# PROGRESS REPORT ON STAFF'S EVALUATION OF GE LICENSING TOPICAL REPORT NEDE-32176P (REVISION 0) "TRACG MODEL DESCRIPTION"

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## ABSTRACT

This progress report reviews GE Licensing Topical Report (LTR) NEDE-32176P, entitled "TRACG Model Description." The acceptable models are indicated in Section 2. The open issues are explicitly listed in Section 3. The evaluations of various models are given in Section 4. The important numerics are evaluated in Section 5. Section 6 presents the summary of the review. Appendix A provides a list of unsatisfactory responses to RAI 901.11. Additional RAIs which were also considered to be unsatisfactory are discussed in Section 3.

## 1. INTRODUCTION

General Electric (GE) has submitted reports NEDE-32176P[1], describing the TRACG models, NEDE-32177P[2], Rev.1, documenting the TRACG qualification, and NEDE-32178P[3], reporting the application of TRACG to SBWR Licensing Safety Analysis. TRACG is a GE's system code being proposed as a tool for licensing safety analyses of the new Simplified Boiling Water Reactor (SBWR).

This report reviews the first topical report NEDE-32176P. The report describes the models, correlations, thermodynamic and material properties, and numerics. We have conducted a review of the subject topical report. A list of questions was compiled and sent to GE as a Request for Additional Information (RAI). GE has submitted a reply[4] to the RAI, which has also been reviewed. This progress report documents the results of these reviews. The review has been conducted in accordance with the guidelines provided by Sections 4.3 and 4.4 of the Standard Review Plan (NUREG-0800). We have focused the review on the models, empirical correlations, experimental data base, assumptions and approximations made, and the solution methods. We have also paid a particular attention to the potential errors in the formulations.

In the process of the review, we have consulted the GE licensing topical reports on the previously approved codes PANACEA[5], REDY [6], ODYN [6], and SAFER [7,8,9].

As discussed in the evaluation sections (Sections 4 & 5) of this report, there were certain sections of the LTR, where the information provided were sufficient and considered to be acceptable. However, the LTR also had serious deficiencies, lacking some significant information that are essential to evaluate a computer code. Important areas such as containment models were not addressed in the report. Several of the items that were addressed in the report were inadequate. RAIs were issued on the material covered in the report with the intention to close some of the open items. However, even after GE provided responses to the RAIs, several items remained open because the responses were either incomplete or inconclusive. Obviously, no significant technical questions could be asked on the material that were missing from the report. It is, therefore, anticipated that when GE addresses the open issues in the upcoming Revision 1 of NEDE-32176P, additional questions/RAIs will be issued on the subject matter after reviewing the revised report.

## 2. LIST OF SATISFACTORY MODELS

Based on review of the GE report (NEDE-32176P, Rev. 0) and the responses for RAIs, the following models are adequately described and judged to be acceptable.

TRACG model for heat conduction has been described in proper detail and is acceptable. Although the model is based on the one-dimensional thermal conduction equation in cylindrical geometry for fuel elements, it does account for axial conduction, which is only needed to model quenching or reflood in the core in a LOCA, via a correlation developed from two-dimensional (r,z) parametric calculations of the heat conduction in a fuel element. This approach is efficient and considered to be acceptable for its intended purpose. The model is also limited to either a lump-parameter or a one-dimensional conduction for heat structures. This is acceptable because the heat structure can be adequately represented as a heat slab.

The code has detailed models for a very comprehensive list of basic building blocks for constructing any control systems. The models are very flexible, adequately described, and judged to be acceptable to represent the control systems in the SBWR.

The code also has a first-principle mechanistic model for the steam separator, which is adequately described. The model has been validated against full-scale performance test data for two-stage and three-stage steam separators, and therefore considered acceptable on the basis of the data bases used and validations performed. The important parameters that were validated are the pressure drop, carryunder and carryover which match the test data by means of the correlation constants AA, BB, CC and DD. Furthermore, the data bases covered the ranges applicable to the SBWR design.

## 3. LIST OF OPEN ISSUES

Although there are areas which are considered satisfactory, as listed above, all the TRACG model descriptions are not well documented in the subject report NEDE-32176P. The following areas have been identified as the most significant information that are open issues, necessary to be addressed in the TRACG code documentation in order to evaluate the quality of the code. Good examples of acceptable code documentation are the RELAP5 Model and Correlation Document (NUREG/CR-5535) and TRAC-PF1 Model and Correlation Document (NUREG/CR-5069).

1) <u>Description of the models and correlations as coded</u>

For either hydraulics or neutron kinetics, model equations are presented without any discussion on the model limitations and assumptions invoked. The report should include not only the description of the models and correlations but also any assumptions and limitations imposed due to numerical considerations such as physical limits or time smoothing.

2) Basis of the models and correlations

In the discussion of constitutive correlations, there is little discussion on the model accuracy from the assessments with test data, nor explicit reference of data bases used for assessments. Data bases for the models and correlations should be clearly stated or referenced. Any adjustments or logic required for implementation should also be included. References, when appropriate, should be provided with respect to the validations done in the companion topical report NEDE-32177P, Revision 1.

3) Critical assessment of models and correlations for intended applications

There is little discussion on the critical assessment of models and correlations for the intended applications in hydraulics, heat conduction, and neutron kinetics. Demonstrate model accuracy by testing with test data, with exact solutions for the conditions similar to the conditions expected in the applications, or with past results calculated by independent computer codes that have been approved by NRC. Provide an estimate of the uncertainty or accuracy for each model and correlation.

There is no discussion on the applicability of models and correlations to the intended applications in hydraulics, heat conduction, and neutron kinetics. A statement of applicability of the models and correlations along with their limitations should be included in the report.

The responses to RAIs (901.11) were not satisfactory. Appendix A gives examples of concerns with these responses.

4) Description of containment models and correlations is missing

Since GE intends to use TRACG for containment transient analyses, it is very important that documentation must cover in detail the containment related models and correlations incorporated in TRACG, and their validations against test data. It should be noted that the SBWR containment response strongly influences the primary system behavior in a LOCA.

5) Containment models should include a multi-species gas model and its validation

TRACG must be able to predict non-condensible gases (nitrogen and hydrogen) distribution accurately in order to assure the effectiveness of PCCS, and thereby, the effectiveness of core cooling capability of SBWR after a LOCA.

6) Lack of discussions on time step control algorithms

Although the report describes the numerics in a general term, there is no discussion on the time step control algorithms for hydraulics, heat conduction, and neutron kinetics regarding both the accuracy and numerical stability (in case of explicit integration). The report should describe the automatic time step control logic and the methods used to control the accuracy and numerical instability in case of the explicit integration.

7) Lack of BOP modeling capability, RAI Number 901.13(a),(r),(s)

The report does not discuss the modeling capability for the balance of plant (BOP). While the basic component models can be used to simulate most of the BOP components, the turbines cannot be represented by any of the basic component models. A turbine model is needed for a realistic simulation of the BOP response. Furthermore, because of the limitations of the basic heat exchanger model, it is difficult to represent adequately the BOP condenser and isolation condenser.

8) Lack of mixing model assessments, RAI number 901.3 and 901.7c

The mixing model for turbulent mixing and molecular diffusion is nonmechanistic using a $c=0.1$ constant value. It lacks critical model assessments. GE states that the mixing model is not used currently for any plant calculations. However, it is expected to be important for containment analyses, feedwater/steam mixing in the downcomer, and turbulent mixing in the upper plenum. Assessments against test data are needed.

9) Lack of Validations for Upper Plenum Model and Steam Dryer Model, Related RAI numbers 901-13(m),(n)

Although the code has very sophisticated analytical models for the upper plenum and steam dryer, they have not been shown to have been validated against real test data. We consider the lack of assessments for these models an open issue.

10) Lack of assessments for boron transport and mixing, RAI number 901.7b & 901.14(l)

GE states that TRACG assumes perfect mixing for boron circulation in a given computational cell. As a result of this assumption, the cell size can have an influence on the calculated results and must be appropriately chosen. Note that the perfect mixing assumption is valid only at a high liquid flow rate. At low flow rates, the heavier boron solution will not travel with the lighter liquid at the same velocity. Since the boron transport model has not been assessed yet against test data, GE states that it intends to qualify the boron mixing process through comparisons with tests in the 1/6 scale boron mixing facility at Vellocitos. This should be done.

11) Accuracy assessments of thermodynamic and material properties, RAI number 901.16

The thermodynamic and material property correlations are presented without any discussions on their accuracies. Uncertainty bands for these correlations should be explicitly stated and referenced.

12) One-group 3D kinetics model needs assessment for transients, RAI number 901.15

TRACG employs a one-group diffusion model for neutron kinetics instead of the standard two-group diffusion model widely used in nuclear industry. To obtain the one-group model, some fundamental assumptions are invoked, which are not critically assessed. It is, in general, very difficult because the impact of the assumptions depends on the transient characteristics of the application. Furthermore, TRACG uses a quasi-static approximation to solve the one-group model equations instead of direct time integration. Since there exists international standard 3D transient benchmark problems[11], the one-group model should be assessed against various published 2-group solutions for these 3D transient benchmarks.

## 4. EVALUATION OF MODELS

### 4.1 Hydraulics

TRACG employs a two-fluid model for two-phase flow. It solves six conservation equations for both the liquid and gas phases along with phasic constitutive relations for closure. In addition, a boron transport equation and a noncondensible gas mass equation are solved. The spatially discretized equations are solved by donor-cell differencing in staggered meshes in one, two, or three dimensions.

The balance equations are presented without any discussions on the model limitations, applicability, and any assumptions invoked. In the description of constitutive correlations, there is no discussion on the model accuracy from assessments with test data, nor explicit reference of data base used for the assessments. The list of constitutive models is impressive, covering all important phenomena that may occur in a SBWR. The unified flow regime map is a strong point. The interfacial shear model was derived from the drift flux model using available experimental data at steady state. This steady-state equivalence is assumed to be valid for transient conditions, an assumption very hard to verify. Also, partitioning of wall heat transfer and wall friction between two phasic equations are not on firm basis.

The two-phase level tracking model invokes some approximations for the void fraction above and below the mixture level that may not be accurate if significant voiding occurs below the mixture level. Furthermore, the model uses an arbitrary cutpoint $\alpha_{cut}$ for level detection.

The two-fluid conservation equations contain a mixing term to account for turbulent mixing and molecular diffusion. This is a good feature, but the mixing model is qualitative at best and lacks experimental validation.

TRACG has a rewet model for post-CHF heat transfer. The rewet model is not well described and should be expanded in the revised report.

Containment relevant models are missing in the report. This is a gross omission because TRACG is slated for applications to containment transient analyses. These models along with their assessments should be included in the revised report.

### 4.2 Heat Conduction

TRACG solves the heat conduction equation for the fuel rods (in cylindrical geometry) and for structural materials (in slab geometry) in the system. The latter has either a lumped slab model or a one-dimensional slab model.

The strengths of the TRACG heat conduction model are the sophisticated transient gap conductance model and the implicit solution method that couples implicitly the heat transfer between the fuel rod and the coolant by iteration.

Although TRACG solves the heat conduction equations in only one dimension (in cylindrical geometry for fuel elements and in slab geometry for heat structures), it does account for axial conduction, which is only needed to model quenching or reflood in the core in a LOCA, by means of a correlation developed from two-dimensional (r,z) parametric calculations of the heat conduction in a fuel element. This approach is efficient and considered acceptable for its intended purpose.

The model is also limited to either a lump-parameter or a one-dimensional conduction for heat structures. This is also acceptable because the heat structure can be adequately represented as a heat slab. A minor weakness is the neglect of source term in the heat slab model equation. Thus, the effect of direct heating (say, due to gamma ray) in the structures cannot be accounted for.

### 4.3 Component Models

TRACG employs basic component models as building blocks to construct physical models for intended applications. Such an approach renders it a very general and flexible tool to simulate a wide variety of systems. The components that are modeled include pipe, pump, valve, tee, channel, jet pump, steam separator, steam dryer, vessel, upper plenum, heat exchanger, and break and fill as boundary conditions. However, a turbine model that is required for BOP simulation is missing. The heat exchanger model contains some simplifying approximations which may not be appropriate for simulating the isolation condenser or the condenser in BOP. A separate condenser model should, therefore, be provided.

TRACG has a first-principle mechanistic model for the steam separator, which is adequately described. The model has been validated against full-scale performance test data for two-stage and three-stage steam separators. The important parameters that were validated are the pressure drop, carryunder and carryover which match the test data by means of the correlation constants AA, BB, CC and DD. Furthermore, the data bases covered the ranges applicable to the SBWR design.

Although the code has very sophisticated analytical models for the upper plenum and steam dryer, they have not been shown to have been validated against real test data. These models should be assessed against test data.

### 4.4 3D Neutron Kinetics

TRACG employs a one-group diffusion model for neutron kinetics instead of the standard two-group diffusion model widely used in nuclear industry. To obtain the one-group model, some fundamental assumptions are invoked, which are not critically assessed. It is, in general, very difficult because the impact of the assumptions depends on the transient characteristics of the application. Furthermore, TRACG uses a quasi-static approximation to solve the one-group model equations instead of direct time integration.

The strength of TRACG's neutron kinetics model is its efficiency which permits detailed bundle-by-bundle representation for the core. Its weakness lies in the basic assumptions and approximations that are required to arrive at the efficient one-group kinetic equations. Since there exist international standard 3D transient benchmark problems, the one-group model should be assessed against various published 2-group solutions using the direct integration for these 3D transient benchmarks.

### 4.5 Thermodynamic and Material Properties

The thermodynamic properties used in TRACG are calculated from polynomial fits to steam table data for water and from ideal gas law for the noncondensible gases. The thermodynamic property routines cover a very wide range of pressures (1 Pa $\leq$ P $\leq$ 45 MPa) and temperatures (27.15K $\leq T_l \leq$ 714K, 273.15K $\leq T_v \leq$ 3000K). Separate liquid and vapor property fits are given along with their fitting constants. However, the accuracies or uncertainties of these property routines are not discussed, and should be explicitly stated and referenced in the revised documentation.

The material properties used in TRACG are based on the "GE Material Properties Handbook," which is an extensive library of temperature-dependent properties of nuclear fuel ($UO_2$, Zircaloy cladding, Zirconium oxide, heater rod insulator, and boron nitride insulator) and structure materials (stainless steel 304 and 316, carbon steel, Inconel 600, and concrete). Again, the accuracies or uncertainties of these material property routines are not discussed, and should be clearly stated and referenced in the revised report.

### 4.6 Control Systems

TRACG control systems are constructed by the user from basic control blocks such as first-order LAG, lead-lag compensator LLAG, simple integrator INT, limited integrator LINT, second-order transfer function SOTF, etc. There is a wealth of control blocks available (63 control block types), sufficient to represent any control system. This user controllable modular approach makes it a very flexible tool. It also allows a flexible interface with the hydraulic component models and among the control blocks themselves. This feature makes it possible to simulate various dynamic processes with the control system models.

## 5. EVALUATION OF NUMERICS

### 5.1 Hydraulics

TRACG numerics is a significant improvement over its predecessor TRAC-BD1/MOD1. As a default, it employs a fully implicit integration for hydraulic equations. For time-domain stability analyses, it uses an optional explicit integration because the implicit integration may suppress real physical oscillations. The fully implicit integration is accomplished by means of a predictor-corrector iterative technique. The detail of the explicit integration is not described and should be included in the upcoming revised report.

Time step control algorithms are not provided in the report. They are an important part of the numerics as they can impact the results of calculations, therefore should also be included. The control algorithms should address both the accuracy criteria and stability criteria (for the explicit integration).

### 5.2 Heat Conduction

TRACG solves heat conduction equations by implicit integration. The heat transfer coupling between the heat conduction and coolant hydraulics is also treated implicitly via an iterative technique. This implicit coupling represents a significant improvement over commonly used explicit coupling, which may incur an error on the phase shift and amplitude in a thermally induced oscillation.

Once again, the time step control algorithms are not described for heat conduction, and should be included in the revised documentation.

### 5.3 Neutron Kinetics

TRACG solves the neutron kinetic equations by means of a quasi-static approximation, which separates the neutron flux as a product of an amplitude function and a shape function. The amplitude function is obtained by solving the conventional point kinetics equations using the hydraulic time step as its time-integration step called "reactivity step."

The point kinetic equations are solved implicitly by the Kaganove method. The shape function is obtained by solving a shape function equation with a source term by iteration. The shape function equation is derived from the original neutron kinetics equations via the quasi-static approximation. The shape function is recalculated every other reactivity step called "shape step." To improve the accuracy of the quasi-static approximation, a so-called "shape step iteration" is used to estimate the shape function for each reactivity step by linear extrapolation.

The use of a hydraulic step to solve the point kinetic equations may be of concern because the hydraulic step can take a relatively large time step size (e.g., 250 ms) depending on the characteristics of the transient. Again, the time step control details are not discussed and should be included in the revised report.

### 5.4 Control Systems

TRACG solves the control system equations sequentially based on the order in which the control blocks are specified on input. This makes it a potentially explicit integration scheme. If a feedback loop exists in the control system, an implicit solution of the control system equations is impossible. To make sure that the control system will be stable, TRACG uses a sufficiently small time step size (always less than or equal to the hydraulic time step size) to integrate the control system equations.

## 6. SUMMARY

TRACG is a detailed best-estimate BWR transient analysis code. It is based on a two-fluid thermal-hydraulic model for the reactor vessel, primary coolant system and containment, and a three-dimensional neutron kinetics model for the reactor core. The modular approach used makes it a general-purpose system code. In general, TRACG is a significant improvement over the predecessors (REDY, ODYN, SAFER) in many respects. Table 1 summarizes our review of the TRACG model description.

The documentation of TRACG model description is not adequate. Many questions have been raised and sent to GE as a Request for Additional Information (RAI). GE has submitted a response to the RAI which has also been reviewed. GE has agreed on expanding the subject report NEDE-32176P to address most of the raised questions. The tentative revised table of contents sent to NRC appears to be a significant improvement. It is recommended that GE , when referring to a book or report, provide the page number, equation number and table number along with the reference in the text (i.e., Wallis, 1969, pg# ).

There are still many open issues regarding the report, even after reviewing the RAI responses. They are listed in Section 3.

Table 1

**TRACG Model Review Summary**

| MODEL | PROS | CONS | QUALIFICATION |
|---|---|---|---|
| **Hydraulics** | State-of-art two-fluid model, unified flow regime map, 3D vessel representation | Constitutive relations for interfacial laws lack experimental supports | Extensive validations vs. Separate effects tests, integral tests, component tests, and plant data (BWRs) |
| **Heat Conduction** | Sophisticated transient gap conductance model | Source term neglected in heat slab model | Implicit in validations in hydraulics above |
| **Component Models** | General, flexible and modular | Turbine model missing, some limitations on heat exchanger model | Limited validation, mostly integral tests, limited separate effect tests |
| **3D Kinetics** | Bundle-by-bundle 3D representation, efficient quasi-static solution method | Coarse-mesh feedback model, use of TH time step for point kinetics, some basic assumptions | Extensive steady-state validations, limited transient validation. No benchmark against International 3D problems |
| **Numerics** | Improved predictor-corrector method, implicit coupling between hydraulics and heat conduction | Energy conservation not as good as mass conservation | Implicit in validation above, independent assessments against standard problems desired |
| **Control Systems** | General and modular | Burden on the user to construct models | Qualification quite limited |
| **Property Correlations** | Cover wide range of pressures and temperatures | Uncertainty of the correlations not given | Accuracy assessment needed or present the past assessments |

## 7. REFERENCES


1. J. G. M. Andersen, Md. Alamgir, Y. K. Cheung, L. A. Klebanov, and J. C. Shaug, "Licensing Topical Report - TRACG Model Description," NEDE-32176P, General Electric Company, February 1993.

2. J. G. M. Andersen, et. al., "TRACG Qualification," NEDE-32177P, Rev. 1, General Electric Company, June 1993.

3. H. T. Kim, W. Marquino, F. M. Paradiso, and J. R. Fitch, "Application of TRACG Model to SBWR Licensing Safety Analysis," NEDE-32178P, Revision 0, General Electric Company, February 1993.

4. R. H. Buchholz, "Submittal of Additional Information on Licensing Topical Reports (NEDE-32176P, NEDE-32177P and NEDE-32178P)," Letter to USNRC, Docket STN 52004, September 20, 1994.

5. "Licensing Topical Report - Steady-State Nuclear Methods," NEDE-30130PA,General Electric Company, April 1985.

6. R. B. Linford, "Analytical Methods of Plant Transient Evaluations for the General Electric Boiling Water Reactor," NEDO-10802, General Electric Company 1973.

7. S. O. Akerlund, et. al., "Licensing Topical Report - The GESTR-LOCA and SAFER Models for the Evaluation of the Loss-Of-Coolant Accident," NEDE-23785PA, Vol. 1, Revision 1, General Electric Company, June 1984.

8. K. C. Chan, et. al., "The GESTR-LOCA and SAFER Models for the Evaluation of the Loss-Of-Coolant Accident - Long Term Inventory Model for BWR LOCA Analysis," NEDE-23785-1-PA, Vol. 2, Revision 1, General Electric Company, October 1984.

9. J. E. Leonard, et. al., "General Electric Company Analytical Model for Loss-Of-Coolant Analysis in Accordance With 10CFR50 Appendix K Amendment No. 1 - Calculation of Low Flow Film Boiling Heat Transfer for BWR LOCA Analysis," NEDO-20566-1-A, Rev.1, General Electric Company, October 1982.

10. S. Levy, et. al., "Licensing Topical Report - General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application," NEDO-10958A, General Electric Company, January 1977.

11. Herbert Finnenmann and Aldo Galati, "NEACRP 3-D LWR Core Transient Benchmark Final Specifications," NEACRP-L-335 (Rev.1), January 1992.

## APPENDIX A. LIST OF UNSATISFACTORY RESPONSES TO RAI

| RAI # | Comments |
|---|---|
| 901.11g | The explanation of partitioning of wall shear between phasic equations is not general and applicable to all flow regimes. |
| 901.11j | The test selected is only for onset of instability. There are other tests which will test the correlation better such as FRIGG dynamic tests, Peach Bottom Instability Tests. |
| 901.11k | The expression goes to correct limits but how is it valid for intermediate values of a void fraction? |
| 901.11m | Wallis mentioned a value of 12 for Weber number for stable drops. He also provided an expression for Weber number based on stability number. What is the basis of using a value of 13 and why a value of 6.5 will provide mean interfacial area density ? |
| 901.11p | The equation of concern could not be found in the reference cited. Please provide page number. |
| 901.11q | The question about assuming the void fraction below the level equal to the void fraction in the cell below and similarly void fraction above the level equal to cell above is not answered. What is the inaccuracy in this assumption. How is the effect of vapor generation in the cell accounted for? |
| 901.11r | What Weber number is used? Are the Weber number used in interfacial heat transfer and interfacial shear consistent? |
| 901.11s | Is there a separate effects test or data base to support Eq 3.2-87 ? |
| 901.11t | No basis or limitation of the model provided. |
| 901.11u&v | No basis or limitation of the model provided |
| 901.11w | Please explain what is used for degradation of condensation in different flow regimes due to non-condensibles and the basis of the correlations. |
| 901.11x | Is the heated surface wetted. How is the wetted fraction calculated from minimum film thickness? What is the basis? |

901.11z Is the boiling curve and transitions valid for low pressure conditions with a soft inlet.

901.11hh No basis (data or tests, applicability) provided for Eq 3.2-120.

901.11mm No basis ( data, tests, applicability ) provided for Eq 3.2-181.