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

October 30, 1993

Mr. Y. Y. Yung, Chairman
VIPRE-01 Maintenance Group
Washington Public Power Supply System
P.O. Box 968
Richland, WA 99352

Dear Mr. Yung:

SUBJECT: ACCEPTANCE FOR REFERENCING OF THE MODIFIED LICENSING TOPICAL REPORT, EPRI NP-2511-CCM, REVISION 3, "VIPRE-01: A THERMAL-HYDRAULIC ANALYSIS CODE FOR REACTOR CORES", (TAC NO. M79498)

We have completed our review of the subject topical report submitted by the VIPRE-01 Maintenance Group (VMG) by letter dated February 28, 1990. We find the report to be acceptable for referencing in license applications to the extent specified and under the limitations delineated in the report and the associated NRC evaluation, which is enclosed. The evaluation defines the basis for acceptance of the report.

We do not intend to repeat our review of the matters described in the report and found acceptable when the report appears as a reference in the license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to the matters described in the report.

In accordance with procedures established in NUREG-390, it is requested that VMG publish accepted versions of this report, proprietary and non-proprietary, within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed evaluation between the title page and the abstract. The accepted versions shall include an -A (designating accepted) following the report identification symbol.

Should our criteria or regulations change such that our conclusions as to the acceptability of the report are invalidated, VMG and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

Ashok C. Thadani, Assistant Director
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

Enclosure:
NRC Evaluation

UNITED STATES
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ENCLOSURE 1

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATING TO VIPRE-01 MOD 02 FOR PWR AND BWR APPLICATIONS EPRI-NP-2511-CCM-A, REVISION 3

1.0 INTRODUCTION

By letter dated February 28, 1990 (Ref. 1), the VIPRE-01 Maintenance Group (VMG) submitted for staff review a package consisting of a summary of changes in VIPRE-01 between MOD-01 and MOD-02 and verification of VIPRE-01 for use in BWR analysis. The five-volume set of VIPRE-01 MOD-02 computer code documentation (Ref. 2) reflected changes up to Revision 3. Documentation of error corrections (Ref. 3) was later forwarded to the NRC in support of the review.

The submittal consisted of the five volume set of the VIPRE-01 MOD-02 code documentation and user's manuals. The mathematical modeling used in the code is discussed in Volume 1. Volume 2 is the user's manual and the programmer's manual is contained in Volume 3. Volume 4 documents the experimental data comparisons, sensitivity studies and plant behavior simulations. Input guidelines and capabilities and limitations of the code are presented in Volume 5. Also submitted was a summary of changes in VIPRE-01 between MOD-01 and MOD-02. For demonstration of the adequacy of VIPRE-01 for BWR analysis a series of sensitivity studies and benchmark analyses were submitted for review.

The purpose of this review was to evaluate the acceptability of new models and changes contained in the VIPRE-01 MOD-02 version for application in both PWR and BWR analysis based upon the submitted materials (Refs. 1, 3, 5 - 7). Therefore, the review was conducted in order to : (1) assure that corrections and any changes introduced in the MOD-02 version of the code do not alter the code's acceptability and applicability to PWR applications as granted under the existing SER; and (2) determine acceptability of MOD-02 for generic BWR and PWR applications. This was a generic review of the VIPRE-01 MOD-02: it

was not a review of any specific licensing application or examination of the actual coding.

2.0 BACKGROUND

VIPRE-01 was developed by Battelle Pacific Northwest Laboratories for the Electric Power Research Institute (EPRI) for use to evaluate nuclear reactor parameters including minimum departure from nucleate boiling ratio (MDNBR), critical power ratio (CPR), fuel and clad temperatures, and reactor coolant state in normal and off-normal conditions.

VIPRE-01 MOD-01, was submitted in 1985 to the NRC for review regarding its use in PWR and BWR licensing applications. It was approved by issuance of a Safety Evaluation Report (SER) by the NRC in 1986 (Ref. 4). The SER contained certain specific restrictions and qualifications. The NRC accepted MOD-01 for PWR licensing applications for heat transfer regimes up to the point of critical heat flux (CHF), provided that (a) the CHF correlation and its limit used in the application is approved by the NRC, and (b) each organization using VIPRE for licensing calculations submit separate documentation justifying their input selection and modeling assumptions. Thus, use of VIPRE-01 MOD-01 is ccurrently limited to PWR applications only.

VIPRE-01 MOD-02 is an improved and updated version of VIPRE-01 MOD-01 in that the code version includes 77 changes/corrections (Refs. 1, 3) from the MOD-01 version. One major modification was to include an optional drift-flux model to improve the code's ability to calculate the evolution of void fraction profiles in transients with two-phase flow conditions. Two other models, a "water tube channel model" and a "water leakage model" were also added.

3.0 STAFF EVALUATION

The review of the submittal of the VIPRE-01 MOD-02 computer code for PWR and BWR applications was performed with technical assistance from International Technical Services (ITS). The ITS review findings are contained in the

Technical Evaluation Report (TER) with its review findings attached to this report. The staff has reviewed the TER and has concurred with all its findings.

During the review of VIPRE-01 MOD-01, it was found that lack of documentation of model qualification necessitated restrictions upon use of the code for BWR applications. This was primarily because of insufficient data provided to the reviewer regarding qualification of thermal-hydraulic correlations used by the code for the computation of critical power ratio (CPR) in BWR systems, which is a measure similar to DNBR for PWR systems. The Safety Evaluation Report (SER) (Ref. 2), however, approved the code's use for PWR application, provided that the user would document and submit to the NRC for approval descriptions of how the code is to be used, including justification of all input, default parameters, selection of correlations, etc.

The MOD-02 version was developed to address, in particular, issues related to BWR applications, but it also addressed correction of errors reported to the VIPRE Maintenance Group (VMG) for MOD-01 (Refs. 3 & 4). VMG submitted the MOD-02 version of VIPRE for review of its acceptability of use for both PWR and BWR analysis.

In the performance of this work, the review included the VIPRE-01 MOD-02 code manual entitled "VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores," (Ref. 1) and supplemental information (Refs. 5 - 7). For the current review, not only were those model modifications made to the previous version of VIPRE1-01 reviewed, but also reviewed were the changes to the overall documentation of the code, since new volumes of code manuals have been issued. These materials were provided by the VIPRE-01 Maintenance Group (VMG). This was a generic review of VIPRE-01 MOD-02: it was not a review of a specific application or an examination of the actual coding.

This review was conducted with respect to the following items:

1. To assure that corrections and changes introduced in the code do

not alter its acceptability and applicability for PWR applications as granted under the existing SER; and

2. To determine acceptability of MOD-02 for generic BWR applications.

Three significant major models were added to this code version specifically to assist in its application to BWR conditions:

1. Drift Flux Model
2. Water Tube Channel Model
3. Water Leakage Model

The balance of the code remains the same as previously reviewed (except for the error corrections). Therefore, the previously issued requirements placed upon the contents of the submittal to the NRC remain unchanged. Similarly, the restrictions with respect to the use of MOD-01 for PWR applications remain applicable to MOD-02.

The error corrections make the MOD-02 version of the code run better than MOD-01. However, two error corrections impact the calculations of DNBR in PWR applications. These corrections changed the thermal conductivity of Zircaloy resulting in the retention of more heat in the fuel. Its impact on a sample loss of flow transient resulted in a reduction of DNBR by roughly 2.3%, which is the trend to be expected. When PWR users switch to VIPRE-01 MOD-02, they will find that the computed DNBR will be lower for identical cases of this type. Some VIPRE PWR users are using this code to compute coefficients of response surface equations at a number of varying conditions.

4.0 SUMMARY

The staff has reviewed (1) the lists of corrections and changes to the VIPRE-01 MOD-01 code provided by the VIPRE-01 Maintenance Group, (2) the identified modeling changes implemented in the VIPRE-01 MOD-02 version, together with (3) the responses to questions provided by computer simulation analysts. Based

upon the foregoing, and subject to the limitations and restrictions contained in the original SER and set forth below with respect to correction of Zircaloy conductivity, we conclude that there are reasonable assurances that the VIPRE-01 MOD-02 computer code version is acceptable for use in PWR and BWR licensing applications.

Since there were not substantive modeling changes which would impact PWR calculations, VIPRE-01 MOD-02 is acceptable for PWR applications subject to the original SER.

With respect to PWR applications of VIPRE-01 MOD-01, the limitations on use contained in the original SER remain applicable. Because of the improved modeling capabilities in VIPRE-01 MOD-02, its use in BWR applications in computation of CPR is hereby approved subject to the conditions cited in the existing SER and the further conditions set forth below. Furthermore, the requirements regarding submittal of separate documentation of use and input selection by each organization must still be observed.

For the various models/correlations presented for use as options in the VIPRE-01 code, the code developers did not endorse any particular model/correlation for use in a particular application. Therefore, it is incumbant upon each user to choose the appropriate option for their particular application subject.

In addition, with respect to MOD-02

1. The use of this code for BWR licensing applications is contingent upon full qualification of the models described in TER Section 3.2.2.

   For example, models added to the code for use specifically for BWR applications are: (1) water tube channel modeling, (2) leakage flow path connection, and (3) drift flux model. Since no model verification or qualification was provided with the submittal,

each licensee must justify the use of thermal-hydraulic models and the selected parameters related there to, on a transient-by-transient basis and over the range of two-phase flow conditions expected to be encountered.

In this respect, each user may choose to perform one of the following:

a. perform a thorough benchmark check against plant specific data, including identification of measurement uncertainty. This approach is not acceptable if any of the key parameters or the sequence of events are not known; or

b. benchmark against the vendors test or approved code. If any of the key parameters used by the vendor are not known for comparison, this is not acceptable.

We note that there is limited transient void fraction data available which could be compared to code results over some ranges of parameters. However, a user attempting to qualify the model for use by comparison to those data must demonstrate that the data cover the range of phenomena to be encountered in the analysis to be performed.

c. A user may also take the approach of demonstrating that global results (such as power, pressure and core inlet-outlet temperature difference) computed with the code while using a particular drift flux formulation are conservative overall when compared to actual plant data over the range expected to be encountered during the transient being analyzed.

2. The GEXL Correlation is the only correlation currently having NRC approval for use in CPR calculations of a core containing GE

fuels. However, use of the GEXL correlation for other vendors' fuels or use of any other correlation requires a separate submittal for NRC review and approval.

3. Section 2.2 of Volume 5 of the submittal identifies a spectrum of limitations of the code. Each user, should ensure that the code is not being used in violation of these limitations.

4. By acceptance of this code version, we do not necessarily endorse procedures and uses of this code described in Volume 5 as appropriate for licensing applications. As the code developer stated in Reference 5, the materials were provided by the code developers as their non-binding advice on efficient use of the code.

   Each user is advised to note that values of input recommended by the code developers are for best-estimate use only and do not necessarily incorporate the conservatism appropriate for licensing type analysis. Therefore, the user is expected to justify or qualify input selections for licensing applications.

5.0 REFERENCES

1. Letter from Y. Y. Yung, VIPRE-01 Maintenance Group, to USNRC, "Notification of Release and Request for NRC Review of VIPRE-01 MOD-02," February 28, 1990.

2. "VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores," Volumes 1 - 5, EPRI-NP-2511-CCM-A, Revision 3, August 1989.

3. Letter from Y. Y. Yung, VMG, to USNRC, "VIPRE-01 Error/Change Log," February 26, 1991.

4. "Safety Evaluation Report on the VIPRE-01 Computer Code," May 1986.

5. Letter from Y. Y. Yung, VMG, to R. C. Jones, NRC, "Response to Request for Additional Information on VIPRE-01: A thermal-Hydraulic Analysis Code for Reactor Cores, " March 16, 1992.

6. Letter from Y. Y. Young, VMG, to R. C. Jones, USNRC, "Responses to Request for Additional Information on VIPRE-01 MOD-02 Documentation EPRI NP-2511-CCM, VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores (TAC No. M79498)," September 24, 1992.

7. Letter from Y. Y. Yung, VMG, to R. C. Jones, USNRC, "Supplement to Response to VIPRE-01 MOD-02 Review Questions," November 23, 1992.

ITS-NRC-93-1

TECHNICAL EVALUATION REPORT:

VIPRE-01 MOD-02 FOR PWR AND BWR APPLICATIONS

EPRI-NP-2511-CCM-A, REVISION 3

Prepared for
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under NRC Contract No. NRC-03-90-062
FIN No. L1318

International Technical Services, Inc.
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TECHNICAL EVALUATION:
VIPRE-01 MOD-02 FOR BWR AND PWR APPLICATIONS
EPRI-NP-2511-CCM-A, REVISION 3

1.0 INTRODUCTION

By letter dated February 28, 1990 (Ref. 1), the VIPRE-01 Maintenance Group (VMG) submitted for staff review a package consisting of a summary of changes in VIPRE-01 between MOD-01 and MOD-02 and verification of VIPRE-01 for BWR analysis. The five-volume set of VIPRE-01 MOD-02 computer code documentation (Ref. 2) reflecting changes up to Revision 3 as well as documentation of error corrections (Ref. 3) was later forwarded to the NRC in support of the review.

VIPRE-01 was developed by Battelle Pacific Northwest Laboratories for the Electric Power Research Institute (EPRI) for use to evaluate nuclear reactor safety limits including minimum departure from nucleate boiling ratio (MDNBR), critical power ratio (CPR), and fuel and clad temperatures, and reactor coolant state in normal and off-normal conditions.

VIPRE-01 MOD-01, submitted in 1985 to the NRC for review for use in PWR and BWR licensing applications, was approved by issuance of a Safety Evaluation Report (SER) by the NRC in 1986 (Ref. 4). The SER contained certain specific restrictions and qualifications. The NRC accepted MOD-01 for PWR licensing applications for heat transfer regimes up to the point of critical heat flux (CHF), provided that (a) the CHF correlation and its limit used in the application is approved by the NRC, and (b) each organization using VIPRE for licensing calculations submit separate documentation justifying their input selection and modeling assumptions. Thus, the current use of VIPRE-01 MOD-01 is limited to PWR applications only.

MOD-02 is an improved and updated version of VIPRE-01 MOD-01 in that the code version includes 77 changes/corrections (Refs. 1, 3) from the MOD-01 version. One major modification was to include an optional drift-flux model to improve the code's abilities to calculate the evolution of void fraction profiles in transients with two-phase flow conditions. Two other models, a "water tube channel model" and a "water leakage model" were also added.

The purpose of this review is to evaluate the acceptability of models and changes contained in the VIPRE-01 MOD-02 version for application in <u>both</u> PWR and BWR analysis based upon the submitted materials (Refs. 1, 3, 5 - 7). Therefore, the review was conducted in order to: (1) assure that corrections and any changes introduced in the MOD-02 version of the code do not alter the code's acceptability and applicability to PWR applications as granted under the existing SER; and (2) determine acceptability of MOD-02 for generic BWR and PWR applications. This was a generic review of the VIPRE-01 MOD-02: it

was not a review of any specific licensing application or examination of the actual coding.

2.0 SUMMARY OF THE SUBMITTAL

The Submittal consists of the five volume set of the VIPRE-01 MOD-02 code documentation and user's manuals. The mathematical modeling used in the code is discussed in Volume 1. Volume 2 is the user's manual and the programmer's manual is contained in Volume 3. Volume 4 documents the experimental data comparisons, sensitivity studies and plant behavior simulations. Input guidelines and capabilities and limitations of the code are presented in Volume 5. Also submitted was a summary of changes in VIPRE-01 between MOD-01 and MOD-02. For demonstration of the adequacy of VIPRE-02 for BWR analysis a series of sensitivity studies and benchmark analyses was submitted for review.

3.0 TECHNICAL EVALUATION

3.1 VIPRE-01

VIPRE-01 is a finite-volume subchannel analysis code capable of three-dimensional modeling of reactor cores and other similar geometries in steady-state and transients. Given the geometry of the reactor core and coolant channel, and the boundary conditions or forcing functions, VIPRE-01 calculates core flow distributions, coolant conditions, fuel rod temperature and the minimum departure from nucleate boiling ratio (MDNBR) for steady and certain operational transients and abnormal events. Any of the boundary conditions (inlet flow and temperature conditions and fluid properties) may be obtained from calculations performed by reactor systems codes such as RETRAN or varied by user input.

A good overview and brief description of VIPRE-01 is provided in the Safety Evaluation Report (Ref. 4). The code modifications made in MOD-02 did not substantially alter any models contained in MOD-01 (except for error corrections). Therefore the description of the code in this report is limited to brief highlights.

The VIPRE modeling structure is based on subchannel analysis. The core or a section of symmetry is designed as an array of parallel flow channels with lateral connections between adjacent channels. A channel may represent a true subchannel within a rod array, a closed tube or a larger flow area representing several subchannels or rod bundles. The user has a great deal of flexibility for modeling reactor cores or any other fluid flow geometry. However, its use is limited to analysis of steady and transient conditions of the reactor core only.

It can compute single-phase and homogeneous two-phase flow from subcooled to superheated and super critical conditions in water using the homogeneous equilibrium (three-equation) assumptions with empirical subcooled quality correlations for subcooled boiling and void-quality relationships to approximate the effects of the presence of two phase. A wide variety of correlations are available for boiling heat transfer. Wall friction can be

computed for fluids other than water through the code's capability to input a properties table. MOD-02 incorporates an option for modeling slip between the liquid and vapor phases through a drift-flux formulation.

A finite-volume conduction model is also used to compute temperature distributions and surface heat flux for walls, hollow tubes, cylindrical rods, and nuclear fuel rods. Internal UO2 and zircaloy thermal properties functions are installed and properties of other materials may be specified by input. For nuclear fuel rods, a dynamic fuel-clad gap heat conduction model is available to account for the effects of thermal expansion and internal pressure.

The core power is specified in terms of an average power, with radial power factors and axial power profiles for each rod.

Volume 1 of Reference 1, "Mathematical Modeling" addresses the theoretical development of general conservation equations, constitutive relationships, correlations and numerical solution methods. Volume 2 is the User's Manual, and provides descriptions of input parameters and correlation selection and sample problems and output. Volume 3 is the Programmer's Manual which describes general coding philosophy, routines, data files and auxiliary programs. Volume 4 is an Applications volume which describes the VIPRE-01 validation efforts and results for various applications.

In the review of MOD-01, Revisions 1 and 2 of Volumes 1, 2 and 3 were reviewed. The draft version of Volume 4 was also reviewed with the understanding that the published version would be essentially the same. Volume 5 was published in March 1988 containing capabilities and limitations of the code and input guidelines. A brief discussion of core thermal-hydraulic safety analysis is also presented in Volume 5. While this is a useful document for a user to read, the code developers have clearly stated on several instances that the contents of Volume 5 are only guidelines and each user must qualify its use of the code model for its particular application.

The error corrections and changes as well as the addition of the water tube channels, leakage flow path connections and drift-flux models incorporated in MOD-02 are reviewed in the following sections. Qualification of these models as well as features unique to BWR applications are also discussed.

3.2 Error Corrections and Changes

The VIPRE-01 Error/Change Log (Ref. 3) was reviewed. Of the 77 changes, 50 were cosmetic corrections in that they do not affect the numerical performance of the code. 22 of these 50 changes were made to the post-processor graphics program while the other 28 were made to enhance the appearance of the output. Therefore, these 50 changes do not affect calculations.

Of the other 27 changes which resulted in differences in code performance, 11 changes were necessary to correct problems which resulted in code execution failure due to the use of code options in unforseen ways or in combinations

of options untested by the code developers. Due to the nature of the failure, these changes do not impact previously submitted and approved analyses. In future submittals, the existing SER condition for the user to document and justify use of the code options will remain in force. This will require close examination of any unusual combination of options or use of the code beyond the range of its applicability.

In some cases it may still be desirable to have the code fail rather than to mislead the user by continued execution when some options or input are misused. Therefore we recommend that the NRC require the code developers to either install warning print-outs when the code is being operated outside the range of proven applicability of correlations or cause the computation execution to cease in those circumstances.

The remaining 16 changes resulted in numerical differences of varying magnitude in calculations. For the most part, these differences were minor and have little impact of analysis results. However some changes did result in some significant differences which are discussed below.

3.2.1 Impact of Error Corrections

This section focuses on evaluation of the impact of error corrections on PWR applications, since the relevant code version had not been approved for use in BWR applications.

Most of the corrections made to the code since its last review are benign in that the numerical impact is negligible.

However, changes 125 and 128 corrected the coefficients for the empirical correlation for thermal conductivity of Zircaloy. The general effect of the correction, according to the code developer, is to decrease the thermal conductivity, and thereby increase the inner clad and fuel node temperatures. A test case was performed at typical PWR conditions (Ref. 7) during a loss of flow transient based on a case presented in Volume 4 of the code documentation.

The comparison showed that the peak centerline temperature of the fuel pellet increased nearly 1% representing a slight increase in the stored energy in a fuel rod. The computed DNBR by MOD-02 was roughly 2.3% smaller than that by MOD-01. The time of MDNBR also shifted slightly. This indicates that the error corrections led to prediction of more conservative MDNBR, and therefore, implies that previous computations with MOD-01 may not have been sufficiently conservative.

3.2.2 Model Additions and Improvements

Models added to the code for use specifically in BWR applications are (1) water tube channel modeling, (2) leakage flow path connection, and (3) a drift flux model. None of these models has been presented with verification or qualification calculations.

3.2.2.1 Water Tube Channels

This model simulates the behavior of the hollow "water" rods that replace fuel rods in some BWR designs. One method to model these channels is as an isolated subchannel with thermal communication with the bundle channel through a conducting tube rod. This method can be used only when the active fuel section of the core is being modeled.

When the inlet and outlet structures of the BWR core are modeled, a special model in VIPRE allows the user to represent the channel as a subchannel that does not extend along the full core. The inlet and outlet boundary conditions for this subchannel are the pressure in the bundle cells just below the inlet and just above the top of the water tube, respectively.

The finite difference mass, energy, axial, and lateral momentum equations are modified to account for flow into and out of the water tube.

The solution scheme for the water channel uses user selected correlation for flow and heat transfer with one exception: subcooled boiling is not permitted in the water tube.

No qualification analysis was presented or provided. Therefore, each user of this model must qualify this model over the range of its intended use and submit such qualification to the NRC for review and approval.

3.2.2.2 Leakage Flow Path Connections

The lateral leakage paths that exist in the BWR lower regions (below the active core) can be modeled in VIPRE as gap connections that exist only over a few axial nodes, rather than the full length of the channel.

The continuity equations for mass, energy, and momentum, are treated in the same manner as for water tubes, with one exception: the axial momentum of water that flows from the fuel channel to the bypass region is subtracted from the donor cell but it is not added to the receiver cell. This implies a small momentum sink when leakage crossflow exists, which is assumed to be dissipated by the physical structure of the path.

The use of a gap-type leakage path requires the definition of a lateral momentum cell, with a specific width and area. The lateral width of this control volume, as recommended by the code developer, must be very small, and the related cross-flow length is recommended to be the diameter of the leakage hole or the width of the leakage slit. However, the definition of these dimensions and the corresponding loss coefficients used in the equations are left up to the user to select. This will require the user to have a great deal of knowledge about actual conditions and experimental supporting data over the thermal hydraulic conditions of interest.

No qualification analysis was presented or provided. Therefore, each user of this model must qualify this model over the range of its intended use and submit such qualification to the NRC for review and approval.

3.2.2.3 Drift Flux Model

Due to the modeling assumptions and correlations used in the homogeneous flow model and its constitutive models to account for subcooled boiling, one of major limitations in the type of flow solution is that convergence problems are introduced when attempting to model phase slip that can arise in transient boiling calculations. According to the code developers, in some boiling transients, particularly with small time steps, the subcooled boiling models used in the code, such as Levy and EPRI, and in some cases the bulk void correlations, can make the solution numerically unstable.

The drift flux model, as installed in the code, uses a vapor transport equation to calculate the void fraction via the vapor mass conservation equation rather than defining the void as a function of flow and quality with an empirical slip correlation. This treats the transport equation for vapor in a physically more realistic manner, particularly if the void is changing with time, and provides the appropriate time-rate-of-change. Addition of the drift-flux model requires solution of three additional constitutive relations. These are the vapor generation term, the drift velocity, and the distribution parameter as used in the covariance of convective momentum flux in the mixture momentum relation. The default for these relations in the model are based on those empirical relations used in the EPRI void model developed by Lellouche and Zolotar (believed by the developers to be applicable to the flow of water in vertical tubes, channels, and rod bundles). Thus in steady state applications the drift flux model gives results which are essentially equivalent to the EPRI void model, which is the default in the code. The user may, however, specify different numerical constants for defining the coefficient values used in the equations, in which case the steady state results would not reproduce the EPRI void correlation void profile.

The vapor generation term in the VIPRE-01 drift flux model is assumed to be composed of only the vapor generation due to wall superheat since vapor generation due to voiding because of direct energy deposition into the coolant is negligeable and an assumption of vapor generation due to transient local pressure effect is inconsistent with the default assumption in VIPRE-01 of a uniform reference pressure.

Relations between the weighted mean local drift velocity and the distribution parameter are developed empirically. These parameters depend on flow regime, operating range, and system geometry and account for the effects of buoyancy, interphase shear stress and interphase momentum exchange. These relations are in general neither simple nor widely applicable to a large class of problems. A set of drift velocity relations developed by Ishii for the full range of anticipated flow regimes, from low-void bubbly flow to mist flow, is incorporated in the code. These correlations, however, are applicable only to vertical upflow that can be described as one-dimensional.

In addition, the developers stated that the drift-flux model is generally applicable only to relatively high flow rates at pressures above a few hundred psia: at very low flow values, the predicted slip may be incorrect, and the model cannot be applied to recirculating or countercurrent flows.

No qualification analysis was presented or provided. Therefore, each user of this model must qualify this model and any selected correlations over the range of its intended use and submit such qualification to the NRC for review and approval.

3.2.2.4 Use of RECIRC solution method for BWR applications

Two solution options, UPFLOW and RECIRC, are available in VIPRE which differ in the manner in which the flow and pressure fields are obtained. Both of these options were approved during review of VIPRE-01 MOD-01 for strongly vertical flow. It was recommended that RECIRC be used when cross-flow is present.

When water tubes and crossflow leakage paths are modeled, the RECIRC option is the only available method. Similarly, the drift-flux model operates only with the RECIRC solution method.

3.3 Qualification for BWR Applications

For BWR application, a limited amount of model qualification and benchmark with test data was presented in Volume 4 of Reference 2: This document was reviewed during the original review of MOD-01. No further benchmark comparisons were provided, and therefore the concluding paragraph on page 9 of the existing SER remains applicable to BWR applications.

Volume 4 was issued prior to the implementation of the Drift-Flux model or other new models, and therefore contains no benchmark calculations with respect to these models.

Since the results were mixed and the test conditions were not necessarily applicable to BWR conditions, it would be difficult to draw conclusions based upon the analyses presented in Volume 4. It is recommended that the users review this document prior to selecting any model, but a user may not rely solely upon the contents of Volume 4 in making a submittal.

3.4 CHF/CPR Correlations

Two correlations in VIPRE-01, Hench-Levy CHF limit equations and Hench-Gillis critical quality correlation, can be used to compute CPR of BWRs. However, neither of these correlation has been approved for licensing analysis. At this time, each user performing licensing type calculation must implement the GEXL correlation, an NRC approved correlation, for this purpose. However, applicability of the GEXL correlation for other than GE fuels or use of any other correlation must be determined by NRC review of a thorough and detailed description and qualification to be presented by each future user to the NRC for review and approval.

3.5 Verification Analysis

A set of calculations performed based on Washington Nuclear Plant No. 2 (WNP-2) in support of BWR applications of VIPRE-01 was reviewed. It should be noted that these calculations were performed using VIPRE-01 MOD-01, therefore

new models were not reflected in these analyses. Later a set of calculations was submitted to show the impact of the Drift Flux Model. However, some general observations can be made from these analyses.

WNP-2 is a BWR/5 reactor with 8x8 fuel. The sensitivity studies with the core models were presented. Benchmark calculations against GE design calculations for core pressure drop, FSAR steady state results and WNP-2 core follow calculations were also presented. Comparison against the FSAR transient calculations were also performed and presented. These calculations were included in the submittal to demonstrate the capability of the code and not to qualify any specific model. Unless otherwise noted, all calculations were performed at BWR operating steady state conditions.

3.5.1 Sensitivity Studies

Selected sensitivity Studies were performed with respect to (1) radial nodalization, (2) axial nodalization, (3) water properties, (4) Rohsenow-Clark Viscosity Model, (5) local pressure option, (6) numerical solution schemes and (7) flow correlation for BWR core models.

In almost all cases, these sensitivity studies indicated insensitivity with respect to the variable in question. However, it should be stressed that these analyses were performed to demonstrate the code's capabilities and were not in the nature of code verification. Nearly all cases were performed at nominal steady state conditions and not at transient conditions. Therefore, these conclusion are limited to steady state conditions and may not be extended to transient applications or other plants or cores.

3.6. Benchmark Studies

Calculations were performed to confirm the accuracy and applicability of VIPRE to BWR analysis using the 4-channel full core model for steady state BWR analysis. Comparisons were made to (1) core pressure drop design data provided by GE for WNP-2, (2) steady state FSAR results, and (3) core follow analysis of WNP-2.

3.6.1 Core Pressure Drop Comparisons

The core Pressure drop data for WNP-2 were provided by GE using the GE proprietary code ISCOR. The data for core pressure drop as a function of rated power and flow were provided for 23 cases with no other boundary conditions defined. Calculations were performed assuming a range of system pressures of 900, 100, and 1050 psia and inlet subcooling of 20 and 30 btu/lbm for each case. Good agreement was achieved between the two sets of predictions.

3.6.2 FSAR Comparison

The VIPRE 4-channel model predictions were compared to the FSAR values (using ISCOR) for the void and quality axial distributions for the core average and the hot channel for WNP-2 under normal operating conditions.

Results indicate that more than 6% more flow is predicted in the central hot assembly by VIPRE than for the FSAR while in average assemblies similar relative flow was computed. Although this is not a conservative result, for the intended purpose of this comparison as demonstration of code performance, this is acceptable. However, in a licensing application, the user would be expected to justify its acceptability.

Similarly, the VIPRE predicted average orifice pressure drop in the peripheral region matched well with the FSAR value, while the pressure drop in the central region was predicted to be more than 30% higher by VIPRE than by ISCOR. This difference was attributed to different modeling assumptions in GE and VIPRE calculations.

The flow quality distribution comparisons showed generally good agreement in the core average values. For the maximum channel values, VIPRE tended to be higher and in the low quality regions, VIPRE predictions were much higher than ISCOR values.

3.6.3 Core Follow Comparisons

Comparisons were made against SIMULATE-2 predictions. Core Follow analysis for WNP-2 is performed using SIMULATE-2, a three dimensional steady state nodal analysis program. The detailed 191-channel quarter core model was used for easy comparison and input preparation due to the same channel layout used by the SIMULATE-2 core model. SIMULATE-2, an EPRI code, is a predecessor of SIMULATE-E and has been benchmarked against GE's Process Computer Data Bank.

The results from 21 cases indicate a good agreement in core pressure drop and core average void fraction.

3.7 FSAR Transient Calculation Comparisons

Six transients were analyzed for comparison to the FSAR reported values of the delta CPR. The transients chosen were; loss of feedwater heater, feedwater controller failure, generator load rejection with and without bypass) and turbine trip with and without bypass. No detailed description was provided for any transient analyzed, except for the delta-CPR.

VIPRE calculations were performed using the GEXL correlation in the 4-channel core model with the initial conditions and forcing functions obtained from the FSAR. The FSAR calculations were performed with ODYN.

The results showed that for five transients VIPRE predicted a higher delta-CPR and a nearly identical result for the sixth case. Therefore, VIPRE, as used, was conservative with respect to the ISCOR predictions to which it was being compared.

Finally a time step sensitivity was performed to determine a reasonable range for use. The conclusion reached was to use the time step size equal to or less than the largest time step that can follow the forcing function accurately.

4.0 CONCLUSIONS

We have reviewed (1) the lists of corrections and changes to the VIPRE-01 MOD-01 code provided by VIPRE-01 Maintenance Group, (2) the identified modeling changes implemented in the VIPRE-01 MOD-02 version, together with (3) the responses to questions provided by Computer Simulation Analysts. Based upon the foregoing, and <u>subject to the limitations and restrictions contained in the original SER and set forth below</u> with respect to correction of Zircaloy conductivity, we conclude that there are reasonable assurances that the VIPRE-01 MOD-02 computer code version is acceptable for use in PWR and BWR licensing applications.

Since there were no substantive modeling changes which would impact PWR calculations, VIPRE-01 MOD-02 is acceptable for PWR applications subject to the original SER and subject to confirmation of adequate conservatism in previously approved analyses and methodologies.

With respect to PWR applications of VIPRE-01 MOD-01, the limitations on use contained in the original SER remain applicable. Because of the improved modeling capabilities in VIPRE-01 MOD-02, its use in BWR applications in computation of CPR is hereby approved subject to the conditions cited in the existing SER and the further conditions set forth below. Furthermore, the requirements regarding submittal of separate documentation of use and input selection by each organization must still be observed.

Since it was not the intent of the code developers to qualify adequacy of the model/correlation, or BWR or PWR analysis, or to endorse use of particular model/correlations or modeling for applications, each user must perform (and submit for review) careful qualification and validation.

In addition, with respect to MOD-02:

1. The use of this code is contingent upon full qualification of the models described in Section 3.2.2 of this report before implementation into a licensing model.

   For example, since no model verification or qualification was provided with the submittal, each user of the drift flux model should be required to justify the use of the model and the selected parameters related thereto on a transient-by-transient basis over the range of two-phase flow conditions expected to be encountered;

2. The GEXL Correlation is the only correlation currently having NRC approval for use in CPR calculations of a core containing GE fuels. However, use of the GEXL correlation for other vendors' fuels or use of any other correlation requires a separate submittal of full qualification for NRC review and approval.

3. Section 2.2 of Volume 5 of the submittal identifies a spectrum of limitations of the code. Each user, in its documentation for NRC approval, should certify that the code is not being used in

violation of these limitations.

4. By acceptance of this code version, we do not endorse procedures and uses of this code described in Volume 5 as appropriate for licensing applications. As the code developers stated in Reference 5, the materials were provided by the code developers as their non-binding advise on efficient use of the code.

   Each user is advised to note that values of input recommended by the code developers are for best-estimate use only and do not necessarily incorporate the conservatism appropriate for licensing type analysis. Therefore, the user is expected to justify or qualify its use for licensing applications.

5. The comparisons between the sets of FRIGG and ANL Void Fraction test measured data and VIPRE predicted data showed generally inconclusive results. These comparisons do not support qualification of phenomenological models (although at higher pressure, the two tests performed by Martin do indicate better agreement). Therefore each code user must submit to the NRC for approval, as stipulated in the SER for VIPRE-01 MOD-01, qualification of its model use. In this respect, each user may choose to perform one of the following:

   a. benchmark thoroughly against plant specific data identifying measurement uncertainty. This approach is not acceptable if any of the key parameters or the sequence of events are not known; or

   b. benchmark against the vendors test/code. If any of the key parameters used by the vendor are not known for comparison this is not acceptable.

      A licensee should not simply reanalyze the same sets of tests presented by the code developers.

   We note that there is limited transient void fraction data available which could be compared to code results over some range of parameters. However, a user attempting to qualify the model for use by comparison to those data must demonstrate that the data cover the range of phenomena to be encountered in the analysis to be performed.

   c. A user may also take the approach of demonstrating that global results (such as power, pressure and core dT) computed with the code while using a particular drift flux formulation are overall conservative when compared to actual plant data over the range expected to be encountered during the analysis to be performed.

With respect to MOD-01:

1. Since the analysis of a typical PWR loss of flow analysis indicates that the corrected Zircaloy conductivity produces more conservative results than did MOD-01, each VIPRE-01 MOD-01 user should be so advised, and those whose safety analyses were approved should be required to certify that there remains a sufficient margin of safety and that all affected transients using MOD-02 result in acceptable range of conservatism. Furthermore, affected licensees should be required to inform the NRC of the impact of these error corrections on safety limits, response surface equations and the methodologies.

5.0 REFERENCES

1. Letter to USNRC from Y.Y. Yung (VMG), "Notification of Release and Request for NRC Review of VIPRE-01 MOD-02," February 28, 1990.

2. "VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores," Volumes 1 - 4, EPRI-NP-2511-CCM-A, Revision 3, August 1989.

3. Letter to USNRC from Y. Y. Yung (VMG), "VIPRE-01 Error/Change Log," February 26, 1991.

4. "Safety Evaluation Report on the VIPRE-01 Computer Code," May 1986.

5. Letter to R.C. Jones (NRC) from Y. Y. Yung (VMG), "Response to Request for Additional Information on VIPRE-01 MOD-02 Documentation EPRI NP-2511-CCM, VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores," March 16, 1992.

6. Letter to R.C. Jones (USNRC) from Y.Y. Yung (VIPRE-01 Maintenance Group), "Responses to Request for Additional Information on VIPRE-01 MOD-02 Documentation EPRI NP-2511-CCM, VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores (TAC No. M79498)," September 24, 1992

7. Letter to R.C. Jones (USNRC) from Y.Y. Yung (VIPRE-01 Maintenance Group), "Supplement to Response to VIPRE-01 MOD-02 Review Questions," November 23, 1992.