UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 25, 2001

Mr. Gary L. Vine
Senior Washington Representative
Electric Power Research Institute
2000 L Street, NW., Suite 205
Washington, DC 20036

SUBJECT: SAFETY EVALUATION REPORT ON EPRI TOPICAL REPORT NP-7450(P), REVISION 4, "RETRAN-3D - A PROGRAM FOR TRANSIENT THERMAL-HYDRAULIC ANALYSIS OF COMPLEX FLUID FLOW SYSTEMS" (TAC NO. MA4311)

Dear Mr. Vine:

The U.S. Nuclear Regulatory Commission (NRC) staff has reviewed the Electric Power Research Institute (EPRI) Topical Report NP-7450(P), Revision 4, "RETRAN-3D - A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems," for analysis of Standard Format Chapter 15 accidents and transients. The report describes modifications to the approved RETRAN-02 analysis code which include the addition of three-dimensional kinetics capability and other changes to the thermal-hydraulic modeling capability.

The staff previously reviewed and accepted earlier versions of this analysis methodology, subject to several conditions and limitations on their use. The review of the new version has found the proposed changes to be acceptable, subject to the conditions and limitations on its use described in the enclosed safety evaluation, that you accepted in your December 13, 2000, letter. Please note that even with this generic approval of the new version, the responsibility for assessment of the code and the new modeling changes continues to rest with the individual user, and approval of all future applications of this code will require the formal submittal of detailed assessment documentation by the code user.

The staff finds that the subject topical report is acceptable for referencing in licensing applications to the extent specified and under the limitations delineated in the report and in the associated NRC safety evaluation. The safety evaluation, which is enclosed, defines the basis for acceptance of the topical report.

The staff will not repeat its review of the matters described in the subject report, when the report appears as a reference in license applications, except to ensure that the material presented applies to the specific plant involved. In accordance with the procedures established in NUREG-0390, the NRC requests that EPRI publish an accepted version of the report within 3 months of receipt of this letter. The accepted version shall incorporate (1) this letter and the enclosed safety evaluation between the title page and the abstract, (2) all requests for additional information from the staff and all associated responses, and (3) an "-A" (designating "accepted") following the report identification symbol.

If the NRC's criteria or regulations change so that its conclusions about the acceptability of the report are invalidated, EPRI or the applicant referencing the report, or both, will be expected to revise and resubmit its respective documentation, or submit justification for the continued effective applicability of the report without revision of the respective documentation.

Pursuant to 10 CFR 2.790, we have determined that the enclosed safety evaluation does not contain proprietary information. However, we will delay placing the safety evaluation in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

If you have any further questions regarding this review, please contact Leonard Olshan at (301) 415-1419.

Sincerely, /RA by Stephen Dembek for/

Stuart A. Richards, Director
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 669

Enclosure: Safety Evaluation

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FOR

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATED TO EPRI NP-7450(P), "RETRAN-3D - A PROGRAM FOR TRANSIENT THERMAL-HYDRAULIC ANALYSIS OF COMPLEX FLUID FLOW SYSTEMS"

ELECTRIC POWER RESEARCH INSTITUTE

PROJECT NO. 669

1.0 INTRODUCTION

RETRAN-3D is a flexible general purpose, thermal/hydraulic computer code that is used to evaluate the effects of various upset reactor conditions in the reactor coolant system (RCS). The code models the reactor coolant as a single phase or as two equilibrium phases with the exception that a non-equilibrium pressurizer component can be included. Conductive heat structures can be described, including the fuel elements in the reactor core. Changes in reactor power from neutron kinetics and decay heat considerations are calculated to occur with time. The name, RETRAN-3D, refers to the ability of the code to perform three-dimensional neutronic calculations in the core, but not three-dimensional fluid dynamic capability.

RETRAN-3D was developed by CSA, Inc, for the Electric Power Research Institute (EPRI) based on the RETRAN-02 computer code. RETRAN-02 was based on the RELAP4 thermal/hydraulic computer code developed by the NRC. The original code version, RETRAN-01, was released by EPRI in December 1978. The code was subsequently improved to account for slip between the phases, two-phase natural convection heat transfer, improved numerics, and other improvements. The NRC staff completed its review of RETRAN-02 MOD002 and RETRAN-02 MOD003 as described in Reference 1. The countercurrent flow logic and the slip flow modeling were modified and a new heat slab model was added to the non-equilibrium pressurizer in RETRAN-02 MOD003. A new control rod model was added as an option to produce RETRAN-02 MOD004. These modifications were also approved by the NRC staff in Reference 2. The 1979 ANS5.1 decay heat model was added to the code as RETRAN-02 MOD005. This version was approved by the NRC staff in Reference 3. The last version of the revised code as described in Reference 4, was submitted to the NRC for review as RETRAN-3D MOD3.

The staff's approval of RETRAN-02 was subject to a number of limitations described in the safety evaluations (SE) for the various RETRAN-02 versions and in the technical evaluation reports (TERs) prepared by the NRC staff's contractors. Those limitations have been reviewed in the process of preparing this SE. Because of the large amount of flexibility in the user-supplied input selection and choice of nodalization schemes, the NRC staff has required, and will continue to require, that proposed applications of RETRAN-3D be accompanied by a detailed review of the suitability of the code for each specific application.

2.0 STAFF APPROACH TO THE REVIEW

The proposal to review RETRAN-3D was made by the RETRAN Maintenance Group to the staff on July 8, 1998 (Reference 5). The code documentation was then submitted in September of that year. The staff performed the review by assembling a group of four staff members with expertise in thermal-hydraulics, kinetics, and RETRAN use. The review was originally planned to concentrate on those portions of the code which were different from the RETRAN-02 code previously reviewed.

During the course of the review, requests for additional information (RAIs) were developed and transmitted to the applicant (Reference 6). Several meetings were also held with the Advisory Committee on Reactor Safeguards (ACRS) Thermal-Hydraulic and Severe Accident Phenomena Subcommittee. Those meetings and reviews conducted by ACRS members and their consultants along with subsequent staff review resulted in additional RAIs (Reference 7). In addition, as will be discussed later in this report, problems and errors with the "momentum equation" were identified.

The RETRAN-3D review departed from previous computer code reviews in that the code itself was requested from the applicant, was installed on the NRC's computer system, and was exercised extensively. The experience gained in doing so led the staff to several insights regarding needed code user training and guidance on acceptable model, correlation, and option specification.

As a part of the review of RETRAN-3D, the limitations and conditions on use of the previous code versions were reviewed to determine which were no longer applicable and could, thus, be removed on the current code version. In addition, the staff identified the limitations that would be necessary to determine whether or not RETRAN-3D could be used as a direct substitute for RETRAN-02, in other words, use of RETRAN-3D in a RETRAN-02 mode.

Milestones in the Review

- Request for review of RETRAN-3D: July 8, 1998. Receipt of code and documentation: September 1998. Acceptance of code for review by NRC: December 4, 1998.
- Requests for additional information by the staff: April 27, 1999 and August 25, 1999. Responses were submitted by the RETRAN Maintenance Group in References 8 and 9.
- Advisory Committee on Reactor Safeguards, Thermal-Hydraulic Phenomena Subcommittee meetings: December 1998, March, May, July 1999, March 2000
- Staff participation in RETRAN-3D training: August 1999.
- Staff/EPRI meetings: September, December 1998; March, April, May, June, July, August, December 1999; March, April 2000.

3.0 RETRAN-3D MODIFICATIONS AND ADDITIONS

The following RETRAN-02 models were modified or revised in developing RETRAN-3D:

- Mixture Momentum Equation
  - Added EPRI two-phase multiplier
  - Added Colebrook wall friction with pipe roughness

- Dynamic-Slip Equation
  - Added local momentum sources and sinks
  - Added continuous wall-to-phase and interphase friction model
  - Added Govier horizontal flow regime map
  - Added correlation for interphase friction for stratifies flow

- Algebraic Slip
  - Added model option based on EPRI-NP-3989-SR for countercurrent flow

- Point Neutron Kinetics
  - Added 1979 ANS decay heat standard

- Neutron Kinetics
  - Added multidimensional kinetics option
  - Added boron feedback capability
  - Added 1979 ANS decay heat

- Critical Heat Flux (CHF)
  - Added EPRI CHF correlation
  - Updated GE correlation

- Fuel Cladding Interaction
  - Added model from VIPRE-01

- Junction Enthalpy
  - Modified countercurrent flow model
  - Added option using level tracking model

- Iterative Time-Step Controls
  - User controls for dependent variables

- Boundary Conditions
  - Extended for noncondensable gases

- Compilers and Operating Systems
  - Adapted source for FORTRAN 77
  - Converted environmental library to FORTRAN 77

The following new models were added in developing RETRAN-3D (General Applications):

- Fluid Field Equations
  - Added continuity equation for noncondensable gases
- Dynamic-Slip Equation
  - Added dynamic area model and other models for complex geometry
- Neutron Kinetics
  - Added option for multidimensional kinetics
- Accumulator
  - Polytropic expansion model for the cover gas
- Generalized Transport
  - Transport soluble chemical impurities with either the liquid phase or the vapor phase
- Flow Structure Models
  - Added Duckler model for stratified flow
  - Added Zuber model for stratified critical flow
- Transient Solution of Field Equations
  - Implicit solution method for basic equations, components and auxiliary models
- Steady-State Initialization
  - Added implicit solution method option
  - Added option for initialization of steam generators at low power
- Flow Field, Component, and Auxiliary Model Solutions
  - Made implicit with coupling to basic fluid solution
- Method of Characteristics
  - Minimizes numerical dispersion within the energy equation
- Heat Transfer
  - Added correlations for condensation
- Dynamic Gap Conductance
  - New model to account for effects of clad deformation

The following new models were added in developing RETRAN-3D (Nonequilibrium Applications):

- Fluid Field Equations
  - Added vapor mass equations (5-equation model)
  - Added equation for noncondensable gas
- Neutron Kinetics
  - Added option for multidimensional kinetics

- Wall Heat Transfer
  - Added wall-to-phase for 5-equation model

- Interphase Heat and Mass Exchange
  - Added subcooled boiling, condensation and flashing models for 5-eqn. model

- Implicit Solution Method
  - Modified basic linearization for thermal nonequilibrium equation of state

- Iterative Time-Step Controls
  - Extended to nonequilibrium models

- Heat Conduction Solution
  - Extended boundary conditions to nonequilibrium models

- Thermal-Hydraulic Boundary Conditions
  - Extended as necessary for nonequilibrium models

- Solution for Flow Field, Component, and Auxiliary Models
  - Extended for nonequilibrium models as necessary

4.0 EVALUATION OF RETRAN-3D

The review of the RETRAN-3D code and documentation was broken down into four main sections: the thermal-hydraulic models and associated numerics, the neutron kinetics and associated numerics, the code assessment, and code use. Code use included a review of the user guidance, training, and experience in running the code on NRC computers. In performing its review, the staff took into consideration views and concerns raised by members of the ACRS, Thermal-Hydraulic Phenomena Subcommittee and the subcommittee's consultants. As a result, the original plan to review only material that had not previously been reviewed as part of the RETRAN-02 review was expanded to include several aspects of the code that were previously found to present difficulties. This especially included the formulation of the momentum equation. Discussions among the reviewers identified problems that had been raised with the formulation of the momentum equation dating back to 1974. These problems still exist in the older generation of codes, such as RETRAN, that are based on the RELAP3 and RELAP4 codes. Care must be taken in the use of these codes to ensure that situations do not arise in which violation of basic principles of physics occur.

The documentation for RETRAN-3D, as will be mentioned later in the discussions, was found to be misleading in part, and erroneous in part. The known errors will be corrected when the approved version of the documentation is prepared. The user must exercise caution in the use of the documentation when, as noted below, the text and nomenclature are inconsistent and do not follow standard usage. In addition, one significant section of the documentation is incomplete because well-defined user guidelines do not exist at this time. The high degree of complexity in the use of the code coupled with the large number of available options and code flexibility make high quality user guidelines critical to reliable code use.

This review of RETRAN-3D departs from previous computer code reviews in that the staff has installed a copy of the code on NRC computers. This has permitted the staff to exercise the code to assess its ability to perform as intended, evaluate its degree of user-friendliness, and roughly determine its level of robustness. The staff's experience in use of the code is described along with an evaluation of the basic level training being offered for the code user.

4.1 Thermal/Hydraulic Models

Vector Momentum Equation

During the course of the review, it became evident that problems were present in the derivation of the vector momentum equation. Several of the points of concern raised during the staff review of the documentation follow.

- Rigor: in an effort to show a rigorous approach, much effort has been expended on forms of the equation containing (for example) three-dimensional fluid shear stress terms and terms accounting for moving solid surfaces, neither of which are present in RETRAN-3D. This only confuses the exposition being attempted.

- Notation: the momentum equation derivation begins using the indicial notation common to computational fluid dynamics (CFD) texts and then transitions to a non-standard RETRAN-specific notation. The notation changes considerably as one goes through the description so that an equation that was understood on one page is almost unrecognizable on another.

- Typographic Errors: the numerous sections dealing with the momentum equation contain typographical errors, so that one is often not sure whether there has been a typographic error or whether a new notation has been introduced.

- Distributed Description: the description of the momentum equation is strewn over a large number of sections making it very difficult to comprehend.

- Terms Missing from Nomenclature: a number of terms used in the momentum equation are not to be found in the nomenclature causing a lot of time to be wasted trying to find their definition in the text.

- Missing Steps: despite the incredible detail lavished on the initial steps of the derivation; later on, large gaps appear as the interaction of terms are defined.

The code documentation should include a clear and concise statement of the partial differential equations being solved and the implicit assumptions involved, the process used to volume average the equations, how the resulting volume averaged conservation equations are differenced, and the specification of the interaction terms. To lessen confusion on the part of the code user, EPRI will clarify the documentation to address these deficiencies.

Specific Errors in the Momentum Equation

The "RETRAN-3D vector momentum equation" is actually a scalar equation of motion that is the projection of the vector momentum along a control volume dependent direction. The neglect of the momentum in the two directions perpendicular to this direction are never discussed in the documentation. The derivation of the momentum equation needs to be corrected. The "RETRAN-3D vector momentum equation" contains two errors that are manifested in simple demonstration problems such as tees and bends. The errors are discussed in greater detail in the following paragraphs. The equations and figures referred to are found in Volume 1 of Reference 4.

The first error occurs in going from Equation II.3-6 to Equation II.3-7. The last term on the right hand side of Equation II.3-6 will contain a cosine term from the vector dot product. The cosine term is missing in Equation II.3-7. The cosine term is required for a vector momentum equation since the pressure force is normal to the surface in question and the orientation of the surface changes with geometry such as for an elbow. This error will affect pipe bends of any angle. The answer (Reference 10) to Question 15 of the August 25, 1999 RAI (Reference 7) indicates that the effect of the constant pressure approximation stated on page II-74 was not considered. The pressure integral in Equation II.3-6 is not equal to the pressure difference term in Equation II.3-7 if a two region constant pressure approximation is used. If the pressures are not assumed to be constant, then in general, the p's in the pressure difference term of Equation II.3-7 are not the pressures at the end faces of the momentum control volume as is shown in the Porsching paper (Reference 11). Even if the equation was correct, the flow behavior in an actual elbow is far more complex than could be predicted by a one dimensional flow model. In an actual elbow there will be a pressure rise from the entrance to the outside radius of the elbow and a pressure drop to the inside radius (Reference 12). In addition, a multidimensional recirculating pattern will be established and flow separation can occur on the exit side of the elbow. The best that can be achieved with a one dimensional model is the prediction of the pressure drop through the elbow as a function of flow conditions and geometry. If the details of the flow in the elbow make a difference in the solution, a one dimensional flow model is not adequate.

The RETRAN-3D documentation also gives conflicting accounts of the assumed functional dependencies. For example, in the answer to Question 5 of the August 25, 1999, RAI, the pressure is assumed to vary linearly across the volume but page II-74 discusses using a piecewise constant pressure profile.

In a meeting with the staff on November 3, 2000, EPRI provided additional steps for the derivation but the additional information did not resolve the problem with the equation of motion. It is mathematically possible to obtain an equation of motion without a cosine multiplier on the pressure difference term by assuming that the pressure is decomposed into a volume constant pressure and a pressure that has variation over the volume. It is easy to show mathematically that the volume constant pressure integrated over the surface of the control volume results in a pressure difference term with no cosine multiplier. This approach just moves the difficulties into the φ projection of the F_{loc} term which is the projection on the nonuniform normal wall forces in the φ direction. The RETRAN-3D documentation states that this quantity will be computed using empirical models. The anticipated source of information for this specific quantity is

unknown to the staff. An additional problem is that an equation for mechanical energy conservation cannot be derived from the resulting equation of motion and therefore it cannot be shown that mechanical energy is conserved by RETRAN-3D.

The second error appears in pipe configurations that contain flow splits such as a tee or an injection mixer like a jet pump. An example that applies the RETRAN-3D vector momentum equation to a flow split begins on page II-87 of Reference 4. To illustrate the error, consider the trivial case where junctions 2 and 4 are both horizontal and $A_2 + A_4 = A_1$. Also let the velocities at all junctions be equal. (This is the inverse of the configuration used for the RETRAN-3D jet pump which is based on the liquid-liquid ejector model from Bird, Stewart and Lightfoot (Reference 13). The jet pump model avoids the error that is contained in the tee example by adding a source term to the RETRAN-3D momentum equation, Δp_{mix}.) In the absence of wall friction, $p_1 - p_2$ should clearly be 0. Applying Equation II.3-35a the calculated pressure is:

$$p_1 - p_2 = \frac{W_2^2}{2\rho}\left[\frac{1}{A_2^2} - \frac{1}{A_1^2}\right].$$

Not only is the pressure difference non-zero, it depends on the area of the exit path and will predict different pressures for p_2 and p_4 if A_2 and A_4 are not equal. The error in Equation II.3-35a is contained in the term:

$$\frac{W_2^2}{2\rho}\left[\frac{1}{A_2^2} - \frac{1}{A_1^2}\right]$$

The term should actually be:

$$\frac{W_2^2}{2\rho}\left[\frac{1}{A_2^2} - \frac{1}{\frac{W_2^2}{W_1^2}A_1^2}\right].$$

to properly account for the pressure difference that is analogous to the pressure difference resulting from the contraction or expansion of a Bernoulli stream tube. The error in the tee EPRI has agreed to fix in order to avoid artificial pressure drops that result from this effective numerical loss. The best that can be done is to insure that the Bernoulli head is conserved in RETRAN-3D and use appropriate experimentally derived loss coefficients that apply to the specific geometry being modeled. In general, the true loss coefficients in the branches of a tee depend on the geometry, the absolute flow rates, and the flow rate ratios between the branches.

Subsequent discussions with the applicant have resulted in agreement to correct this error in the RETRAN-3D code. Therefore, with this correction, the staff accepts the formulation of the momentum equation.

Applicability of Porsching Paper to RETRAN-3D Momentum Equation

The Porsching Paper was submitted on March 6, 2000, in support of the RETRAN-3D "vector momentum equation." The paper does not appear to have any mathematical errors. Unfortunately, the definitions and restrictions on control volumes that are required to be consistent with the mean value theorem make the paper irrelevant to the RETRAN-3D code. The pressures and flows in RETRAN-3D are defined in a control volume with specified functional dependencies. The integrals should be evaluated with the RETRAN-3D assumed function dependence for pressure and flow.

Momentum Transfer Due to Phase Change

The RETRAN-3D four- and five-equation models neglect momentum transfer due to phase change. Neglecting this term can lead to unphysical results. An example of an unphysical result that can occur is that droplets will accelerate as they evaporate in mist flow. The neglect of this momentum transfer may also cause numerical problems and instabilities for the code. This approximation will be fixed so that unphysical results and numerical problems do not occur.

Therefore, with the above corrections, the staff accepts the models.

Constitutive Equations

RETRAN-3D provides many options for heat, mass and momentum transfer that can be selected by the user. Unfortunately, the range of applicability for the correlations is not given and there is a lack assessment for these models. A licensee wishing to use the correlations will have to provide both separate effects and integral effects assessment over the full range of conditions encountered during the application of interest. An assessment of the uncertainties must also be provided. The assessment must address the consistency between the RETRAN-3D calculations and any auxiliary calculations that are part of the overall methodology. Examples of auxiliary calculations are departure from nucleate boiling, critical power ratio or reactor physics calculations.

Generalized Laminar Friction Model

Generalizing the laminar wall friction model is an improvement over using a pipe laminar friction coefficient. Unfortunately there is no proper assessment of the capability of the model. The Purdue thermosyphon test uses this capability to apply a curve fit to both the constant and the exponential dependence of the Reynolds number. Proper modeling of the test facility was not performed using geometry dependent friction coefficients and the theoretically correct inverse Reynolds number dependence.

EPRI will perform the above assessment correctly. When this assessment is complete, the staff will review it for acceptance.

Pressurizer Model

The pressurizer model is not well assessed and is highly dependent upon the user. In the limited assessment provided, there appears to be a large discrepancy between the implicit solution method and the standard solution method. No discussion or assessment is given of this discrepancy. The discrepancy between the two predictions needs to be explained. Assessment and justification of all input parameters must be provided by the user.

While the model does not directly account for thermal stratification, its effects can be included by use of normal nodes below the pressurizer volume. The user will have to justify the lack of thermal stratification or the use of normal nodes below the pressurizer should there be an indication that it would be important in the analysis.

The mixture and two-region energy equations are consistent for the implicit solution method where the mixture energy equation is used with the vapor-region energy equation. This eliminates inconsistency between the two-region and mixture energy equations and the concern regarding a potential drift in the region energies.

The staff notes that when a pressurizer fills or drains, a single region exists for which the normal pressure equation of state is used. Lack of numerical discontinuities in validation analyses of filling and draining pressurizers indicates that the model is functioning properly. It is the responsibility of the code user to justify any numerical discontinuity in the pressurizer during a filling or draining event.

The pressurizer model has options that require user-supplied parameters. Users must provide justification for these model parameters.

5 Equation Non-Equilibrium Model

The 5-equation non-equilibrium model has not been assessed and therefore is not approved for use. Licensees who wish to use the model will have to provide both separate effects and integral effects assessment over the full range of conditions encountered during the application of interest. An assessment of the uncertainties must also be provided. Demonstration problems provided in Volume 4 of Reference 4 show that the peak power in BWR pressurization problems is significantly changed when going from the four equation model to the five equation model. The peak power is reduced in the five equation model apparently due to a less severe void collapse caused by the interfacial heat transfer resistance of the five equation model. In a four equation equilibrium model the interfacial heat transfer rate is effectively infinite. Due to this sensitivity of BWR pressurization applications to the interfacial heat transfer, licensees who decide to use this option will need to specifically address the uncertainty in peak power due to interfacial heat transfer.

Critical Flow

Three critical flow models are included in RETRAN-3D:

- Extended Henry/Fauske
- Moody
- Isoenthalpic Expansion/Homogenous Equilibrium

The three models are stated as acting to put an upper bound on junction flow. However, the staff notes that the code does not have the ability to calculate critical flow in Fanno or Rayleigh like situations such as would occur from broken pipes or steam generator tubes where acceleration is driven by friction or heat addition instead of by area change. While Moody and Henry/Fauske are standard, accepted models in the nuclear industry, no explanation is given to justify what is meant by "extended" Henry/Fauske. The data used in assessing the model was limited to the Fauske straight tube and Marviken data rather than critical flow through nozzles. With only three data sets used for assessment, there is great uncertainty in the results. The Isoenthalpic Expansion Model is really the Isentropic Homogeneous Equilibrium Model. The model can readily give the critical pressure and mass flux (Reference 14).

None of the critical flow models noted above are appropriate when noncondensable gases are present. In the presence of noncondensables, the critical flow model is automatically bypassed by the code. This should exclude the code from analyzing shutdown transients where air can be present in the system. Also, it is not considered good practice to have a code bypass model on its own without warning the code user that this is being done. Doing so places an added burden on the analyst who needs to know when the code is invoking limits and restrictions.

Drift Flux Model - Chexal-Lellouche Model

Although the Chexal-Lellouche model is based on a curve fit rather than being mechanistic, the data base upon which the model is based is large and fairly comprehensive. On the other hand, the model uses a "fluid parameter" that directly affects the value of the distribution coefficient, C_0. If the model were mechanistic in nature, or even based on the appropriate property groups, fluid scaling would be implicit in the model. However, the fluid parameter is a set of empirical relations which have a dependence as a function of void fraction. There is a significant difference in the behavior for steam-water and air-water mixture. This raised three potential concerns:

- Range of Applicability: for steam-water, the fluid parameter is an explicit function of pressure, not a function of fluid properties. Due to its empirical nature, it cannot be extrapolated beyond its database. However, this is not a significant problem as the diabatic steam-water database extends to a pressure of 150 bar, and the adiabatic extends to 180 bar.
- Applicability of Air-Water Validation: a fair amount of the validation work was performed for air-water mixtures. Because of the fluid parameter, this is the validation of a

separate and distinct model. It is not relevant to any steam-water used in RETRAN-3D calculations.

- Slip with Noncondensable: if different fluid parameters are used for steam-water and air-water cases, for the case of a gas phase that is a mixture of steam and noncondensable gas the user must be aware that there is no guidance or provision for determining the appropriate fluid parameters. Justification on a case-by-case basis is needed if the steam-water parameter is used.

Normally the drift flux model is used for vertical flow where the two phases are tightly coupled, as would be expected since a fundamental principle of drift flux is that buoyancy and interfacial forces balance each other. Other codes are careful to use drift flux for regimes such as bubbly-slug flow, but not for the annular flow regime. In annular flow, the buoyancy force becomes progressively less important as the wall shear begins to offset the interfacial friction. Drift flux models are used in which the drift velocity is a function of flow regime.

The Chexal-Lellouche model retains the bubble rise velocity as the cornerstone of the drift velocity. Multipliers are added to adjust the drift velocity for the various flow regimes, annular, horizontal, etc. The multipliers are based, once again, on elaborate curve fits and do not clearly represent the governing physical phenomena. Retaining the bubble rise velocity as a principle component of the drift velocity for flow regimes where it is clearly not relevant raises questions about the applicability of the model itself. The very large database behind the Chexal-Lellouche model leads to the conclusion that there are likely one or more multiplying factors that must be compensating for this error. It is not possible to discern how or where these compensating errors exist from the code documentation. This is seen in the code application manual (Volume 4 of Reference 4), Figures IV.4-9 through IV.4-11, wherein the model does well in bubbly-slug flow but at high values of the void fraction consistently underpredicts the void fraction.

The application of the Chexal-Lellouche model to the annular and annular/mist flow regimes must therefore be used with caution and the effect of underprediction of the void fraction must be explained.

Besides the concerns noted with application of the Chexal-Lellouche model to annular flow, its applicability to horizontal flow must be avoided. In horizontal flow, the balancing forces are now wall drag and interfacial friction. Using the bubble terminal velocity as the foundation of the drift velocity is clearly incorrect. In the steam-water database given in Reference 6, three tube diameters are included ranging from 22 to 75 mm. Less than 3 inches are too small to represent the large diameter pipes found in reactor coolant systems. If the air-water database is included, ignoring the disqualifying effect of the fluid parameter, then the largest pipe diameter is 127 mm which is large enough. However, the mass flux range is so large (3,600-4,700 kg/s-m^2) that the regime would be dispersed. Therefore, the database is insufficient for an empirical model for horizontal flow in reactor scale piping.

Regarding application of the Chexal-Lellouche model to the counter-current flooding limit (CCFL), the staff identified the following concerns:

- Geometry Effects: CCFL in complicated geometries such as tie plates requires a highly empirical correlation specific to that particular geometry. The Chexal-Lellouche model makes no distinction between a tube and a tie plate.

- Air-Water Data Applicability: due to the fluid parameter the air-water data must be excluded from the model's validation database.

- RETRAN-3D Validation: there are no data comparisons given for CCFL in the RETRAN-3D applications manual (Volume 4 of Reference 4). It is unclear if or how CCFL is implemented in RETRAN-3D.

- Pressure Dependency: based on the data comparisons given in Reference 15, Figures 5-6 and 5-10, the pressure dependency of the predicted CCFL seems to be incorrect. In Figure 5-6, which is plotted using the Kutateladze number, the pressure effect is greatly overstated in the calculation, while in Figure 5-10, plotted using the Wallis scaling, the predicted pressure trend is opposite that of the data.

The staff therefore concludes that Chexal-Lellouche cannot be used in situations where CCFL is important unless validation for the precise geometry and expected flow conditions has been perfomed.

The Chexal-Lellouche drift flux model appears to be an improvement over the previous RETRAN drift flux models based on the limited assessment provided. Licensees who wish to use the correlation will have to provide assessment over the full range of conditions encountered during the application of interest. Since the correlation is purely empirical in nature the assessment must be provided for full scale in all variables of interest. An assessment of the uncertainties must also be provided.

In summary, overall the Chexal-Lellouche model is accurate for most applications. However, due to its empirical nature, care must be taken to avoid extrapolation. Also, for the cases noted, such as annular flow in large pipes, horizontal flow, and CCFL, the model should not be used or an explanation should be provided for the effect its use has on the calculation. The user is referred to Condition 16 below for further guidance on use of the Chexal-Lellouche model.

Boron Transport

There are several models in RETRAN-3D to minimize numerical diffusion or provide front tracking for fluid temperature fronts: the method-of-characteristics, the transport delay model, and the enthalpy transport model. Each of these models is used in a particular circumstance as a user option. Boron transport is handled as a passive contaminant by the "general transport model" (Volume 1, Section VII-5.0 of Reference 4). This model uses a first order accurate upwind difference scheme with an implicit temporal differencing. This approach is highly diffusive, especially if the Courant limit is exceeded. This scheme can result in a front arrival that can be spread out over a long period and its amplitude reduced to about half that of the peak. Since RETRAN-3D has the same model as RETRAN-02 MOD003 and subsequent versions that have been approved for use, the RETRAN-3D model is also approved with the

caveat that the potential to produce misleading results with this scheme necessitates careful review of the results for any case where boron transport/dilution is important.

4.2 Neutron Kinetics Models

Existing approved versions of RETRAN have a one-dimensional kinetics capability. EPRI has introduced a three dimensional kinetics capability to eliminate some of the limitations in previous versions caused by the use of a one-dimensional model by introducing a solver based on the analytical nodal method (Reference 16). The method used was originally implemented by EPRI in the ARROTTA code and was adapted for use in RETRAN-3D. The current review is limited to the kinetics models that have been introduced into RETRAN since the last approved code version. All of the kinetics models discussed are related to the implementation of the three dimensional solver. Therefore, the review considered the following:

1. Development and implementation of the Analytic Nodal Method (ANM) solver.
2. The performance (validation) of the ANM solver.
3. The cross section model.
4. Coupling to the thermal-hydraulics model.

The staff position that the documentation for a code under review, and the code itself, must be submitted allowed a direct evaluation of the capabilities of the ANM solver relative to the staff's own kinetics methods.

Theoretical Development

The theoretical development of the 3-D kinetics models is described in the RETRAN Theory and Numerics Manual (Volume 1 of Reference 4). This information and the availability of the source code formed the basis of the review of the development and implementation of the ANM solver. The model was developed in a manner similar to other equivalent methods, such as Reference 17, and no apparent deficiencies were identified. The major differences between the methods is in the solution of the 1-D nodal coupling equations. The review began with equations V.2-44 through V.2-46 (the two-group diffusion equations and the precursor equation), but the staff did not review the information presented in Chapter 2 on the derivation of the diffusion equation from the transport equation because there are several different equally acceptable techniques available to derive the diffusion equations and the form of the diffusion equation solved in RETRAN is correct. The global diffusion theory equations and the 1-dimensional nodal balance equations are solved with a technique referred to as the non-linear method which has been successfully implemented in other methods (Reference 20). The nodal leakage source terms can be determined by one of three methods: an explicit method or one of two implicit algorithms. The explicit method is a Gauss-Seidel iterative method which "explicitly" calculates the leakage terms. The basis of the implicit methods is that the leakage equations can be evaluated by using a truncated Neumann Series that "implicitly" calculates the leakage terms.

RETRAN-3D includes a model to calculate the individual contributions to the system reactivity balance from relevant variables such as moderator temperature and fuel temperature. This model is based upon the assumption of space-time separability and the use of the steady state

adjoint flux as the weighting function. The equations are separated and the time dependent amplitude function is recast into the point kinetics equation. An equation for reactivity is then extracted from this formulation and separately solved for the reactivity contribution from fuel temperature, moderator temperature, moderator density and control rod insertion. A parameter called residual reactivity is calculated which is the difference between the total reactivity and all of the components of reactivity. The residual reactivity is used to assess the error from the assumption of space-time separability.

Validation of the ANM Solver

The RETRAN-3D three dimensional kinetics solver has been assessed by code-to-code comparisons and comparison to experimental data. RETRAN-3D was originally assessed by EPRI against international standard problems and comparison to other codes. Both of these types of assessment are basically code-to-code comparisons. They are good for evaluating a code's capabilities relative to other solvers, but they do not answer the fundamental question of assessment: do the equations really calculate the physical phenomena? To answer this question, the staff developed a benchmark problem based upon the SPERT series of tests. The cross sections and problem definition were supplied to EPRI and they used RETRAN-3D to predict the problem. This section discusses the results of the assessment of the three dimensional kinetics solver in RETRAN-3D.

Code-to-code comparisons using RETRAN-3D were peformed by both EPRI and the staff. These problems can be further subdivided into steady state assessments and transient assessments. For steady state assessment, EPRI compared its results with two NEACRP problems (NEA sponsored international standard problems) and HERMITE calculations. The staff used RETRAN-3D to compare its results with NESTLE calculations and TORT calculations. All of these comparisons consisted of power distribution and eigenvalue calculations. All of the comparisons demonstrated that RETRAN-3D is capable of predicting power distributions and eigenvalues with accuracy comparable to other codes. The TORT comparison is unique because TORT is a three-dimensional transport theory code capable of calculating higher modes of the flux. The staff performed what is known as an S_8/P_5 calculation, that is, an eighth-order quadrature is used to expand the angular flux with a fifth-order expansion of the scattering kernel. Both rodded and unrodded cases were studied. For more information, refer to Appendix A. Although these types of methods are not necessarily any more accurate for reactor calculations than diffusion theory methods, the staff performed this analysis to confirm the calculation of RETRAN-3D. For transient assessment, EPRI compared RETRAN-3D results to two NEACRP problems and HERMITE calculations. Once again, these comparisons demonstrated that RETRAN-3D is as accurate as other similar methods.

Due to the limitations of code-to-code comparisons, the staff defined a problem using experimental data from the SPERT test series (Reference 19). The staff developed cross sections for the SPERT E-core using a pre-release version of sas2d (a module of SCALE 5 under development) and used these cross sections in a NESTLE, Reference 17, model to predict two rod ejection tests referred to as Tests 81 and 86. Test 81 was initiated from hot zero power conditions and Test 86 was a hot full power case. Figures 1 and 2 indicate that the NESTLE predictions of the experiment are very accurate. The cross sections and geometry

information were provided to EPRI to assist their prediction of the SPERT tests with RETRAN-3D. Figures 3 through 6 show that RETRAN-3D also accurately predicted the test results.

The SPERT benchmark is an excellent source of data for prompt critical excursions. However, the SPERT E-core was a very small, tightly coupled reactor and when one examines the results it becomes obvious that the flux does not significantly deviate from the fundamental mode during the rod ejections. This is important because it limits the usefulness of the benchmark. Accurate prediction of these experiments only shows that the balance equations are accurately predicting the neutron population; not that they can accurately predict the neutron population when the flux deviates from the fundamental mode. This discussion is not meant to minimize the importance of the SPERT validation, but, rather, to clarify its value. The SPERT benchmark is important because it demonstrates that the neutron diffusion equation is valid during super-prompt critical excursions and that it accurately predicts the neutron balance which is directly proportional to the power. There is no known experimental data for super-prompt critical excursions involving larger reactors which would exhibit higher modes of the flux. One must, therefore, defer to the types of code-to-code comparisons previously discussed to assess a code's ability to predict super-prompt critical excursions with asymmetric power distributions.

In summary, the validation of the three dimensional kinetics solver in RETRAN-3D which was reviewed allows the staff to conclude that the neutron diffusion equations as solved in RETRAN-3D accurately predict the neutron population and that the code's ability to predict spatial asymmetries is as accurate as higher order methods.

Cross Section Model

The cross section model is a polynomial fit of pre-calculated static cross sections over a range of thermal and hydraulic conditions which will bound the problem of interest. This type of model has been used with considerable success in many other applications (Reference 17). The cross sections are a function of fuel temperature, moderator temperature, moderator density, control fraction, and soluble boron concentration. Assembly discontinuity factors are similarly defined to be functions of these variables. These coefficients are calculated offline and provided to RETRAN-3D through one of several interface files. The use of static cross sections to predict transient conditions is justified by the SPERT validation discussed in the previous section.

Coupling with Thermal-Hydraulics

RETRAN-3D, like many other similar codes, allows for a coarser thermal-hydraulic mesh than what is used to resolve the flux. Furthermore, RETRAN-3D has only a one-dimensional flow and heat transfer capability. The "3D" in the name refers only to the neutron kinetics capability. The applicability of these types of assumptions can only be assessed on a case-by-case basis. For example, the SPERT validation demonstrates that for that reactor, cross flow (radial flow between assemblies) is not important because the predicted power was very accurate. The SPERT validation cannot, however, be extended to the general case for which one does not have experimental data to assess the applicability of a given modeling scheme. The staff concludes that the three-dimensional neutron kinetics model in RETRAN-3D can adequately predict the neutronic response of a neutronics dominated event. However, caution needs to be

exercised when applying a model such as RETRAN-3D to analyses where multi-dimensional flow may significantly effect the results, such as the main steam line break. Without adequate data to assess three-dimensional thermal-hydraulics the staff can only conclude that for tightly coupled thermal-hydraulic and neutronic events RETRAN-3D produces results comparable to those of other accident analysis codes. Application of the code to these types of events requires specific assessment and justification by the user.

4.3 Code Assessment

Computer code assessment generally consists of three phases: phenomenological assessment, separate effects assessment, and integral systems tests and full scale plant data (when they exist) assessment. There have been numerous attempts at defining what constitutes adequate assessment and two of the best examples are the work of the Nuclear Energy Agency in Paris, France (Reference 20), and the development of the Code Scaling, Applicability, and Uncertainty (CSAU) effort of the NRC (Reference 21). These efforts have shown that a simple list of data against which a computer code is to be assessed is not sufficient. It is also necessary to determine what the use of the code will be, which models are important, what phenomena are important, and how they rank relative to one another during the application of the code. The clearest way this is done is through use of a Phenomena Identification and Ranking Table (PIRT) as described in the CSAU documents. From the PIRT results, the range of parameters over which a given highly ranked phenomenon is considered to be important will be determined along with a test matrix to assess the model over this range of parameters. Without a PIRT it is more difficult to determine that the model is performing acceptably for the specific application.

The code documentation for RETRAN-3D presents assessment against a brief list of phenomenological, separate effects, and integral systems tests. The assessments have not been performed with the forethought and planning that would be done as part of a PIRT development scheme. No PIRT has been developed or presented. The bulk of the assessment consists of actual plant calculations performed by various participating utilities. Many of the figures provided do not indicate what code version was used for the calculation. As would be expected, actual plant data are very limited in scope and qualification. This makes the evaluation of the applicability and validity of the assessment very difficult.

Additionally, the applicant states in Volume 4, Assessment Manual, of Reference 4,

> Qualification (of the code) is an additional step that lies beyond both verification and validation. Qualification is the process of demonstrating that the code and a specific plant model are adequate for a given application, e.g., analysis of a boiling water reactor response to a turbine trip event for support of reload fuel licensing. Although the code developer can perform generic demonstration analyses to support qualification, completing the qualification is ultimately the responsibility of each individual code user. This statement is particularly appropriate for RETRAN because of the flexibility of the code and because much of the modeling is established by user input.

Assessment of the RETRAN-3D code for the models not explicitly approved in this safety evaluation will be the responsibility of the licensee or applicant. In addition, application of the RETRAN-02 or RETRAN-3D codes for best estimate analysis of UFSAR Chapter 15 licensing basis events may require additional code and model assessment, and an evaluation of uncertainties to assure accurate prediction of best estimate response. This condition is based on the absence, in the best estimate analysis approach, of the conservative assumptions in traditional UFSAR Chapter 15 licensing basis analyses. For each use of RETRAN-3D in a licensing calculation, it will be necessary for a valid approach to assessment to be submitted, which is expected to include a PIRT for each use of the code and the appropriate assessment cases and their results. The scope of the PIRT and validation/assessment will be commensurate with the complexity of the application.

4.4 Code Use

User Options Available in RETRAN

RETRAN is a generalized thermal-hydraulic computer program which can be used to model a variety of thermal-hydraulic configurations. Noding detail and layout are options left to the user. As RETRAN has evolved, numerous options became available to the user. The options include surface heat transfer correlations, critical heat transfer correlations, two phase friction and drift flux correlations. The various correlations are applicable for different fluid conditions. The correct application is strongly influenced by the experience of the user.

The developers of other analysis codes have generally observed the policy of replacing old mathematical models and correlations as new models and correlations were developed, thus keeping the number of options available to the user to a minimum. The developers of RETRAN have used the policy of preserving the ability of the code to "look back" and utilize all previously developed models as options. This policy greatly increases the number of options available to users. During the training course, only the most frequently used options were presented to the students; thus there is a high potential that students could incorrectly apply the other options that were not presented.

The numerics of RETRAN-3D are limited to a maximum of 5 conservation equations, one of which is the relative velocity "slip" between the steam and water phases. Steam in RETRAN-3D is always assumed to be saturated. For this reason the code cannot accurately model emergency feedwater injection into the steam space of a B&W once-through steam generator or ECCS injection into a steam filled pipe during a LOCA. The liquid phase in RETRAN-3D can be either subcooled or superheated. Although code limitations were described by the course instructors, the code limitations are a potential source of error for inexperienced users. The RETRAN-3D retains the older 3 equation and 4 equation formulations from RETRAN-02 giving users the option of assuming complete thermal equilibrium.

In addition to slip models to calculate separation between the steam and liquid phases RETRAN contains bubble rise models from RELAP4. Bubble rise models were useful when reactor systems were described using a few large control volumes. With the more detailed noding, bubble rise models can produce unphysical alternating layers of steam and water in vertical components. Location of slip components adjacent to bubble rise components can

result in code errors. It was mentioned that different bubble rise models are used for different steam generator components; however, the theory and calculation needed to obtain the correct bubble rise coefficients were not described.

Some models in RETRAN require particular knowledge by the user. For example, the code can calculate decay heat using either the 1973 or the 1979 ANS5.1 standards. The code does not provide a direct method of inputting the additional energy contribution from neutron capture in stable fission products or the variation in standard deviation with time. These can be input as control functions by experienced users but could be easily left out by a novice.

An accumulator model has been added to RETRAN-3D. Previously users modeled accumulators as equilibrium volumes. Since the accumulator gas may become very cold during discharge from adiabatic expansion, this was a potential source of error. Some users tried to account for the non-equilibrium effect by using increased loss coefficients in the accumulator discharge line. Additionally, the new accumulator model eliminates the use of a valve to inhibit nitrogen from entering the system since RETRAN-3D is capable of handling non-condensables.

Control system (blocks) are now evaluated implicitly with the fluid conservation equations in RETRAN-3D. Previously control systems were solved consecutively. This caused the results to be dependant on the order that the control systems were entered. This section was briefly covered during the training; however, for such a complex input modeling, it was insufficient to give the student an appreciation of the differences in results that are created through the use of the different types of control systems.

One potential source of error in RETRAN-3D is that the spacial power distribution for decay heat is assumed to be the same as that for the neutron flux. The 3D kinetics can calculate instantaneous changes in the spacial neutron flux resulting from control rod movement or local voiding. The decay heat power distribution should be a function of the previous power history which could result in a larger value for the decay heat.

User Experience

During the course of the RETRAN-3D review, the staff built several models to test the user options and exercise the code. Using the code to develop models enabled the staff to evaluate the user's manual and understand the ease of using the code by experienced analysts faced with the new version of RETRAN for the first time. It also gave the staff the understanding of the impact of attempting to upgrade RETRAN-02 MOD5 decks to RETRAN-3D. In addition, building new models enabled the staff to understand the use of new models and options implemented in RETRAN-3D that were not available in previous versions of the code. Exercising the code to assess the user friendliness of the code is especially important for RETRAN because the code is targeted at an audience of multiple users in diverse locations who have varying levels of code experience. These users are not exclusively those working within the company who developed the code; therefore, the users do not have direct access to the code developers when questions need to be answered and detailed understanding of models and how they were intended to be used are needed.

One of the models the staff developed is a RETRAN-3D model of the HERMITE test case. This model was developed based on the BWR rod drop sample problem. The sample problem was extended to include multiple channels. The channels created were developed from the original method of using volumes and heat components to create channels. The user manual did not clearly explain how to create individual channels and the staff found it to be a confusing process. Additionally, the input deck was very difficult to bring to steady state with the steady state initialization scheme because of multiple flow paths through the core and difficulty in dividing the flow into the channels which did not divide into an even number. The small error in flow this created made the code difficult to achieve steady state initialization. While this demonstrates that the code very accurately accounts for mass, it will be more problematic for users, especially those with little experience, building detailed models. The staff also found, when trying to make full core models with multiple channels, that the models exceeded a limit on the number of volumes allowed. This forced a compromise to the modeling and created a less detailed model than was sought. The staff also found that the channel rod mapping was very confusing. It is not well defined in the user manual, and using the sample problem as a guide, required trial and error to obtain the correct solution.

A number of small errors in the user's manual created confusion for the staff while attempting to use new options in the code. These errors ranged from options used in sample problems neither being supported in the user's manual nor there being a discussion of what the option does, to typographical errors that made the user stumble until they figured out the error, or being sent to a section of the documentation that was not relevant.

A concern raised during the use of the code, is that the manual does not explain how to lump and unlump components. This is an area where many inexperienced users will have difficulty without guidance. User guidelines are expected to deal with this concern when they are prepared.

During the experience with the code, it was noted that many of the newer options do not have corresponding minor edits as an option. The lack of minor edits makes it difficult to check the results of the code output to ensure that the code is predicting what is expected and that the input used in the code is what was desired. The lack of user guidance was a hindrance when using the code, especially when trying the new options. The combination of a lack of minor edits and guidance results in even an experienced user introducing errors in the input deck that should not have been there.

Conclusion Regarding User Experience

Both inexperienced and experienced users must use a great deal of caution with RETRAN-3D. The confusion in developing input models, due to the lack of user guidance combined with the lack of minor edits to verify output, could cause excessive undetected errors in input decks. The staff believes that it would be beneficial if the discussion of the new models and their applicability was expanded and part of the discussion that is currently in the theory section where the user is referred was reiterated in the user manual to assist the user with refreshing the memory of applicability and ranges of options.

Training

The NRC staff attended a RETRAN-3D training course in Idaho Falls, Idaho from August 16 to 20, 1999. The purpose was to evaluate the effectiveness of the training program and to obtain more knowledge of the RETRAN-3D computer code. The basic RETRAN-3D training course is intended for users that have no previous experience with the RETRAN-3D code but have a basic understanding of physics and engineering concepts.

The RETRAN Training Course

The principal instructors had worked with the RETRAN code for many years. They had taught RETRAN training classes for years. They appeared to be very familiar with the details of the code, were very comfortable answering a wide range of questions, and reacted graciously when we found an error in the code during the training session. The instructional material was well organized. Over the years of teaching RETRAN the instructors had responded to comments by students and improved the material. The course is a blend of theory and application. The actual fluid and heat transfer equations solved by the code were presented and explained. The strengths and weaknesses of many of the user options were discussed. Although the course was excellent, RETRAN is sufficiently complex that considerably more than one week of training will be required to produce qualified users.

The instructors taught positive modeling techniques for incorporating enhancements to the basic model. These modeling techniques include using additional cards to override previous modeling input instead of changing the original cards in the model and breaking control systems into pieces and adding them into the model in pieces which makes it easier to troubleshoot if errors are introduced into the model. Students were encouraged to draw schematics of their system to visually place problem specifications. Using this modeling technique reduces overspecification problems that arise during the steady state initialization routine which is unique to RETRAN. They also encouraged the exchange of information on modeling techniques through the RETRAN newsletter, which is distributed to the RETRAN users group members.

Since the intended target students are those that have a basic understanding of physics and engineering, some basic engineering concepts were not fully explained. These concepts were those that are used in computer modeling of thermal-hydraulic phenomena such as the Courant limit. When questioned, the instructors were unable to provide a visual representation so that the student understood what the limitation actually represents and how to use it. This lack of understanding might result in development of an inadequate model that could miss key phenomena or result in unreliable results due to numerical instability introduced by the model.

The training course utilized a computer interface to ease model development and preclude introduction of computer dependent behavior. This interface is currently not included in the code release package, so when students return to their site the interface between user and code will be significantly different. Training this way can introduce confusion in users who are unfamiliar with the code. Computer dependencies can occur and ultimately interfere with the proper RETRAN application and analysis of the results.

The students, other than the NRC staff members, had little experience with the code. Achieving code proficiency and analytical judgement requires concentrated and dedicated involvement with a large analysis tool such as RETRAN-3D.

Conclusions Regarding the RETRAN-3D Training

The one week RETRAN training course was excellent in content and the course material was well organized. Considerably more than one week of training will be needed to produce experienced users. The utility personnel at the course appeared to be new RETRAN users with little experienced backup at the home office. The combination of inexperienced users and lack of readily available support will make progress in acquiring the skill necessary to develop adequate code input models and interpretation of analysis results in a long and difficult process.

Users need to read the NRC safety evaluations on RETRAN so as to be appraised of the applications for which the code has been approved. Users also need to review the EPRI code qualification documents showing comparisons to experimental data so as not to use the code for applications and conditions for which it has not been qualified. This was not addressed in the training but needs to be added for the sake of the inexperienced new user.

The training course was a good beginning in the process of development of a competent analyst. The utilities involved in the use of the code should understand that the new user attending the first training course is not sufficiently trained to provide reliable analytic results and insights. Additional training and experience are necessary and should be sufficient to satisfy the position stated in Generic Letter 83-11, Supplement 1, "Licensee Qualification for Performing Safety Analyses," June 24, 1999, Section 2.3, Training and Qualification of Licensee Personnel.

> A training program should be established and implemented to ensure that each qualified user of an approved methodology has a good working knowledge of the codes and methods, and will be able to set up the input, to understand and interpret the output results, to understand the applications and limitations of the code, and to perform analyses in compliance with the application procedure. Training should be provided by either the developer of the code or method, or someone who has been previously qualified in the use of the code or method.

User Guidelines

The development of advanced thermal-hydraulic analysis codes has prompted close examination of the effect of the code user on analysis results. For the last two decades this has been an increasing concern to the international community. Much has been written about the "user-effect," especially following experience in performing International Standard Problems under the auspices of the Nuclear Energy Agency in Paris, France. Multiple users of the same computer code have been given the assignment of modeling one well-documented experiment in an integral test facility but their results have often diverged.

The large number of options available in RETRAN-3D make the affect of the code user on the results significant. For example, there are at least three different ways to model a volume:

thermodynamic equilibrium, partial non-equilibrium, or two-region non-equilibrium. In addition there are multiple options for determining the temperature profile within a volume: the temperature transport delay model, the enthalpy transport model, and the method-of-characteristics, and the options for phase separation within a volume and it is easy to see that there are an almost infinite number of combinations of models from which the user can select.

The situation becomes even more complicated for junctions where there are seven slip options, in at least two of which the user can adjust the model's coefficients. In other places the modeling guidelines acknowledge a modeling deficiency in the code and suggest that the user overcome it by using the control system to adjust a model. Thus, such a large user effect coupled with the opportunities to misuse the code to get a desired answer necessitates well defined code user guidelines and code user training.

Code-specific user guidelines do not exist for RETRAN-3D. EPRI has stated in response to staff RAIs that user guidelines will not be developed for two to five years in the future and not until additional experience with the code has been gained. The staff concludes that the lack of a detailed RETRAN-3D specific user guideline document mandates a statement on the user's experience and qualification with the code when analyses are submitted in support of licensing actions. This statement is expected to be consistent with the guidance of Generic Letter 83-11.

The RETRAN-3D Maintenance Group informed the staff in a meeting in November 2000, that a peer review process was being established by which applications of the RETRAN-3D code would be reviewed for consistency with accepted nodalization and option selection practices. The staff is encouraged by this move on the part of the RETRAN-3D user community. The staff believes that this peer review will be responsive to many of our concerns about application of the code and confidence in the user.

5.0 EVALUATION OF RETRAN-02 CONDITIONS OF USE

Staff reviews of previous versions of RETRAN have resulted in a number of limitations and conditions on use of the code. As a part of the review of RETRAN-3D, the staff has examined the limitations and conditions on the use of the earlier version to determine which are still applicable to RETRAN-3D and which have been responded to through the new models and additions in RETRAN-3D. The staff's evaluation of the limitations and conditions on use follows. Each condition is stated followed by the staff's position on that condition.

1. *Multidimensional neutronic space-time effects cannot be simulated as the maximum number of dimensions is one. Conservative usage has to be demonstrated.*

Staff position: RETRAN-3D has been modified to include a 3-dimensional nodal kinetics model based on the analytic nodalization method similar to accepted codes. The code has been assessed by calculation of the response of the SPERT prompt-critical tests and has been confirmed by the staff by comparisons with calculations performed with the NESTLE and TORT codes. The staff concludes that the code can adequately predict the response to prompt-critical events such as the PWR rod ejection accident and the BWR rod drop accident. If void generation occurs from an initially un-voided case, the user will have to justify crediting this negative feedback in the analysis.

The code was used by a participant in the Nuclear Energy Agency's International Standard Problem calculation of a hypothetical main steam line break (MSLB) at the Three Mile Island Unit 1 plant. The results of the calculation comparison indicates that RETRAN-3D is comparable to any of the other participating codes.

RETRAN-3D is approved for main steam line break analyses subject to the following conditions. Thermal-hydraulic effects can have a large impact on the cross section evaluation and thus on the resulting power distribution and magnitude. Therefore, the licensee must justify the primary side nodalization for mixing in the vessel and core. The licensee must also evaluate the uncertainties in the modeling.

2. *There is no source term in the neutronics and the maximum number of energy groups is two. The space-time options assume an initially critical system. Initial conditions with zero fission power cannot be simulated by the kinetics. The neutronic models should not be started from subcritical or with zero fission power without further justification.*

Staff position: The basic models in RETRAN-3D are unchanged and, therefore, this condition of use applies.

3. *A boron transport model is unavailable. User input models will have to be reviewed on an individual basis.*

Staff position: As noted previously in this report, boron transport is handled as a "contaminant" by the "general transport model." This model uses first order accurate upwind difference scheme with an implicit temporal differencing. This approach is well known for being highly diffusive, especially if the Courant limit is exceeded. Since RETRAN-3D has the same model as RETRAN-02 MOD003 and subsequent versions that have been approved for use, the RETRAN-3D model is also approved with the caveat that the potential to produce misleading results with this scheme necessitates careful review of the results for any case where boron transport/dilution is important.

4. *Moving control rod banks are assumed to travel together. The BWR plant qualification work shows that this is an acceptable approximation.*

Staff position: The control bank limitation is applied only to the one-dimensional kinetics model. The staff agrees that the 3-dimensional kinetics model need not be restricted in this way.

5. *The metal-water heat generation model is for slab geometry. The reaction rate is therefore underpredicted for cylindrical cladding. Justification will have to be provided for specific analyses.*

Staff position: The basic models in RETRAN-3D are unchanged and, therefore, this condition of use applies. However, since RETRAN-3D is not being reviewed for loss-of-coolant accident analysis, where core uncovery and heatup are significant, this condition does not occur in the transients for which application of RETRAN-3D has been reviewed.

6. *Equilibrium thermodynamics is assumed for the thermal-hydraulics field equations although there are nonequilibrium models for the pressurizer and the subcooled boiling region.*

Staff position: The RETRAN-3D five equation model permits thermal-hydraulic nonequilibrium between the liquid and vapor phases. While it allows subcooled liquid and saturated steam to be concurrently present, it does not account for subcooled liquid and superheated vapor being concurrently present. Use of the code is not approved for LOCA. Also, the user must be aware of this limitation and avoid conditions which will place subcooled liquid and superheated vapor in contact.

7. *While the vector momentum model allows the simulation of some vector momentum flux effects in complex geometry the thermal-hydraulics are basically one-dimensional.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this comment still applies.

8. *Further justification is required for the use of the homogeneous slip options with BWRs.*

Staff position: RETRAN-3D has five slip equation options for the user to choose from, three of which are retained from RETRAN-02 for compatibility. The recommended model options are based on the Chexal-Lellouche drift flux correlation. The first is the algebraic slip model, which is approved for use with BWR bundle geometry as given in condition (9). The second is a form of the dynamic slip model that uses the Chexal-Lellouche drift flux correlation to evaluate the interfacial friction approved in condition (10). The user must justify the use of any other slip options.

9. *The drift flux correlation used was originally calibrated to BWR situations and the qualification work for both this option and for the dynamic slip option only cover BWRs. The drift flux option can be approved for BWR bundle geometry if the conditions of (16) are met.*

Staff position: The Chexal-Lellouche drift flux model has been used in comparisons with FRIGG-2 and FRIGG-4 void fraction data and is acceptable for use in BWR bundle geometry.

10. *The profile effect on the interphase drag (among all the profile effects) is neglected in the dynamic slip option. Form loss is also neglected for the slip velocity. For the acceptability of these approximations refer to (17).*

Staff position: Form loss terms have been included in the RETRAN-3D dynamic slip model. The Taugl form of the dynamic slip equation also includes profile effects in the interphase drag model. These RETRAN-3D model improvements adequately address the concerns and the model is approved for use when the Chexal-Lellouche model is used to compute the interphase friction. Approval is subject to the conditions given in (16) for the Chexal-Lellouche drift flux correlation. Users must justify use of any other dynamic slip option.

11. *Only one-dimensional heat conduction is modeled. The use of the optional gap linear thermal expansion model requires further justification.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use still applies.

12. *Air is assumed to be an ideal gas with a constant specific heat representative of that at containment conditions. It is restricted to separated and single-phase vapor volumes. There are no other noncondensables.*

Staff position: RETRAN-3D has been extended to include a general noncondensable gas capability which resolves the original concern. However, the noncondensable gas flow model is approved for use subject to the following restriction.

As noted in Section III.3.0 of the RETRAN-3D Theory Manual (Reference 4), none of the models available for calculating critical flow are appropriate when noncondensable gases are present. Consequently, the code automatically bypasses the critical flow model when noncondensable gases are present in a junction. Users must confirm that noncondensable flows do not exceed appropriate critical flow values or justify use of values that may exceed critical flow values.

13. *The use of the water properties polynomials should be restricted to the subcritical region. Further justification is required for other regions.*

Staff position: For enthalpies less than approximately 820 Btu/lbm, the difference between the ASME and RETRAN-3D curve fit values of the specific volume range from less than 0.2 percent to approximately 1.3 percent for pressures ranging from 0.1 to 6,000 psia. Further, for enthalpies greater than 820 Btu/lbm and pressures greater than 4200 psia, the differences in specific volume are also less than 1.0 percent. RETRAN-3D is approved for use with PWR ATWS analyses where the peak pressure resides in the regions described above.

For enthalpies greater than 820 Btu/lbm and pressures between 3200 and 4200 psia, the differences in specific volume increase as the enthalpy increases and the pressure decreases. The maximum error of approximately 3.8 percent occurs at the critical point. PWR ATWS analysis using RETRAN-3D in this region will require additional justification that the difference in specific volume does not adversely affect the calculation of the peak pressure.

14. *A number of regime-dependent minimum and maximum heat fluxes are hardwired. The use of the heat transfer correlations should be restricted to situations where the pre-CHF heat transfer or single-phase heat transfer dominates.*

Staff position: RETRAN-3D contains both the "forced convection option" contained in RETRAN-02 which is the basis for this restriction, and a second option referred to as the "combination heat transfer map." If the first option is chosen, the "forced convection option," approval is granted only for use in pre-CHF and single-phase heat transfer regimes. If the second option is chosen, the "combination heat transfer map," then there are no discontinuities between successive heat transfer regimes and the appropriate heat transfer value should result. Therefore, the combination heat transfer option is approved for use.

15. *The Bennet flow map should only be used for vertical flow within the conditions of the data base and the Beattie two-phase multiplier option requires qualification work.*

Staff position: The Beattie two-phase multiplier has been removed from RETRAN-3D. The Govier horizontal flow map has been added to supplement the Bennett map for vertical flow and is acceptable.

16. *No separate effects comparison have been presented for the algebraic slip option and it would be prudent to request comparisons with the FRIGG tests before the approval of the algebraic slip option.*

Staff position: The algebraic slip option has been modified to include the Chexal-Lellouche drift flux model. Use of the Chexal-Lellouche drift flux model for BWR and PWR applications within the range of conditions covered by the steam-water database used to develop and validate the model is approved. The model has been qualified with data from a number of steady-state and two-component tests. While the small dimensions of the fuel assembly are covered, as noted previously in this safety evaluation, the data for large pipe diameters, such as reactor coolant system pipes, are not extensive and use of the Chexal-Lellouche model will need justification. Assessment work indicates that the model tends to underpredict the void profile in the range of 12 to 17 MPa. In addition, the accuracy of the model in the range of 7.5 to 10 Mpa, which covers BWR ATWS conditions, has not been fully demonstrated. Results of analyses using the model in these ranges must be carefully reviewed.

The Chexal-Lellouche correlation cannot be used in situations where CCFL is important unless validation for appropriate geometry and expected flow conditions is provided.

17. *While FRIGG tests comparisons have been presented for the dynamic slip option the issues concerning the Schrock-Grossman round tube data comparisons should be resolved before the dynamic slip option is approved. Plant comparisons using the option should also be required.*

Staff position: Assessment analyses (Reference 4), have shown that "the issues concerning the Schrock-Grossman round tube data comparisons" (actually the Bennett round tube data) are due to early prediction of CHF, which is nearly independent of the slip model used. Since the issue raised in the limitation is not related to the dynamic slip model, the limitation is considered to be resolved. The dynamic slip model is approved for use as given in condition (10).

18. *The nonequilibrium pressurizer model has no fluid boundary heat losses, cannot treat thermal stratification in the liquid region and assumes instantaneous spray effectiveness and a constant rainout velocity. A constant L/A is used and flow detail within the component cannot be simulated. There will be a numerical drift in energy due to the inconsistency between the two-region and the mixture energy equations but it should be small. No comparisons were presented involving a full or empty pressurizer. Specific application of this model should justify the lack of fluid boundary heat transfer on a conservative basis.*

Staff position: The concern raised in this limitation of use is partially resolved in RETRAN-3D. Wall heat transfer can be included in the RETRAN-3D pressurizer model. Including wall heat transfer resolves this concern.

While the model does not directly account for thermal stratification, its effects can be included by use of normal nodes below the pressurizer volume. The user will have to justify the lack of thermal stratification or the use of normal nodes below the pressurizer should there be an indication that it would be important in the analysis.

The mixture and two-region energy equations are consistent for the implicit solution method where the mixture energy equation is used with the vapor-region energy equation. This eliminates inconsistency between the two-region and mixture energy equations and the concern regarding a potential drift in the region energies.

The staff notes that when a pressurizer fills or drains, a single region exists for which the normal pressure equation of state is used. Lack of numerical discontinuities in validation analyses of filling and draining pressurizers indicates that the model is functioning properly. It is the responsibility of the code user to justify any numerical discontinuity in the pressurizer during a filling or draining event.

The pressurizer model has options that require user-supplied parameters. Users must provide justification for these model parameters.

19. *The nonmechanistic separator model assumes quasistatics (time constant approximately few tenths of seconds) and uses GE BWR6 carryover/carryunder curves for default values. Use of default curves has to be justified for specific applications. As with the pressurizer a constant L/A is used. The treatment in the off normal flow quadrant is limited and those quadrants should be avoided. Attenuation of pressure waves at low flow/low quality conditions are not simulated well. Specific applications to BWR pressurization transients under those conditions should be justified.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies.

20. *The centrifugal pump head is divided equally between the two junctions of the pump volume. Bingham pump and Westinghouse pump data are used for the default single-phase homologous curves. The SEMISCALE MOD-1 pump and Westinghouse Canada data are for the degradation multiplier approach in the two-phase regime. Use of the default curves has to be justified for specific applications. Pump simulation should be restricted to single-phase conditions.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies.

21. *The jet pump model should be restricted to the forward flow quadrant as the treatment in the other quadrants is conceptually not well founded. Specific modeling of the pump in terms of volumes and junctions is at the user's discretion and should therefore be reviewed with the specific application.*

Staff position: Subsequent revisions of RETRAN-02 addressed this limitation. Since RETRAN-3D has the same model as RETRAN-02 MOD003, and subsequent versions, their acceptance applies to RETRAN-3D.

22. *The nonmechanistic turbine model assumes symmetrical reaction staging, maximum stage efficiency at design conditions, a constant L/A and a pressure behavior dictated by a constant loss coefficient. It should only be used for quasistatic conditions and in the normal operating quadrant.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies.

23. *The subcooled void model is a nonmechanistic profile fit using a modification of EPRI recommendations for the bubble departure point. It is used only for the void reactivity computation and has no direct effect on the thermal-hydraulics. Comparisons have only been presented for BWR situations. The model should be restricted to the conditions of the qualification data base. Sensitivity studies should be requested for specific applications. The profile blending algorithm used will be reviewed when submitted as part of the new manual (MOD003) modifications.*

Staff position: The profile blending algorithm approved for RETRAN-02 MOD003 is used in RETRAN-3D, therefore this condition has been satisfied.

24. *The bubble rise model assumes a linear void profile, a constant rise velocity (but adjustable through the control system), a constant L/A, thermodynamic equilibrium, and makes no attempt to mitigate layering effects. The bubble mass equation assumes zero junction slip which is contrary to the dynamic and algebraic slip model. The model has limited application and each application must be separately justified.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies. However, the layering effects encountered in RETRAN-02 can be eliminated using the RETRAN-3D stack model. This partially resolves the concern by resolving the layering limitation through use of the stack model.

25. *The transport delay model should be restricted to situations with a dominant flow direction.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies. The appropriate application of the model is for one-dimensional flow. The user will have to justify use of this option in the absence of a dominant flow direction.

26. *The stand-alone auxiliary DNBR model is very approximate and is limited to solving a one-dimensional steady-state simplified HEM energy equation. It should be restricted to indicating trends.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies.

27. *Phase separation and heat addition cannot be treated simultaneously in the enthalpy transport model. For heat addition with multidirectional, multifunction volumes the enthalpy transport model should not be used without further justification. Approval of this model will require submittal of the new manual (MOD003) modifications.*

Staff position: A number of the simplifying assumptions in the RETRAN-02 enthalpy transport model have been eliminated in RETRAN-3D which now allows multiple inlet and outlet flows and eliminates the simplifying assumptions related to mass distribution and pressure change effects. This condition has been adequately addressed.

28. *The local conditions heat transfer model assumes saturated fluid conditions, one-dimensional heat conduction and a linear void profile. If the heat transfer is from a local condition volume to another fluid volume, that fluid volume should be restricted to a nonseparated volume. There is no qualification work for this model and its use will therefore require further justification.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies.

29. *The initializer does not absolutely eliminate all ill-posed data and could have differences with the algorithm used for transient calculations. A null transient computation is recommended. A heat transfer surface area adjustment is made and biases are added to feedwater inlet enthalpies in order to justify steady-state heat balances. These adjustments should be reviewed on a specific application basis.*

Staff position: The over specified condition is identified by the RETRAN-3D steady-state input checking, resolving the concern regarding ill-posed data. The user must still run null transients to ensure that unwanted control or trip actions are not affecting the transient solution.

RETRAN-3D has available a low power steady-state steam generator initialization option that eliminates the heat conductor area change used in the RETRAN-02 initialization scheme. When this option is used, no adjustments are made to the heat transfer area and this specific concern is resolved. However, either the pressure or temperature is adjusted on the secondary side. These adjustments should be reviewed by the user on a specific application basis. The low power steady-state initialization option is approved for use.

30. *Justification of the extrapolation of FRIGG data or other data to secondary-side conditions for PWRs should be provided. Transient analysis of the secondary side must be substantiated. For any transients in which two-phase flow is encountered in the primary all the two-phase flow models must be justified.*

Staff position: The Chexal-Lellouche correlation is approved for use with PWR applications as stated in conditions (10) and (16). The user must justify choosing any other two-phase flow correlation.

31. *The pressurizer model requires model qualification work for the situations where the pressurizer either goes solid or completely empties.*

Staff position: The pressurizer model is approved for use with filling and draining events as given in condition (18).

32. *Transients which involve three-dimensional space-time effects such as rod ejection transients would have to be justified on a conservative basis.*

Staff position: The 3-dimensional kinetics model, as noted in limitation 1 above, satisfies this limitation.

33. *Transients from subcritical, such as those associated with reactivity anomalies should not be run.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies.

34. *Transients where boron injection is important, such as steamline break will require separate justification for the user-specified boron transport model.*

Staff position: The generalized transport model was added to RETRAN-3D to provide the capability to track materials such as boron. Specific application of the model to steam line break transients must be justified by the user. The model is approved for use as given in condition (3).

35. *For transients where mixing and cross flow are important, the use of various cross flow loss coefficients has to be justified on a conservative basis.*

Staff position: The basic model in RETRAN-3D is unchanged and, therefore, this condition of use applies.

36. *ATWS events will require additional submittals.*

Staff position: RETRAN-3D is approved for PWR ATWS analyses as given in condition (13).

37. *For PWR transients where the pressurizer goes solid or completely drains, the pressurizer behavior will require comparison against real plant or appropriate experimental data.*

Staff position: The pressurizer model is approved for use with filling and draining events as noted in the discussion of conditions (18) and (31).

38. *PWR transients, such as steam generator tube rupture, should not be analyzed for two-phase conditions beyond the point where significant voiding occurs on the primary side.*

Staff position: The use of slip models for PWR applications is approved for use as given in conditions (16) and (30).

39. *BWR transients were asymmetry leads to reverse jet pump flow, such as the one recirculation pump trip, should be avoided.*

Staff position: As noted in the discussion of condition (21), this is resolved.

6.0 RETRAN-3D USE IN A RETRAN-02 MODE

During the RETRAN-3D review, the applicant suggested an approval of use of RETRAN-3D as a substitute for RETRAN-02 when operated in that mode. The staff has determined that it is not possible to use RETRAN-3D in a pure RETRAN-02 mode. The code's numerical solution scheme and various models have been changed so that there is no exact RETRAN-02 substitution that can be performed. However, the code can be used in a near RETRAN-02 mode provided that the user carefully selects models and options that reduce the divergence from those not available to the RETRAN-02 user.

While functionally equivalent to RETRAN-02, RETRAN-3D is more robust. The following models are always active when using RETRAN-3D:

- Improved transient numerical solution (fully implicit solution of the balance equations, component models and source terms are linearized).
- Improvements to the time-step selection logic.
- Improved water property curve fits.

Other model options have been improved with the improvements being active when the particular option is selected in an input model. For these options, the RETRAN-02 model was replaced by the improved model and there is no backward compatibility option. Consequently, the following improvements, if selected by the user, may be used for RETRAN-02 mode analyses:

- Fully implicit steady-state solution,
- Implicit pressurizer solution,
- Wall friction model revised to use the Colebrook equation, allowing consideration of wall roughness rather than assuming smooth pipe,
- Control system solution revised to solve a coupled system of equations using a Gauss-Seidel method rather than the single pass marching scheme,
- Enthalpy transport model revised by eliminating several simplifying assumptions,
- Improved dynamic slip formulation adding form losses,
- Improved countercurrent flow junction properties,
- Implicit solution of the heat conduction equation,
- Combined heat transfer map updated with an improved set of heat transfer correlations and smoothed transitions, and
- Wall friction and hydrostatic head losses included in critical flow pressure.

The new steady-state option available for initializing models with steam generators makes some problems easier to initialize. The low power steam generator steady-state option can be used with RETRAN-02 mode analyses.

A RETRAN-02 mode model must not use any of the new RETRAN-3D features such as:

- Generalized laminar friction model,
- Dynamic gap conductance model,
- Accumulator model,
- Dynamic flow regime model,
- New control blocks added to improve functionality,
- Govier horizontal flow regime map and stratified flow friction model,
- Chexal-Lellouche drift flux model,
- Method of characteristics enthalpy option,
- Noncondensable gas flow model,
- 3D kinetics, and
- 5-equation nonequilibrium model,

40. *Organizations with NRC-approved RETRAN-02 methodologies can use the RETRAN-3D code in the RETRAN-02 mode without additional NRC approval, provided that none of the new RETRAN-3D models listed in the definition are used. Organizations with NRC-approved RETRAN-02 methodologies must obtain NRC approval prior to applying any of the new RETRAN-3D models listed above for UFSAR Chapter 15 licensing basis applications. Organizations without NRC-approved RETRAN-02 methologies must obtain NRC approval for such methodologies or a specific application before applying the RETRAN-02 code or the RETRAN-3D code for UFSAR Chapter 15 licensing basis applications. Generic Letter 83-11 provides additional guidance in this area. Licensees who specifically reference RETRAN-02 in their technical specifications will have to request a Technical Specification change to use RETRAN-3D.*

7.0 ADDITIONAL CONDITIONS OF USE

BWR ATWS

RETRAN may be used for BWR ATWS subject to the following restrictions:

41. *The licensee must validate the chosen void model over the range of pressure, channel inlet flow, and inlet subcooling encountered during the transient that are outside the range of conditions for which assessment is available. Furthermore, the licensee should validate the choice of steam separator model and evaluate its use relative to steam separator performance data relevant to the conditions present during the ATWS simulation. The licensee must also evaluate the uncertainties in the modeling. See Condition (16) and the Staff Position for related information.*

Heat, Mass, and Momentum Transfer

42. *The RETRAN-3D five-equation, or nonequilibrium, model uses flow regime maps and flow pattern dependent heat transfer and interfacial area models to simulate the heat and mass transfer processes between phases. A licensee wishing to apply the five-equation model will have to justify its use outside areas of operation where assessment has been documented. This may include either separate effects or integral systems assessment that cover the range of conditions encountered by the application of interest. An assessment of the uncertainties must also be provided. The model is approved subject to these conditions.*

43. *Assessment performed in support of use of RETRAN-3D must also address consistency between the RETRAN-3D calculations and any auxiliary calculations that are a part of the overall methodology, such as, departure from nucleate boiling or critical power ratio.*

User Guidelines and User Qualification

44. *The staff concludes that the lack of a detailed RETRAN-3D specific user guideline document mandates a statement on the user's experience and qualification with the code when analyses are submitted in support of licensing actions. This statement is expected to be consistent with the guidance of Generic Letter 83-11.*

Code Assessment

45. *Assessment of the RETRAN-3D code for the models not explicitly approved in this safety evaluation will be the responsibility of the licensee or applicant. In addition, application of the RETRAN-02 or RETRAN-3D codes for best estimate analysis of UFSAR Chapter 15 licensing basis events may require additional code and model assessment, and an evaluation of uncertainties to assure accurate prediction of best estimate response. This condition is based on the absence, in the best estimate analysis approach, of the conservative assumptions in traditional UFSAR Chapter 15 licensing basis analyses. For each use of RETRAN-3D in a licensing calculation, it will be necessary for a valid approach to assessment to be submitted, which is expected to include a PIRT for each use of the code and the appropriate assessment cases and their results. The scope of the PIRT and validation/assessment will be commensurate with the complexity of the application.*

8.0 CONCLUSIONS

Development of RETRAN-3D is a significant advancement in analysis tools versus RETRAN-02. The RETRAN-3D code, however, due to its flexibility is a very complex tool to use. The degree to which the user can affect calculational results necessitates stringent controls over the training of the user and close examination of the modeling, assumptions and options used.

RETRAN-3D was submitted for staff review to be a code applicable to all Standard Review and Format Chapter 15 events except the loss-of-coolant accidents. As such it would be expected that broad and extensive assessment of the code would be provided addressing all models and correlations, a broad spectrum of separate effects tests, and a wide range of integral systems tests and actual plant data. This would also be expected to include a wide range of plant types and configurations. The lack of sufficient code assessment makes it incumbent upon the individual licensee or applicant to provide appropriate assessment for each use and application of the code. In addition, the user will have to provide verification that the code is used within the proper range of each and every correlation and model selected.

As a condition on the code used in a "RETRAN-02 mode," it will be necessary to provide adequate demonstration that the code is actually used in that mode where possible and that the only divergences are due to mandatory use of modified numerics and models. It will be essential that demonstration be provided that margins similar to those that would be obtained with RETRAN-02 have been obtained.

The addition of 3-dimensional neutron kinetics is a significant advancement in the code's capability. The performance of the kinetics models has been demonstrated to be consistent with that of other similar methodologies. The models have been compared with other methodologies by the staff and assessed by comparison with existing prompt critical experimental data. The staff concludes that use of the RETRAN-3D kinetics models is acceptable for transients such as the PWR rod ejection and BWR rod drop. In the case of the main steam line break in the PWR, the results are comparable to those obtained with lower order kinetics models since the transient is driven by the thermal-hydraulic conditions. Approval is not given for use of the code for the BWR instability calculation.

The staff believes that establishment of a RETRAN-3D peer review process by the RETRAN-3D Maintenance Group is a positive step in alleviation of staff concerns about user experience and consistency and uniformity in application of the code.

The staff review of RETRAN-02 resulted in a list of 39 limitations and conditions of use. The review of RETRAN-3D results in a reduction of that list, but does not eliminate all of the conditions. Many of the conditions still apply to RETRAN-3D and are, therefore, still in force. The forty-five conditions and limitations discussed above have been agreed to by EPRI and the RETRAN-3D Maintenance Group in a letter dated December 13, 2000.

The Chexal-Lellouche drift flux model appears to be an improvement over the previous RETRAN drift flux models based on the limited assessment provided. A licensee wishing to use the correlation will have to assure its use is in conformance with the conditions noted in Condition 16 above. Use outside the noted range of acceptance, or where CCFL is important, will necessitate that an applicant provide assessment over the full range of conditions

encountered during the application of interest. Since the correlation is purely empirical in nature the assessment must be provided for full scale in all variables of interest. An assessment of the uncertainties must also be provided.

Final acceptance of RETRAN-3D for licensing basis calculations depends upon successful adherence to the conditions and limitations on use discussed in this report. The RETRAN-3D documentation is expected to be republished with noted errors corrected and this safety evaluation included. The staff will audit the use of the RETRAN-3D code to verify that the conditions and limitations on use are followed.

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Attachment: Appendix A

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Date: January 25, 2001

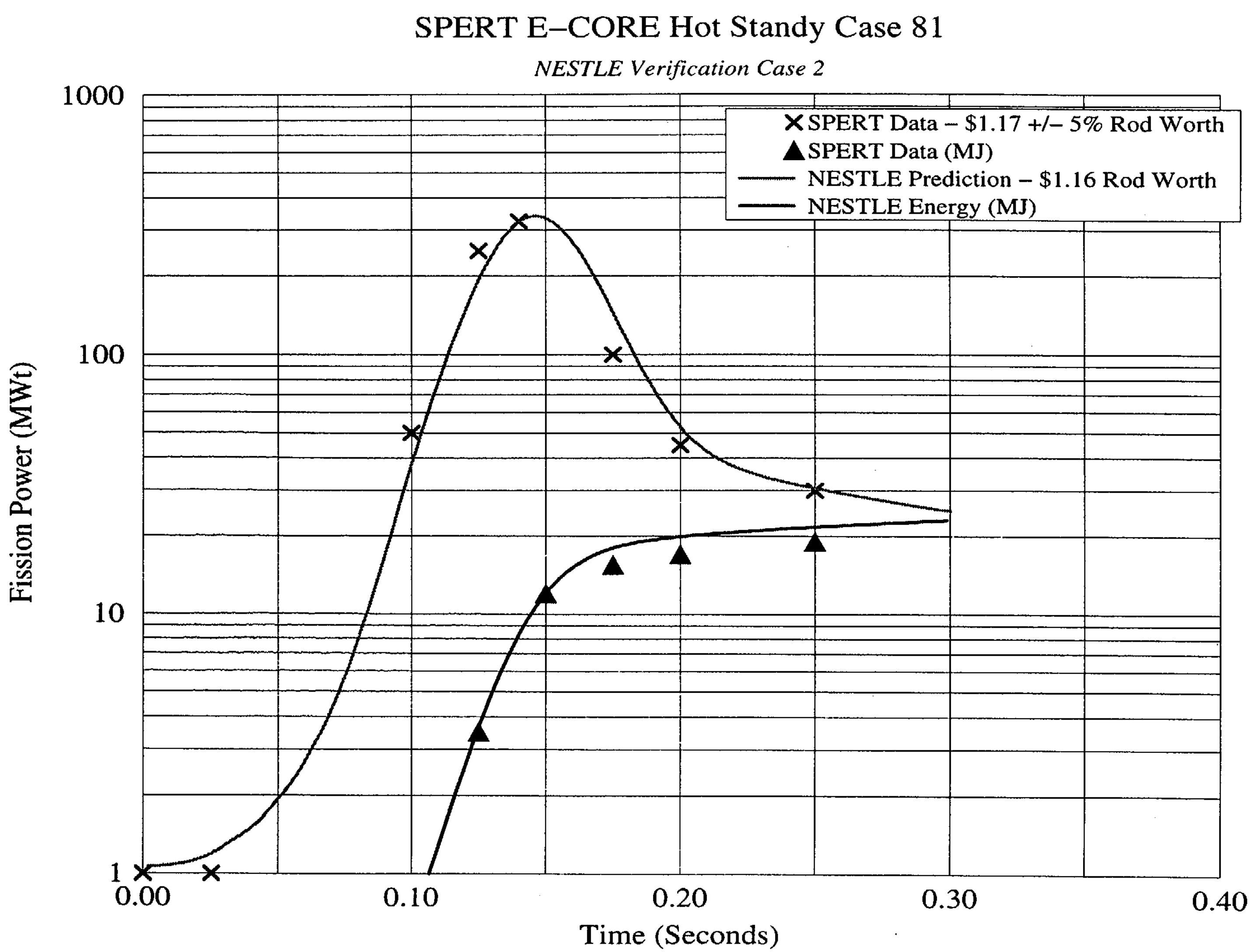

Figure 1 NESTLE Prediction of Spert III E-Core Test 81 - Hot Zero Power Super Prompt Critical Reactivity Excursion

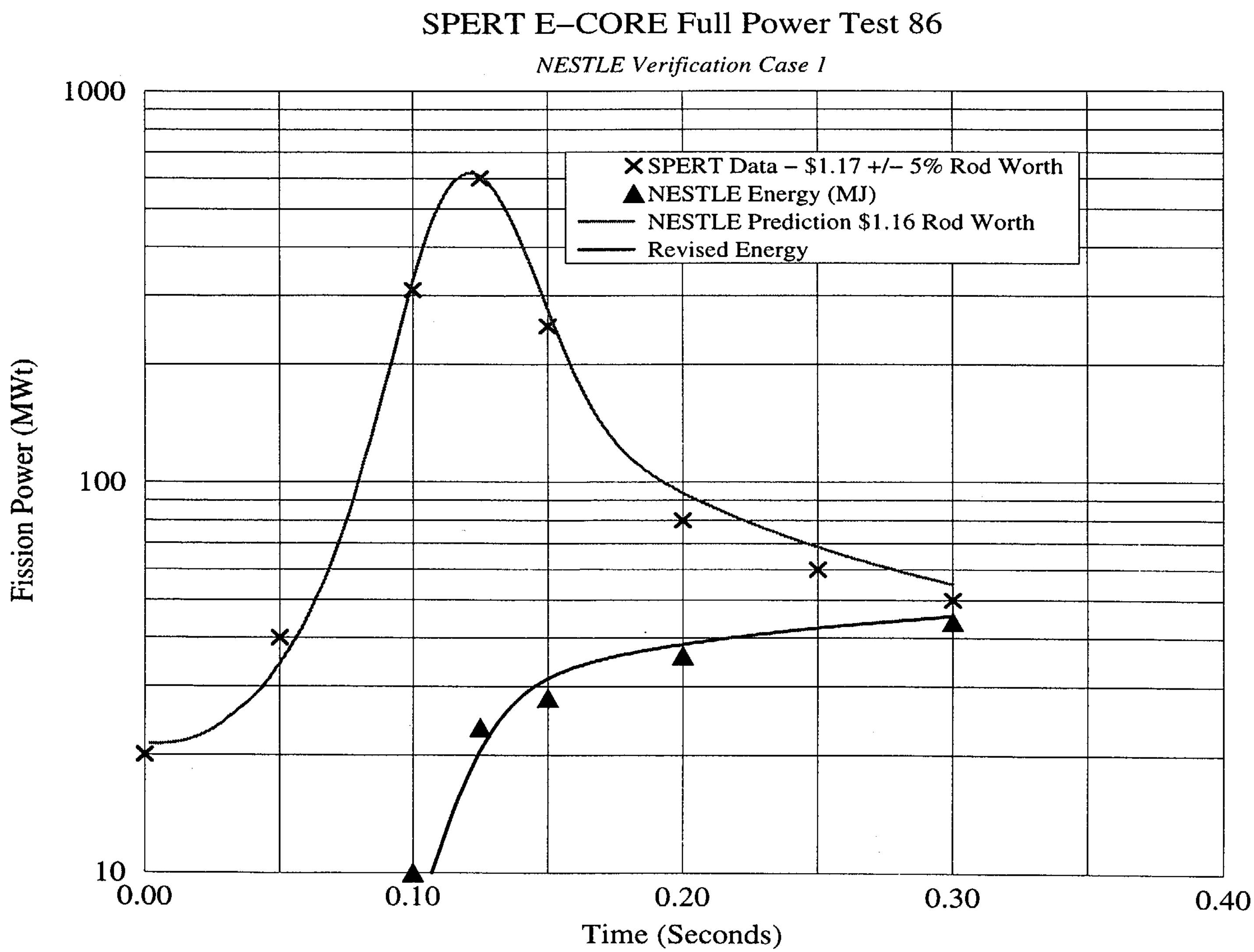

Figure 2 NESTLE Prediction of Spert III E-Core Test 86 - Full Power Super Prompt Critical Reactivity Excursion

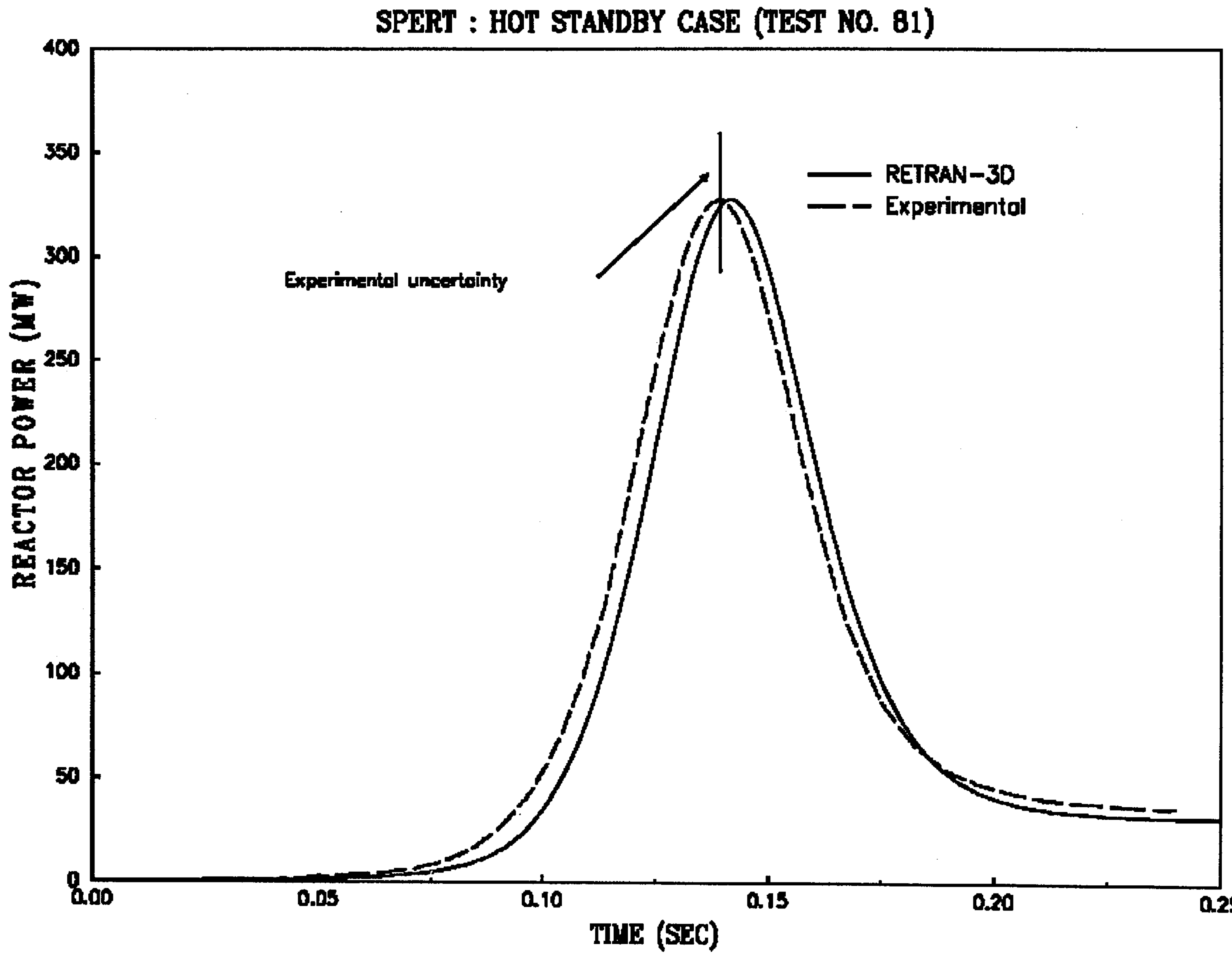

Figure 3 RETRAN-3D Predicted Power for SPERT III E-Core Test 81

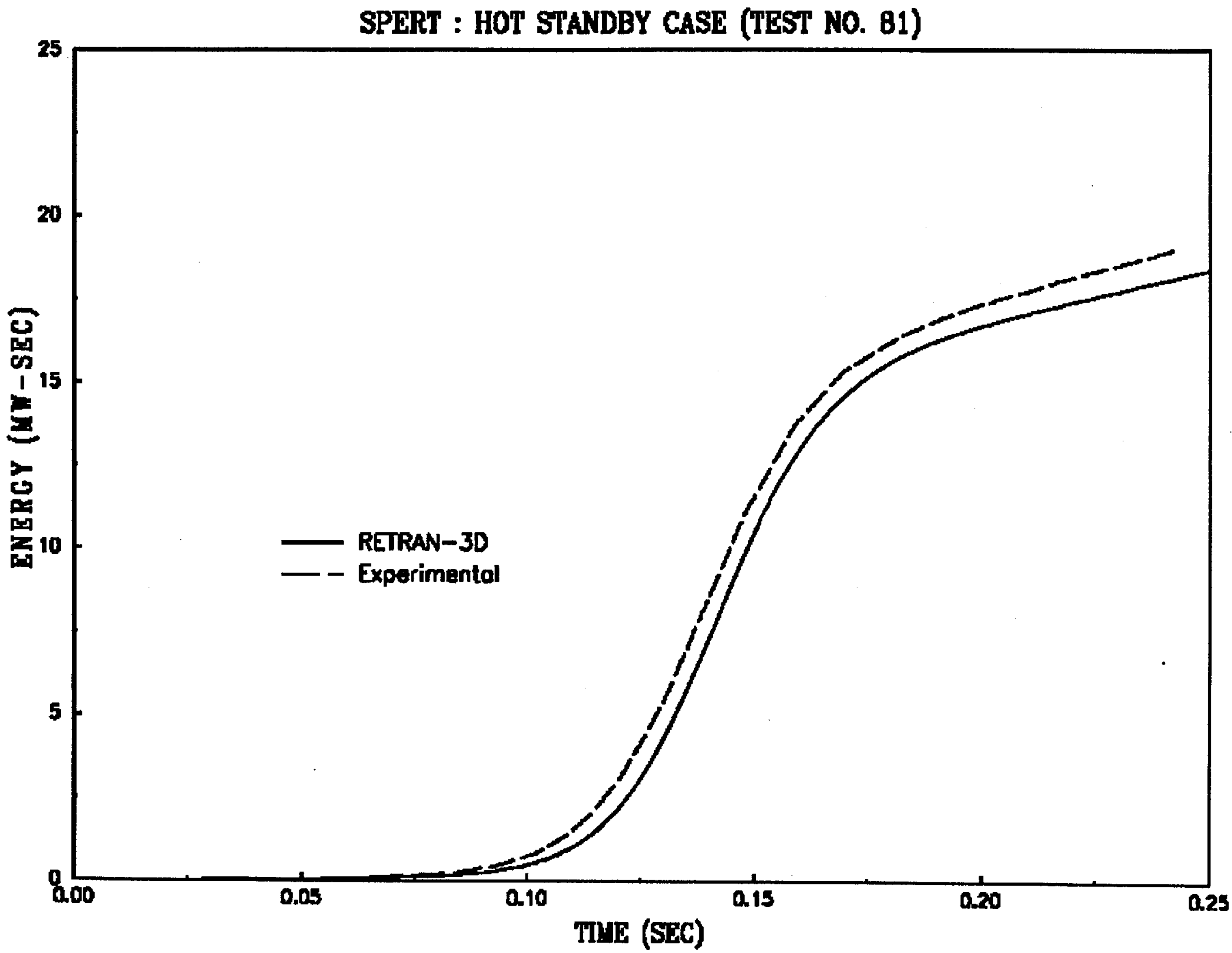

Figure 4 RETRAN-3D Predicted Energy Deposition for SPERT III E-Core Test 81

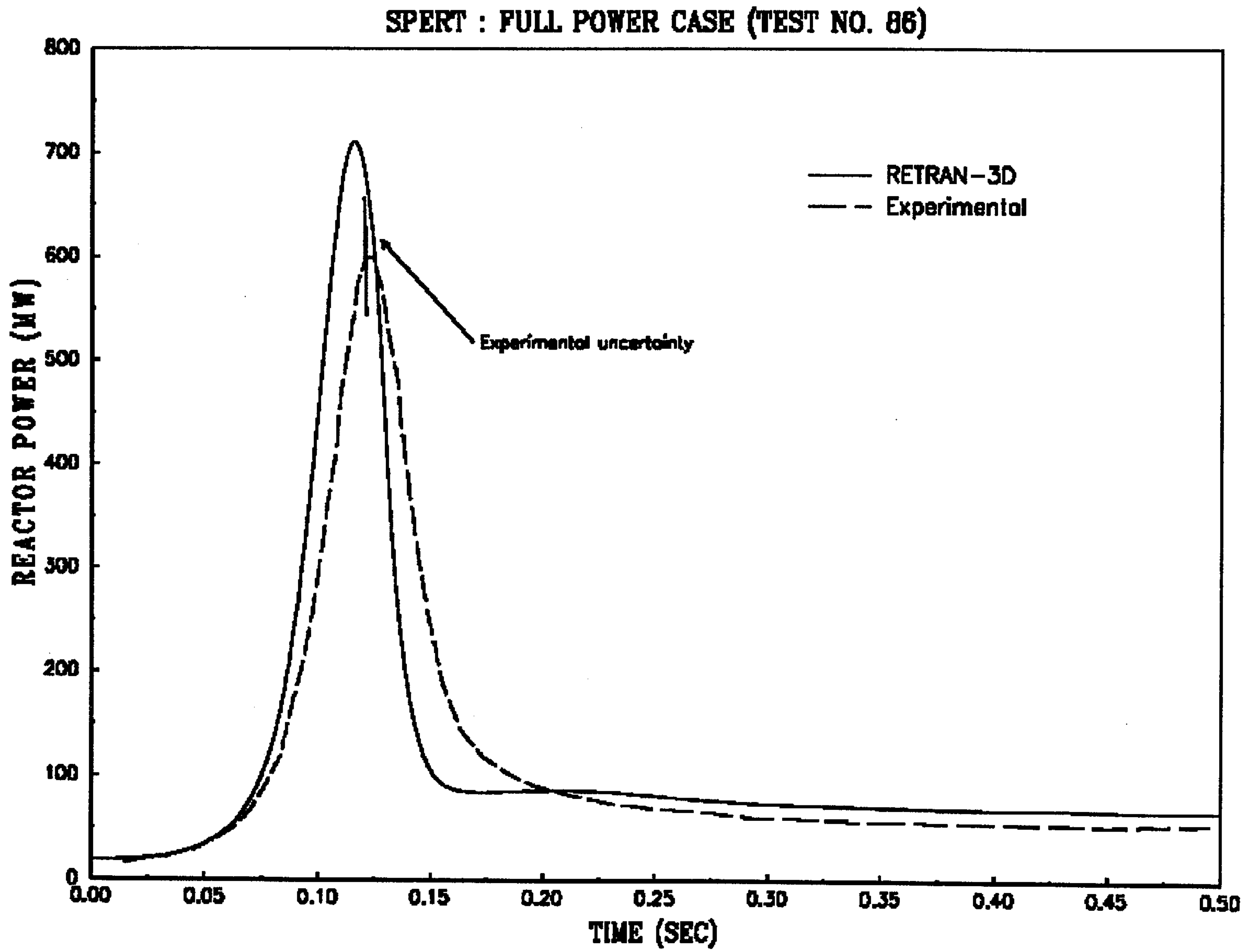

Figure 5 RETRAN-3D Predicted Power for SPERT II E-Core Test 86

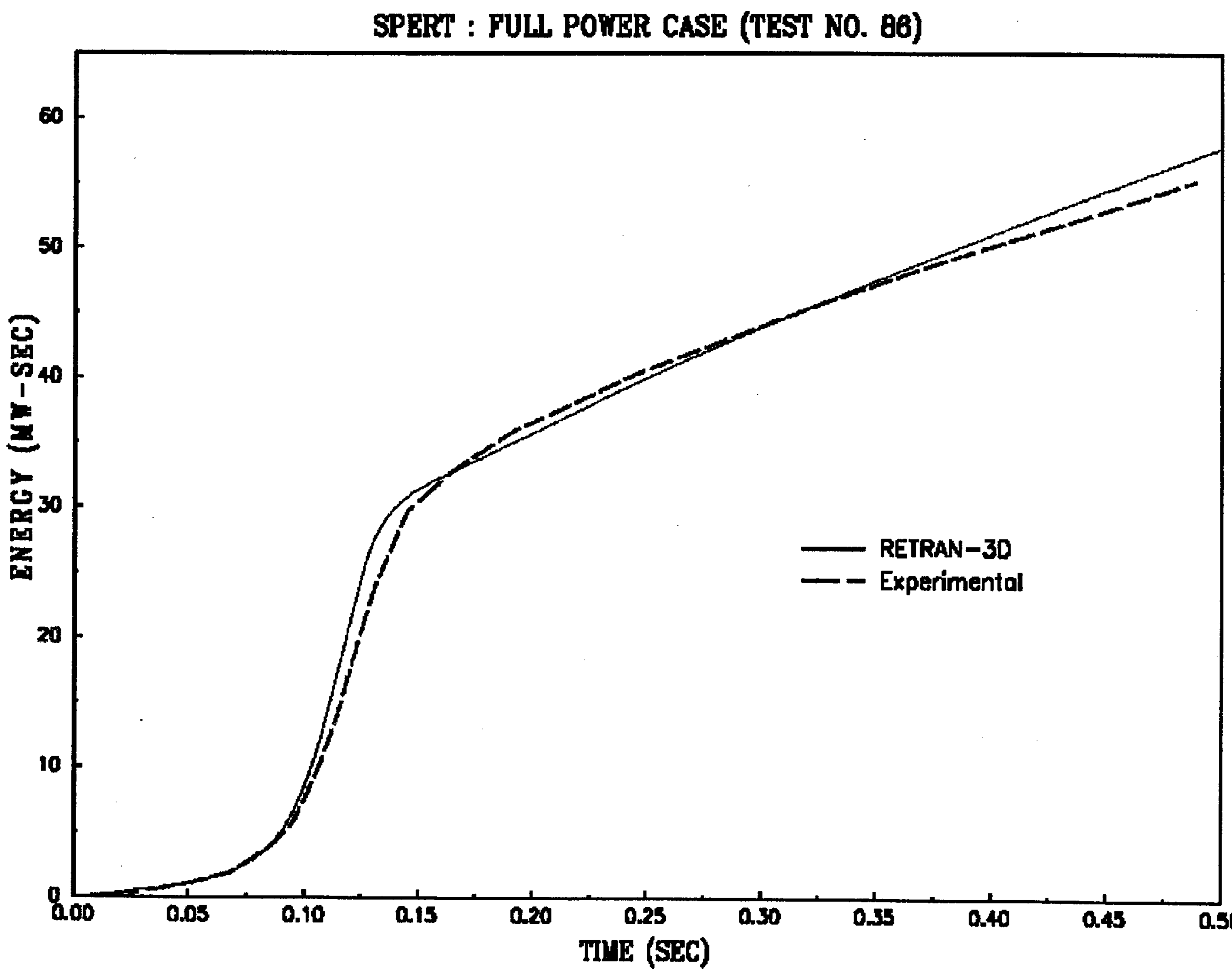

Figure 6 RETRAN-3D Predicted Energy Deposition for SPERT III E-Core Test 86

Appendix A

AP-600 CORE EVALUATED WITH BOTH DIFFUSION THEORY AND TRANSPORT THEORY

INTRODUCTION

The reference AP-600 core was used as a sample problem with which to compare diffusion theory methods and transport theory base methods. The comparison was based on the predicted flux and eigenvalue. The staff used the NESTLE code as the diffusion theory solver and TORT as the transport theory code. This evaluation is by extension by an evaluation of RETRAN-3D because the staff has demonstrated that RETRAN-3D and NESTLE yield essentially identical answers. The intent of this exercise is to assess the capabilities of diffusion theory methods relative to higher order transport methods. For the purposes of this problem, the transport theory results are taken to be the reference (or the "correct") answers.

DESCRIPTION OF PROBLEM

The reference AP-600 core (Reference A.1) was chosen as the core for analysis. This core is attractive for this purpose because it is unburned. The core consists of three different fuel types and has no burnable absorbers. Cross sections were prepared with a pre-release version of sas2d (under development for SCALE-5) which is a two-dimensional S_N solver using the method of characteristics. It also has the unique capability to develop the 5th Order Legendre Polynomial expansion coefficients which are needed for the TORT calculations. Both models used the same cross sections with the obvious exception that TORT used a 5th order Legendre Polynomial expansion to represent the scattering kernel. All other inputs including nodalization were identical. Both rodded and unrodded cases were studied. The control rod was a B_4C control cluster. The figure of merit for this study was the axial flux distribution. The input files are included at the end of this Appendix.

RESULTS AND DISCUSSION

Two plots were created and presented as Figures A.1 and A.2. Figure A.1 shows the axial power distribution averaged for all of the fuel. As expected, the flux follows the familiar cosine shape and the fast (or group 1) flux has a larger magnitude. The TORT and NESTLE predictions are in excellent agreement. Figure A.2 shows the axial flux profiles for the assembly where the B_4C control rod is inserted. This case is much more challenging due to the presence of the strong absorber, but the diffusion theory code still predicts acceptable results with a maximum error of 6 percent for the fast flux. This is considered excellent given that theoretically diffusion theory breaks down in the presence of strong absorbers such as B_4C.

This study provides the staff with some insight into the accuracy of diffusion theory methods relative to higher order transport theory based codes. The two figures presented show that for the reactor which was studied, diffusion theory can accurately predict flux profiles (and, therefore, power distributions) compared to transport theory methods for both rodded and unrodded cases. Although limited in its scope, this study is further confirmation that diffusion theory is adequate for reactor analyses. As a final note, the eigenvalues compared to within 0.6

%Δk/k (approximately 600 pcm) which is considered acceptable for this study. The nodal method employed in TORT is designed for accurate prediction of surface fluxes and is not rigorously validated for eigenvalue predictions so some difference in the eigenvalue was expected.

REFERENCES

A.1 "AP600 Standard Plant Design," Chapter 4, Westinghouse Electric Corporation.

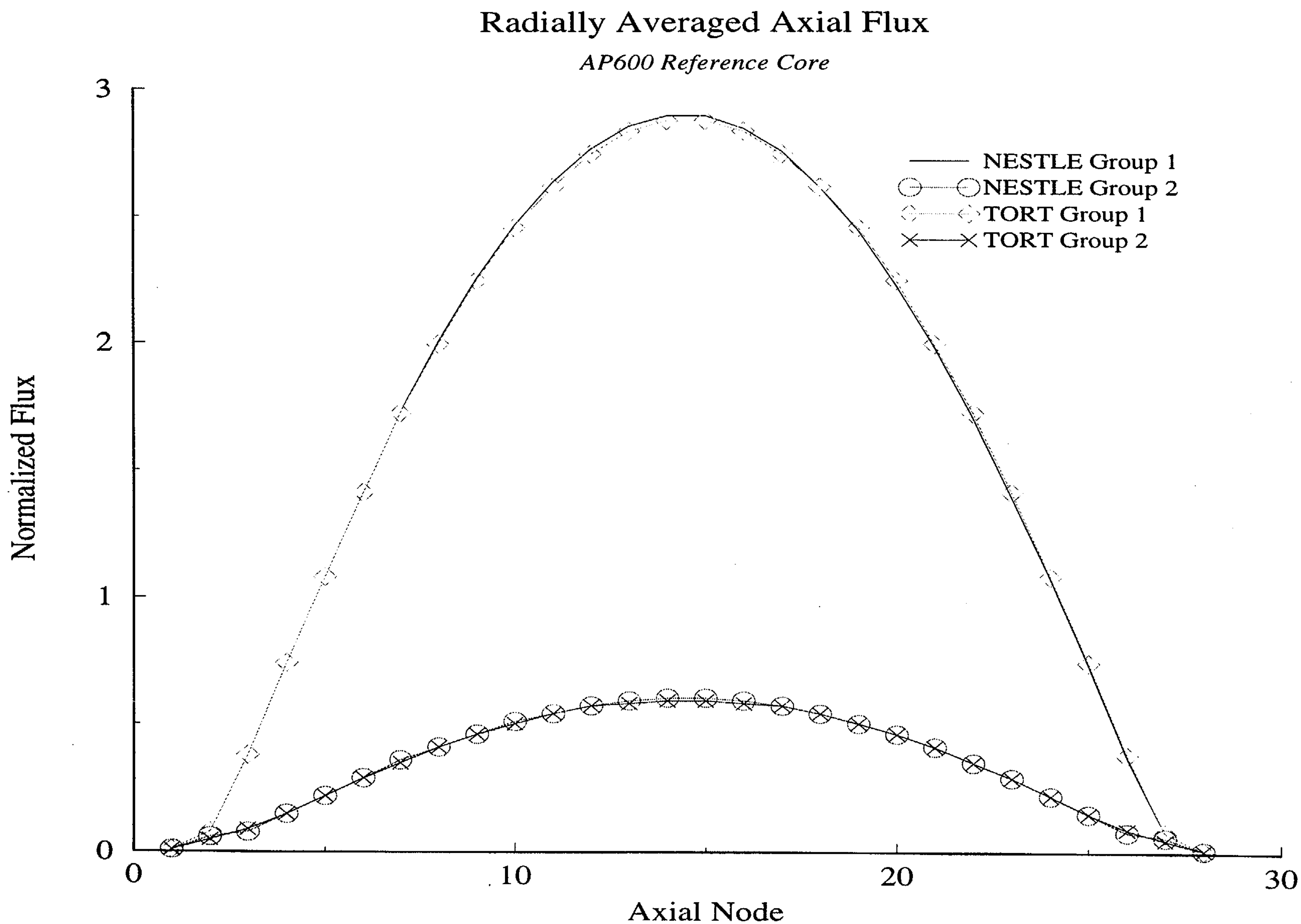

Figure A.1 Radially Averaged Axial Power Distributions

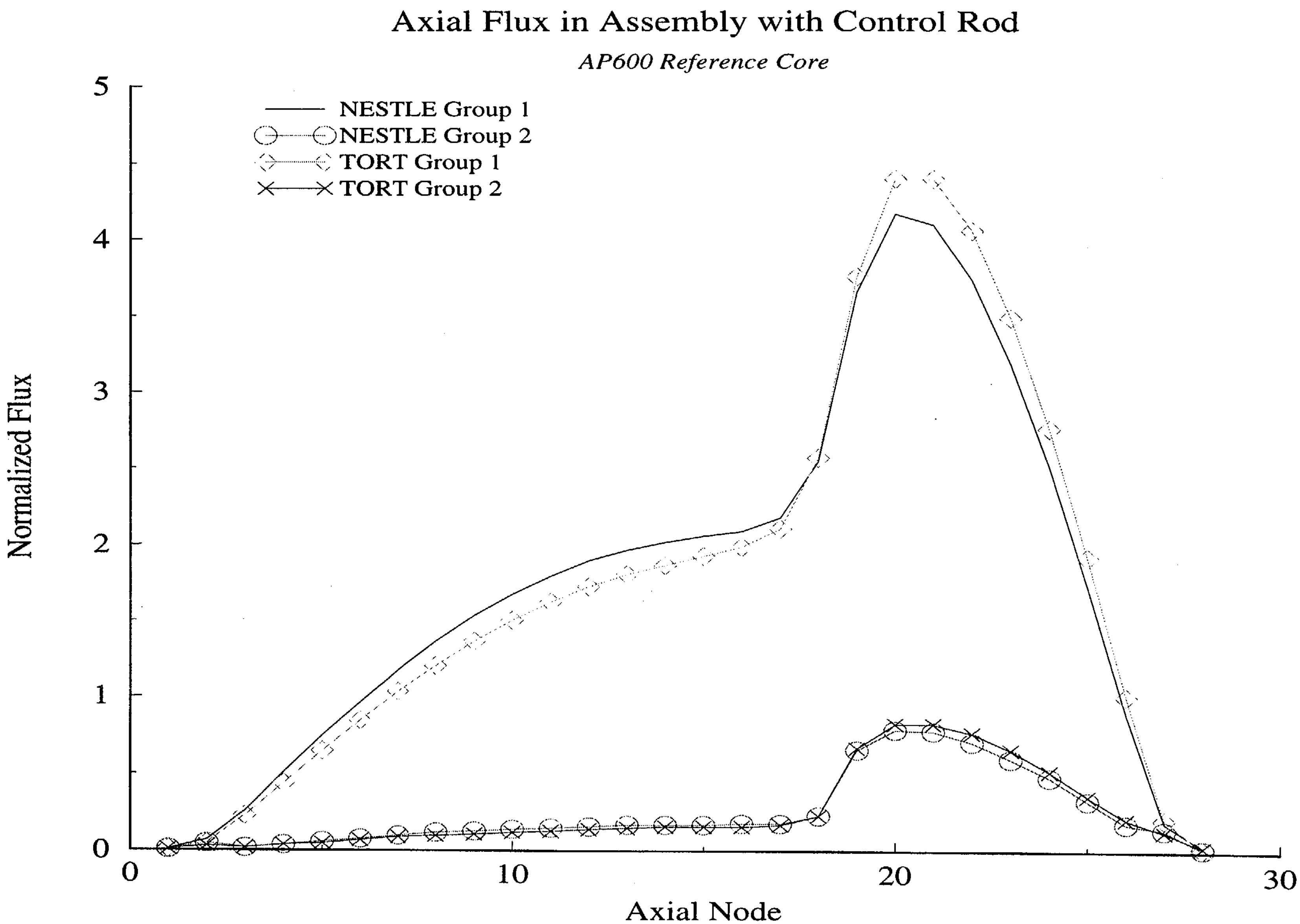

Figure A.2 Axial Power Distribution for Assembly with Control Rod Inserted