

The GEH TRACG code model description, qualification, application for anticipated operational occurrences, and use in the DSS-CD process are documented in LTRs NEDE-32176P (Reference 2), NEDE-32177P (Reference 3), NEDE-32906P-A (Reference 4), NEDE-32906P Supplement 3-A (Reference 5) and NEDC-33075P-A (Reference 1), respectively. All of these LTRs have been reviewed by the Nuclear Regulatory Commission (NRC). This LTR incorporates the essential information from the above five LTRs to describe and justify the use of TRACG for modeling instabilities in the DSS-CD process.

REVISION SUMMARY

Revision 1:

1. Update scope of TRACG application for DSS-CD in Section 2.3.
2. Update Figures 8-1 through 8-17 (new Figure 8-12 was omitted in Revision 0) and the bounding CSAU oscillation component relative uncertainty in Section 8.2 to account for a void reactivity coefficient correction and the use of a transient CPR model in TRACG.
3. Update Reference 1 to the current revision.

Revision 2:

1. Created '-A' version by adding the NRC's Final Safety Evaluation and GEH's responses to the NRC's Requests for Additional Information (RAIs) (Reference 6).
2. Updated Section 2.4.1 to address code updates consistent with the response to RAI 3 in GEH's letter, MFN 05-133, dated November 11, 2005 (Reference 6).
3. Added Reference 6.
4. Deleted acknowledgement page.

Revision 3:

1. Used the TRACG04 version (References 2 and 3), including PRIME (Reference 7) fuel properties and gap conductance fuel input files.
2. Used PANAC11 as three-dimensional neutron kinetics model (References 5, 8, and 9).
3. [[ ]]
4. Added Sections 1.2 and 2.3.1 for completeness; taken from NEDC-33075P-A Revision 6 (Reference 1).
5. Updated Sections 1.3 and 2.1 to clarify changes in this LTR revision and the scope of review.
6. Updated Section 2.2 and added Sections 2.2.1 to clarify CSAU steps; taken from NEDC-33075P-A Revision 6 (Reference 1).
7. Updated Table 2-1 to reflect TRACG04 and statistical CSAU demonstration case.
8. Updated Section 3.0 to clarify confirmation of [[ ]].

9. Updated Section 4.2.6 to reflect the adoption of full-core individual bundle model in the TRACG Thermal-Hydraulic (T-H) nodalization (i.e., each fuel bundle is modeled with an individual TRACG T-H channel and channel grouping is no longer necessary).
10. Updated References 1, 2, 3, and 4. Combined References 13 and 14 from Revision 2 into Reference 6.
11. Added References 5, 6, 7, 9, 10, 11, and 18.
12. Deleted Reference 9 from Revision 2.
13. Tables 3-1, 4-1, 4-2, 5-1, and 6-1 have been updated accordingly to the changes in the DSS-CD PIRT.
14. Deleted Table 4-3.
15. Updated Section 7.0 and added Sections 7.1, 7.2 to describe CSAU statistical approach and confirmation of [[ ]].
16. [[ ]]
17. Added Table 8-1 and Figure 8-23 to describe the bounding margin confirmation through the CSAU demonstration analyses.
18. Updated Figures 8-1 through 8-12 and new Figures 8-13 through 8-16 to show TRACG04 transient results.
19. Deleted Figures 8-13 through 8-17 because the CSAU demonstration bounding case has been replaced by the statistical CSAU demonstration case.
20. Added Figures 8-17 through 8-22 to include TRACG04 transient results for the feedwater reduction and single pump trip cases.
21. Added Section 9.0 for “Conclusions.”
22. Moved References to Section 10.0 and renumbered references in order of appearance.
23. Updated Acronym list.

ACRONYMS AND ABBREVIATIONS

Term	Definition
AOO	Anticipated Operational Occurrence
BOC	Beginning Of Cycle
BT	Boiling Transition
BWR	Boiling Water Reactor
CCFL	Counter Current Flow Limitation
CDA	Confirmation Density Algorithm
CFR	Code of Federal Regulations
CHAN	Fuel Channel component in TRACG
CPR	Critical Power Ratio
CSAU	Code Scaling, Applicability and Uncertainty
ΔCPR	Delta CPR
DSS-CD	Detect and Suppress Solution – Confirmation Density
DVC	Dynamic Void Coefficient
ECCS	Emergency Core Cooling System
ECP	Engineering Computer Program
EOC	End Of Cycle
EPU	Extended Power Uprate
ESBWR	Economic Simplified Boiling Water Reactor
FCL	Flow Control Line
FFWTR	Final Feedwater Temperature Reduction
FTTC	Fuel Thermal Time Constant
FW	Feedwater
FWHOOS	Feedwater Heater Out-Of-Service
GDC	General Design Criteria
GE	General Electric
GEH	GE Hitachi Nuclear Energy
GESTAR	General Electric Standard Application for Reload Fuel
GESTR	General Electric Stress and Thermal Analysis of Fuel Rods
GEXL	General Electric Boiling Transition Correlation
GNF	Global Nuclear Fuel

Term	**Definition**
GT	Guide Tube
H	High Importance
HT	Heat Transfer
ICPR	Initial Critical Power Ratio
ID	Identification
IMCPR	Initial Minimum Critical Power Ratio
JP	Jet Pump
L	Low Importance
LOCA	Loss-Of-Coolant Accident
LP	Lower Plenum
LPCI	Low Pressure Coolant Injection
LTP	Lower Tie-Plate
LTR	Licensing Topical Report
M	Medium Importance
MCPR	Minimum Critical Power Ratio
MELLLA+, M+	Maximum Extended Load Line Limit Analysis Plus
MG	Motor-Generator
MOC	Middle Of Cycle
NA	Not Applicable
ND	Normal Distribution
NRC	Nuclear Regulatory Commission
NRSBT	Number of Rods Subject to Boiling Transition
ODYN	One-Dimensional Reactor Dynamics Code
OLMCPR	Operating Limit MCPR
OLTP	Original Licensed Thermal Power
Option III	Stability OPRM-Based Detect and Suppress Long Term Solution
OSUTL	One-Sided, Upper Tolerance Limit
PANAC11	PANACEA, GEH BWR Core Simulator
PDF	Probability Density Function
PFR	Partial Flow Reduction
PIRT	Phenomena Identification and Ranking Table
PHE	Peak Hot Excess

Term	**Definition**
RAI	Request for Additional Information
RPT	Recirculation Pump Trip
SEO	Side Entry Orifice
SLMCPR	Safety Limit MCPR
SLO	Single Loop Operation
T-H	Thermal-Hydraulic
TLO	Two Loop Operation
TMIN	Minimum Stable Film Boiling Temperature
TRAC	Transient Reactor Analysis Code
TRACG	Transient Reactor Analysis Code (GEH proprietary version)
UTP	Upper Tie-Plate
1-D	One-Dimensional
1P	Single-Phase Pressure Drop
1RPT	Single Recirculation Pump Trip
2P	Two-Phase Pressure Drop
2RPT	Two Recirculation Pumps Trip
3-D	Three-Dimensional

1.0 INTRODUCTION

1.1 Background

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

The Detect and Suppress Solution – Confirmation Density (DSS-CD) solution, documented in Reference 1, consists of hardware and software that provide for reliable, automatic detection and suppression of stability related power oscillations. It is designed to identify the power oscillation upon inception and initiate control rod insertion to terminate the oscillations prior to any significant amplitude growth. The combination of hardware, software, and system setpoints provides protection against violation of the Safety Limit Minimum Critical Power Ratio (SLMCPR) for anticipated oscillations. Thus, compliance with General Design Criteria (GDC) 10 and 12 of 10 Code of Federal Regulations (CFR) 50, Appendix A is accomplished via an automatic action.

The DSS-CD is designed to provide adequate automatic SLMCPR protection for anticipated reactor instability events. The existing Option III algorithms are retained (with generic setpoints) to provide defense-in-depth protection for unanticipated reactor instability events. To support DSS-CD implementation, the TRACG code is used to simulate events to confirm the capability of the DSS-CD solution for early oscillation detection and suppression. The purpose of the TRACG qualification review summarized herein and described in Reference 1 is to provide background in support of the DSS-CD application. The TRACG model description, qualification, and application to transient analyses together with Nuclear Regulatory Commission (NRC) Safety Evaluation Report are documented in NEDE-31176P, NEDE-31177P, NEDE-32906P-A, respectively (References 2 through 4), and NEDE-32906P Supplement 3-A (Reference 5).

Revision 2 of this Licensing Topical Report (LTR) was based on TRACG02 (Reference 6). This report provides a generic licensing basis for TRACG04 application methodology in support of the DSS-CD solution. Throughout this report, unless otherwise noted, the TRACG term is used to represent the current version (TRACG04) or whenever the discussion generically applies to TRACG rather than a specific version.

1.2 TRACG Qualifications

TRACG is a GE Hitachi Nuclear Energy (GEH) proprietary version of the Transient Reactor Analysis Code (TRAC). TRACG uses advanced best-estimate one-dimensional (1-D) and three-dimensional (3-D) methods to model the phenomena that are important in evaluating the operation of BWRs. Best-estimate analyses performed with TRACG have been approved by the

NRC to support licensing applications in different areas, including specific T-H instability performance and Anticipated Operational Occurrence (AOO) transients.

TRACG includes a multi-dimensional, two-fluid model for the reactor thermal-hydraulics and a 3-D reactor kinetics model. The models can be used to simulate a large variety of test and reactor configurations. These features allow for detailed, best-estimate simulation of a wide range of BWR phenomena, and are described in detail in the TRACG Model Description LTR (Reference 2).

TRACG has been extensively qualified against separate effects tests, component performance data, integral system effects tests and full-scale BWR plant data. The details are presented in the TRACG Qualification LTR (Reference 3).

1.3 Purpose and Scope

This report provides the licensing basis and methodology to demonstrate the adequacy of the TRACG analyses as part of the DSS-CD solution.

The following main improvements were included in this revision:

1) Use of the TRACG04 version (References 2 and 3), including PRIME (Reference 7) fuel properties and gap conductance fuel input files. The TRACG implementation of the PRIME fuel conductivity (Approved in Reference 5) is used and the PRIME gap conductance files are attached.
2) Use of the PANAC11 as 3-D neutron kinetics model (References 5, 8, and 9).
3) Update the Phenomena Identification and Ranking Table (PIRT) to include/modify some of the parameters mostly due to the additional experience gained from the Economic Simplified Boiling Water Reactor (ESBWR) PIRT (References 10 and 11).
4) [[

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5) Adopt full-core individual bundle model in the TRACG T-H nodalization (i.e., each fuel bundle is modeled with an individual TRACG T-H channel and channel grouping is no longer necessary).

Section 2.0 describes the licensing requirements and the scope of the TRACG application to DSS-CD. Section 3.0 describes the identification and ranking of BWR phenomena for stability. Section 4.0 describes and justifies the applicability of TRACG models to DSS-CD. Section 5.0 describes the model uncertainties. Section 6.0 describes the application uncertainties and biases. Section 7.0 describes the combination of uncertainties. Section 8.0 provides a demonstration analysis. Section 9.0 provides the conclusions.

GEH requests approval of the TRACG04 code for the application to the analysis of BWR/3-6 plants employing the DSS-CD stability solution. This application may include all power/flow domains up to and including the Maximum Extended Limit Load Line Analysis Plus (MELLLA+) domain and all licensed operational enhancements. [[

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2.0 LICENSING REQUIREMENTS AND SCOPE OF APPLICATION

2.1 Licensing Compliance

The DSS-CD solution and related licensing basis comply with the requirements of 10 CFR 50, Appendix A, "General Design Criteria for Nuclear Power Plants." The Appendix A criteria related to stability are Criteria 10 and 12.

Criterion 10 (Reactor Design) requires that:

> "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."

Criterion 12 (Suppression of Reactor Power Oscillations) requires that:

> "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."

The DSS-CD hardware and software reliably and readily detect and suppress both core wide and regional mode oscillations prior to violating the SLMCPR for anticipated oscillations. The ability to trip the reactor is automatically enabled at power and flow conditions at which stability related oscillations are possible.

The DSS-CD licensing basis provides a high degree of confidence that power oscillations are terminated at relatively low amplitude by the DSS-CD solution, prior to any significant MCPR degradation, and therefore, obviates SLMCPR violations for anticipated instability events. Thus, the DSS-CD solution complies with GDC 10 and 12. The purpose of the DSS-CD TRACG analysis is to confirm the inherent MCPR margin afforded by the solution design.

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2.2 TRACG Analysis Approach For Licensing Compliance

The CSAU demonstration application to TRACG BWR stability analysis addresses all the elements of the NRC-developed CSAU evaluation methodology. The CSAU approach is a rigorous process for evaluating the total model and plant parameter uncertainty for nuclear power plant calculations. The process for applying best-estimate codes and quantifying the overall model and plant parameter uncertainties represents the best available practice. While the CSAU methodology was developed for application to Loss-of-Coolant Accident (LOCA) scenarios, there are no technical reasons that prevent CSAU methodology from being applied to other event scenarios, such as stability.

In the CSAU process, the model uncertainty is derived from the propagation of individual model uncertainties through code calculations, and experimental comparisons are used as a check on the derived uncertainty.

The overall TRACG demonstration analysis approach for DSS-CD is consistent with the CSAU analysis methodology (Reference 12) and Regulatory Guide 1.157 (Reference 13), and addresses the applicable elements of the NRC-developed CSAU evaluation methodology. The CSAU methodology consists of 14 steps, as outlined in Table 2-1, which summarizes how these steps are addressed for the TRACG DSS-CD demonstration. Additional information on the CSAU application for DSS-CD is provided in Section 2.2.1 and the detailed demonstration of the CSAU analysis methodology for DSS-CD is addressed in Sections 3-8 of this report.

2.2.1 CSAU Methodology Application

This Section introduces the CSAU methodology demonstration for DSS-CD. [[

]] and documented in Section 4.4.3 of Reference 1.

[[

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Details about the 14 steps of the CSAU methodology application to the DSS-CD demonstration summarized in Table 2-1 are discussed below, whereas some of the steps are thoroughly discussed in the next Sections of this report.

Step 1: Stability Scenario Specification

The stability scenarios are those associated with anticipated stability events in BWR/3-6 type plants. [[

]].

Step 2: Nuclear Power Plant Selection

The DSS-CD is applicable to BWR/3-6 plant product lines.

Step 3: Phenomena Identification and Ranking

See Section 3.0.

Step 4: Frozen Code Version Selection

A frozen code version (TRACG04P) has been used in this evaluation.

Step 5: Code Documentation

The TRACG program is a controlled Engineering Computer Program (ECP), and therefore, the documentation provided to the users is also maintained in a controlled manner. References 2 and 3 document both the TRACG licensing basis and application methodology.

Step 6: Determination of Code Applicability

See Section 4.0.

Step 7: Establishment of Assessment Matrix

See Section 4.1.

Step 8: Nuclear Power Plant Nodalization Definition

The nodalization strategy for the various reactor components was developed from the qualification of TRACG against test data for these components. The same consistent nodalization strategy was then applied for full-scale plant calculations. The adequacy of the nodalization has been demonstrated and supported by sensitivity studies. Standard nodalization for modeling of BWR reactor vessels and other components have been presented in the TRACG Qualification LTR (Reference 3). Additional sensitivity studies on vessel nodalization have been provided in Reference 6.

Specific nodalization and additional details for the nodalization for some components may be critical for specific applications. [[
]]

Step 9: Definition of Code and Experimental Accuracy

The code definition and experimental accuracy has been addressed in Reference 3. The TRACG code has been qualified against the LaSalle-2 instability event (March 1988), the Leibstadt Cycle 1 regional instability tests, the Nine Mile Point 2 instability event (July 2003), and the Peach Bottom Unit 2 Cycle 2 stability tests (April 1977). The overall TRACG prediction agrees well with the experimental data.

Step 10: Determination of Effect of Scale

Effects of scale have been addressed as part of the model development as well as the qualification. In the TRACG model description report (Reference 2), the applicability of the basic models and correlations are stated and shown to cover the scale and operating range of BWRs. The qualification of TRACG (Reference 3) covers separate effects tests, scaled as well as full-scale component performance tests, scaled integral system effects tests, and full-scale BWR plant tests. The qualification shows that data from scaled test facilities and full-scale plants are both well predicted. There is no apparent effect of scale in TRACG. In addition, demonstrations of the application methodology for TRACG have shown that full-scale plant data are bounded, when the effect of the model uncertainties are accounted for. Because these model uncertainties have primarily been determined from scaled experiments, this again demonstrates that there is no significant effect of scale on TRACG.

Step 11: Determination of the Effect of Reactor Input Parameters and State

Overall model biases and uncertainties for the stability application are assessed for each high and medium ranked phenomena by using a combination of comparisons of calculated results to: (1) separate effects test facility data; (2) integral test facility test data; (3) component qualification test data; and (4) BWR plant data. Where data is not available, cross-code comparisons or engineering judgment are used to obtain approximations for the biases and uncertainties. For some phenomena that have little effect on the calculated results, it is appropriate to simply use a nominal value or to conservatively estimate the bias and uncertainty.

The phenomena for BWR stability are identified and ranked, as indicated in Step 3 above and in Table 2-1.

Step 12: Performance of Nuclear Power Plant Sensitivity Calculations

Two plant types (BWR/3-5 and BWR/6) with different limiting operating conditions are evaluated for the stability application. [[

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Step 13: Determination of Combined Bias and Uncertainty

See Sections 5.0, 6.0 and 7.0.

Step 14: Determination of Total Uncertainty

See Sections 7.0 and 8.0.

2.3 Scope of TRACG Application for DSS-CD

The TRACG code is used to simulate reasonably limiting [[ ]] events to confirm the early oscillation detection and suppression capability of DSS-CD solution. The purpose of the TRACG qualification review is to provide background for the code use in support of the DSS-CD application.

2.3.1 Advantages of TRACG Use for Stability Evaluations

TRACG use for stability analyses includes the following advantages:

- [[ ]] TRACG is not only capable of simulating core response, but also determining the response of individual (including limiting) channels, including transient critical power response.
- With its 3-D kinetics model, TRACG is capable of simulating the complex T-H and neutronic interactions of the core. The nuclear model is consistent with the PANAC11 3-D steady-state simulator (References 8 and 9), which is constantly being benchmarked against steady-state nuclear data.
- TRACG calculates the CPR directly.

2.4 NRC Review Requirements for TRACG Code Updates

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

2.4.1 Updates to TRACG Code

Modifications to the basic models described in Reference 2 that significantly reduce the MCPR margin may <u>not</u> be used for licensing calculations without NRC review and approval. However, modifications to the basic models that add conservatism or are judged to be insignificant would not require NRC review and approval.

Updates to the TRACG nuclear methods to ensure compatibility with the NRC-approved steady-state nuclear methods may be used for licensing calculations without NRC review and approval as long as the ΔCPR/Initial Critical Power Ratio (ICPR) shows less than 1 sigma deviation difference compared to the method presented in this LTR. A typical 2RPT case will be compared and the results from the comparison will be transmitted for information.

Changes to the numerical method that have insignificant effect on or would lead to an increase in decay ratio or oscillation amplitude can be introduced without NRC approval. Changes to the numerical method that lead to a reduction in decay ratio or oscillation amplitude should not be introduced without NRC approval.

Features that support effective code input/output may be added without NRC review and approval.

2.4.2 Updates to TRACG Model Uncertainties

New data may become available with which the specific model uncertainties described in Section 5 of Reference 4 may be reassessed. If the reassessment results in a need to change specific model uncertainty, the specific model uncertainty may be revised for licensing calculations without NRC review and approval as long as the process for determining the uncertainty is unchanged.

The nuclear uncertainties (void coefficient, Doppler coefficient, and scram coefficient) may be revised without review and approval as long as the process for determining the uncertainty is unchanged. In all cases, changes made to model uncertainties without NRC review and approval will be transmitted for information.

2.4.3 Updates to TRACG Statistical Method

Revisions to the TRACG statistical method described in Section 7 may not be used for licensing calculations without NRC review and approval.

Table 2-1 14 Step CSAU Methodology

CSAU Step	Step Description	DSS-CD
1	Scenario Specification	[[ ]]
2	Nuclear Power Plant Selection	BWR/3-6
3	Phenomena Identification and Ranking	Addressed in Table 3-1
4	Frozen Code Version Selection	TRACG04P
5	Code Documentation	References 2 and 3
6	Determination of Code Applicability	Table 4-1
7	Establishment of Assessment Matrix	Table 4-2
8	Nuclear Power Plant Nodalization Definition	Nodalization defined. Plant nodalization study performed. References 3 and 6
9	Definition of Code and Experimental Accuracy	References 3 and 4
10	Determination of Effect of Scale	Full scale data available, addressed in Section 5.2, Item 10 of Reference 1
11	Determination of the Effect of Reactor Input Parameters and State	Addressed in Tables 3-1, 5-1 and 6-1
12	Performance of Nuclear Power Plant Sensitivity Calculations	Addressed in Tables 5-1 and 6-1
13	Determination of Combined Bias and Uncertainty	[[ ]]
14	Determination of Total Uncertainty	See Sections 7.0 and 8.0. DSS-CD statistical calculations demonstrate that FMCPR > SLMCPR and confirm the application of the [[ ]] approach established in Section 4.4.1.2 of Reference 1.

3.0 PHENOMENA IDENTIFICATION AND RANKING

The critical safety parameter for stability events is the MCPR. The MCPR value is determined by the governing physical phenomena. The PIRT is used to delineate the important physical phenomena. PIRTs are ranked with respect to their effect on the critical safety parameters. For example, the MCPR is determined by the reactor short-term response to stability events. The coupled core neutronic and T-H characteristics govern the neutron flux, reactor pressure, and core flow in a stability transient.

All processes and phenomena that occur during a transient do not equally influence plant behavior. Disposition analysis is used to reduce all candidate phenomena to a manageable set by identifying and ranking the phenomena with respect to their influence on the critical safety parameters. The phases of the events and the important components are investigated. The processes and phenomena associated with each component are examined. Cause and effect are differentiated. After the processes and phenomena have been identified, they are ranked with respect to their effect on the critical safety parameters for the event.

PIRTs are developed with only the importance of the phenomena in mind and are independent of whether or not the model is capable of handling the phenomena and whether or not the model shows a strong sensitivity to the phenomena. For example, two phenomena may be of high importance yet may tend to cancel each other so that there is little sensitivity to either phenomenon. Both phenomena are of high importance because the balance between these competing phenomena is important.

Table 3-1 was developed to identify the phenomena that govern BWR/3-6 stability responses, and represents a consensus of GEH expert opinions. The stability transient events have been categorized into three distinct groups:

- Channel T-H instability,
- Core-wide instability, and
- Regional instability.

For each event type, the phenomena are listed and ranked for each major component in the reactor system. The ranking of the phenomena is done on a scale of high importance to low importance or not applicable, as defined by the following categories:

- **High importance (H):** These phenomena have a significant effect on the primary safety parameters and should be included in the overall uncertainty evaluation.
- **Medium importance (M):** These phenomena have insignificant effect on the primary safety parameters and may be excluded in the overall uncertainty evaluation.
- **Low importance (L) or not applicable (NA):** These phenomena have no effect on the primary safety parameters and need not be considered in the overall uncertainty evaluation.

The PIRT serves a number of purposes. First, the phenomena are identified and compared to the modeling capability of the code to assess whether the code has the necessary models to simulate the phenomena. Second, the identified phenomena are cross-referenced to the qualification basis to determine what qualification data are available to assess and qualify the code models and to determine whether additional qualification is needed. As part of this assessment, the range of the PIRT phenomena covered in the tests is compared with the corresponding range for the intended application to establish that the code has been qualified for the highly ranked phenomena over the appropriate range.

Table 3-1 also tabulates a number of derived parameters (e.g., ratio of core power to core flow) important to reactor instability.

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Table 3-1 Phenomena Governing BWR/3-6 Stability Transients

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4.0 APPLICABILITY OF TRACG TO DSS-CD APPLICATIONS

This section demonstrates the applicability of TRACG for the analysis of anticipated instability events in BWRs through a two-step process. First, the identified phenomena are compared to the modeling capability of the code to determine that the code has the necessary models to simulate the phenomena, as shown in Table 4-1.

Second, the capability of the TRACG models to treat the highly ranked phenomena and the qualification assessment of the TRACG code for stability applications are examined.

The capability to simulate an event for a nuclear power plant depends on four elements:

- Conservation equations, which provide the code capability to address global processes,
- Correlations and models, which provide the code capability to model and scale particular processes,
- Numerics, which provide the code capability to perform efficient and reliable calculations, and
- Structure and nodalization, which address the code capability to model plant geometry and perform efficient and accurate calculations.

Consequently, these four elements must be considered when evaluating the applicability of the code to the event of interest for the nuclear power plant calculation. The key phenomena for each event are identified in generating the PIRTs for the intended application. The capability of the code to simulate the key phenomena for AOO applications is addressed, documented in Reference 4 and supported by code qualification in Reference 3. In Reference 14 the applicability of TRACG for the stability analysis for BWR is demonstrated. In Reference 10 the applicability of TRACG for the stability analysis for ESBWR is demonstrated. A similar demonstration for DSS-CD stability application is made in Section 4.1. There are only minor differences between the (H) ranked PIRTs (see Table 3-1) for stability and those for AOOs with the inclusion of:

- [[
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-]]

4.1 Phenomena vs. Qualification Basis Cross-Reference

The identified phenomena are cross-referenced to the qualification basis to determine what qualification data are available to assess and qualify the code models, and to determine whether additional qualification is needed for some phenomena. As part of this assessment, the range of the PIRT phenomena covered in the tests is compared with the corresponding range for the intended application to establish that the code has been qualified for the highly ranked phenomena over the appropriate range.

The qualification assessment of TRACG models is summarized in Table 4-2. The models are identified so that they may be easily correlated to the model description and qualification reports. For each model, the relevant elements from the Model Description LTR (Reference 2) and the Qualification LTR (Reference 3) are identified.

For each of the governing BWR phenomena, TRACG qualification has been performed against a wide range of data. In this section, the qualification basis is related to the phenomena that are important for the intended application. This is a necessary step to confirm that the code has been adequately qualified for the intended application.

The complete list of phenomena is cross-referenced to the model capabilities in Table 4-1. Similarly, as shown in Table 4-2, the complete list of phenomena is cross-referenced to the qualification assessment basis. Data from separate effects tests, component tests, integral system tests and plant tests as well as plant data have been used to qualify the capability of TRACG to model the phenomena.

4.2 Other Topics Relevant To TRACG Modeling Instability

This section addresses other topics relevant to TRACG modeling of instability, including the selection of numerical integration scheme and nodalization approach for the channel component, numerical formulations used, and channel grouping approach used in TRACG stability analysis.

4.2.1 Explicit Integration Scheme for the Channel Component

TRACG uses a fully implicit integration technique for the heat conduction and hydraulic equations when integrating from time step n to time step n+1. In the implicit formulation, the convective terms are calculated based on the new properties at time step n+1. The fully implicit technique is the default option. The governing hydraulic equations in the implicit form are provided in Section 8.2 of Reference 2. For time domain stability calculations, an optional explicit integration technique can be employed. To minimize numerical damping, the use of explicit scheme changes the convective terms to use the current properties at time step n properties in place of the new properties at time step n+1.

T-H instability caused by density waves can occur in boiling two-phase flow, where there is a mismatch between the power and flow (i.e., high power and low flow). Traditionally, this instability has been analyzed using frequency domain methods. The frequency domain method consists of a first order perturbation at a given frequency to the steady-state solution. Neglecting all second order terms, a linear system of equations is formed, which can be solved for growth rate or damping as a function of frequency. The maximum growth rate characterizes the T-H stability of the channel. Frequency domain methods generally predict the onset of instability well. However, because they are based on a linearized model, they cannot predict what will happen after the system becomes unstable. To capture the nonlinear effects of an unstable system, time domain methods are developed. The TRACG T-H instability modeling has been evaluated for adequacy by comparison to experimental data of the FRIGG facility, as discussed throughout Section 3.7 of Reference 3. Two types of tests were run in the FRIGG facility. One test series used a pseudo random signal imposed on the system to determine the system response as a function of frequency. A second test series provided a more deterministic measurement of the onset of unstable behavior. In these tests, which started from steady-state natural circulation operation, the system power was slowly increased until the onset of unsteady behavior was observed. This second series of tests have been simulated by TRACG. Comparisons of TRACG predictions of the channel power for the onset of limit cycle oscillations to the power measured in the tests is considered the best assessment of the code's ability to predict the onset of unstable operation.

4.2.2 Detailed Nodalization Scheme for the Channel Component

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4.2.3 Coupling of Conduction and Hydraulic Equations

The coupling scheme used for the conduction and hydraulic equations does not change for stability applications, relative to AOOs.

The heat transfer coupling between the structures and the hydraulics is treated implicitly, when the implicit integration technique is used. For this purpose, the heat conduction equation is solved in two steps, and thus integration of the combined equations involves the following steps:

(1) The heat conduction equation for structures is linearized with respect to fluid temperatures. The result of this step is a system of linear equations for structure temperatures and surface heat flow as functions of the fluid temperatures.

(2) The hydraulic equations are solved using an iterative technique. This step results in new values for the fluid pressures, void fraction, temperatures and velocities.

(3) A corrector step is utilized for the hydraulic solution. Due to use of an iterative solution technique, the conservation of the properties is affected by the convergence. The corrector step is employed to correct any lack of conservation due to imperfect convergence.

(4) Back-substitution into the heat conduction equation is performed to obtain new temperatures for structures.

The linearization of the heat conduction equation and subsequent back-substitution (Steps 1 and 4) are described in Section 8.1 of Reference 2. The hydraulic solution (Steps 2 and 3) is described in Section 8.2 of Reference 2.

4.2.4 Coupling of the Vessel and Channel Components

The coupling scheme used between the vessel component and the channel components does not change for stability applications, relative to AOOs. A network solution scheme is applied, as described in Section 8.2.2 of Reference 2.

4.2.5 Coupled 3-D Kinetics and Thermal-Hydraulics Model

The coupled 3-D kinetics and thermal-hydraulics model used does not change for stability applications, relative to AOOs. The 3-D kinetics model is described in Section 9 of Reference 2.

TRACG solves the 3-D transient neutron diffusion equations using one neutron energy group and up to six delayed neutron precursors groups. The basic formulation and assumptions are consistent with the GEH 3-D BWR Core Simulator (References 8 and 9). This same one-group formulation collapsed radially to one axial dimension is the basis for the NRC-approved One-Dimensional Reactor Dynamics Code (ODYN) (Reference 15). The formulation described fully in Reference 15 is used in ODYN for BWR transient simulations. The simplifying assumptions made in ODYN to yield a 1-D transient kinetics model are not used in the TRACG 3-D model. Instead, neutron flux and delayed neutron precursor concentrations at every (i,j,k) node are integrated in time in response to moderator density, fuel temperature, boron concentration or control rod changes. [[
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4.2.6 Channel Grouping for Stability Applications

Individual fuel bundles in the core may be modeled in TRACG as individual channels or may be grouped together into a single TRACG channel. In the current version of TRACG, the code limitation on the number of components has been increased such that it is currently possible to model every fuel bundle as a single TRACG channel. Consequently, it is no longer necessary to group or combine individual fuel bundles. A full core of individual bundle model is adopted for TRACG DSS-CD applications.

The full core individual bundle model eliminates the T-H lumping due to channel grouping, hence reducing the approximation caused by the selected T-H lumping model. This is a best-estimate model consistent with the integrated TRACG best-estimate approach used for DSS-CD applications.

Coupled neutronic/T-H instabilities in BWRs are typically characterized by core-wide or regional oscillation modes. [[

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By eliminating channel grouping, a core is no longer restricted to oscillate according to a certain mode and is instead allowed to oscillate in the actual mode that characterizes it, which for instance depends upon its core design, power distribution, and other characteristics.

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4.2.7 Instability Solution Uniqueness

This section addresses the solution uniqueness of TRACG analysis results for licensing BWR/3-6 power plants to support the DSS-CD licensing basis. GEH has provided information to support the use of TRACG as an extension to the previously approved method of analyzing BWR stability and demonstrating compliance with licensing limits (References 16 and 17). Stability events are analyzed to establish the reactor system response, including the calculation of the CPR. This report addresses TRACG capabilities to confirm that acceptable fuel design limits are not exceeded during specified stability event.

Table 4-1 Stability Phenomena and TRACG Model Capability Matrix

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Table 4-2 Qualification Assessment Matrix for BWR/3-6 Stability Phenomena

ID	REGION or PHENOMENA DESCRIPTION	Channel Thermal Hydraulic Stability	Core wide Stability	Regional Stability	Highest Ranking	Critical Safety Parameter	1. CPR: Controlled by heat flux, flow, pressure, and inlet subcooling - Power oscillations - Flow oscillations 2. Decay Ratio - controls stability margin/growth rate of perturbations COMMENTS	Qualification Basis Reference to Section Number in the *TRACG Qualification*, LTR NEDE-32177, (Reference 3)			
								Separate Effects Qualification	Component Performance Qualification	Integral System Qualification	Plant Data Qualification
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ID	REGION or PHENOMENA DESCRIPTION	Channel Thermal Hydraulic Stability	Core wide Stability	Regional Stability	Highest Ranking	Critical Safety Parameter	1. CPR: Controlled by heat flux, flow, pressure, and inlet subcooling - Power oscillations - Flow oscillations 2. Decay Ratio - controls stability margin/growth rate of perturbations COMMENTS	Qualification Basis Reference to Section Number in the *TRACG Qualification*, LTR NEDE-32177, (Reference 3)			
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COMMENTS</th><th colspan="4">Qualification Basis
Reference to Section Number in the
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ID	REGION or PHENOMENA DESCRIPTION	Channel Thermal Hydraulic Stability	Core wide Stability	Regional Stability	Highest Ranking	Critical Safety Parameter	1. CPR: Controlled by heat flux, flow, pressure, and inlet subcooling - Power oscillations - Flow oscillations 2. Decay Ratio - controls stability margin/growth rate of perturbations COMMENTS	Qualification Basis Reference to Section Number in the *TRACG Qualification*, LTR NEDE-32177, (Reference 3)			
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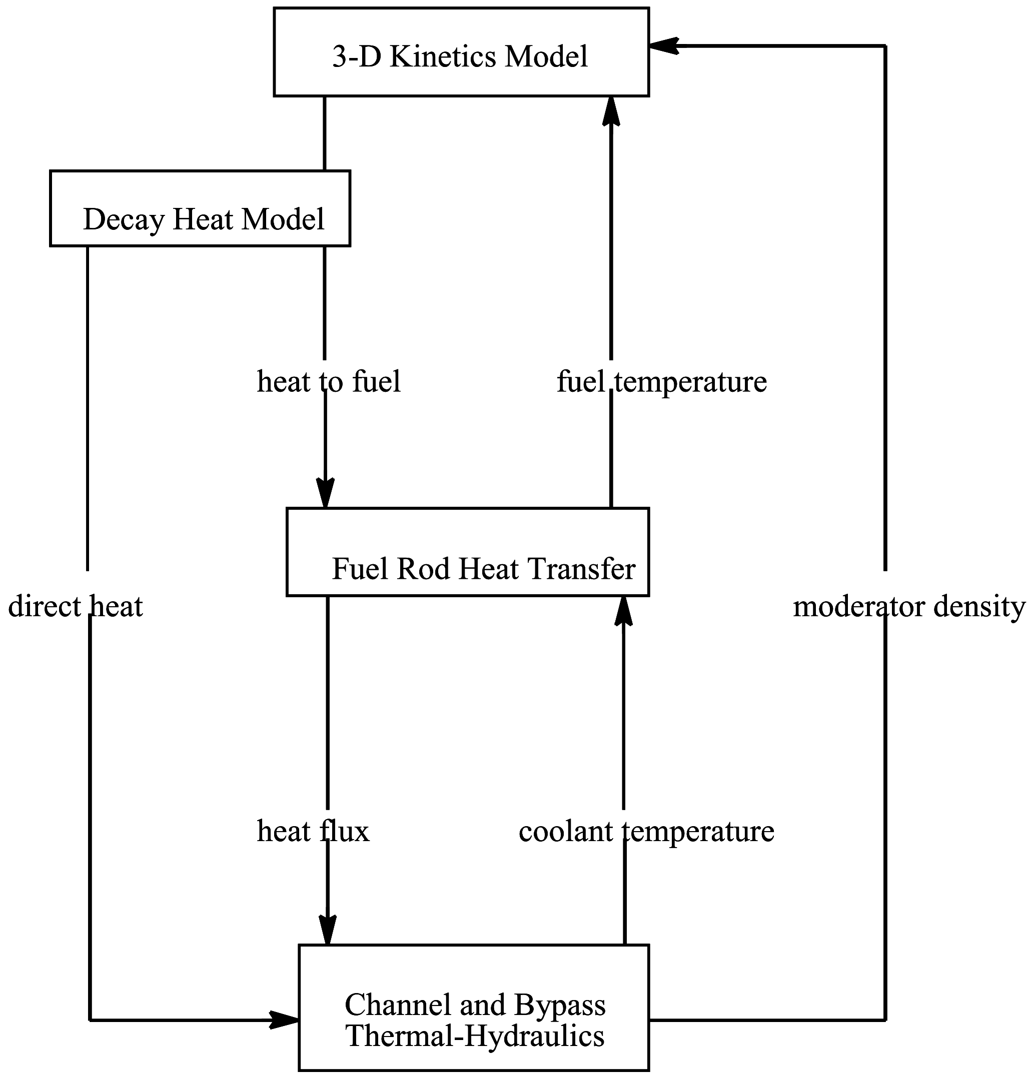
Figure 4-1 Data Transfer Between TRACG Models



5.0 MODEL BIASES AND UNCERTAINTIES

The model biases and uncertainties for all items from the PIRT (Table 3-1), which have been identified as having a high effect on the critical safety parameters, have been evaluated. Overall model biases and uncertainties for the stability application are assessed for each high and medium ranked phenomena by using a combination of comparisons of calculated results to: (1) separate effects test facility data; (2) integral test facility test data; (3) component qualification test data; and (4) BWR plant data. Where data is not available, cross-code comparisons or engineering judgment are used to obtain approximations for the biases and uncertainties. For some phenomena that have little effect on the calculated results, it is appropriate to simply use a nominal value or to conservatively estimate the bias and uncertainty. Table 5-1 provides the dispositions of the high and medium ranked stability model parameters from Table 3-1. These items are represented in the table by identification (ID), description, ranking (H for High, M for Medium), and bias and deviation information.

The phenomena for BWR/3-6 stability events are identified and ranked, as indicated in Section 3.0. For the high and medium ranked phenomena, the bases or references used to establish the nominal value, bias and uncertainty for that parameter are documented in Table 5-1. Also, the basis or references for the selection of the probability density function used to model the uncertainty is provided in Table 5-1.

Table 5-1 Disposition of High and Medium Ranked Stability Model Parameters

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Notes for Table 5-1:

N-1: Multiple Channel Effect

The DSS-CD solution is designed to detect instabilities as the oscillations first develop, and possibly the oscillations are often not fully developed upon detection. The DSS-CD TRACG application is improved by implementing a full core individual bundle T-H simulation where every fuel bundle is modeled by a separate T-H channel. Therefore, the need to develop an appropriate channel grouping is eliminated.

6.0 APPLICATION UNCERTAINTIES AND BIASES

Code inputs can be divided into four broad categories: (1) geometry inputs; (2) model selection inputs; (3) initial condition inputs; and (4) plant parameters. For each type of input, it is necessary to specify the value for the input. If the calculated result is sensitive to the input value, then it is also necessary to quantify the uncertainty in the input.

The geometry inputs specify lengths, areas and volumes. Uncertainties in these quantities are due to measurement uncertainties and manufacturing tolerances. These uncertainties usually have a much smaller effect on the results than do uncertainties associated with the modeling simplifications.

Individual geometric inputs are the building blocks for the spatial nodalization. The spatial nodalization includes modeling simplifications such as the lumping together of individual elements into a single model component. An assessment of these kinds of simplifications, along with the sensitivities to spatial nodalization, is included in the TRACG Qualification LTR (Reference 3).

Inputs are used to select the features of the model that apply for the intended application. Once established, these inputs are fully specified in the procedure for the application and do not change.

A plant parameter is defined as a plant-specific quantity such as a protection system scram characteristic. Plant parameters influence the characteristics of the transient response and have essentially no effect on steady-state operation.

Initial conditions are those conditions that define a steady-state operating condition. Initial conditions may vary due to the allowable operating range or due to uncertainty in the measurement at a given operating condition. The plant Technical Specifications and Operating Procedures provide the means by which controls are instituted and the allowable initial conditions are defined. At a given operating condition, the plant’s measurement system has inaccuracies that also must be dispositioned or accounted for as an uncertainty.

Table 6-1 lists the key plant initial conditions/parameters that are high and medium ranked for the stability application. For the high and medium ranked phenomena, the bases used to establish the nominal value, bias and uncertainty for that parameter are documented.

Table 6-1 Key Plant Initial Conditions/Parameters

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Notes for Table 6-1:

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7.0 COMBINATION OF UNCERTAINTIES

This section provides the statistical approach for combining the uncertainties due to model uncertainties, scaling uncertainties, and plant condition or state uncertainties.

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7.1 Selected Approach for Combining Uncertainties

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7.2 Implementation of Statistical Methodology

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8.0 EXAMPLE DEMONSTRATION ANALYSES

8.1 Best Estimate TRACG Simulation

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The simulation results are used to assess the MCPR response and margin to the SLMCPR. The transient responses of key simulation parameters, including core power and flow, core inlet subcooling, hot channel power, hot channel flow and hot channel CPR, [[

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8.2 MCPR Uncertainty Assessment

The CSAU approach described in this report was applied to both the [[

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8.3 MCPR Uncertainty Application to DSS-CD

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Table 8-1 [[ ]]

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Figure 8-1 [[ ]]

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Figure 8-2 [[ ]]

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Figure 8-3 [[ ]]

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Figure 8-4 [[ ]]

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Figure 8-5 [[ ]]

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Figure 8-6 [[ ]]

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Figure 8-7 [[ ]]

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Figure 8-8 [[ ]]

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Figure 8-21 [[ ]]

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Figure 8-22 [[ ]]

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Figure 8-23 [[ ]]

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9.0 CONCLUSIONS

This report provides the licensing basis and methodology to demonstrate the adequacy of the TRACG analyses as part of the DSS-CD solution.

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The DSS-CD solution and related licensing basis comply with the requirements of 10 CFR 50, Appendix A, GDC 10 and 12. [[

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