

ENCLOSURE 2

MFN 13-072

NEDO-33766, Revision 0,
“GEH Simplified Stability Solution (GS3),”
September 2013

Non-Proprietary Information– Class I (Public)

IMPORTANT NOTICE

This is a non-proprietary version of NEDE-33766P, Revision 0, from which the proprietary information has been removed. Portions of the enclosure that have been removed are indicated by an open and closed bracket as shown here [[]].



HITACHI

GE Hitachi Nuclear Energy

NEDO-33766
Revision 0
DRF 0000-0157-6515
DRF Section 0000-0157-6516-R1
September 2013

Non-Proprietary Information—Class I (Public)

Licensing Topical Report

GEH Simplified Stability Solution (GS3)

Juswald Vedovi

David G. Vreeland

Lander Ibarra

Scott Pfeffer

Justin Lamy

Copyright 2013 GE-Hitachi Nuclear Energy Americas LLC

All Rights Reserved

INFORMATION NOTICE

This is a non-proprietary version of the document NEDE-33766P, Revision 0, which has the proprietary information removed. Portions of the document that have been removed are indicated by an open and closed bracket as shown here [[]].

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

Please Read Carefully

The design, engineering, and other information contained in this document are furnished for the purpose of obtaining Nuclear Regulatory Commission (NRC) approval of the GEH Simplified Stability Solution (GS3). The only undertakings of GEH with respect to information in this document are contained in the contracts between GEH and its customers or participating utilities, and nothing contained in this document will be construed as changing that contract. The use of this information by anyone for any purpose other than that for which it is intended is not authorized; and with respect to any unauthorized use, GEH makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

TABLE OF CONTENTS

	Page
1. Introduction.....	1-1
1.1 Background.....	1-1
1.2 Overview of Existing Stability Solutions	1-2
1.2.1 Changes in Stability LTSs and in Designs	1-4
1.2.2 Historical Events with Low OPRM Setpoints and Plant-Specific Noise Results ..	1-6
1.2.3 Conservative Versus BEPU Methodologies	1-7
1.3 TRACG Qualification.....	1-10
1.4 Purpose and Scope.....	1-10
2. Licensing Requirements and Scope of Application	2-1
2.1 Licensing Compliance	2-1
2.2 TRACG Analysis Approach for Licensing Compliance	2-2
2.2.1 CSAU Methodology Application.....	2-3
2.3 Scope of TRACG Application for GS3	2-7
2.3.1 Advantages of TRACG Use for Stability Evaluations.....	2-7
2.4 NRC Review Requirements for TRACG Code Updates.....	2-7
2.4.1 Updates to the TRACG Code.....	2-7
2.4.2 Updates to TRACG Model Uncertainties	2-7
2.4.3 Updates to TRACG Statistical Method.....	2-8
3. Phenomena Identification and Ranking	3-1
4. Applicability of TRACG to GS3 Applications	4-1
4.1 Phenomena Versus Qualification Basis Cross-Reference	4-1
4.2 Other Topics Relevant to TRACG Modeling of Instability	4-2
4.2.1 Explicit Integration Scheme for the Channel Component.....	4-2
4.2.2 Detailed Nodalization Scheme for the Channel Component	4-3
4.2.3 Coupling of Conduction and Hydraulic Equations	4-3
4.2.4 Coupling of the Vessel and Channel Components.....	4-3
4.2.5 Coupled 3-D Kinetics and Thermal-Hydraulics Model	4-4
4.2.6 Channel Grouping for Stability Applications.....	4-4
5. Model Biases and Uncertainties.....	5-1
6. Application Uncertainty and Biases.....	6-1
7. Combination of Uncertainties	7-1
7.1 Selected Approach for Combining Uncertainties	7-1
7.2 Implementation of Statistical Methodology	7-2
7.2.1 Statistical Methodology Implementation	7-2
7.2.2 Statistical Methodology Implementation for Option I-D Plants	7-3
7.2.3 Statistical Methodology Implementation for Option II Plants	7-4

7.2.4	Statistical Methodology Implementation for Option III Plants.....	7-4
7.3	Example of the Combination of Uncertainties	7-5
8.	Example Demonstration Analyses	8-1
8.1	Best-Estimate TRACG Simulation.....	8-1
8.2	MCPR Uncertainty Assessment.....	8-3
8.3	MCPR Uncertainty Application to GS3	8-3
9.	Licensing Basis for Generic Envelope and Fuel Reload Applications	9-1
9.1	Approach.....	9-1
9.2	Generic Applicability Envelope.....	9-2
9.3	SLMCPR Protection Confirmation.....	9-4
9.3.1	Two Loop Operation	9-5
9.3.2	Single Loop Operation	9-15
9.4	Fuel Reload Analysis Application	9-17
9.4.1	Demonstration of Fuel Reload Analysis for a GS3 Option III Plant	9-18
9.5	Extension of Generic Envelope	9-20
10.	Plant-Specific Applications.....	10-1
10.1	Plant-Specific Review Process	10-1
10.2	Lead Use Assembly	10-3
10.3	Technical Specifications	10-3
11.	Conclusions	11-1
12.	References	12-1

LIST OF TABLES

Table	Title	Page
Table 1-1	[[]]	1-12
Table 2-1	14 Step CSAU Methodology	2-9
Table 5-1	BWR/2-6 Disposition of High and Medium Ranked Stability Model Parameters	5-3
Table 6-1	Key Plant Initial Conditions/Parameters	6-2
Table 7-1	GS3 CSAU Combination of Uncertainty Procedure	7-7
Table 7-2	Combination of Uncertainty Data Summary - Option III Plants	7-8
Table 7-3	Combination of Uncertainty Data Summary - Option II Plants	7-9
Table 7-4	Combination of Uncertainty Data Summary - Option I-D Plants	7-10
Table 9-1	[[]]	9-21
Table 9-2	GS3 [[]] TRACG Analysis Event Matrix	9-22
Table 9-3	GS3 [[]] TRACG Analysis Event Matrix	9-23
Table 9-4	GS3 [[]] TRACG Analysis Event Matrix	9-24
Table 9-5	[[]]	9-25
Table 9-6	[[]]	9-26
Table 9-7	[[]]	9-27
Table 9-8	[[]]	9-28
Table 9-9	[[]]	9-29
Table 9-10	Relationship Between OPRM Successive Confirmation Count Setpoint and OPRM Amplitude Setpoint	9-30
Table 9-11	Conservatisms Included in GS3 Methodology	9-31
Table 9-12	[[]]	9-32
Table 10-1	GS3 Plant-Specific Applicability Checklist	10-4
Table 10-2	[[]]	10-5
Table 10-3	Required TRACG Cases for Fuel Design Transition Scenarios	10-6

LIST OF FIGURES

Figure	Title	Page
Figure 7-1	NRSBT Determination with Transient Uncertainty Included	7-1
Figure 8-1	[[]]	8-5
Figure 8-2	[[]]	8-6
Figure 8-3	[[]]	8-7
Figure 8-4	[[]]	8-8
Figure 8-5	[[]]	8-9
Figure 8-6	[[]]	8-10
Figure 8-7	[[]]	8-11
Figure 8-8	[[]]	8-12
Figure 8-9	[[]]	8-13
Figure 8-10	[[]]	8-14
Figure 8-11	[[]]	8-15
Figure 8-12	[[]]	8-16
Figure 8-13	[[]]	8-17
Figure 8-14	[[]]	8-18
Figure 8-15	[[]]	8-19
Figure 8-16	[[]]	8-20
Figure 8-17	[[]]	8-21
Figure 8-18	[[]]	8-22
Figure 8-19	[[]]	8-23
Figure 8-20	[[]]	8-24
Figure 8-21	[[]]	8-25
Figure 8-22	[[]]	8-26
Figure 8-23	[[]]	8-27
Figure 8-24	[[]]	8-28
Figure 8-25	[[]]	8-29
Figure 8-26	[[]]	8-30
Figure 8-27	[[]]	8-31
Figure 8-28	[[]]	8-32
Figure 8-29	[[]]	8-33
Figure 8-30	[[]]	8-34
Figure 8-31	[[]]	8-35

NON-PROPRIETARY INFORMATION—CLASS I (PUBLIC)

Figure 8-32	[[]].....	8-36
Figure 8-33	[[]].....	8-37
Figure 8-34	[[]].....	8-38
Figure 8-35	[[]].....	8-39
Figure 8-36	[[]].....	8-40
Figure 8-37	[[]].....	8-41
Figure 8-38	[[]].....	8-42
Figure 8-39	[[]].....	8-43
Figure 8-40	[[]].....	8-44
Figure 8-41	[[]].....	8-45
Figure 8-42	[[]].....	8-46
Figure 8-43	[[]].....	8-47
Figure 8-44	[[]].....	8-48
Figure 8-45	[[]].....	8-49
Figure 9-1	Flow Chart of the Overall GS3 Process.....	9-33
Figure 9-2	OPRM Channel Configuration for BWR/6 TRACG Instability Events.....	9-34
Figure 9-3	Full Core Individual Bundle Model for BWR/6 TRACG 2RPT Instability Event.....	9-35
Figure 9-4	OPRM Cell Signal Processing.....	9-36
Figure 9-5	MCPR Determination.....	9-37
Figure 9-6	Simulation of an APRM Scram Line Logic for an Option I-D Plant.....	9-38

EXECUTIVE SUMMARY

Several different stability Long-Term Solution (LTS) options have been developed for Boiling Water Reactors (BWRs), including Option I-D, Option II, Option III and the Detect and Suppress Solution – Confirmation Density (DSS-CD). The GEH Simplified Stability Solution (GS3) is a Best-Estimate Plus Uncertainty (BEPU) stability methodology directly applicable to plants implementing Option I-D, Option II, or Option III stability LTSs. The GS3 methodology is based and built upon the TRACG DSS-CD methodology documented in NEDE-33147P-A (Reference 1) and can replace the TRACG Delta over Initial MCPR Versus Oscillation Magnitude (DIVOM) methodology described in NEDO-32465-A (Reference 2) and NEDO-32465 Supplement 1 (Reference 3).

GS3 is a methodology improvement rather than a new LTS. Therefore, GS3 does not require any hardware and software changes for plants licensed with Option I-D, Option II, or Option III stability LTSs. For Option III plants, GS3 uses the existing detection algorithm, the Period Based Detection Algorithm (PBDA), which reliably detects the inception of power oscillations and generates a power suppression trip signal prior to exceeding the Safety Limit Minimum Critical Power Ratio (SLMCPR). For Option I-D and Option II plants, GS3 uses the existing hardware and software for the Average Power Range Monitor (APRM) and flow-biased scram line, which reliably detects the power oscillations and generates a power suppression trip signal prior to exceeding the SLMCPR.

GS3 methodology contributes to a reduction in the likelihood of spurious scrams by supporting implementation of higher setpoints for fuel reload analyses, while ensuring protection of the SLMCPR.

The TRACG code is used to determine the Minimum Critical Power Ratio (MCPR) margin during reasonably limiting instability event simulations for GS3 applications. This Licensing Topical Report (LTR) provides the GS3 generic licensing basis for the GE BWR/2-6 product lines, and describes a standard procedure for plant-specific confirmations of reload designs and other design changes that may affect the GS3 generic licensing basis.

The GEH TRACG code model description, qualification, application for Anticipated Operational Occurrences (AOOs), and use in the DSS-CD process are documented in LTRs NEDE-32176P (Reference 4); NEDE-32177P (Reference 5); NEDE-32906P-A (Reference 6); NEDE-32906P Supplement 3-A (Reference 7); NEDE-33147P-A (Reference 1); and NEDC-33075P (Reference 8), respectively. All of these LTRs have been reviewed by the Nuclear Regulatory Commission (NRC). This LTR incorporates the essential information from the above six LTRs to describe and justify the use of TRACG for modeling instabilities as part of the GS3 process.

ACRONYMS AND ABBREVIATIONS

Term	Definition
ABA	Amplitude Based Algorithm
ABB	Asea Brown Boveri
ABWR	Advanced Boiling Water Reactor
AGE	Approved GEH/GNF
AL	Analytical Limit
ANGE	Approved Non-GEH/GNF
APRM	Average Power Range Monitor
AOO	Anticipated Operational Occurrence
BEPU	Best-Estimate Plus Uncertainty
BOC	Beginning of Cycle
BSP	Backup Stability Protection
BWR	Boiling Water Reactor
BWROG	BWR Owners' Group
CDA	Confirmation Density Algorithm
CFR	Code of Federal Regulations
CHAN	Fuel Channel Component in TRACG
CLTP	Current Licensed Thermal Power
CPR	Critical Power Ratio
Δ CPR	Delta CPR
CSAU	Code Scaling, Applicability and Uncertainty
D&S	Detect and Suppress
DID	Defense-in-Depth
DIVOM	Delta over Initial MCPR Versus Oscillation Magnitude
DR	Decay Ratio
DSS-CD	Detect and Suppress Solution – Confirmation Density
DVC	Dynamic Void Coefficient
ECP	Engineering Computer Program
ECPR	Experimental Critical Power Ratio
ELLLA	Extended Load Line Limit Analysis
EOC	End of Cycle

NEDO-33766, REVISION 0
NON-PROPRIETARY INFORMATION—CLASS I (PUBLIC)

Term	Definition
EPU	Extended Power Uprate
ER	Exclusion Region
ESBWR	Economic Simplified Boiling Water Reactor
FCL	Flow Control Line
FCV	Flow Control Valve
FFWTR	Final Feedwater Temperature Reduction
FM CPR	Final Minimum Critical Power Ratio
FTTC	Fuel Thermal Time Constant
FWHOOS	Feedwater Heater Out-Of-Service
FWTR	Feedwater Temperature Reduction
GDC	General Design Criteria
GE	General Electric
GEH	GE Hitachi Nuclear Energy Americas LLC
GESTAR	General Electric Standard Application for Reactor Fuel
GESTR	General Electric Stress and Thermal Analysis of Fuel Rods
GEXL	General Electric Boiling Transition Correlation
GNF	Global Nuclear Fuel
GRA	Growth Rate Algorithm
GS3	GEH Simplified Stability Solution
H	High Importance
HCGS	Hope Creek Generating Station
ICPR	Initial Critical Power Ratio
ID	Identification
IMCPR	Initial Minimum Critical Power Ratio
JP	Jet Pump
L	Low Importance
LOCA	Loss-of-Coolant Accident
LPRM	Local Power Range Monitor
LSCS	LaSalle County Station
LTP	Lower Tie-Plate
LTR	Licensing Topical Report

NEDO-33766, REVISION 0
NON-PROPRIETARY INFORMATION–CLASS I (PUBLIC)

Term	Definition
LTS	Long-Term Solution
LUA	Lead Use Assembly
M	Medium Importance
MCPR	Minimum Critical Power Ratio
Δ MCPR	Delta MCPR
MELLLA	Maximum Extended Load Line Limit Analysis
MELLLA+	Maximum Extended Load Line Limit Analysis Plus
MOC	Middle of Cycle
NA	Not Applicable
NC	Natural Circulation
NCL	Natural Circulation Line
ND	Normal Distribution
ND-OSUTL	Normal Distribution – One-Sided, Upper Tolerance Limit
NFI	New Fuel Introduction
NMP2	Nine Mile Point 2
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRSBT	Number of Rods Subject to Boiling Transition
NTSP	Nominal Trip Setpoint
NUMAC	Nuclear Measurement Analysis and Control
ODYN	One-Dimensional Reactor Dynamics Code
OLMCPR	Operating Limit MCPR
OLTP	Original Licensed Thermal Power
OPRM	Oscillation Power Range Monitor
Option III	Stability OPRM-Based Detect and Suppress Long-Term Solution
OSUTL	One-Sided, Upper Tolerance Limit
PANAC11	PANACEA, GEH BWR Core Simulator
PBA	Period Based Algorithm
PBDA	Period Based Detection Algorithm
PDF	Probability Density Function
PFR	Partial Flow Reduction

NEDO-33766, REVISION 0
NON-PROPRIETARY INFORMATION—CLASS I (PUBLIC)

Term	Definition
PHE	Peak Hot Excess
PIRT	Phenomena Identification and Ranking Table
PRIME	The PRIME Model for Analysis of Fuel Rod Thermal-Mechanical Performance
PRNM	Power Range Neutron Monitor
RAI	Request for Additional Information
RPS	Reactor Protection System
RPT	Recirculation Pump Trip
SAFDL	Specified Acceptable Fuel Design Limit
SCC	Successive Confirmation Count
SD	Standard Deviation
SEO	Side Entry Orifice
SLMCPR	Safety Limit MCPR
SLO	Single Loop Operation
T-H	Thermal-Hydraulic
THI	Thermal-Hydraulic Instability
TLO	Two Loop Operation
TRAC	Transient Reactor Analysis Code
TRACG	Transient Reactor Analysis Code (GEH proprietary version)
TS	Technical Specification
UGE	Unapproved GEH/GNF
UNGE	Unapproved Non-GEH/GNF
US	United States
UTP	Upper Tie-Plate
1-D	One-Dimensional
1P	Single-Phase Pressure Drop
1RPT	One Recirculation Pump Trip
2P	Two-Phase Pressure Drop
2RPT	Two Recirculation Pump Trip
3RPT	Three-Loops Recirculation Pump Trip
3-D	Three-Dimensional

NEDO-33766, REVISION 0
NON-PROPRIETARY INFORMATION-CLASS I (PUBLIC)

Term	Definition
5RPT	Five-Loops Recirculation Pump Trip

1. 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.

Several stability Long-Term Solutions (LTSs), including the Detect and Suppress Solution – Confirmation Density (DSS-CD), documented in Reference 8, Options I-D and III documented in Reference 2, and Option II documented in References 9 and 10, consist of hardware and software that provide reliable, automatic detection and suppression of stability-related power oscillations. These stability LTSs are designed to identify the power oscillation and initiate control rod insertion to terminate the oscillations prior to exceeding the safety limits. The combination of hardware, software, and setpoints for these stability LTSs provides protection against exceeding 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 GE Hitachi Nuclear Energy Americas LLC (GEH) Simplified Stability Solution (GS3) is a methodology improvement rather than a new stability LTS. Therefore, GS3 does not require any hardware and/or software change for plants already implementing Option I-D, Option II, Option III stability LTSs. For Option III plants, GS3 uses the existing detection algorithm, the Period Based Detection Algorithm (PBDA), which reliably detects the inception of power oscillations and generates a power suppression trip signal prior to exceeding the SLMCPR. For Option I-D and Option II plants, GS3 uses the existing Average Power Range Monitor (APRM) and flow-biased scram lines hardware and software, which reliably detects the power oscillations and generates a power suppression trip signal prior to exceeding the SLMCPR.

GS3 methodology is based and built upon the TRACG DSS-CD methodology documented in NEDE-33147P-A (Reference 1) and can replace the TRACG DIVOM (Delta over Initial MCPR Versus Oscillation Magnitude) methodology described in NEDO-32465-A (Reference 2) and NEDO-32465 Supplement 1 (Reference 3) that is applied to determine or confirm the stability setpoints for Option I-D, II, and III plants. GS3 is a Best-Estimate Plus Uncertainty (BEPU) stability methodology that uses the TRACG code (References 4 and 5) to simulate events to confirm the capability of the GS3 process to simulate oscillation detection and suppression. The TRACG qualification review summarized herein and described in Reference 1 provides background in support of the DSS-CD application, which is applicable to the GS3 methodology. The TRACG model description and qualification are documented in NEDE-32176P and NEDE-32177P (References 4 and 5). The application to transient and stability analyses, together with the Nuclear Regulatory Commission (NRC) Safety Evaluation Reports, is documented in

NEDE-32906P-A (Reference 6), NEDE-32906P Supplement 3-A (Reference 7), and NEDE-33147P-A (Reference 1).

This Licensing Topical Report (LTR) provides a generic licensing basis for TRACG04 application methodology in support of the GS3 methodology for application to stability Option I-D, II, and III LTSs and for the GE BWR/2-6 product lines. This LTR also describes a standard procedure for plant-specific confirmations of reload designs and other design changes that may affect the GS3 generic licensing basis. Throughout this LTR, 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 OVERVIEW OF EXISTING STABILITY SOLUTIONS

This section provides an overview of the historical overview of the stability LTSs, focusing on the Detect and Suppress (D&S) approaches. The changes that have occurred in recent year and the effect on operating plants that have prompted the development of the GS3 methodology is discussed in the subsequent sections.

The presence of reactor instability can challenge the fuel SLMCPR. This occurs when fuel cladding heat flux and channel coolant flow rates deviate from steady-state conditions during power oscillations significantly above the normal neutron noise level. To comply with GDC 12, protection of the SLMCPR can be accomplished by either detecting and suppressing instability induced power oscillations, or preventing them altogether.

Following the March 1988 instability event at a LaSalle County Station (LSCS) BWR, the BWR Owners' Group (BWROG) investigated actions that industry should take to resolve the stability issue as an operational concern. Through analysis, the BWROG found that the existing plant protection system, which was based on a scram on high APRM signal, may not provide enough protection against out-of-phase modes of instability; thus, the BWROG decided that a new automatic instability suppression function was required as a LTS and that this function should have a rapid and automatic response which does not rely on operator action.

The BWROG submitted and the NRC staff approved three different stability LTS options (References 11 and 12). These options can be summarized as follows:

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

Option I-A Immediate protection action (either scram or select rod insert) upon entrance to the exclusion region.

Option I-D Some small-core plants with tight inlet orifices have a reduced likelihood of out-of-phase instabilities. For these plants, the existing flow-biased

high APRM scram provides a D&S function to avoid safety limits being exceeded for the expected instability mode. In addition, administrative controls are proposed to maintain the reactor outside the exclusion region.

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

Option III. LPRM-Based D&S. Local Power Range Monitor (LPRM) signals or combinations of a small number of LPRMs are analyzed on-line by using three diverse algorithms. If any of the algorithms detects instability, automatic protective action is taken to suppress the oscillations before safety margins are compromised. The licensing algorithm is the PBDA, whereas the Amplitude Based Algorithm (ABA) and the Growth Rate Algorithm (GRA) have a Defense-in-Depth (DID) function.

The existing “detect and suppress” algorithms of LTS Option III (References 2, 3, 11, and 12) are based on a common approach. An Oscillation Power Range Monitor (OPRM) cell signal oscillation, consistent with that characteristic of the reactor T-H oscillation frequencies, is identified. The presence of these characteristic power oscillations is then confirmed by various methods. The PBDA monitors successive oscillation periods and provides an oscillation amplitude trigger to generate a reactor trip signal. The GRA consists of an oscillation growth rate limit, which if exceeded, generates a reactor trip. Finally, the ABA consists of an oscillation amplitude limit, which if exceeded, generates a reactor trip.

The Option III licensing basis (References 2 and 3) relies on the PBDA, with setpoints based on a combination of power oscillation period successive confirmation counts (SCCs) and oscillation amplitude. These setpoints are designed to ensure that the SLMCPR is not exceeded by the presence of growing power oscillations resulting from anticipated instability events.

In addition to these, several other stability solutions have been developed and adopted for other BWRs worldwide. Most notably, the DSS-CD is an evolutionary stability LTS approved by the NRC (References 1 and 8). DSS-CD is based on the same hardware design as Option III. However, it introduces an enhanced detection algorithm that detects the inception of power oscillations and generates an early power suppression trip signal based on successive period confirmation recognition and an amplitude component. 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 DID protection for unanticipated reactor instability events. To support DSS-CD implementation, the best-estimate TRACG code is used to confirm the Minimum Critical Power Ratio (MCPR) margin during reasonably limiting instability event simulations for DSS-CD applications (Reference 1). The combination of hardware, software, and system setpoints provides protection against exceeding the SLMCPR for anticipated oscillations. Thus, compliance with GDC 10 and 12 of 10 CFR 50, Appendix A is accomplished via an automatic action. The TRACG DSS-CD application is based on a BEPU methodology, in which the uncertainty is quantified by applying the Code Scaling, Applicability

and Uncertainty (CSAU) process. This TRACG DSS-CD methodology is documented and has been approved by the NRC in Reference 1.

The first notable design approach difference is between solutions that are preventive in nature and those based on a D&S approach. In “preventive” type solutions (e.g., Option I-A), the basic approach is to determine regions of operation where the plant is susceptible to develop growing power oscillations that can threaten specified safety limits and operate the plant to stay out of these regions. Should plant operation or anticipated transients bring the plant inside these regions, a manual or automatic scram is actuated. On the other hand, in D&S type solutions (e.g., Option III and DSS-CD) plant operation in the entire licensed region domain (namely, the BWR “power-flow” map) is allowed and these solutions have hardware and software capable of detecting and suppressing (by tripping the plant) growing power oscillations before they can threaten the applicable safety limits. For instance, if a BWR experiences a One Recirculation Pump Trip (1RPT), the forced flow will reduce and the total core flow will decrease accordingly. As a result, the plant will end up operating at a new statepoint on the power-flow map at lower core flow. If this statepoint is inside a pre-determined exclusion region and the plant is operating based on a licensed “preventive” type of stability LTS, then the plant will be forced to scram. On the other hand, if the plant is operating based on a licensed “D&S” type of stability LTS, no scram is required, but the plant can rely on its ability to automatically detect an oscillation before action is taken.

Growing power oscillations as a result of Thermal-Hydraulic Instability (THI) phenomena may or may not develop in that particular statepoint. If growing power oscillations occur, the D&S system will scram the reactor once they meet the algorithm criteria (e.g., certain oscillation magnitude and frequency). Even in this case, it may take some time (e.g., a few minutes) for oscillations to become coherent and grow to magnitudes that require suppression. Therefore, in a D&S LTS, the operators will have time to take actions to move out of the regions susceptible to developing THI prior to undergoing a reactor scram. This differentiation has key implications on operations as well as on the long-term safety of the reactor – the more scrams a plant experiences, the faster it ages. Plant aging due to spurious scram causes a strain on safety systems and thus there is degradation of safety in addition to aging of the plant.

Notably, all D&S solutions have some kind of Backup Stability Protection (BSP) solution (“preventive” type) that is temporarily implemented in those rare instances in which the system providing the D&S function is not operable for any reason (References 8 and 13). The implementation of the GS3 methodology does not change any aspect of the implemented BSP solutions.

The other notable design approach difference in the existing LTS is between solutions that are based on conservative methodologies instead of BEPU. DSS-CD is currently the most advanced stability solution in the world and uses BEPU for stability analyses.

1.2.1 Changes in Stability LTSs and in Designs

Options I-D, II and III are all based on a D&S approach and have been implemented as stability LTS in most of the commercial BWR Nuclear Power Plants (NPPs) in the United States (US).

Nevertheless there are three significant areas of consideration, which merit a revisit of these three LTSs. These areas are: (a) deficiencies identified in the Critical Power Ratio (CPR) versus oscillation amplitude correlation used for D&S solutions (i.e., the DIVOM correlation), which resulted in a 10 CFR Part 21 notification, (b) proposed increases in power density, and (c) advanced fuel bundles designs with increased array size and changes in core design/fuel cycle length.

Options I-D, II and III are currently based on a DIVOM methodology (References 2, 3, 9, and 10) to determine/confirm acceptable OPRM/APRM setpoints and corresponding Operating Limit Minimum Critical Power Ratios (OLMCPRs) required to ensure that SLMCPRs are not exceeded as a result of anticipated stability events in BWRs. The DIVOM methodology is based on a correlation that is used to estimate the Δ CPR as a function of oscillation amplitude, and it is required to select the scram setpoint for D&S solutions. The generic DIVOM correlation was approved on the basis that it would be bounding for all reasonable circumstances; however, later analysis demonstrated that some plant-specific calculations result in larger loss of CPR margin than the DIVOM prediction. Therefore, the generic DIVOM curve may be non-conservative for some plant applications. A non-conservative DIVOM curve would then result in stability-related setpoints that would not guarantee that Specified Acceptable Fuel Design Limits (SAFDLs) would be maintained if a limiting instability event were to occur. This potential for a non-conservative generic DIVOM curve introduced the use of plant and cycle-specific DIVOM correlations, which is the approach used by most plants today. The Option I-D, II and III are all based on this plant and cycle-specific DIVOM methodology.

In recent years, the industry has been moving to reactor operation at higher and higher power densities and power-to-flow ratios. This operation is, in principle, detrimental to the stability characteristics of the reactor and results in two consequences: (a) it may increase the probability of instability events, and (b) it may increase the severity of the event should it occur (e.g., larger amplitude oscillations). Indeed, simulations of Two Recirculation Pump Trip (2RPT) transients initiated at minimum flow conditions and 120% Original Licensed Thermal Power (OLTP) indicate that instabilities of sufficiently large amplitude to compromise the SLMCPR are possible.

In addition to power uprates and flow domain expansions in recent years, advanced BWR fuel designs have been introduced in many plants along with much longer fuel burn-ups. Several US plants now have fuel cycles running on a 24-month schedule with fuel reload performed approximately every two years. As a result, core design strategies have also changed and become more sophisticated. These extended flow and power domains, along with fuel and core design changes, have introduced additional elements of complexity that required more sophisticated tools and analyses of plant conditions under normal operation, anticipated transients, or accident scenarios. These changes require the validation of models and the development of methodologies capable of providing proper predictions of the underlying physical phenomena that are relevant under these new conditions. All of these changes have introduced challenges to the use of conservative, and, in some instances, excessively conservative methodologies such as DIVOM to determine cycle-specific stability based setpoints and OLMCPRs used for reload licensing and

plant operation. The results of the excessive conservatism in DIVOM methodology have caused a significant increase in the stability-based OLMCPRs (for any given setpoint), making stability the limiting event setting the OLMCPR for several units operating cycles. In order to counter this increase in OLMCPR, which makes it difficult to meet some of the other thermal limits and in some instance even design a core altogether, [[

]]

1.2.2 Historical Events with Low OPRM Setpoints and Plant-Specific Noise Results

As previously discussed, because of the multiple elements of conservatism in the DIVOM methodology (References 2 and 3), not only is there no room to allow for additional margin to the SLMCPR, but, the OPRM amplitude setpoints for suitable OLMCPRs might be “too low” and significantly increase the chance of a spurious scram. This is demonstrated by several events that occurred in commercial BWR plants operating with Option III LTS as documented in References 14 through 19. A few of these events are discussed in more detail below.

Hope Creek Half Scram Event (2006)

On August 7, 2006, Hope Creek Generating Station (HCGS) experienced a half scram (Reactor Protection System (RPS) 'A' trip) during a scheduled power reduction for control rod sequence exchange and scram time testing (Reference 14). The half scram was initiated by a trip of OPRM Module A1. No other indications of actual reactor instability (e.g., APRM signal oscillations, concurrent multiple channel OPRM trip signals) were evident. HCGS received the half scram during scram time testing while a scrammed control rod (near the periphery) was being continuously withdrawn. The OPRM module was unable to distinguish between the power change from the control rod withdrawal and a power change due to an oscillation. Potential for this type of OPRM actuation is highest at the core periphery where the ratio of the peak-to-average local power can make the largest changes in OPRM signal input. The plant had a setting of 10 Successive Confirmation Counts (SCCs) and an amplitude setpoint of 1.06 when the half scram occurred. Based on some post-event data, GEH found that the use of lower-range OPRM settings of 10 SCCs and a 1.06 OPRM amplitude setpoint was a factor contributing to the spurious signal.

Perry Half Scram Event (2006)

On December 20, 2006, Perry had a half scram in their Asea Brown Boveri (ABB)-based OPRM system while the operators were performing a sequence exchange (Reference 18). During reactor startup with the reactor at 47.1% power and 55.5% flow and control rods being withdrawn, OPRM Channel E caused an unexpected half scram. GEH has reviewed these types of events as typical of those where a control rod in a low power area of the core is withdrawn past an LPRM causing a significant detector output rate-of-change. Apparently, the OPRM PBDA detects the change in LPRM reading as an instability event and causes the OPRM to trip. This type of event

also occurs at plants with low OPRM amplitude setpoints. The same contributing factors (low PBDA setpoints of 1.07 amplitude and 10 SCCs) contributed to the half scram event.

Dresden OPRM Alarm (2009)

Dresden Unit 3 had an OPRM alarm in October 2009 (AR 00976243, Reference 17) following a forced outage. During the power ascension, at 69% core thermal power and 60% rated core flow, a single channel OPRM alarm was received. The alarm cleared within 1 second of being received and no other OPRM alarms were received. All operating parameters were evaluated and no oscillations were present. Dresden Unit 3 is also an Option III plant with a Westinghouse ABB OPRM system. The alarm feature for the ABB system installed at Dresden 3 is based on the SCC only. There is no amplitude component on the alarm. In the unlikely event that an oscillation developed just above 60% rated core flow, the oscillation amplitude growth rate is expected to be very low, providing limited MCPR degradation and sufficient time for the operator to observe the increase in noise level and take appropriate actions. Therefore, the above events are not limiting. Additionally, Dresden Unit 3 has OPRM setpoints (1.17 amplitude and 17 SCCs based on Reference 17) higher than those of most plants in the BWR fleet. The possibility for spurious alarms from the OPRM system at high power/low flow conditions does exist; however, the frequency at which they occur should be lower at Dresden. This can be attributed to the higher setpoints and Dresden's operating strategy at high power low flow conditions. Dresden Reactor Engineering is aware of the potential for more spurious alarms if the OPRM setpoints are lowered below previous values. An internal investigation at Dresden Unit 3 concluded that the OPRM alarm setpoints remain valid (Reference 17).

[[

]] A summary of key results for some of the analyses of BWR plants data GEH has performed is documented in Table 1-1.

[[

]]

1.2.3 Conservative Versus BEPU Methodologies

Methodologies to perform safety analyses can be subdivided in two main categories: (1) conservative and (2) best-estimate.

Conservative methodologies use pessimistic or worst-case assumptions and models. Historically, the majority of the analyses presented to regulatory bodies have followed this approach. The

conservative aspect of these methodologies may include use of conservative codes (i.e., codes implementing pessimistic or conservative models), use of conservative inputs and/or use of conservative bounding assumptions to apply the codes to perform a certain analysis.

In best-estimate or realistic methodologies most assumptions and models are realistic (some conservatisms are maintained) and they include a proper uncertainty analysis. These methodologies require more sophisticated and refined analyses and calculation tools; consequently, they have been submitted only (relatively) recently to regulatory bodies. The best-estimate aspects of these methodologies include the use of best-estimate codes (i.e., TRACG), use of best-estimate inputs and/or use of realistic assumptions to perform a certain analysis. These methodologies require the application of uncertainty analyses that account for biases and uncertainties.

This LTR documents the BEPU GS3 TRACG methodology and its application to BWR T-H stability analyses. The statistical CSAU methodology defined in NUREG/CR-5249 (Reference 20) is used to calculate the MCPR uncertainty.

The CSAU demonstration application to TRACG BWR stability analysis documented in Section 8 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 NPP calculations. The process for applying best-estimate codes and quantifying the overall model and plant parameter uncertainties represents the best available practice today.

In the CSAU process, 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 TRACG GS3 CSAU methodology consists of 14 steps, as outlined in Table 2-1. These steps are detailed in Sections 2 through 7. The applicable safety limit to be protected in a D&S LTS is the SLMCPR. The parameter of interest for the stability application methodology and in the uncertainty analysis, as a result, is the MCPR at the time of oscillation suppression. The fundamental D&S question for an OPRM system based LTS, such as Option III or DSS-CD, is the following: “What is the OPRM trip setpoint(s) to set for the plant with a given core design in order to avoid reaching the SLMCPR following the reference limiting transient scenario (e.g., 2RPT) and starting from the most limiting operating condition (i.e., the OLMCPR)?” For an Option I-D or II plant, the logic is similar, only that instead of OPRM setpoints there is the APRM flow-biased scram line to provide the D&S function. Option I-D plants must also demonstrate on a cycle-specific basis that the regional oscillation mode is not likely to occur (i.e., the core-wide mode is the predominant mode of reactor oscillations). This demonstration is necessary to ensure that the APRM flow-biased flux scram setpoints offer adequate stability protection against anticipated stability events. Typically there is only one available APRM flow-biased scram line for these plants. Therefore, in contrast to Option III, where different OPRM setpoints can be selected, in Option I-D or II the margin to the SLMCPR can only be adjusted by changing the OLMCPR.

During a 2RPT, the CPR changes over time. The CPR will initially tend to increase as the flow reduction occurs due to the mismatch between the core flow and power reductions. Subsequently, the power will increase, reducing the CPR as the feedwater temperature reaches a new equilibrium. Eventually this may lead to an instability event with growing oscillations. It is typically assumed that the Initial MCPR (IMCPR) of the plant for the reference event is right at the OLMCPR, which represents the lowest allowable value (cycle-specific) at which the reactor is licensed to operate. In Option III, it is assumed that the Final Minimum Critical Power Ratio (FMCPR) at the time of oscillation suppression is equal to the SLMCPR and the OPRM setpoints are determined with the stability analyses to meet this condition with zero margin on the SLMCPR (References 2 and 3).

[[

]]

The $OLMCPR_{BEPU}$ can hence be calculated as described in Section 7 to provide the desired margin to the SLMCPR for any given OPRM or APRM setpoint. In doing so, the OPRM setpoints are to be optimized between the two aforementioned conditions of providing SLMCPR protection and minimizing the chance of spurious scram.

Consequently, there are two key elements to be considered in applying BEPU methodology such as TRACG GS3. The first important element of BEPU is that only by realistically modeling and simulating the relevant physical phenomena, the most relevant aspects of the phenomena themselves can be understood and properly investigated. This particularly holds true for some of the underlying issues that might only surface in unusual or unanalyzed conditions. There are not, for instance, many available experimental data and/or analyses performed at some of the new operating and fuel design conditions. There is also limited availability of historical data to cover the range of parameter variations observed for some of these new domains. It is essential in these instances to be able to realistically model the phenomena so that the effect of individual parameters can be effectively and accurately assessed through the BEPU process and not hidden by the inherent conservatism of a methodology. The second key element to consider is that with these extended power domains, introductions of advanced fuel and core designs and changes in operation strategies, the conservative methodologies determine stability related setpoints that are too conservative to be supported by actual implementation, which ultimately can negatively affect reactor operation.

For conservative methodologies (such as DIVOM), unlike BEPU, it is typically very difficult to quantify the actual level of conservatism built into a certain analysis. This is particularly an issue when there is the need to assess how a given change will affect the available margin to the applicable safety limits. Furthermore, conservative (and overly-conservative in some instances) methodologies do not necessarily ensure safer results. If certain physical phenomena cannot fully be understood, then they cannot be properly modeled and predicted via simulations.

Another concern that follows with conservative methodologies is the capability to detect a trend in reduced margin due to a relatively small change of one or few parameters in time. Because conservative methodologies typically have a fairly large “grey” band of uncertainty, in which individual parameters do not necessarily correlate to the change in the output of the critical parameter of interest (e.g., CPR), a trend of reduced margin due to a change in design or operations might not be promptly apparent. On the other hand, BEPU methodologies such as GS3 have the accuracy to resolve these kinds of variation thanks to the more advanced and refined models as well as the rigorous quantification of uncertainty.

Ultimately, by applying a BEPU methodology, neither the (safety) limit nor the vehicle (i.e., plant hardware and firmware) is changed, but the measurement of the actual margin changes, and its variation becomes more accurate, and, hence, more reliable.

1.3 TRACG QUALIFICATION

TRACG is a 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 THI performance and Anticipated Operational Occurrence (AOO) transients.

TRACG includes a multi-dimensional, two-fluid model for the reactor T-H 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 4).

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 5).

1.4 PURPOSE AND SCOPE

This LTR provides the licensing basis and methodology to demonstrate the adequacy of the TRACG analyses as part of the GS3 methodology.

The following key elements are part of the GS3 methodology:

- Use of the TRACG04 version (References 4 and 5), including PRIME (References 21 and 22) fuel properties and gap conductance fuel input files. The TRACG

implementation of the PRIME fuel conductivity (approved in Reference 7) is used and the PRIME gap conductance files are used.

- Use of the PANAC11 3-D neutron kinetics model (References 7, 23, and 24).
- Use of the Phenomena Identification and Ranking Table (PIRT) approved for DSS-CD in Reference 1 for the GE BWR/3-6 product lines and expanded in this LTR to include the GE BWR/2 product line.
- Use of the statistical CSAU methodology (NUREG/CR-5249, Reference 20) to determine the MCPR uncertainty.
- Use of 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 describes the licensing requirements and the scope of the TRACG application to GS3. Section 3 describes the identification and ranking of BWR phenomena for stability. Section 4 describes and justifies the applicability of TRACG models to GS3. Section 5 describes the model uncertainties. Section 6 describes the application uncertainties and biases. Section 7 describes the combination of uncertainties. Section 8 provides a demonstration analysis. Section 9 describes the solution's licensing basis for applications that fall within the generic licensing envelope of the LTR, as well as the process for fuel reload applications. Section 10 describes a standard procedure for plant-specific confirmations of reload designs and other design changes that may affect the GS3 generic licensing basis. Section 11 provides the conclusions.

GEH requests approval of the GS3 stability methodology for the application to the analysis of BWR/2-6 plants employing stability Option I-D, II, and III LTSs. This application may include all power/flow domains up to and including the Extended Power Uprate (EPU) domain and all licensed operational enhancements with the exception of the Maximum Extended Load Line Limit Analysis Plus (MELLLA+) domain. [[

]]

Table 1-1

[[

]]

[[

]]

2. LICENSING REQUIREMENTS AND SCOPE OF APPLICATION

2.1 LICENSING COMPLIANCE

The stability Option I-D, II and III solutions and related licensing bases 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.”

GS3 is a methodology improvement rather than a new stability LTS. Therefore, GS3 does not require any hardware and/or software change for plants already implementing Option I-D, Option II, or Option III stability LTSs. The application of GS3 to Option I-D, Option II, or Option III stability LTSs maintains compliance with requirements of 10 CFR 50, Appendix A, GDC 10 and 12.

For Option III plants, GS3 uses the existing detection algorithm, the PBDA, which reliably detects the inception of power oscillations and generates a power suppression trip signal prior to exceeding the SLMCPR. For Option I-D and Option II plants, GS3 uses the existing hardware and software for the APRM and flow-biased scram line, which reliably detects power oscillations and generates a power suppression trip signal prior to exceeding the SLMCPR. A summary description of the D&S function for each of the stability LTSs supported by GS3 is provided in Section 9. Option I-D plants must also demonstrate on a cycle-specific basis that regional oscillation modes are not likely to occur (i.e., the core-wide mode is the predominant mode of reactor oscillations). This demonstration is necessary to ensure that the APRM flow-biased flux scram setpoints offer adequate stability protection against anticipated stability events. The criteria to satisfy this requirement are documented in Reference 13.

Notably, all D&S solutions have some kind of BSP solution (“preventive” type) that is temporarily implemented in those rare instances in which the system providing the D&S function is not operable for any reason (References 8 and 13). The implementation of the GS3 methodology does not change any aspect of the implemented BSP solutions. The parameter of interest in the GS3 methodology is the CPR in the time domain analysis, rather than the Decay Ratio (DR) or frequency domain analysis. Therefore, GS3 does not include any change to the BSP aspect of Option I-D, II and III (e.g., BSP or Exclusion Region (ER)).

The GS3 is a BEPU methodology and its licensing basis provides a high degree of confidence that flow reduction and power oscillation events can be properly and realistically simulated and the APRM/OPRM setpoints accurately determined. The application of GS3 ensures that the setpoints provided using this methodology are such that power oscillations for anticipated instability events are terminated prior to exceeding the SLMCPR. Therefore, the application of GS3 to Option I-D, Option II, or Option III stability LTSs maintains compliance with the requirements of 10 CFR 50, Appendix A, GDC 10 and 12. The purpose of the GS3 TRACG analysis is to confirm the inherent SLMCPR protection afforded by the Option I-D, II, and III LTS designs.

One of the important elements of BEPU is that by realistically modeling and simulating the relevant physical phenomena, the most relevant aspects of the phenomena themselves can be understood and properly investigated. This particularly holds true for some of the underlying issues that might only surface in unusual or unanalyzed conditions. It is essential that the physical phenomena be realistically modeled so that the effect of individual parameters can be accurately assessed through the BEPU process and not hidden by arbitrary conservatisms in a methodology.

[[

]] This

LTR demonstrates that these OPRM/APRM setpoints and GS3 based OLMCPRs, when applied to each plant in the cycle reload analysis (following the procedure detailed in this LTR), provide assurance that for postulated events resulting in power oscillations threatening acceptable fuel design limits, the SLMCPR at oscillation suppression is protected.

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 NPP 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 the 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 GS3 is consistent with the CSAU analysis methodology (Reference 20) and Regulatory Guide 1.157 (Reference 25) 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 GS3 demonstration. Additional information on the CSAU application for GS3 is provided in Section 2.2.1 and the detailed demonstration of the CSAU analysis methodology for GS3 is addressed in Sections 3 through 8 of this LTR. The application of TRACG GS3 CSAU is based on the methodology approved for stability analysis using the DSS-CD solution (Reference 1). Because the GS3 CSAU is built upon the approved DSS-CD CSAU methodology, as described in detail in each section of this LTR, there are a number of steps that are identical between the two processes. In these instances, the applicable and previously approved steps are not duplicated in this LTR, rather a proper applicable reference is provided.

2.2.1 CSAU Methodology Application

This section introduces the CSAU methodology demonstration for GS3. The TRACG GS3 application of the CSAU methodology is based on the approved TRACG DSS-CD and TRACG AOO applications (References 1 and 6). Flow reduction events from both Two Loop Operation (TLO) and Single Loop Operation (SLO) terminate at or above the Natural Circulation Line (NCL). [[

]]

Details about the 14 steps of the CSAU methodology application to the GS3 demonstration summarized in Table 2-1 are discussed below, and some of the steps are thoroughly discussed in the next sections of this LTR.

Step 1: Stability Scenario Specification

The stability scenarios are those associated with anticipated stability events in BWR/2-6 type plants. [[

]] A 2RPT event is initiated by the inadvertent simultaneous opening of the recirculation pump motor line breakers. A PFR event is initiated by any inadvertent event that causes a rapid flow reduction to an intermediate core flow value (e.g., single pump trip). The rapid reduction in core flow increases the core void fraction and thereby reduces reactor power. [[

]]

Step 2: Nuclear Power Plant Selection

The GS3 methodology is applicable to the BWR/2-6 plant product lines.

Step 3: Phenomena Identification and Ranking

See Section 3.

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 4 and 5 document the TRACG model description and qualification.

Step 6: Determination of Code Applicability

See Section 4.

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 has been presented in the TRACG Qualification LTR (Reference 5). Additional sensitivity studies on vessel nodalization have been provided in Reference 1.

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

]]

Step 9: Definition of Code and Experimental Accuracy

The code definition and experimental accuracy has been addressed in Reference 5. The TRACG code has been qualified against the LSCS Unit 2 instability event (March 1988), the Leibstadt Cycle 1 regional instability tests, the Nine Mile Point 2 (NMP2) 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 LTR (Reference 4), 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 5) 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 is 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 phenomenon 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 are 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. See also Table 5-1 and Table 6-1 of this LTR.

Step 12: Performance of Nuclear Power Plant Sensitivity Calculations

All plant types (BWR/2, BWR/3, BWR/4, BWR/5 and BWR/6) with different limiting operating conditions are evaluated for the stability application. As regional oscillation tends to favor larger core sizes due to the decreased subcriticality, [[

]]

Step 13: Determination of Combined Bias and Uncertainty

See Sections 5, 6, and 7.

Step 14: Determination of Total Uncertainty

See Sections 7 and 8.

2.3 SCOPE OF TRACG APPLICATION FOR GS3

The TRACG code is used to simulate reasonably limiting [[]] events to confirm the oscillation detection and suppression capability of the GS3 methodology applied to Option I-D, II, and III stability LTSs. The purpose of the TRACG qualification review is to provide background for the code use in support of the GS3 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 23 and 24), which has been extensively 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 the TRACG Code

Modifications to the basic models described in Reference 4 that significantly reduce the MCPR margin may not 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 or changes to numerical method may be used for licensing calculations without NRC review and approval as long as the Δ CPR/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 to the NRC for information.

Features that support effective code input/output may be modified or 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 1 and of this LTR 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	GS3
1	Scenario Specification	[[]]
2	Nuclear Power Plant Selection	BWR/2-6
3	Phenomena Identification and Ranking	Addressed in Table 3-1 of Reference 1 and Section 3
4	Frozen Code Version Selection	TRACG04P
5	Code Documentation	References 4 and 5
6	Determination of Code Applicability	Table 4-1 of Reference 1
7	Establishment of Assessment Matrix	Table 4-2 of Reference 1
8	Nuclear Power Plant Nodalization Definition	Nodalization defined. Plant nodalization study performed. References 1 and 5
9	Definition of Code and Experimental Accuracy	References 1, 5 and 6
10	Determination of Effect of Scale	Full scale data available, addressed in Section 2.2.1, 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 of Reference 1; Table 5-1 and Table 6-1 of this LTR
12	Performance of Nuclear Power Plant Sensitivity Calculations	Addressed in Tables 5-1 and 6-1 of Reference 1; Table 5-1 and Table 6-1 of this LTR
13	Determination of Combined Bias and Uncertainty	Perform statistical calculations, See Sections 7 and 8, and References 1 and 6
14	Determination of Total Uncertainty	See Sections 7, 8, and 9. GS3 statistical calculations demonstrate that $FMCP \geq SLMCP$

3. 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 in Reference 1 was developed to identify the phenomena that govern BWR/3-6 stability responses. The phenomena governing BWR/3-6 stability transients are the same as those governing the BWR/2. Therefore, the PIRT table for TRACG DSS-CD applications (Table 3-1 in Reference 1) was reviewed and it was confirmed that it is also applicable to the BWR/2 product line because the PIRTs related to the recirculation loops (frictional pressure drops and pump inertia) are already ranked high and included in the table. At the same time, it was also confirmed that the PIRT table (Table 3-1 in Reference 1), which was developed for the TRACG DSS-CD application, is applicable for GS3 applications because both methodologies and supported stability solutions protect against identical phenomena and transients. Therefore, because Table 3-1 in Reference 1 has been already approved for stability applications in the framework of the TRACG DSS-CD review (Reference 1), its content and its application to GS3 are not parts of the scope for the review of this LTR. Specific PIRT types, unique to BWR/2 applications, along with any specific updated values of biases and uncertainties are discussed in Sections 5 and 6. The disposition of all biases and uncertainties including BWR/2 is provided in Table 5-1.

The stability transient events have been categorized into three distinct groups:

- Channel THI,
- 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 an 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 in Reference 1 also tabulates a number of derived parameters (e.g., ratio of core power to core flow) important to reactor instability.

[[

]]

4. APPLICABILITY OF TRACG TO GS3 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 in Reference 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 NPP 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 NPP 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 6 and supported by code qualification in Reference 5. In References 1 and 2 the applicability of TRACG for BWR stability analysis is demonstrated. In Reference 26 the applicability of TRACG for Economic Simplified Boiling Water Reactor (ESBWR) stability analysis is demonstrated. There are no differences between the (H) and (M) ranked PIRTs (see Table 3-1 in Reference 1) for DSS-CD stability and those for GS3 stability. Therefore, the applicability demonstration for DSS-CD stability application made in Section 4.1 in Reference 1, including Table 4-1 (“Stability Phenomena and TRACG Model Capability Matrix”), is directly applicable to the GS3 stability application.

4.1 PHENOMENA VERSUS 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 in Reference 1. 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 4) and the Qualification LTR (Reference 5) are identified.

For each of the governing BWR phenomena, TRACG qualification has been performed against a wide range of data. In Section 4.1 in Reference 1, 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 as documented in Table 4-1 in Reference 1. Similarly, as shown in Table 4-2 in Reference 1, 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 successfully qualify the capability of TRACG to model the phenomena.

4.2 OTHER TOPICS RELEVANT TO TRACG MODELING OF INSTABILITY

This section addresses other topics relevant to TRACG modeling of instability, including the selection of the numerical integration scheme and the nodalization approach for the channel component, the numerical formulations used, and the 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 4. 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 in place of the new properties at time step $n+1$.

THI 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). Historically, these instability phenomena have been analyzed using either frequency domain or time 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 may 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 THI modeling has been evaluated for adequacy by comparison to experimental data of the FRIGG facility, as discussed throughout Section 3.7 of Reference 5. 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 NC 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

TRACG GS3 applications adopted and use the same detailed channel component nodalization implemented in the approved TRACG DSS-CD application and documented in Section 4.2.2 of Reference 1. This nodalization is consistent with the models adopted for the stability cases in Section 7.0 of the TRACG Qualification LTR (Reference 5).

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. TRACG GS3 applications use the same scheme adopted for the approved TRACG DSS-CD methodology (Reference 1).

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 4. The hydraulic solution (Steps 2 and 3) is described in Section 8.2 of Reference 4.

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. TRACG GS3 applications use the same scheme adopted for the approved TRACG DSS-CD methodology (Reference 1). A network solution scheme is applied, as described in Section 8.2.2 of Reference 4.

4.2.5 Coupled 3-D Kinetics and Thermal-Hydraulics Model

The coupled 3-D kinetics and T-H model used does not change for stability applications, relative to AOOs. TRACG GS3 applications use the same model adopted for the approved TRACG DSS-CD methodology (Reference 1). The 3-D kinetics model is described in Section 9 of Reference 4.

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 23 and 24). 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 27). The formulation described fully in Reference 27 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. [[

]]

The kinetics and T-H coupling scheme is fully described in Section 9.4 of Reference 4. Power distribution in the core is calculated in the orthogonal 3-D (x-y-z) geometry in the kinetics model, which takes into account feedback due to changes in fuel temperature and coolant density, and control rod movement. In the channel T-H and fuel heat transfer models, the core is simulated with multiple parallel channels, each having one or more fuel bundles associated with it. Their properties are solved for each axial node for each channel. Hydraulic boundary conditions for these channels are determined in the external core model in the code. Each component is coupled by such data, as shown in Figure 4-1 of Reference 1.

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 it is 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 model of individual bundles is adopted for TRACG GS3. This is the same model used in the approved TRACG DSS-CD applications (Reference 1).

The full core individual bundle model eliminates the T-H lumping due to channel grouping, thus 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 (Reference 1).

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

The full core individual bundle model allows the simulation of the actual oscillation mode of a certain core design. Therefore, the TRACG04 cases documented in Section 8 for GS3 Option I-D, II and III analyses include this full core individual bundle model without using a channel grouping that targets a specific oscillation mode based on the stability LTS option that is being analyzed [[

]]

5. MODEL BIASES AND UNCERTAINTIES

The model biases and uncertainties for all items from the PIRT (Table 3-1 in Reference 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 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 in Reference 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 data presented in Table 5-1 are obtained from the biases and uncertainties established for the DSS-CD application in Table 5-1 of Reference 1.

As described in Section 2.4.2, specific model uncertainties described in Table 5-1 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. These high and medium ranked PIRT values obtained from Table 5-1 in Reference 1 were reviewed to identify any change necessary to be consistent with the TRACG channel model for GNF2 fuel design as well as to include any other update based on more recent available data. Only a few PIRT values were identified as being fuel-dependent and possibly needing to be updated based on the use of GNF2 fuel, which are: [[

]]

As described in Section 3, the PIRT for stability events (Table 3-1 in Reference 1) was developed following the CSAU process approved for DSS-CD and it was confirmed that it is applicable also to the BWR/2 product line. Then, Table 5-1 in Reference 1 was reviewed to address the disposition of biases and uncertainties relative to BWR/2. Based on the review it was concluded that Table 5-1 in Reference 1 is applicable to BWR/2 with the exception of one PIRT value. It was identified that it is necessary to remove PIRT71, which is related to the Jet Pump (JP), because BWR/2s do not have JPs, but rather external loops. [[

]]

In order to present in this LTR a complete set of biases and uncertainties the entire set of high and medium ranked stability model parameters used for the GS3 methodology are documented in Table 5-1 of this LTR, instead of just documenting the values that changed from Table 5-1 of Reference 1.

The resulting Table 5-1 included in this LTR is therefore applicable to the BWR/2-6 product line (or type). The phenomena for BWR/2-6 stability events are identified and ranked, as indicated in Section 3. 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 below. Also, the bases or references for the selection of the Probability Density Function (PDF) used to model the uncertainty are provided in Table 5-1 below.

**Table 5-1 BWR/2-6 Disposition of High and Medium Ranked Stability Model
Parameters**

[[

]]

Notes:

N-1: Multiple Channel Effect

The GS3 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. APPLICATION UNCERTAINTY 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 5). The spatial nodalization adopted for GS3 methodology is consistent with the nodalization used for DSS-CD as specified in the response to the Request for Additional Information (RAI)-13 of TRACG DSS-CD (Reference 1).

Inputs are used to select the features of the component model that apply for the intended application. Once established, these inputs are 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

[[

Notes:

[[

]]

]]

7. 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.

A proven Monte Carlo technique is used to combine the individual biases and uncertainties into an overall bias and uncertainty. The Monte Carlo sample is developed by performing random perturbations of model and plant parameters over their individual uncertainty ranges. Using the histogram generated by the Monte Carlo sampling technique, a combined PDF is generated in order to calculate the primary safety criteria parameter(s).

In order to determine the total uncertainty in predictions with a computer code, it is necessary to combine the uncertainties due to model uncertainties (CSAU Step 9 in Table 2-1), scaling uncertainties (CSAU Step 10 in Table 2-1), and plant condition or state uncertainties (CSAU Step 11 in Table 2-1). As discussed in References 1 and 6 there are various methods for combining uncertainties and all these approaches are within the framework of the CSAU methodology. The method for combining uncertainties that is used for application to GS3 stability analyses is the same approach that has been approved and successfully used in analyses of TRACG AOO transient scenarios and accident scenarios in References 1 and 6.

7.1 SELECTED APPROACH FOR COMBINING UNCERTAINTIES

Consistent with the recommended approach in References 1 and 6 the statistical basis for combining uncertainties suggests that a relatively small number of TRACG runs suffice to determine the 95% Content with 95% Confidence (95/95) One-Sided, Upper Tolerance Limits (OSUTLs) for TRACG output variables using either the Normal Distribution-OSUTL (ND-OSUTL) method or the order statistics method. These runs (trials) are made with certain inputs selected randomly, considering the range and distribution of the uncertainties in the inputs.

It is important to recognize that the random sampling is identical for the ND-OSUTL and the order statistics methods. Therefore, the recommended approach is to perform the random sampling as it applies to both methods and evaluate the PDF of the output variable by means of one or several goodness-of-fit tests. If the PDF of the output variable is compatible with the normal model, then the ND-OSUTL method is used for the OSUTL, otherwise the order statistics method is used.

This approach is used to compute the MCPR uncertainty inherent to the best-estimate TRACG GS3 stability analyses. The implementation of this approach is discussed in the following section. The uncertainty combination process overview and its overall integration to the entire GS3 stability analysis process are shown in Figure 9-1. This section covers Steps 1 through 6 of overall GS3 methodology process shown in Figure 9-1; Steps 7 and 8 are covered in Section 9; Step 9 is covered in Section 10.

7.2 IMPLEMENTATION OF STATISTICAL METHODOLOGY

The purpose of this section is: (1) to describe the high level process by which the statistical results are used to determine the uncertainty [[
]] and (2) to detail the few differences in the process for the application of this statistical methodology to [[
]]

7.2.1 Statistical Methodology Implementation

[[

]]

There are a few minor differences in this process as specifically applied to Option I-D, II, or III plants. The process is discussed for each of these stability LTS applications in the following sections to detail these differences.

7.2.2 Statistical Methodology Implementation for Option I-D Plants

[[

]]

7.2.3 Statistical Methodology Implementation for Option II Plants

[[

]]

7.2.4 Statistical Methodology Implementation for Option III Plants

[[

]]

7.3 EXAMPLE OF THE COMBINATION OF UNCERTAINTIES

[[

]]

Table 7-1 GS3 CSAU Combination of Uncertainty Procedure

[[

]]

Table 7-2 Combination of Uncertainty Data Summary - Option III Plants

[[

]]

Table 7-3 Combination of Uncertainty Data Summary - Option II Plants

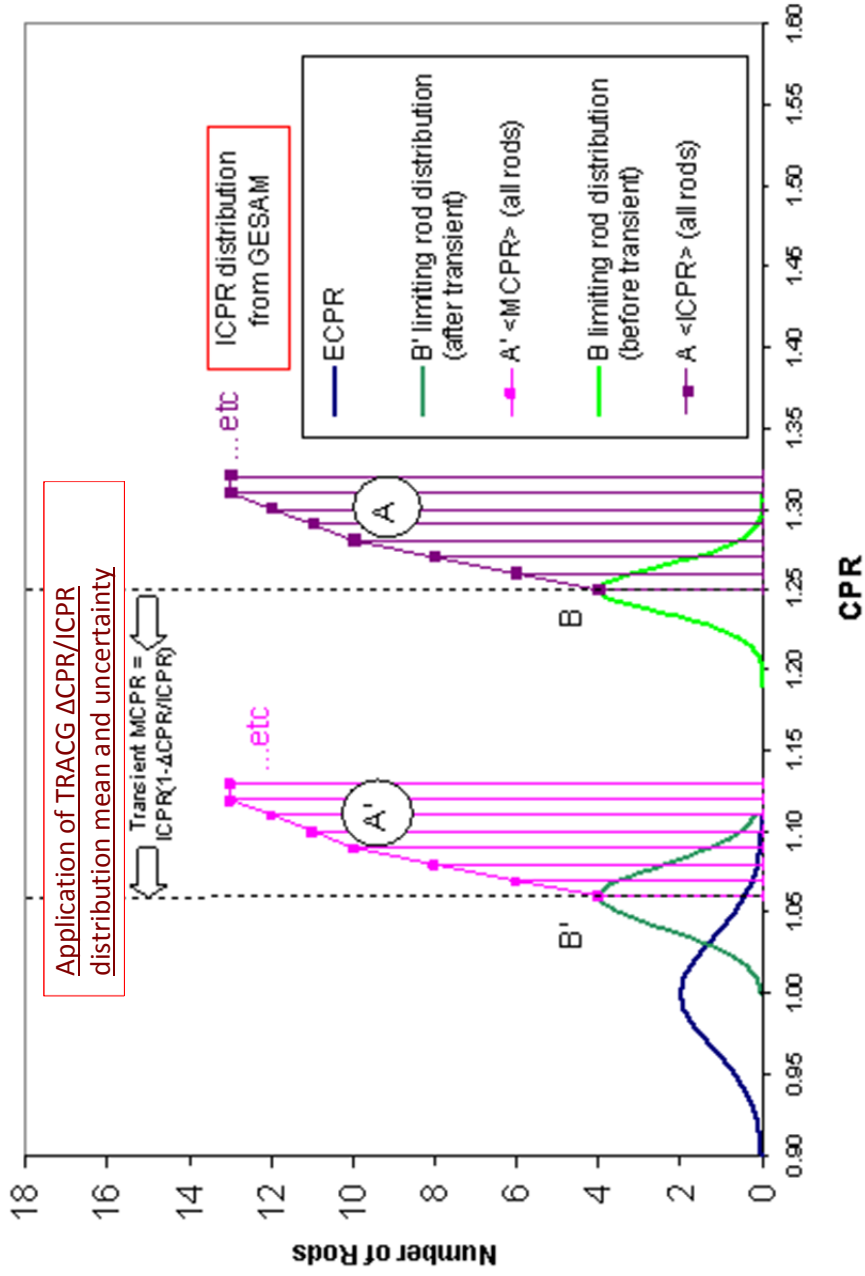
[[

]]

Table 7-4 Combination of Uncertainty Data Summary - Option I-D Plants

[[

]]



Note: ECPR = Experimental Critical Power Ratio

Figure 7-1 NRSBT Determination with Transient Uncertainty Included

8. EXAMPLE DEMONSTRATION ANALYSES

This section provides examples of the nominal transient and statistical results for the overall GS3 CSAU methodology described in previous sections. With respect to the nominal results the examples include [[

]] The application of the statistical results to the GS3 licensing basis is presented in Section 9. This is consistent with the process shown in Figure 9-1.

8.1 BEST-ESTIMATE TRACG SIMULATION

TRACG is used to perform best-estimate simulations of [[

]] A 2RPT event is initiated by the inadvertent simultaneous opening of the recirculation pump motor line breakers. The rapid reduction in core flow increases the core void fraction and thereby reduces reactor power. [[

]]

The simulation results for the nominal cases (corresponding to Steps 1 and 2 in Figure 9-1) are used to assess the MCPR response and margin to the SLMCPR. The transient responses of key simulation parameters, including [[

]]

The transient response of key simulation parameters for the [[

]]

8.2 MCPR UNCERTAINTY ASSESSMENT

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

]] Key results of these CSAU Monte Carlo cases are presented in Figure 8-26 through Figure 8-45 (corresponding to Steps 3 and 4 in Figure 9-1), whereas the application of these statistical results is documented in Section 9. [[

]]

8.3 MCPR UNCERTAINTY APPLICATION TO GS3

[[

]] The summaries of the key statistical results for all analyzed cases are documented in Table 7-2, Table 7-3, and Table 7-4. [[

] resulting from anticipated oscillations does not exceed the SLMCPR. Thus, because this result is achieved via automatic action in Option I-D, II, and III LTSs, compliance with GDC 10 and 12 of 10 CFR 50, Appendix A is established using the GS3 methodology in the Option I-D, II, and III stability LTSs.

[[

]]

Figure 8-1

[[

]]

II

II

II

II

Figure 8-2

II

II

Figure 8-3

II

II

II

]]

]]

II

Figure 8-4

II

II

Figure 8-5 II II

II

II

Figure 8-6

II

II

II

II

II

II

Figure 8-7

II

II

Figure 8-8

II

II

II

II

Figure 8-9

II

II

II

II

II

II

Figure 8-10

II

II

II

II

Figure 8-11

II

II

Figure 8-12 II

II

II

II

Figure 8-13 II

II

II

II

Figure 8-14 II

II

II

II

Figure 8-15 II II

II

II

Figure 8-16 II II

II

II

II

II

Figure 8-17

II

II

II

II

Figure 8-18

II

II

II

II

Figure 8-19

II

II

II

II

Figure 8-20

II

II

Figure 8-21 II

II

II

II

Figure 8-22 II

II

II

II

II

II

Figure 8-23

II

II

Figure 8-24 II II

II

II

Figure 8-25 II

II

II

II

II

II

Figure 8-26

II

II

II

II

Figure 8-27

II

II

II

II

Figure 8-28

II

II

II

II

Figure 8-29

II

II

II

II

Figure 8-30

II

]]

]]

]]

Figure 8-31

II

II

II

II

Figure 8-32

II

II

II
Figure 8-33

II

II

II

II

Figure 8-34 II

II

II

Figure 8-35 II

II

II

II

II

Figure 8-36

II

II

Figure 8-37 II

II

II

II

Figure 8-38 II

II

II

II

II
Figure 8-39

II

II

]]

]]

]]

Figure 8-40

II

II

II

II

Figure 8-41

II

II

II

II

Figure 8-42

II

II

II

Figure 8-43 II

II

II

Figure 8-44 II

II

II

II

Figure 8-45 II

II

9. LICENSING BASIS FOR GENERIC ENVELOPE AND FUEL RELOAD APPLICATIONS

This section demonstrates on a generic basis that the GS3 methodology and its associated setpoints result in timely suppression of oscillations without exceeding the SLMCPR for anticipated instability events. A plant-specific confirmation assessment is performed whenever design changes beyond a specified generic applicability envelope are introduced that may affect stability performance, and for each cycle to ensure that the generic GS3 basis remains valid for plant reload applications. The plant-specific GS3 application process is described in Section 10.

9.1 APPROACH

The PBDA and its associated setpoints are described in References 2, 3, 11, and 12. The amplitude and SCC setpoints are used by the PBDA to protect the SLMCPR from anticipated instability events. The function of the APRM flow-biased scram setpoints for stability protection in Option I-D and II plants is described in References 2, 3, 9, and 10.

There are a number of anticipated events that exhibit gradual reactor transition from a stable to an unstable configuration. The physical parameters in a reactor that are critical to the coupled T-H and neutronic stability characteristics require a finite time to realign following an anticipated transient that results in power oscillations. These conditions may be reached as a result of:

- a. Normal operational maneuvers, which maintain significant MCPR margin at off-rated conditions,
- b. Anticipated events from off-rated conditions, which are expected to be mild and retain substantial MCPR margin, or
- c. Anticipated flow reduction events from rated conditions, which are expected to result in a MCPR margin increase from the required margin at the initial rated conditions (i.e., OLMCPR).

In order to detect these power oscillations, certain setpoints (either OPRM or APRM) are determined such that under the most limiting IMCPR conditions (i.e., OLMCPR) at oscillation suppression the FMCP of any fuel bundle is at least equal to the SLMCPR. [[

]]

Option III methodology reliance on a fixed amplitude setpoint, which is associated with the SLMCPR, requires quantification of the MCPR performance as a function of power oscillation

scenarios for the full spectrum of core designs and operating conditions. [[

]]

In this framework, the GS3 methodology is an alternative methodology to the DIVOM process for use in the licensing reload applications of plants implementing stability Option I-D, II, and III LTSs. More details about the licensing approach summarized in this section and the applicability to the GS3 generic licensing basis envelope are provided in Section 9.2.

[[

]]

9.2 GENERIC APPLICABILITY ENVELOPE

[[

]]

The specified range established for each of these parameters is summarized in Table 9-1. [[

]]

9.3 SLMCPR PROTECTION CONFIRMATION

[[

]]

9.3.1 Two Loop Operation

The TLO limiting events, selected to confirm that the SLMCPR is protected by the GS3 methodology applied to Option I-D, II, and III designs, are established based on a review of all potential anticipated instability event initiators. Anticipated instability events may be initiated as a result of:

- a. Normal operational maneuvers,
- b. Anticipated events from off-rated operating conditions, or
- c. Anticipated flow reduction events from rated conditions.

[[

]]

9.3.1.1 Event Simulation

[[

]] A 2RPT event is initiated by the inadvertent simultaneous opening of the recirculation pump motor line breakers. A PFR event is initiated by any inadvertent event that causes a rapid flow reduction to an intermediate core flow value (e.g., single pump trip). The rapid reduction in core flow increases the core void fraction and thereby reduces reactor power. [[

]]

The simulation results in the following section are used to assess the MCPR response and margin to the SLMCPR. As an example, the transient responses of key simulation parameters, including

[[

]]

9.3.1.2 MCPR Performance

The margin to the SLMCPR for each of the TRACG simulated events is calculated by applying the GS3 methodology process described in Table 7-1 to the [[

]]

9.3.1.2.1 Evaluation Methodology

The GS3 evaluation methodology establishes the time sequence from the oscillation detection through suppression, and determines the SLMCPR margin from the TRACG generated MCPR results. The TRACG simulations represent best-estimate calculations for reasonably limiting instability scenarios. The complete CSAU results determining the BEPU Δ MCPR/ICPR (or Δ MCPR/ICPR_{BEPU}) for the GS3 methodology as described in Section 7.2 are provided in Section 8.

The GS3 evaluation methodology represents a significant improvement and simplification from the DIVOM based methodology used in the Option I-D, II and III licensing methodologies.

[[

]]

- a. Definition of generic MCPR performance curves (DIVOM curves),
- b. Calculation of pre-oscillation MCPR (change in MCPR prior to onset of oscillations),
- c. Statistical calculation of peak hot channel oscillation magnitude for a given OPRM amplitude setpoint, and
- d. Setpoint calculation based on MCPR performance of the hot channel.

[[

]]

9.3.1.2.2 *Best-Estimate Plus Uncertainty MCPR Margin*

The GS3 evaluation methodology has been applied to the cases specified in the TRACG analysis event matrix (Table 9-2, Table 9-3, and Table 9-4). The demonstration results from the best-estimate TRACG analyses for multiple of BWR types and LTSs are shown in Figure 8-1 through Figure 8-25. These results correspond to Steps 1 and 2 in Figure 9-1. However, because the
[[

]] resulting from anticipated oscillations for that plant and its setpoint(s) does not exceed the SLMCPR. Thus, because this result is achieved via automatic action in Option I-D, II, and III plants, compliance with GDC 10 and 12 of 10 CFR 50, Appendix A is maintained using GS3 methodology in these stability LTSs. The process for the cycle-specific [[

]]

9.3.2 Single Loop Operation

[[

]] All the details about the case initial conditions are provided in Table 9-2, Table 9-3, and Table 9-4.

[[

]] resulting from anticipated oscillations for that plant and that setpoint(s) do not exceed the SLMCPR.

[[

]]

9.4 FUEL RELOAD ANALYSIS APPLICATION

This section describes the application of the GS3 methodology for plants that fall within the generic licensing basis envelope of this LTR for fuel reload analyses, which corresponds to Step 8 of the overall GS3 process illustrated in Figure 9-1. Applications that fall outside the generic licensing basis envelope are discussed in Section 10, which corresponds to Step 9 of the overall GS3 process illustrated in Figure 9-1.

[[

]] This approach is consistent with the approved DSS-CD process in NEDC-33075P (Reference 8). Once the OPRM amplitude setpoint(s) are selected from Table 9-5, Table 9-6, or Table 9-7, each corresponding SCC setpoint is selected per Table 9-10, which is obtained from the approved Table E-1 in Reference 2. Table 9-10 is duplicated in this LTR for convenience in referencing both PBDA OPRM setpoints (i.e., amplitude and SCC) from the same source. There is no change introduced between the SCC versus OPRM amplitude setpoint relationship approved in Reference 2.

[[

]]

9.4.1 Demonstration of Fuel Reload Analysis for a GS3 Option III Plant

[[

]]

9.5 EXTENSION OF GENERIC ENVELOPE

The generic GS3 licensing basis allows the implementation of the GS3 methodology for GE BWR/2-6 product lines and existing GEH/GNF fuel designs. GS3 provides SLMCPR protection during anticipated instability events. The generic GS3 licensing basis is applicable when [[

]] the GS3 plant-specific procedure defined in Table 10-2 will be performed to demonstrate adequate SLMCPR protection.

Any extension of the GS3 applicability envelope requires confirmation analysis based on the procedure defined in Table 10-2, which is based on the methodology outlined in Section 9.3. The plant-specific application is described in Section 10.1. [[

]]

Table 9-1

[[

]]

[[

]]

Table 9-2

GS3 [[

]] TRACG Analysis Event Matrix

[[

]]

Table 9-3 GS3]] **]] TRACG Analysis Event Matrix**

]]

]]

Table 9-4

GS3 [[

]] TRACG Analysis Event Matrix

[[

]]

Table 9-5

[[

]]

[[

]]

Table 9-6

[[

]]

[[

]]

Table 9-7

[[

]]

[[

]]

Table 9-8

[[

]]

[[

]]

Table 9-9

[[

]]

[[

]]

Table 9-10 Relationship Between OPRM Successive Confirmation Count Setpoint and OPRM Amplitude Setpoint

Successive Confirmation Count Setpoint	OPRM Amplitude Setpoint ^{1,2}
8	≥1.05
9	≥1.06
10	≥1.07
11	≥1.08
12	≥1.09
13	≥1.10
14	≥1.11
15	≥1.13
16	≥1.14

Notes:

1. The relationship between the OPRM SCC setpoint and the OPRM amplitude setpoint is obtained from Table E-1 of Reference 2.
2. Once the OPRM amplitude setpoint(s) are selected from Table 9-5, Table 9-6, and Table 9-7, each corresponding SCC setpoint is selected from this table.

Table 9-11 Conservatism Included in GS3 Methodology

[[

]]

Table 9-12

[[

]]

[[

]]

[[

]]

Figure 9-1 Flow Chart of the Overall GS3 Process

[[

Figure 9-2

**OPRM Channel Configuration for BWR/6 TRACG Instability
Events**

]]

NEDO-33766, REVISION 0
NON-PROPRIETARY INFORMATION—CLASS I (PUBLIC)

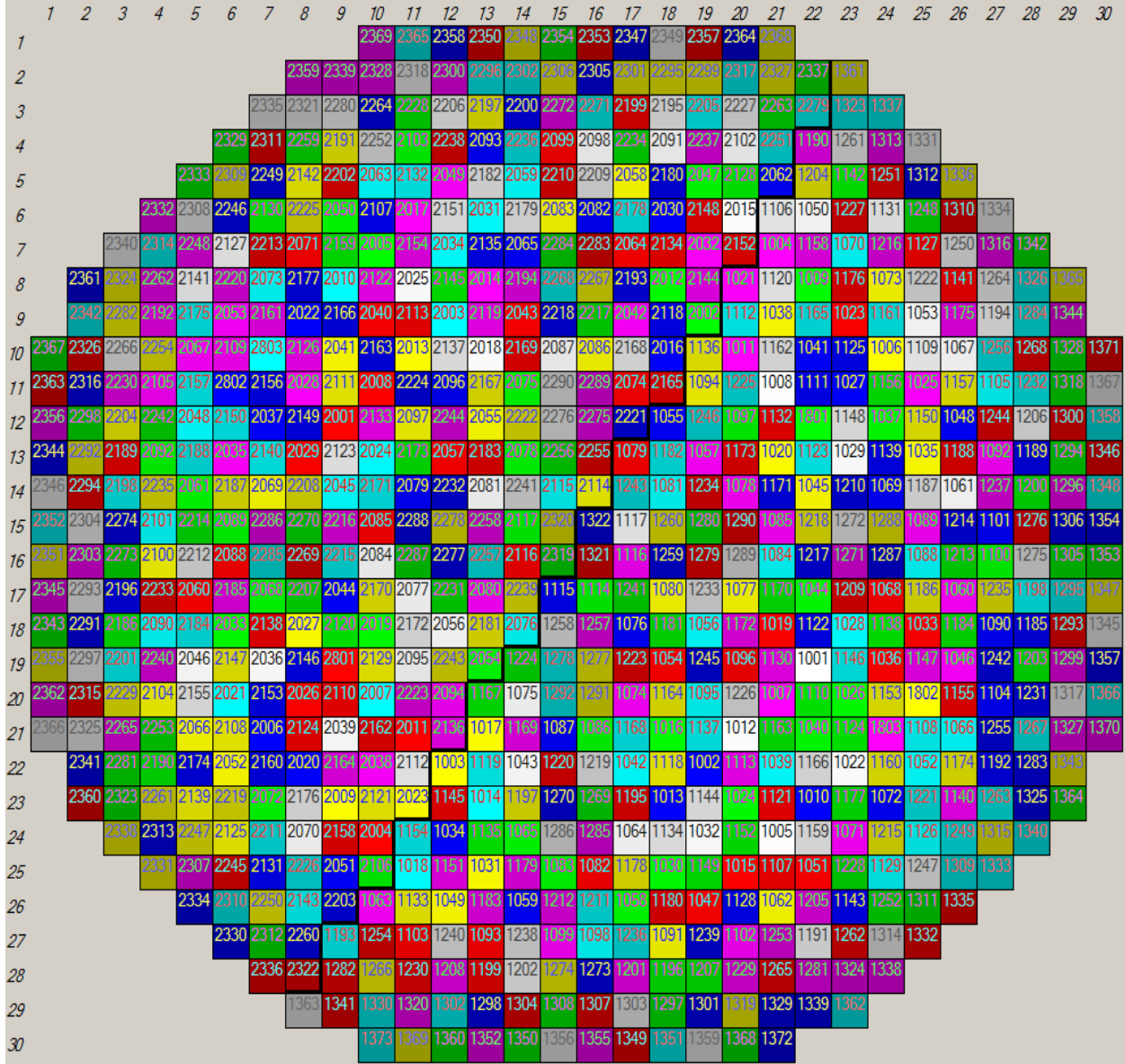


Figure 9-3 Full Core Individual Bundle Model for BWR/6 TRACG 2RPT Instability Event

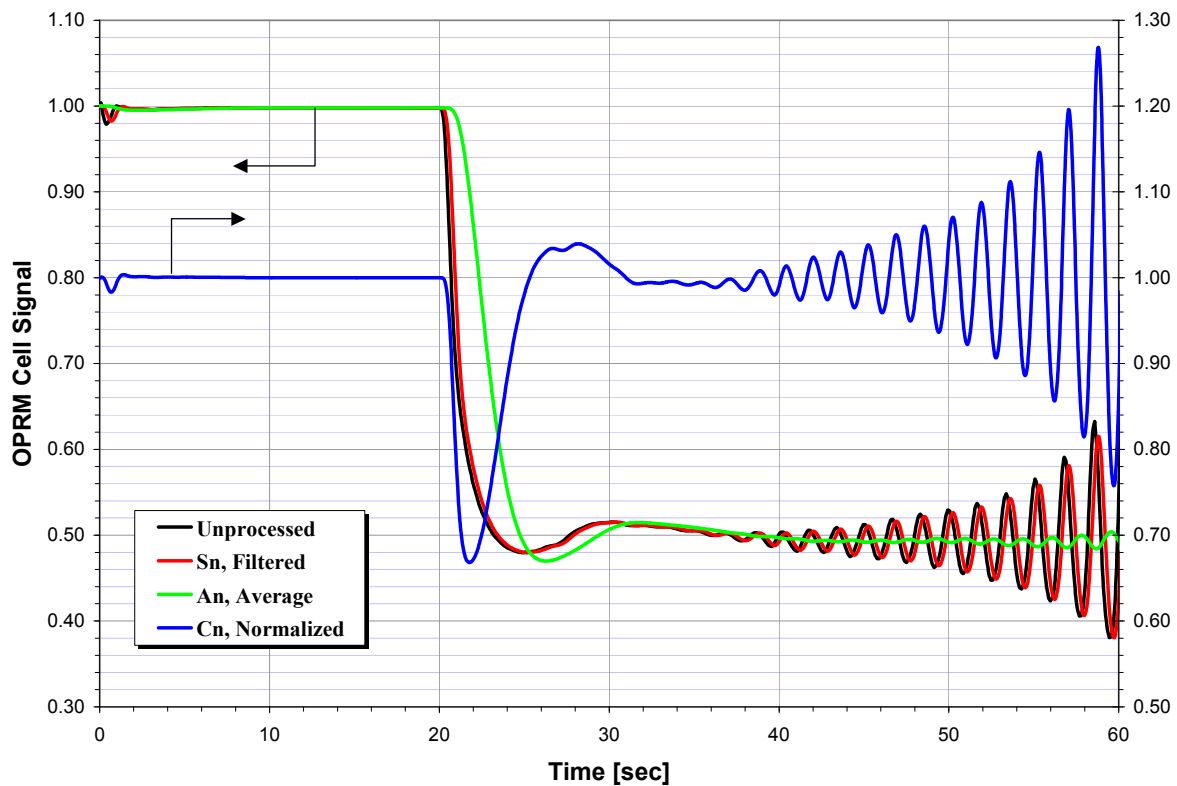


Figure 9-4

OPRM Cell Signal Processing

||

Figure 9-5

MCPR Determination

||

[[

]]

Figure 9-6

Simulation of an APRM Scram Line Logic for an Option I-D Plant

10. PLANT-SPECIFIC APPLICATIONS

A plant-specific review procedure is established to confirm that the generic GS3 licensing basis is applicable to plant-specific designs, including reload designs, thereby demonstrating SLMCPR protection by the GS3 methodology for anticipated stability-related oscillations. If the generic GS3 licensing basis is not applicable to a plant-specific design, additional analyses are necessary to demonstrate applicability. The process described in this section corresponds to Step 9 of the overall GS3 process illustrated in Figure 9-1.

10.1 PLANT-SPECIFIC REVIEW PROCESS

The generic GS3 licensing basis allows the implementation for GE BWR/2-6 product lines and existing GEH/GNF fuel designs. The solution provides for SLMCPR protection during anticipated instability events. The calculated MCPR Margin criteria documented in Table 9-5 through Table 9-9 are expected to accommodate future evolution in fuel cycle designs and operating flexibility features that may affect stability performance.

The standard plant-specific review process, which also applies to the reload process, consists of an applicability checklist confirming that the generic applicability envelope, as defined in Sections 9.2 and 9.3, is not exceeded. The plant-specific applicability checklist is provided in Table 10-1.

If any checklist criterion is not met as a result of a plant-specific design change that may affect reactor stability performance, then the GS3 plant-specific procedure defined in Table 10-2 will be performed to demonstrate adequate SLMCPR protection. If the design change is either within the GS3 plant-specific applicability checklist envelope or does not affect the reactor stability performance, then [[

]]

[[

]] The GS3 procedure uncertainty (or equivalent), documented in Sections 7 and 9, is then applied to confirm the protection of the

SLMCPR for any applicable OPRM/APRM setpoint(s). The GS3 applicability extension procedure is documented in Table 10-2.

[[

]]

If the GS3 applicability extension involves a new GEH/GNF fuel design beyond GNF2 or non-GEH/GNF fuel designs, then the procedure documented in Table 10-3 is applied. This table lists the possible fuel design transitions among approved and unapproved GEH/GNF and non-GEH/GNF fuel designs for GS3 applications. [[

]]

Table 10-3 specifies the required [[

]] This process would apply to both cases where a new fuel design product line (e.g., GNF3) loaded core is implementing GS3 and where a GS3 licensed plant has a core introducing a new fuel design product line such as GNF3 fuel. Both of these scenarios are consistent with the DSS-CD approved methodology as documented in Reference 8 [[

]]

10.2 LEAD USE ASSEMBLY

The introduction of lead use assemblies (LUAs) in a reload core that is implementing the GS3 methodology should follow the process required by the implemented stability LTS Option I-D, II, or III.

10.3 TECHNICAL SPECIFICATIONS

No Technical Specification (TS) or TS Bases revisions are required with the implementation of the TRACG GS3 methodology for plants licensed for operation with Option I-D, II, or III stability LTS if the GS3 LTR, or GESTAR II, including the approved GS3 LTR, is referenced in in the TS section for methods.

Table 10-1 GS3 Plant-Specific Applicability Checklist

[[

]]

Table 10-3 Required TRACG Cases for Fuel Design Transition Scenarios

[[

]]

11. CONCLUSIONS

Recent developments in nuclear technology such as improvements in fuel, core, and reactor designs; refined operational strategies; and implementation of EPUs have necessitated more advanced nuclear safety analysis techniques to better analyze and predict NPP behaviors under anticipated operational transients. These same technology developments have also exposed the limitations of excessively conservative analyses used for licensing calculations. In particular, the application of the conservative DIVOM methodology has presented certain challenges for T-H stability analyses.

[[

]] some plants have opted to reduce their amplitude setpoints (so that the OLMCPRs are also lowered). This reduction in setpoints might cause an increase in the likelihood of a spurious scram, which is detrimental to the safety of NPPs.

GS3 is a TRACG BEPU methodology that, when applied to stability Option I-D, II, and III LTSs, complies with GDC 10 and 12 of 10 CFR 50 Appendix A. GS3 methodology provides [[

]] in operating BWRs; hence, it contributes to a reduction in the likelihood of spurious scrams while ensuring protection of the SLMCPR. In essence, like the DSS-CD methodology it is built upon, GS3 provides stability setpoints that are: [[

]]

The GS3 methodology provides quantification of uncertainty and contains the right amount of conservatism to ensure SLMCPR protection without affecting plant operation with excessive conservatism. In fact, the GS3 methodology, unlike the DIVOM methodology, does not cause strict constraints on core design due to too low OLMCPRs, thereby simplifying the design of the core for meeting all other thermal limits.

The GS3 methodology can be applied to any plant licensed for stability Option I-D, II, or III LTSs. Because GS3 is a methodology that does not introduce, or modify, any aspects of existing software and hardware in a given plant, GS3 can be applied to all Option III plants that have an OPRM system, regardless of the vendor for the firmware platform. Therefore, it is applicable to both GEH and ABB OPRM systems. With respect to GEH systems, it is applicable to both the

standard GEH PRNM NUMAC Option III platform and the GEH PRNM NUMAC Option III/DSS-CD platform. A plant operating under an Option III license with an installed Option III/DSS-CD PRNM platform (e.g., during the transition period to a DSS-CD license), can implement the GS3 methodology per the licensing basis provided in this LTR.

By relying on a well proven CSAU approach to account for realistic uncertainty, GS3 is a robust methodology that is insensitive to changes that are below the level of uncertainty. The GS3 methodology provides a unified, consistent, standard, and simplified stability analysis process for reload application to Option I-D, II, and III LTSs. With the methodology consistently applied to all these stability LTSs, all the analyses and reload processes become essentially the same, regardless of which stability LTS applies. This outcome reduces human error factors and simplifies the reload analysis process as well as future licensing amendments for plant changes affecting stability.

The tables of MCPR Margin criteria (Table 9-5 through Table 9-9) documented in this LTR are based on [[

]]

BWR/2-6 plants employing stability Option I-D, II, or III LTSs. This application may include all power/flow domains up to and including the EPU domain and all licensed operational enhancements with the exception of the MELLLA+ domain. [[

]] defined in Table 10-2 must be performed to demonstrate adequate SLMCPR protection. This approach provides an adequate basis for the proposed change, and because it is based on an [[

]]

Table 10-3 describes the required fuel transition scenario analyses to be performed. The Table 10-3 procedure is the same as the approved DSS-CD process defined in Table 6-5 of Reference 8. This approach provides an adequate basis for the proposed change and [[

]] Therefore, if the GS3 application involves a new GEH/GNF fuel design beyond GNF2 or a non-GEH/GNF fuel design, then the procedure documented in Table 10-3 is applied. [[

]]

The TRACG GS3 methodology and its CSAU application are consistent with, and based on, the approved TRACG DSS-CD LTR (Reference 1) and TRACG AOO LTR (Reference 6) applications.

GS3 does not include any change to the backup stability protection aspects of Option I-D, II or III LTS (e.g., BSP or ER).

No TS or TS Bases revisions are required with the implementation of TRACG GS3 for plants licensed for operation with Option I-D, II, or III stability LTS if the GS3 LTR, or GESTAR II including the approved GS3 LTR, is referenced in the proposed TS changes for implementation of GS3.

In conclusion, it is GEH's opinion that it is essential to analyze and better understand the physical phenomena governing the transient and accident scenarios that are modeled and ultimately need to be predicted in the safety analysis of NPPs. It is currently a challenge for many areas of the safety analysis to be able to more accurately predict the real behavior of NPPs and to capture their performance beyond just the main phenomena that are simulated. Typically, conservative methodologies have behaviors that cannot be easily correlated to the physical phenomena being simulated. On the contrary, BEPU methodologies represent a more advanced and refined approach to perform safety analyses, to predict a more realistic plant response, and therefore to better assess their safety.

In this framework, GS3 is a BEPU methodology, based on the approved DSS-CD methodology, for safety analysis of T-H stability transients, and it is the result of approximately [[]] The adoption of BEPU methodologies for stability analyses such as GS3 and DSS-CD advances the understanding of the associated physical phenomena and increases nuclear plant safety by significantly reducing the chance of a spurious scram caused by too low setpoints.

12. REFERENCES

1. GE Hitachi Nuclear Energy, “DSS-CD TRACG Application,” NEDE-33147P-A, Revision 4, August 2013.
2. GE Nuclear Energy, “BWR Owners' Group Reactor Stability Detect and Suppress Solutions Licensing Basis Methodology for Reload Applications,” NEDO-32465-A, August 1996.
3. GE Hitachi Nuclear Energy, “Migration to TRACG04/PANAC11 from TRACG02/PANAC10 for Reactor Stability Detect and Suppress Solutions Licensing Basis Methodology for Reload Applications,” NEDO-32465 Supplement 1, Revision 0, September 2011.
4. GE Hitachi Nuclear Energy, “TRACG Model Description,” NEDE-32176P, Revision 4, January 2008.
5. GE Nuclear Energy, “TRACG Qualification,” NEDE-32177P, Revision 3, August 2007.
6. GE Nuclear Energy, “TRACG Application for Anticipated Operational Occurrences Transient Analyses,” NEDE-32906P-A, Revision 3, September 2006.
7. GE Hitachi Nuclear Energy, “Migration to TRACG04/PANAC11 from TRACG02/PANAC10 for TRACG AOO and ATWS Overpressure Transients,” NEDE-32906P, Supplement 3-A, Revision 1, April 2010.
8. GE Hitachi Nuclear Energy, “GE Hitachi Boiling Water Reactor, Detect and Suppress Solution – Confirmation Density,” NEDC-33075P, Revision 7, June 2011; and Anthony J. Mendiola (NRC) to Jerald G. Head (GEH), “Revised Draft Safety Evaluation for GE-Hitachi Nuclear Energy Americas, LLC Topical Report NEDC-33075P, Revision 7, ‘GE Hitachi Boiling Water Reactor Detect and Suppress Solution – Confirmation Density’ (TAC No. ME6577),” MFN-13-045, August 6, 2013.
9. GE Nuclear Energy, “Application of Stability Long-Term Solution Option II to Nine Mile Point Nuclear Station Unit 1,” GENE-A13-00360-02, Revision 1, November 1998.
10. GE Nuclear Energy, “Application of Stability Long-Term Solution Option II to Oyster Creek,” NEDC-33065P, Revision 0, April 2002.
11. GE Nuclear Energy, “BWR Owners' Group Long-Term Stability Solutions Licensing Methodology,” NEDO-31960-A, November 1995.
12. GE Nuclear Energy, “BWR Owners' Group Long-Term Stability Solutions Licensing Methodology,” NEDO-31960-A, Supplement 1, November 1995.
13. GE Hitachi Nuclear Energy, “ODYSY Application for Stability Licensing Calculations Including Option I-D and II Long Term Solutions,” NEDE-33213P-A, April 2009.

NEDO-33766, REVISION 0
NON-PROPRIETARY INFORMATION—CLASS I (PUBLIC)

14. OE23808, “Conservative Oscillating Power Range Monitor Setpoint Causes Half Scram,” Hope Creek Unit 1, August 7, 2006.
15. GE Nuclear Energy, “LaSalle 1 and 2 OPRM System Performance Evaluation,” GE-NE-0000-0044-5910-R0, March 2006.
16. OE20368, “Oscillation Power Range Monitor Trip Indication in Single Recirculation Loop Operation – Peach Bottom,” Peach Bottom Unit 3, February 11, 2005.
17. AR 00976243 Report, “Unexpected Alarm 903-5 E-6, OPRM Alarm (Dresden Unit 3),” October 7, 2009.
18. OE24212, “Unexpected OPRM-Related Half-Scram During Plant Start-Up (OE24212),” Perry Unit 1, December 20, 2006.
19. OE189536, “Failure of RPS Average Power Range Neutron Monitor Channels,” Dresden Unit 3, November 13, 2000.
20. NRC, “Quantifying Reactor Safety Margins: Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large-Break, Loss-of-Coolant Accident,” NUREG/CR-5249, December 1989.
21. Global Nuclear Fuel, “The PRIME Model for Analysis of Fuel Rod Thermal – Mechanical Performance,” Technical Bases - NEDC-33256P-A, Revision 1, Qualification – NEDC 33257P-A, Revision 1, and Application Methodology – NEDC-33258P-A, Revision 1, September 2010.
22. Letter from Sher Bahadur (NRC) to Jerald G. Head (GEH), “NRC Audit of GE-Hitachi Nuclear Energy Americas Topical Report NEDO-33173, Supplement 4-A, “Implementation of PRIME Models and Data in Downstream Methods, (TAC No. ME9033),” October 22, 2012.
23. GE Nuclear Energy, “Steady State Nuclear Methods,” NEDE-30130P-A, April 1985.
24. Letter from S. A. Richards (NRC) to G. A. Watford (GE), “Amendment 26 to GE Licensing Topical Report NEDE-24011-P-A, “GESTAR II” – Implementing Improved GE Steady-State Methods (TAC No. MA6481),” November 10, 1999.
25. NRC, “Best-Estimate Calculations of Emergency Core Cooling System Performance,” Regulatory Guide 1.157, May 1989.
26. GE Hitachi Nuclear Energy “TRACG Application for ESBWR Stability Analysis,” NEDE-33083P-A, Supplement 1, Revision 2, September 2010.
27. GE Nuclear Energy, “Qualification of the One-Dimensional Core Transient Model for Boiling Water Reactors,” NEDE-24154-P-A, August 1986.

NEDO-33766, REVISION 0
NON-PROPRIETARY INFORMATION—CLASS I (PUBLIC)

28. Global Nuclear Fuel, “General Electric Standard Application for Reactor Fuel,” NEDE-24011-P-A and NEDE-24011-P-A-US, (latest approved revision).
29. S.S. Wilks, “Determination of Sample Sizes for Setting Tolerance Limits,” *The Annals of Mathematical Statistics*, 12, 91-96, 1941.
30. W.T. Nutt and G.B. Wallis, “Evaluation of Nuclear Safety from the Outputs of Computer Codes, *Reliability Engineering and System Safety*,” 83, 57–77, 2004.
31. GE Nuclear Energy, “Methodology and Uncertainties for Safety Limit MCPR Evaluations,” NEDC-32601P-A, August 1999.
32. GE Nuclear Energy, “Power Distribution Uncertainties for Safety Limit MCPR Evaluations,” NEDC-32694P-A, August 1999.
33. General Electric, “General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application,” NEDE-10958-PA, January 1977.