ENCLOSURE 2

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GE Licensing Topical Report NEDE-32906P, Supplement 3, "Migration to TRACG04 / PANAC11 from TRACG02 / PANAC10 for TRACG AOO and ATWS Overpressure Transients," May 2006

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Licensing Topical Report

Migration to TRACG04 / PANAC11 from TRACG02 / PANAC10 for TRACG AOO and ATWS Overpressure Transients

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The information contained in this document is furnished for the purpose of obtaining NRC approval of the migration to PANAC11 / TRACG04 from PANAC10 / TRACG02 for TRACG AOO and ATWS overpressure transients. The only undertakings of General Electric Company with respect to information in this document are contained in contracts between General Electric Company and participating utilities, and nothing contained in this document shall be construed as changing those contracts. The use of this information by anyone other than that for which it is intended is not authorized; and with respect to any unauthorized use, General Electric Company makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

ABSTRACT

This report addresses Anticipated Operational Occurrences (AOO) and Anticipated Transients Without SCRAM (ATWS) overpressure transients as a result of the transition from the TRACG02 / PANAC10 computer codes to the TRACG04 / PANAC11 computer codes. The TRACG04 / PANAC11 computer codes are the current GE state-of-the-art tools for 3D BWR core physics and reactor transient predictions.

This report demonstrates that this code transition is not an adverse methodology change with respect to the calculated transient behavior for AOO and ATWS overpressure transients. Because no inherent margins are being gained as part of this code transition, GE plans to use both code streams (TRACG02 / PANAC10 and TRACG04 / PANAC11) on an as-needed basis going forward for AOO and ATWS overpressure transients.

ACRONYMS AND ABBREVIATIONS

3D	Three Dimensional
ABWR	Advanced Boiling Water Reactor
ANS	American Nuclear Society
AOO	Anticipated Operational Occurrences
APRM	Average Power Range Monitor
ATWS	Anticipated Transient Without SCRAM
BWR	Boiling Water Reactor
BWR/*n*	GE BWR product line *n* (*n* can be 2, 3, 4, 5, or 6)
CFR	Code of Federal Regulations
CPR	Critical Power Ratio
ΔCPR	Delta (Change In) Critical Power Ratio
EOC	End-of-Cycle
ESBWR	Economic Simplified BWR
FWCF	Feed Water Controller Failure
GE	General Electric Company
GE*n*	GE fuel product line *n* (e.g., GE13, GE14, etc.)
GENE	GE Energy, Nuclear
GNF-A	Global Nuclear Fuels - America
ICPR	Initial Critical Power Ratio
K	Kelvin
L8	Level 8
LFWH	Loss of Feed Water Heating
LOCA	Loss of Coolant Accident

LTR	Licensing Topical Report
MCPR	Minimum Critical Power Ratio
M/G	Motor Generator
MSIV	Main Steam Isolation Valve
MSIVF	Main Steam Isolation Valve Closure - Flux SCRAM
MWt	Mega-Watt Thermal
Pa	Pascal
PANAC	Three-Dimensional BWR Core Steady State Simulator Code
PB	Peach Bottom
PIRT	Phenomena Identification and Ranking Table
psi	Pounds per Square Inch
RFCF	Recirculation Flow Control Failure
SCRAM	Reactor Trip
sec	Second (Also s)
SRV	Relief Valve
TRAC	Transient Reactor Analysis Code
TRACG	GE Version of TRAC
TSV	Turbine Stop Valves
TT	Turbine Trip
TTNB	Turbine Trip No Bypass
USNRC	United States Nuclear Regulatory Commission

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1.0 INTRODUCTION

General Electric is in the process of migrating from the code stream of TRACG02 / PANAC10 to TRACG04 / PANAC11. The TRACG04 / PANAC11 computer codes are the current GE state-of-the-art tools for 3D BWR core physics and reactor transient predictions.

This report addresses Anticipated Operational Occurrences (AOO) and Anticipated Transients Without SCRAM (ATWS) overpressure transients as a result of the transition from the TRACG02 / PANAC10 computer codes to the TRACG04 / PANAC11 computer codes. It should be noted that [1] is a more recent revision of the approved topical report for AOO using TRACG, and [1] supplies new TRACG calculations that incorporate a correction to the void coefficient model calculations internal to TRACG.

This report demonstrates that the change in computer codes to TRACG04 / PANAC11 is not an adverse methodology change with respect to the previously approved methods for AOO and ATWS overpressure transients using TRACG02 / PANAC10. Numerous transient calculations are presented in a comparative fashion to illustrate the specific sensitivity of the transient results to the changes being implemented. Upon approval by the USNRC of the use of TRACG04 / PANAC11 for simulation of AOO and ATWS overpressure transients, GE will use TRACG04 / PANAC11 in addition to TRACG02 / PANAC10 for future design analyses.

The general report format used in [1] will be re-used here in a congruent fashion to highlight the differences that require further attention. This should facilitate the review and approval of this document by the USNRC.

2.0 LICENSING REQUIREMENTS AND SCOPE OF APPLICATION

All of the same licensing requirements that applied in [1] will remain applicable for the new code series of PANAC11 / TRACG04. With respect to future updates to the TRACG code beyond TRACG04, the same requirements will apply. The discussion pertaining to updated steady state nuclear methods beyond PANAC11 applies here also. The AOO scenario and nuclear power plant selection specifications still apply to this new code stream.

3.0 PHENOMENA IDENTIFICATION, RANKING

There are no changes to the PIRT tables as a result of the change in code versions. All of the relative importance of specific phenomena remains intact. There are no new phenomena being introduced, and the ranking of phenomena importance remains the same. The data presented in Section 3.0 of [1] still applies here.

4.0 APPLICABILITY OF TRACG TO AOOs

There are no changes to the BWR phenomena and TRACG model capability matrix tables as a result of the change in code versions. A number of the TRACG models have been upgraded to improve or add additional capabilities to TRACG. The main enhancement, which affects the applicability of TRACG to AOO transient and ATWS overpressure analyses, is the implementation of the PANAC11 kinetics. The other enhancements were implemented primarily to extend the applicability of TRACG beyond AOO transient and ATWS overpressure events to applications such as LOCA, ATWS with boron injection and ESBWR applications. These enhancements are summarized in Section 4.1. The same goes for the Qualification assessment matrix tables. Because TRACG04 produces results that are similar in nature to those produced by TRACG02, it can be concluded that data contained in the qualification tables presented in [1] remains applicable for TRACG04 for the application to AOO transient and ATWS overpressure analyses. The data presented in Section 4.0 of [1] still applies here.

4.1 Enhancements to TRACG

The primary enhancement to TRACG for application to AOO transient and ATWS overpressure analyses is the implementation of the PANAC11 kinetics model. The additional enhancements to TRACG expand the scope of TRACG to include the ESBWR in addition to all operating BWRs. Thus, the applicability of TRACG includes BWR/2-6, ABWR, and ESBWR. Finally, TRACG04 includes a number of new models and upgrades to several existing models in order to improve the application of TRACG to LOCA and ATWS. The major new models are:

- Replace the existing PANAC10 kinetics model with the PANAC11 kinetics model [5]. The effect of the PANAC11 kinetics on AOO transient analyses and ATWS overpressure events is evaluated in Section 8.0 of this report.

- The ANS decay heat model [6 and 7]. The ANS decay heat model is implemented as an optional model in addition to the existing May-Witt model. The ANS model improves the simulation of the effect of exposure on the decay heat and was implemented primarily for applications to LOCA. The ANS decay heat model has a negligible effect on AOO transient and ATWS overpressure analyses, where decay heat variations are insignificant compared to the fission power.

- Implement the quench front model for fuel rods and channel box. The quench front model was not activated in the previous version of TRACG. The model has been activated for application to LOCA, where quench front controlled rewetting is important for the calculation of the peak cladding temperature. The quench front model has no effect on AOO transient and ATWS overpressure analyses, where peak cladding temperatures are not calculated.

- A hot rod model for the fuel channel component. The one-dimensional hydraulic model in the TRACG channel component does not simulate the cross sectional variation in void fraction and steam superheat that can exist in a fuel bundle prior to reflooding and quenching during a LOCA. The hot rod model is implemented to capture the effect of cross sectional variations on the peak cladding temperatures. This model has no effect on AOO transient and ATWS overpressure analyses, because the peak cladding temperature is not calculated for AOO transient and ATWS overpressure events.

- The Shumway model for the minimum stable film boiling temperature [8]. The Shumway model is implemented as an optional enhancement to the minimum film boiling temperature correlation. This model primarily effects the rewetting during the reflood phase of a LOCA. The Shumway model has no effect on AOO transient and ATWS overpressure analyses, because the peak cladding temperature is not calculated for these events.

- Enhancement to the entrainment model to give better agreement with data. The models for the interfacial shear in the previous version of TRACG had primarily been qualified for pressure ranges applicable to normal operating conditions and AOO transient and ATWS overpressure analyses. Additional qualification for low pressure was performed to support the expansion of the application of TRACG to LOCA. Minor enhancements to the entrainment model were introduced to improve the application of TRACG at lower pressures. The enhancements affect the onset of entrainment and primarily the calculation of entrainment when some surfaces (e.g., fuel rods in a channel component) have experienced boiling transition. The enhancement to the entrainment model has a negligible effect on AOO transient and ATWS overpressure analyses.

- Enhancement to the flow regime map to give better void fraction predictions for low pressure. The models for the flow regime transitions in the previous version of TRACG had primarily been qualified for pressure ranges applicable to normal operating conditions and AOO transient and ATWS overpressure analyses. Additional qualification for low pressure was performed to support the expansion of the application of TRACG to LOCA. Minor enhancements to the model for transition to annular flow was introduced to improve the application of TRACG at lower pressures. The enhancement to the flow regime transition model has a negligible effect on AOO transient and ATWS overpressure analyses.

- Fuel rod conductivity consistent with PRIME [4]. The fuel conductivity from the PRIME model has been implemented as the default model in TRACG04, while the previous GESTR-based model has been retained as an optional model. The PRIME model improves the effect of temperature, exposure, and Gadolinium on the fuel thermal conductivity. This model does have an effect on the fuel temperature, but has a negligible effect on the hydraulic response. The effect on AOO transient and ATWS overpressure analyses, such as the effect on pressure response and CPR margin, is negligible.

- Models for the uncertainty in fuel rod internal pressure, the cladding yield stress, and the cladding rupture stress. These models were implemented for use in the statistical analysis of a LOCA and are not used for AOO transient and ATWS overpressure analyses. Therefore, these models do not affect the AOO transient and ATWS overpressure analyses.

- Modify the Zircaloy oxidation rate to be consistent with the latest version of the Cathcart & Pawel correlation [9]. This has no effect on AOO transient and ATWS overpressure analyses, as boiling tansition and high fuel temperatures with Zircaloy oxidation do not occur.

- Enhanced default pump homologous curves. The default pump homologous curves, which were based on data from the Semiscale test facility, have been supplemented with curves representative for large pumps. This has no effect on TRACG applications to AOO transient and ATWS overpressure events, because the pump homologous curves are required by procedure to be provided as input (e.g., not left at default values).

- Improved free convection heat transfer. The McAdams correlation correlation for free convection at a liquid surface has been implemented in addition to the current model that was based on Holman. However, the sensitivity of free convection heat transfer on AOO transient and ATWS overpressure events is insignificant.

- Improved condensation heat transfer. The default correlation for condensation heat transfer in the pressence of noncondensibles was changed from the Vierow-Schrock to the Kuhn-Schrock-Peterson correlation. This has an effect on ESBWR applications and has a negligible effect on AOO transient and ATWS overpressure events.

- Optional 6-cell jet pump. One-nozzle jet pumps have a relaively long straight section between the suction inlet and the diffuser. In the standard 5-cell jet pump, a single cell is used for this region. An option to subdivide this region into two cells has been implemented, primarily to improve the accuracy of the calculation of the void profile and static head in the jet pump for low flow two-phase flow conditions such as during the refill/reflood phase of a LOCA. The effect of the nodalization change for single-phase conditions such as during AOO transient and ATWS overpressure events is insignificant.

- Improved boron model. The models for solubility of sodiumpentaborate and the B_{10} absorption cross section have been improved to give better agreement with available data. This has an effect on ATWS events with activation of the standby liquid control system, but has no effect on AOO transient and ATWS overpressure events.

Of these changes, only the PANAC11 kinetics implementation has any significant effect on the previously approved applications for AOO transient and ATWS overpressure events for TRACG [1 and 10]. The remaining changes primarily affect and improve the applications of TRACG for LOCA and ATWS with application of the standby liquid control system. A detailed description of these new models and model enhancements is included in Revision 3 to the TRACG Model Description LTR [4]. Additional discussion of the effect of these model changes is included in Section 8.0.

5.0 MODEL UNCERTAINTIES AND BIASES

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

The phenomena for BWR AOO transients have already been identified and ranked, as indicated in Section 3.0 of [1]. For the high and medium ranked phenomena, the bases used to establish the nominal value, bias and uncertainty for that parameter are documented in Section 5.1 of [1]. Also, the basis for the selection of the probability density function used to model the uncertainty is provided in Section 5.1 of [1].

5.1 Model Parameters and Uncertainties

This section in [1] discusses the uncertainties associated with each item from Table 3-1 from [1] that has been identified as having an effect on one or more critical safety parameters. Only the void coefficient (C1AX) uncertainty has undergone a significant change due to the change from PANAC10 to PANAC11 kinetics and will be discussed in this section. There are other changes that were implemented into TRACG04 for application to LOCA and ESBWR analyses. However, as discussed in Section 4.0 and demonstrated in Section 8.2, these changes have negligible effect on AOO transient and ATWS overpressure transient analyses. Therefore the model uncertainties for all parameters except the void coefficient have been retained from TRACG02 as described in [1].

C1AX Void Coefficient, H

TRACG04 uses a 3-D neutron kinetics model based on the PANAC11 neutronics parameters. The nodal reactivity is calculated [[ ]]. All of these parameters are correlated in terms of the moderator density. The infinite multiplication factor is also dependent on [[ ]] moderator density and nodal exposure.

The biases and uncertainties in void coefficient as determined from the PANAC11 models are predominantly due to biases and uncertainties in the infinite lattice eigenvalues (k_∞) calculated by the TGBLA06 lattice physics code. Values of k_∞ at [[ ]] points were calculated for a representative set of [[ ]] lattices at [[ ]] different exposures for in-channel voids of [[ ]] using both TGBLA06 and MCNP. The results for each lattice and exposure were fit to a [[ ]] function to determine k_∞ as a function of voids. These functional forms were extrapolated to obtain [[ ]] values of k_∞ corresponding to 100% in-channel voids. The void coefficients at a total of [[ ]] points were defined separately for TGBLA06 and MCNP by evaluating the derivative of k_∞ [[ ]]. Biases and uncertainties in TGBLA06 void coefficients

were evaluated by performing [[ ]] comparisons between TGBLA06 and the corresponding MCNP benchmark values. These assessments were made using uncontrolled lattices (lattices without a control blade). An earlier independent set of [[ ]] other TGBLA04 lattices all at zero exposure were evaluated [[ ]] as a check on the process. The check set using TGBLA04 comparisons to MCNP included [[ ]] controlled lattices to confirm that the uncontrolled lattices bound the biases and uncertainties for the controlled lattices. Because of the similarity in the TGBLA04 and TGBLA06 comparisons, the comparisons based on TGBLA06 using uncontrolled lattices are also expected to bound the biases and uncertainties for the controlled lattices.

The set of [[ ]] points was reduced to [[ ]] by eliminating [[ ]] outliers outside the ±2.17 sigma range. The remaining [[ ]] were used to correlate the biases and uncertainties in the void coefficient as a function [[ ]] in order to obtain response surfaces that are modeled in TRACG04. The fraction of the total water volume that is inside the channel box excluding the water rods is given by "g". A typical value is g = [[ ]]. For values of ρ_ℓ and ρ_g representative of operating pressures, and for conditions where the void fraction remains zero in the water rods and bypass, a typical value for the relative water density averaged for the lattice is related to the in-channel void fraction [[ ]]. Curves of the percentage biases and standard deviations for void coefficient are shown in Figure 5-1 for the different exposures that were considered in developing the response surfaces.

[[

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Figure 5-1: Void Coefficient %Bias and %Standard Deviation

Note: The parametric curves have the units of GWd/ST for each exposure point.

The void coefficient biases and uncertainties are implemented in TRACG04 calculations [[

]]. Consider a representative in-channel void fraction of 40% and a core-average exposure of 15 GWd/ST. For $\alpha = 0.4$, Figure 5-1 indicates that the bias is around [[ ]]. The standard deviation from Figure 5-1 is [[ ]] at this condition. For low exposures, the uncertainties tend to be [[

]]. As the poison is burned and the bundles approach their peak reactivity and power, the void coefficient bias and uncertainty [[ ]].

TRACG04 internally models the response surfaces for the void coefficient biases and uncertainties in order to account for the known dominant dependencies due to relative moderator density and exposure [[ ]]. Cross sections are generated within TRACG04 using data from the lattice physics code that gets passed through via the PANAC11 wrap-up. Thus, the lattices are explicitly modeled. [[

]]. Thus, the normality of the [[ ]] residual errors can be tested at each of these locations. This is what was done to get the P-values presented in Table 5-1. All the P-values except for one are significantly larger than the 0.05 threshhold required to confirm normality and reach the conclusion that it is appropriate to assume that the residual errors are random [[ ]]. The single set of [[ ]] points that fails the normality test produces a low P-value because the sample distribution is more centrally concentrated than what is expected for a normal distribution; therefore, it is conservative to model the sample distribution using an assumed normal distribution because that will predict wider scattter than the sample indicates.

TRACG04 input has been structured to allow the internally calculated uncertainties to be correlated [[

]]. For most fast pressurization events, the impact of not modeling the void coefficient biases is on the order of [[ ]] in calculated values of transient ΔCPR/ICPR. Whether the bias is conservative or not depends on the exposure distribution and the relative water density distribution in the core.

For sensitivity studies, a core-wide bias and uncertainty in void coefficient can be specified through the TRACG04 input. As an example of the importance of the void coefficient uncertainty, consider that for a typical BWR/4 plant an [[ ]] variation in the void coefficient when applied to all nodes in the core corresponds to a sensitivity of [[ ]] in the ΔCPR/ICPR for a turbine trip without bypass.

Table 5-1: Normality Test P-values for the Void Coefficient Residual Errors

Void → Exp ↓	[[			]]	Avg	Stdev	Min
[[							
							]]
Avg	[[						
Stdev							
Min							]]

6.0 APPLICATION UNCERTAINTIES AND BIASES

The descriptions for input, initial conditions, and plant parameters in Section 6.0 of [1] remain applicable for PANAC11 / TRACG04. As a result, no new data is presented here.

7.0 COMBINATION OF UNCERTAINTIES

The change in code streams from PANAC10 / TRACG02 to PANAC11 / TRACG04 does not affect the existing statistical methodology. As a result, the method for statistical combination of uncertainties remains unchanged from that presented in [1].

7.1 Statistical Analysis for Qualification Events

Because the data presented in Section 7.6 of [1] was produced using PANAC10 / TRACG02, a new comparison with the Peach Bottom turbine trip tests using PANAC11 / TRACG04 will be presented here to demonstrate the relative effect of the new code versions on this data comparison.

7.1.1 Peach Bottom Turbine Trip Comparison

The "TRACG Nominal - Rev. 2" data from [1] listed as TRACG02 here is overlayed with the new TRACG04 nominal results in addition to the "Data" as taken from [1]. See Figure 7-1 through Figure 7-6 for the results comparisons for each of the three Peach Bottom tests.

[[

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Figure 7-1: PB TT Test 1 Power Response

[[

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Figure 7-2: PB TT Test 1 Pressure Response

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Figure 7-3: PB TT Test 2 Power Response

[[

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Figure 7-4: PB TT Test 2 Pressure Response

[[

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Figure 7-5: PB TT Test 3 Power Response

[[

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Figure 7-6: PB TT Test 3 Pressure Response

The pressure responses are quite similar between TRACG02 and TRACG04 for the nominal calculation. With respect to the power results, both codes continually tend to conservatively overpredict the response. The results show that TRACG04 is capable of accurately modeling the Peach Bottom turbine trip test data.

8.0 DEMONSTRATION ANALYSIS

As was presented in [1] and [2], numerous AOO and ATWS pressurization transients were simulated to demonstrate the capabilities of the TRACG code to accurately predict transient behavior. Because the computer codes used to calculate these demonstration analyses have been modified, comparisons are provided here to illustrate the effect of these computer code changes.

8.1 Baseline Analysis

Six transients (5 AOO and 1 ATWS) are recalculated using both the old code stream and the new code stream to highlight the relative effect of the transition.

This new set of calculations is for a different BWR/4 plant than was used in [1]. The specific plant selected is adequate for comparison purposes. In [1] only a quarter core was represented, and symmetry was assumed. For the new plant selected, a full-core model was developed using more recent fuel types (GE13 9x9 and GE14 10x10) and a higher core power rating (2923 MWt). This plant selection should better illustrate the effect derived from use of the latest fuel types and extended power uprate conditions.

The same general vessel modeling technique as is shown in Figure 8-1 of [1] is used here. Figure 8-1 through Figure 8-4 depict the channel groupings selected for both TRACG02 and TRACG04 calculations and for both initial power levels. The hot assembly channel (GE14 fuel) is highlighted in red for each.

[[

]]

Figure 8-1: 100% Power TRACG02 Channels

[[

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Figure 8-2: 100% Power TRACG04 Channels

[[

]]

Figure 8-3: 53.3% Power TRACG02 Channels

[[

]]

Figure 8-4: 53.3% Power TRACG04 Channels

For the TRACG02 channel groupings, channel groups 20 through 24 are GE13 fuel with the remaining channel groups being GE14 fuel. For the TRACG04 channel groupings, channel groups 26 through 30 are GE13 fuel with the remaining channel groups being GE14 fuel.

Given the nature of the changes in the code, the following events are selected to be compared using both TRACG02 and TRACG04.

1. Pressurization: turbine trip without bypass [TTNB], feed water controller failure [FWCF], and main steam line isolation valve closure with the backup (flux) SCRAM [MSIVF]

2. Core flow transient: recirculation flow controller failure [RFCF]

3. Cold water transient: loss of feed water heating [LFWH]

4. ATWS pressurization transient: main steam line isolation valve closure without SCRAM [MSIV ATWS]

8.1.1 Baseline Analysis of Pressurization Transients

8.1.1.1 Turbine Trip No Bypass (TTNB)

The TTNB event is characterized by the fast closure of the turbine stop valves (TSV). The sudden closure of the stop valves causes a rapid pressurization of the steam lines and reactor vessel, resulting in a rapid power excursion. The event is heightened by the assumed failure of the pressure relief function provided by the turbine bypass valves. The turbine stop valve position switches initiate a reactor SCRAM. Power is mitigated with the help of negative reactivity due to the SCRAM and due to void production as the heat flux rises. The safety/relief valves actuate as the steamline pressure rises to the setpoint. This action limits the pressure rise. The event is modeled at 100% power and 104.6% flow with an EOC nominal power shape. The key parameters for both code streams are presented in Figure 8-5 through Figure 8-12 and Table 8-1.

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Figure 8-5: TTNB Power

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Figure 8-6: TTNB Feed Water Flow

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Figure 8-7: TTNB Core Flow

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Figure 8-8: TTNB Inlet Subcooling

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Figure 8-9: TTNB Dome Pressure Increase

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Figure 8-10: TTNB SRV Flow

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Figure 8-11: TTNB Vessel Flow

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Figure 8-12: TTNB ΔCPR / ICPR

Table 8-1: TTNB Key Transient Parameters

Trip Time Summary (sec)	TRACG02	TRACG04
Turbine Trip	[[	
Reactor SCRAM initiated on TSV position		
Safety/relief valves start to open		]]
Initial Conditions	**TRACG02**	**TRACG04**
Core power (%)	[[	
Core flow (%)		
Dome pressure (Pa)		
Core Inlet Temperature (K)		]]
Key Transient Parameters	**TRACG02**	**TRACG04**
Peak power (%) and time of max. (sec)	[[	
Maximum core flow (%) and time of max. (sec)		
Maximum dome pressure (Pa) and time of max. (sec)		
Maximum vessel bottom pressure (Pa) and time of max. (sec)		]]
CPR Summary	**TRACG02**	**TRACG04**
Hot Channel ICPR	[[	
Hot Channel MCPR		
Hot Channel ΔCPR/ICPR		]]

8.1.1.2 Feed Water Controller Failure (FWCF)

The FWCF event is characterized by the feedwater flow controller failing to the maximum demand value. This causes an increase in the feedwater flow. The water level rises until the high level trip setpoint (L8) is reached. When L8 is reached, a high level turbine trip is initiated, the feedwater pumps are tripped off, and a reactor SCRAM is initiated. The turbine trip causes a rapid pressurization event that results in a power excursion similar to the TTNB. Power is mitigated with the help of negative reactivity due to the SCRAM and due to void production as the heat flux rises. The safety/relief valves actuate as the steamline pressure rises to the setpoint. This action limits the pressure rise. The event is modeled at 100% power and 104.6% flow with an EOC nominal power shape. The key parameters are presented in Figure 8-13 through Figure 8-20 and Table 8-2 for the FWCF event.

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Figure 8-13: FWCF Power

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Figure 8-14: FWCF Feed Water Flow

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Figure 8-15: FWCF Core Flow

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Figure 8-16: FWCF Inlet Subcooling

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Figure 8-17: FWCF Dome Pressure Increase

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Figure 8-18: FWCF SRV Flow

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Figure 8-19: FWCF Vessel Flow

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Figure 8-20: FWCF ΔCPR / ICPR

Table 8-2: FWCF Key Transient Parameters

Trip Time Summary (sec)	TRACG02	TRACG04
Feed water controller at maximum demand	[[	
Level 8 turbine trip and feed water pump trip		
Reactor SCRAM initiated on TSV position		
Safety/relief valves start to open		]]
Initial Conditions	**TRACG02**	**TRACG04**
Core power (%)	[[	
Core flow (%)		
Dome pressure (Pa)		
Core Inlet Temperature (K)		]]
Key Transient Parameters	**TRACG02**	**TRACG04**
Peak power (%) and time of max. (sec)	[[	
Maximum core flow (%) and time of max. (sec)		
Maximum dome pressure (Pa) and time of max. (sec)		
Maximum vessel bottom pressure (Pa) and time of max. (sec)		]]
CPR Summary	**TRACG02**	**TRACG04**
Hot Channel ICPR	[[	
Hot Channel MCPR		
Hot Channel ΔCPR/ICPR		]]

8.1.1.3 MSIV Closure Flux SCRAM (MSIVF)

The MSIV closure is characterized by closure of the main steam isolation valves. The closure causes a rapid pressurization event that leads to a power excursion. The reactor SCRAM is conservatively assumed to occur on high flux rather than the earlier isolation valve position. Power is mitigated with the help of negative reactivity due to the SCRAM and due to void production as the heat flux rises. The safety/relief valves actuate as the steamline pressure rises to the setpoint. This action limits the pressure rise. This is the limiting event for vessel overpressure protection. The primary output is peak pressure response. The event is modeled at 100% power and 104.6% flow with an EOC nominal power shape. The key parameters are presented in Figure 8-21 through Figure 8-27 and Table 8-3 for the MSIVF event.

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Figure 8-21: MSIVF Power

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Figure 8-22: MSIVF Feed Water Flow

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Figure 8-23: MSIVF Core Flow

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Figure 8-24: MSIVF Inlet Subcooling

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Figure 8-25: MSIVF Dome Pressure Increase

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Figure 8-26: MSIVF SRV Flow

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Figure 8-27: MSIVF Vessel Flow

Table 8-3: MSIVF Key Transient Parameters

Trip Time Summary (sec)	TRACG02	TRACG04
Initiate MSIV closure	[[	
Reactor SCRAM initiated on high APRM flux		
Safety/relief valves start to open		
MSIV fully closed		]]
Initial Conditions	**TRACG02**	**TRACG04**
Core power (%)	[[	
Core flow (%)		
Dome pressure (Pa)		
Vessel bottom pressure (Pa)		
Core Inlet Temperature (K)		]]
Key Transient Parameters	**TRACG02**	**TRACG04**
Peak power (%) and time of max. (sec)	[[	
Maximum core flow (%) and time of max. (sec)		
Maximum dome pressure (Pa) and time of max. (sec)		
Maximum vessel bottom pressure (Pa) and time of max. (sec)		]]

8.1.2 Baseline Analysis of a Core Flow Transient

8.1.2.1 Recirculation Flow Controller Failure (RFCF)

The RFCF event is characterized by an upscale failure of the recirculation motor/generator speed controller in one loop. The B loop fluid coupler velocity is assumed to increase at a rate of 25%/sec. The pump speed increases to maximum in about 3 seconds. The APRM high neutron flux trip is assumed to be disabled so that an automatic scram is not initiated for this event. The event is modeled at 53.3% power and 36.1% flow at EOC conditions. The key parameters are presented in Figure 8-28 through Figure 8-35 and Table 8-4 for the RFCF event.

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Figure 8-28: RFCF Power

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Figure 8-29: RFCF Feed Water Flow

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Figure 8-30: RFCF Core Flow

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Figure 8-31: RFCF Pump B Coupler Position

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Figure 8-32: RFCF Pump B Speed

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Figure 8-33: RFCF Dome Pressure Increase

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Figure 8-34: RFCF Vessel Flow

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Figure 8-35: RFCF ΔCPR / ICPR

Table 8-4: RFCF Key Transient Parameters

Trip Time Summary (sec)	**TRACG02**	**TRACG04**
Initiate M/G controller failure	[[	
M/G coupler at maximum position		]]
Initial Conditions	**TRACG02**	**TRACG04**
Core power (%)	[[	
Core flow (%)		
Dome pressure (Pa)		
Core Inlet Temperature (K)		]]
Key Transient Parameters	**TRACG02**	**TRACG04**
Peak power (%) and time of max. (sec)	[[	
Maximum core flow (%) and time of max. (sec)		]]
CPR Summary	**TRACG02**	**TRACG04**
Hot Channel ICPR	[[	
Hot Channel MCPR		
Hot Channel ΔCPR/ICPR		]]

8.1.3 Baseline Analysis of a Cold Water Transient

8.1.3.1 Loss of Feed Water Heating (LFWH)

The LFWH event is characterized by the reduction in core inlet subcooling caused by a reduction in feedwater heating. The increase of inlet subcooling increases moderation and causes an increase in power. An automatic reactor scram does not occur for this event. The event assumes a 30-second feedwater heater time constant. The event is modeled at 100% power and 104.6% flow with an EOC nominal power shape. The key parameters are presented in Figure 8-36 through Figure 8-42 and Table 8-5 for the LFWH event.

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Figure 8-36: LFWH Power

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Figure 8-37: LFWH Feedwater Flow

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Figure 8-38: LFWH Core Flow

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Figure 8-39: LFWH Inlet Subcooling

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Figure 8-40: LFWH Dome Pressure Increase

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Figure 8-41: LFWH Vessel Flow

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Figure 8-42: LFWH ΔCPR / ICPR

Table 8-5: LFWH Key Transient Parameters

Trip Time Summary (sec)	TRACG02	TRACG04
Loss of feed water heating	[[	]]
Initial Conditions	**TRACG02**	**TRACG04**
Core power (%)	[[	
Core flow (%)		
Dome pressure (Pa)		
Feed water temperature (K)		
Core inlet temperature (K)		]]
Key Transient Parameters	**TRACG02**	**TRACG04**
Peak power (%) and time of max. (sec)	[[	
Maximum core flow (%) and time of max. (sec)		
Maximum dome pressure (Pa) and time of max. (sec)		
Minimum feed water temperature (K) and time of min. (sec)		
Maximum core inlet subcooling (%) and time of max. (sec)		]]
CPR Summary	**TRACG02**	**TRACG04**
Hot Channel ICPR	[[	
Hot Channel MCPR		
Hot Channel ΔCPR/ICPR		]]

8.1.4 Baseline Analysis of an ATWS Pressurization Transient

8.1.4.1 MSIV Closure ATWS (MSIV ATWS)

The MSIV closure ATWS is characterized by closure of the main steam isolation valves. The closure causes a rapid pressurization event that leads to a power excursion. No reactor SCRAM is assumed to occur. Power is mitigated with the help of negative reactivity due to void production as the heat flux rises. The safety/relief valves actuate as the steamline pressure rises to the setpoint. This action limits the pressure rise. The primary output is peak pressure response. The event is modeled at 100% power and 104.6% flow with an EOC nominal power shape. The key parameters are presented in Figure 8-43 through Figure 8-49 and Table 8-6 for the MSIV ATWS event.

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Figure 8-43: MSIV ATWS Power

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Figure 8-44: MSIV ATWS Feed Water Flow

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Figure 8-45: MSIV ATWS Core Flow

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Figure 8-46: MSIV ATWS Inlet Subcooling

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Figure 8-47: MSIV ATWS Dome Pressure Increase

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Figure 8-48: MSIV ATWS SRV Flow

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Figure 8-49: MSIV ATWS Vessel Flow

Table 8-6: MSIV ATWS Key Transient Parameters

Trip Time Summary (sec)	TRACG02	TRACG04
Initiate MSIV closure	[[	
Safety/relief valves start to open		
MSIV fully closed		]]
Initial Conditions	**TRACG02**	**TRACG04**
Core power (%)	[[	
Core flow (%)		
Dome pressure (Pa)		
Vessel bottom pressure (Pa)		
Core Inlet Temperature (K)		]]
Key Transient Parameters	**TRACG02**	**TRACG04**
Peak power (%) and time of max. (sec)	[[	
Maximum core flow (%) and time of max. (sec)		
Maximum dome pressure (Pa) and time of max. (sec)		
Maximum vessel bottom pressure (Pa) and time of max. (sec)		]]

8.2 Effect of Kinetics and Thermal Hydraulic Model Changes

The comparisons shown in Sections 7.1 and 8.1 all show that the power response is higher in magnitude with PANAC11 / TRACG04 than with PANAC10 / TRACG02. The initial vessel steam flow and pressure responses are generally very close as seen in Figure 8-9 and Figure 8-11. This would indicate that the thermal hydraulic response of TRACG04 is essentially the same as TRACG02. The propagation of the pressure wave through the steam line following the closure of the turbine stop valve is the same, and the initial pressurization of the reactor pressure vessel is the same. However, the response to this pressurization is higher in magnitude for PANAC11 / TRACG04 than for PANAC10 / TRACG02. Once this higher power response for PANAC11 / TRACG04 is propagated primarily through conductive and convective heat transfer to the coolant, the resulting increased vapor generation leads to a higher pressure for PANAC11 / TRACG04 than for PANAC10 / TRACG02. Similarly, the increased heat flux for PANAC11 / TRACG04 leads to an increased ΔCPR for PANAC11 / TRACG04 relative to PANAC10 / TRACG02. This would indicate that the main cause of the differences between PANAC11 / TRACG04 and PANAC10 / TRACG02 is the change from the PANAC10 to the PANAC11 kinetics and that the effect of the other changes as summarized in Section 4.1 is negligible.

To verify the above assumption, a comparison was made for the turbine trip with no bypass [Section 8.1.1.1] where the power responses were forced to be identical. The same power response versus time based on the TRACG04 calculation was used as input to both TRACG02 and TRACG04. The TRACG04 channel grouping and power distribution was also used for TRACG02. This way, the power versus time and the spatial power distribution were identical for TRACG02 and TRACG04. In addition, the power of the limiting CPR channel in the core was increased to yield an MCPR for the transient that was close to one. Note, the purpose of this comparison was to compare the thermal hydraulic response of TRACG04 and TRACG02 for the an identical power response. Therefore, the results in this section are not directly comparable to the results in Section 8.1.1.1.

An additional case is represented in the following comparisons by the green curves labeled TRACG04+. This case contains the 5-cell TRACG02 jet pump model, the Holman free convection heat transfer, the Vierow-Schrock condensation heat transfer, and the GESTR fuel conductivity models. As described in the following paragraphs, these models were turned back to the TRACG02 default to demonstrate the source of some of the very small differences shown in Figure 8-51 through Figure 8-55.

Figure 8-50 shows the power response for the TTNB comparison. It is seen that the power responses are the same, by design.

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Figure 8-50: TTNB TRACG02 and TRACG04 Power

Figure 8-51 shows the pressure response. It is seen that the pressure responses are virtually identical until the opening of the safety relief valves (SRV). TRACG04 depressurizes slightly slower than TRACG02 following the opening of the SRV.

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Figure 8-51: TTNB TRACG02 and TRACG04 Dome Pressure Increase

The SRV flows are shown in Figure 8-52. The small difference in SRV flow is a direct result of the small difference in pressure between TRACG04 and TRACG02. The difference in pressure occurs after the peak vessel pressure and after the minimum CPR.

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Figure 8-52: TTNB TRACG02 and TRACG04 SRV Flow

Figure 8-53 shows the core flow. It is seen that the core flows are similar for TRACG04 and TRACG02, however there are small differences. TRACG04 used the 6-cell jet pump nodalization as the default while TRACG02 used the 5-cell nodalization. To evaluate the sensitivity to the jet pump nodalization, TRACG04 was also run with the same 5-cell nodalization as TRACG02. This case is represented by the green curves labeled TRACG04+ on the Figure 8-51 through Figure 8-55. The TRACG04 core flow response is nearly identical to that from TRACG02 when the same 5-cell nodalization is used for both cases, but the 6-cell model has an insignificant effect on the results. In addition, three other known differences were eliminated between TRACG04 and TRACG02 in the TRACG04+ calculation. The Holman free convection heat transfer, the Vierow-Schrock condensation heat transfer, and the GESTR fuel conductivity models were used in this TRACG04+ calculation as in the TRACG02 calculation.

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Figure 8-53: TTNB TRACG02 and TRACG04 Core Flow

Figure 8-54 shows the vessel steam flow. The vessel steam flows are virtually the same for TRACG04 and TRACG02.

[[

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Figure 8-54: TTNB TRACG02 and TRACG04 Vessel Flow

Figure 8-55 shows the CPR response for the most limiting channel in the core. The CPR responses are very similar for TRACG04 and TRACG02. The difference in the minimum CPR is [[ ]]. When the 5-cell jet pump model and the same correlations for the free convection heat transfer, condensation heat transfer, and fuel conductivity are used in both calculations, the results are very close, and the difference in the minimum CPR is [[ ]]. In both cases the differences are small, less than [[ ]], which is a general threshold of significance for the minimum CPR. Similarly, the differences in the other parameters as shown in Figure 8-51 through Figure 8-55 are also negligibly small.

Due to the closeness of the thermal hydraulic response between TRACG04 and TRACG02 when the same power response is used, it can be concluded that the major differences between TRACG04 and TRACG02 are due to the difference between the PANAC10 and PANAC11 kinetics models.

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Figure 8-55: TTNB TRACG02 and TRACG04 CPR

8.3 Conclusions

This report documents a comparison of TRACG04 and TRACG02 for AOO transient and ATWS overpressure events. The following observations and conclusions can be made from these comparisons:

- The major difference between TRACG04 and TRACG02 is due to the difference between the PANAC11 kinetics in TRACG04 and the PANAC10 kinetics in TRACG02.
- The other model improvements implemented into TRACG04, primarily to improve the applicability to LOCA and ATWS events and to improve some models significant for the ESBWR, have a negligible effect on AOO transient and ATWS overpressure analyses.
- TRACG04 generally produces more conservative results than TRACG02 when applied to AOO transient and ATWS overpressure events.
- Use of PANAC11 / TRACG04 for AOO transient and ATWS overpressure transients by GE going forward has been shown here to be acceptable.

9.0 TECHNICAL SPECIFICATION MODIFICATIONS

The text presented in Section 9.0 of [1] in relation to the Technical Specifications and Technical Specification Bases remains applicable for the new code stream of PANAC11 / TRACG04.

10.0 REFERENCES

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[2] *TRACG Application for Anticipated Transient Without SCRAM Overpressure Transient Analyses*, NEDE-32906P, Supplement 1, September 2002.

[3] MFN-115, Letter from G. B. Stramback (GE) to M. B. Fields (USNRC), *Transient CPR Calculation for TRACG (TRACG Application for Anticipated Operational Occurrences Transient Analyses, NEDE-32906P, Supplement 2, October 2004)*, November 3, 2004.

[4] J. G. M. Andersen, et. al., *TRACG Model Description*, NEDE-32176P, Rev. 3, April 2006.

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[9] J. V. Cathcart and R. E. Pawel, *Zirconium Metal-Water Oxidation Kinetics: IV. Reaction Rate Studies*, ORNL/NUREG-17, August 1977.

[10] F. T. Bolger and M. A. Holmes, *TRACG Application for Anticipated Transients without Scram Overpressure Transient Analyses*, NEDE-32906P, Supplement 1 -A, November 2003.