WASHINGTON PUBLIC POWER SUPPLY SYSTEM

P.O. Box 968 • 3000 George Washington Way • Richland, Washington 99352

March 16, 1992
G02-92-063

Mr. Robert C. Jones, Chief
Reactor Systems Branch
Division of Systems Technology
US Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Mr. Jones:

Subject: **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 (TAC NO. M79498)**

Reference: 1. Letter from RC Jones (NRC) to YY Yung (VMG), September 3, 1991, "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)"

This letter provides responses to the referenced NRC letter requesting additional information regarding VIPRE-01 MOD-02 review. The responses to this request are attached.

If you have any questions, please contact me at (509) 377-4366.

Sincerely,

Yat Yan Yung
Y. Y. Yung, Chairman (PE16)
VIPRE-01 Maintenance Group

YYY:bw

cc: Ping Huang, NRC
GS Srikantiah, EPRI
J. Cuta, Battelle Pacific Northwest Laboratories
VIPRE Maintenance Group

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Responses to Request for Additional Information on
EPRI NP-2511-CCM, VIPRE-01: A Thermal-
Hydraulic Analysis Code for Reactor Cores

1. For each of the changes listed in Table 1 of Reference 2, quantify the effects (magnitude and direction) of the change on the code results (core T/H parameters and DNBR). If the impact of the change is problem dependent, identify the affected variables, delineate the conditions which result in the extreme cases, and provide the magnitude of differences.

RESPONSE: The changes listed in 'Table 1 of reference 2' are the code changes in the MOD-02 version that might produce noticeable changes in code results. In all these cases, the results are affected only if certain options or models are selected by user input. The intent of Table 1 was to inform the user of these possible effects, so that the user could determine for himself if these changes are important for his own applications.

The testing procedures followed for developing code changes require a test case for each change, which illustrates the effect of the error and demonstrates that the change corrects it. In addition, the standard cases were also run on the new MOD, and comparison of those results with the standard test cases results from MOD-01 was part of the review of the MOD-02 change set. (The new MOD document for MOD-02, NMD-1-1, which is part of the Project Records for the VIPRE-01 Maintenance Project, includes the results of the test cases validating the new MOD.) The differences were in general quite small, as might be expected, since none of these changes significantly alters the basic solution in the code.

Attachment 1 contains a table summarizing the effect of each of the changes in MOD-02 on the code T/H and DNBR results. The changes listed in Table 1 referred to in this question were excerpted from this complete list. Of the 77 changes included in MOD-02, 61 have no effect at all on the T/H or DNBR results obtained with the code, either because the change does not affect the T/H solution or DNBR calculations, or the code simply fails if the error is not corrected. Only 16 changes produce noticeable differences in results, and these are the changes described in Table 1. The following discussion addresses each of these 16 changes and their specific effects on code results in more detail.

Change 101 affects only the DNBR values calculated with the BAW#2 CHF correlation at very low subcoolings, resulting in differences in the first or second decimal place. These conditions are far from CHF, and the change does not affect the results obtained at the location of minimum DNBR. The correlation is applicable to PWR conditions only, and has no relevance to BWR applications.

Change 102 affects the solution only when the option for water tube channels is used in a BWR model. The difference in the water tube flow with this error corrected is less than 0.5% in the test case used to verify the change.

Change 110 corrects an error that affects results only if an unheated inlet length is used with the option for the automatic usineu power profile. The error will be on the order of the ratio of the unheated inlet length to the total length. If the unheated length is small in relation to the total length, the error will be small.

Change 116 corrects an error in the water tube continuity solution. The magnitude of the error is on the order of machine round-off, and is generally not noticeable in the results.

Change 119 affects only subchannel analysis with the Bowring WSC-2 CHF correlation, and the results differ only in the second or third decimal place for the DNBR values. BWR analyses do not use subchannel modeling, and this correlation would not be used for BWR analysis.

Change 125 and 128 can result in different values for the clad and fuel temperatures that are on the order of 5%, at nominal operating conditions.

Change 127 can affect the evolution of the void profile during a transient calculation. However, the differences are within the uncertainty in the boiling models themselves, and will completely wash out in the bulk boiling region. (This problem is moot in BWR applications, since the algebraic subcooled boiling models are generally not stable in boiling transients at BWR conditions. The recommendation is to use the drift flux model for such calculations, and is the reason for installing that model in change 139.)

Change 130 fixes an error that will give significant differences in the results only if the user selects a single-phase heat transfer correlation that gives a heat transfer coefficient significantly different from what Dittus-Boelter would predict for the given conditions. Since this is unlikely in normal applications of the code, differences in the results will generally be negligible.

The error corrected by change 143 is so difficult to invoke that it is for all intents and purposes a negligible problem. In the test case used to determine that the error was fixed, the difference in enthalpy in the affected channel was on the order of 5 Btu/lbm.

The error fixed by change 147 can affect results only if the user-specified nonuniform gap conductance option is used. The magnitude of the error depends on the magnitude of the difference in specified gap conductance in axially adjacent nodes. In general, this difference will be small, and any differences in material temperatures due to the error will also be small; probably on the order of the uncertainty in the gap conductance values themselves.

The round-off error can produce only tiny error in the heat input when conditions that change 148 correct for are encountered. The error is discoverable as a very small but non-zero heat flux from the affected boundary, rather than as an energy balance error.

Change 158 applies only to the post-CHF film boiling heat transfer regime, when using the Groeneveld-Delorme correlation. Depending on the flow conditions, the change in the predicted wall temperature could be quite large, but in general it will not be any larger than the uncertainty in the correlation itself. Even with this error, this correlation yielded reasonable agreement with film boiling heat transfer data, (see VIPRE-01 Volume 4, Section 5.) With the error corrected, it still agreed well with the data, predicting temperature values that are well within the uncertainty of the data.

The error corrected by change 159 is not relevant to BWR applications of the code. The EPRI-2 CPR correlation is not an approved correlation for BWR critical power calculations, nor has it been qualified as applicable to analysis of any commercial fuel. This error can have no effect on any user's application of the code to BWR analysis.

Change 174 will make no difference in code's results, unless the user has specified very strange single-phase heat transfer correlation, and is at the same time using the Levy subcooled boiling model. If the user has specified a heat transfer correlation that gives essentially the same heat transfer coefficient as Dittus-Boelter, there will be no noticeable difference in the results. (If the user-specified heat transfer correlation is significantly different from Dittus-Boelter, the applicability of the Levy model to the conditions might be a more important question than a mere difference in heat transfer coefficient.)

Change 176 is for the most part a non-problem, encountered only in artificially simplified test cases. In general, things are changing enough in a real transient to almost guarantee that more than the minimum number of iterations will be required to achieve convergence on a given time step. In the test case for this change, the error resulted in the individual pressure drops in being different by 3 to 5 psi, rather than uniform in all channels.

2. Provide the following information:

a) Describe the process used to control the distribution of updates and releases. Was any version of the code released to any user after the release of the NRC approved version of MOD-01? If so, provide date and a general description for each such version. At what point in the code updates (date, release number, change number) did VIPRE-01/MOD-01 become VIPRE-01/MOD-02?

b) Which change number corresponds to the addition of the drift flux model to VIPRE-01/MOD-01?

c) It is noted that the code manuals were prepared at different times. Indicate by the volume number which code changes were reflected in the code manuals.

RESPONSE: The process for control and distribution of VIPRE-01 is governed by the VIPRE Code Maintenance Procedures Manual, (FATE-84-100, Rev. 4), an uncontrolled copy of which is furnished for information in Attachment 2. In brief, the procedure for the release of a new MOD is as follows; when the EPRI Project Manager deems it advisable to release a new version, all code changes, error corrections and new modifications that have been accumulated and logged by the code custodian in the interim since the release of the current MOD are collected into a New MOD Change Set.

These changes are tested and reviewed, as described in Section 4 of the Procedures Manual, (see also the response to Question 1, above.) Only after the testing and review of the MOD has been successfully completed is a new version released to the EPRI Software Center, which is the code distribution center, (currently run by Power Computing Company in Dallas, Texas.) The Software Center installs the new version in their code library, and notifies all VIPRE-01 subscribers that a new version is available, which they may request if they wish to upgrade to the new version.

In the interim between formal MOD releases, no new versions are released to users from the Software Center. Only the tested and verified current MOD is available to users. However, as part of the VIPRE Maintenance Project, the code custodian continues to provide user support for the current MOD, which includes logging error reports and change requests, and developing preliminary fixes for reported problems. (See Section 3 of the Procedures Manual for a detailed description of this process.)

The code custodian furnishes a monthly error report to all subscribers, listing any new change requests that have been logged since the previous report. In addition, preliminary fixes to reported errors are supplied to users at their request, and at their own risk, (see section 3.2, p. 8 of the Maintenance Procedures Manual.) Individual users are responsible for proper QA and testing of any changes they put into their copy of the released version of the code. (Typically, the testing and validation of such user-supplied modifications, which often include proprietary CHF or CPR correlations, is included in the topical reports submitted to the NRC for specific plant applications of the code.)

In light of the above explanation of the process for control of released versions of the code, the response to the specific items in part (a) of this question are as follows:

> There have been no interim code versions released to the EPRI Software Center between MOD-01 and MOD-02.
>
> MOD-01 was released in May 1985. This was the supported version of the code until MOD-02 was released.
>
> MOD-02 was released in April 1989.

Users who incorporate interim changes into the current MOD are required by their own QA procedures to document, test, and validate such modifications, and have done so successfully in numerous individual topical reports submitted to the NRC in the years between 1985 and 1989.

Addressing part (b) of Question 2, the drift flux model was installed in VIPRE-01 by Change 139. It should be noted, however, that this change adds the drift flux model as an option in the code. The original 3-equation mixture model, and the three solution options for the direct, iterative, and RECIRC methods, are still available in MOD-02.

Part (c) of Question 2 can be answered by looking at section 5 of the Code Maintenance Procedures Manual, (see p. 12). Release of a new MOD includes release of revisions to the code manuals that are affected by the changes constituting the MOD. Initial publication of Volume 1 ('theory' manual), Volume 2 (user's manual), and Volume 3 (programmer's manual) preceded the first formal release of the code as CYCLE-00. This was done because the code had been furnished to a VIPRE Working Group of utility users in preliminary test versions, as part of the code development project, and it was necessary to provide these users with code documentation.

With the formal release of the code as CYCLE-00 in 1983, error corrections and revisions to the documentation were supplied for these three documents. The document changes were identified as Revision 1, and the change package contained new title sheets for the reports and new manual pages, each of which was clearly marked with 'Revision 1' in the lower right-hand corner. A draft version of Volume 4, (applications manual) was also prepared at this time, documenting the verification and validation of the then-current version of the code.

When MOD-01 was released in May 1985, corrections and additions to the published manuals, (i.e., Volumes 1, 2, and .. were included in the new MOD release as Revision 2. The validation and verification work that had been performed with CYCLE-00 was rerun on the new version, MOD-01, and the results published in April of 1987 as Volume 4; Applications Manual. Volume 5, Guidelines, which consists mainly of friendly but non-binding advice on how to efficiently use the code for LWR core analysis, was published in 1988.

With the release of MOD-02 in April 1989, corrections and additions to the documentation were included in the release as Revision 3. This included changes to Volumes 1, 2, and 3. Volumes 4 and 5 were unchanged between MOD-01 and MOD-02. In particular, it should be noted that the testing and review of the changes for MOD-02 showed no significant changes in the T/H solution between the two versions of the code. Therefore it was deemed unnecessary to repeat the validation and verification testing reported in Volume 4, as the results would not have changed. (Testing of the new drift flux option in the code was included in the new MOD validation and verification, and is documented in the testing of MOD-02, which is part of the project records.)

In summary, the current documentation is related to the released versions of the code as follows:

Volume 1, 'Theory' Manual (Revision 3): MOD-02
Volume 2, User's Manual (Revision 3): MOD-02
Volume 3, Programmer's Manual (Revision 3): MOD-02
Volume 4, Applications Manual: documents results obtained with MOD-01
Volume 5, Guidelines: gives advice on LWR modeling with the VIPRE subchannel code; not tied to specific code versions

3. The EPRI-1 correlation (based on Columbia/EPRI data), a VIPRE default option, has not been qualified for BWR applications. This point was made in the statements that the sensitivity of the EPRI-1 CHF correlation was not determined for BWRs. Volume 4 of the code manual states that "the applicability of the EPRI-1 correlation to lumped assembly analysis in BWRs is another problem, and should be investigated separately, since this data set did not encompass BWR conditions." Therefore justify applicability of the EPRI-1 CHF correlation to BWR conditions and provide results from BWR analyses and experiments using the VIPRE BWR models and the drift flux model to demonstrate that computed CHF results are conservative.

RESPONSE: There are two points to be addressed in this question. First, the applicability of the EPRI-1 CHF correlation to BWR fuel bundles, and second, the applicability of this correlation for licensing calculations in BWR plant analyses. In response to the first point, it would be quite simple to demonstrate the EPRI-1 CHF correlation's applicability to BWR conditions. The second point, however, is not a concern of this submittal, since it is

not asking for approval of the EPRI-1 CFH correlation in licensing calculations for BWR plant analysis.

The EPRI-1 CHF correlation was derived from a large data base obtained at Columbia University that included BWR fuel models and operating conditions. (See EPRI report NP-2609 for complete documentation of the correlation and the data base.) The validation and verification of the CHF correlations in the VIPRE code, as documented in Section 6 of Volume 4, the Applications Manual, includes data from BWR test assemblies.

As can be clearly seen by examining the results presented in Section 6.2, 6.3 and 6.7, the EPRI-1 CHF correlation is in excellent agreement with the BWR data. The caveat noted in the question refers to the fact that these analyses, and the general formulation of the correlation, are for subchannel modeling of the assembly. In actual T/H analyses of BWR cores, the recommended approach for modeling the fuel assemblies is to use one-dimensional lumped channels for the assemblies. The applicability of the EPRI-1 CHF correlation to lumped assembly analysis would have to be verified by the user proposing to make such an application of the code. (However, the sensitivity studies on the CHF correlations reported in Section 8.2 of Volume 4 indicate that this would probably not be beyond the capability of the correlation.)

If a utility intended to use the EPRI-1 CHF correlation for thermal margin calculations in plant licensing analyses, it would be necessary to validate the correlation for that application. It is a perfectly reasonable reservation to note that approval of VIPRE-01 for BWR analysis does not imply a blanket approval of the application of every possible model or option in the code to such analyses. It is up to the individual user in the documentation of his application to demonstrate that he has selected reasonable and qualified models for his calculations.

4. The drift flux model has been implemented without any qualification or verification analyses. Demonstrate the acceptability of the drift flux model by comparison to relevant experimental data. Provide sensitivity studies and guidelines for using the drift flux model.

RESPONSE: It is not precisely correct to say that the drift flux model has been implemented without any qualification or verification analyses. Testing of the new MOD Change Set for MOD-02 included extensive testing of the model

against data from the FRIGG test loop. Attachment 3 contains a summary of the results from this testing.

The test cases run are the void model validation cases from the FRIGG test loop selected for the VIPRE-01 validation and documented in section 3.1 of Volume 4. These results show good agreement with this data, well within the uncertainty of the measurements for these tests. The uncertainty in the average void fraction values, which were determined from the measurements of local void fraction using gamma densitometers combined in an area-weighted algorithm, is on the order of 15%.

The agreement shown by the drift flux model predictions in comparison with this data is consistent with the sort of agreement obtained using steady-state models, most notably the EPRI model, as documented in Volume 4. It should be noted that the drift flux model was developed for vertical two-phase upflow, specifically for analysis of BWR thermal-hydraulics. It is not too surprising that it does a good job of matching experimental data for these conditions.

5. A wide spectrum of BWR sensitivity studies should be made to provide guidance and show the limitations of using VIPRE for BWR calculations. Section 11 of the Volume 4 manual states that "VIPRE is not able to predict void distribution in subchannels with two-phase flow; but axial distribution of void and overall two-phase pressure drop is predicted well." These conclusions should be justified for BWR cores and thermal-hydraulic conditions with complete sensitivity studies and comparisons to relevant data such as GE transient tests.

RESPONSE: First of all, it must be noted that subchannel modeling is not recommended for analysis of BWR assemblies. The statement quoted from Volume 4 in this question is simply an observation of a general short-coming of thermal-hydraulic analysis in two-phase flow with a subchannel formulation of the conservation equations. The standard approach in BWR core thermal-hydraulic analyses for licensing calculations is to use a one-dimensional representation of the flow field within the bundle. This is the recommended approach with VIPRE, and is the model that has been used in all the analyses in this submittal.

The conclusions in Section 11 of Volume 4 about the accuracy of the code in predicting the axial void distribution and pressure drop in two-phase flow when using the recommended 1-dimensional channel modeling approach are based on the code results reported in that

document. Much of the data used to validate the code was obtained at BWR operating conditions; specifically, the comparison with the GE two-phase flow distribution tests in section 2.4, the FRIGG two-phase pressure drop tests in section 2.5, the FRIGG void fraction measurements in section 3.1, the ANL void fraction data in section 3.2, and the GE transient tests reported in section 6.7.

6. The choices for and qualification of CHF, void, two-phase friction multiplier and quality/void relation default options in VIPRE are geared toward PWR applications. Provide a table with default options and their range of applicability and justify via comparison to relevant experimental data and sensitivity studies which include other options in the code that these defaults are applicable to BWR conditions, and that the slip/quality void correlation defaults in VIPRE are conservative for BWR applications. Clarify how the default options are used together with the drift flux model. In addition, demonstrate that time-dependent calculations using these CHF, void, etc. default correlations are conservative for BWR transient applications.

RESPONSE: It is not precisely correct to say that the two-phase thermal-hydraulic model defaults in VIPRE are geared to PWR applications. On the contrary; these models have been validated for PWR applications, but they are in almost every case derived from experimental data that includes BWR conditions. The data ranges of these models are given in Volume 2, (user's manual), in Table 2-4, 'Data Ranges of Two-Phase Flow Correlations", on p. 2-148, and Table 2-7, "Data Ranges of Critical Heat Flux Correlations", on p. 2-161.

The accuracy of these correlations in comparison to experimental data at BWR conditions has also been documented, in Volume 4 (Applications Manual). Comparisons are provided for the GE two-phase flow distribution tests, FRIGG two-phase pressure drop and void distribution tests, and ANL void distribution data, in sections 2 and 3. Comparisons of the CHF correlations with data at BWR conditions is included in section 6.

It should be noted that the default models for void/quality are not used with the drift flux model. When this option is selected, the void is determined using the drift flux relation, as documented in the Revision 3 changes to Volume 1 for MOD-02, (see section 2.8.)

The validation results shown in Volume 4 indicate that the VIPRE code is in general conservative for BWR conditions. In addition, specific comparisons with FSAR calculations included in this submittal show that the code gives the same or sightly more conservative answers for the applications of interest. A blanket endorsement of all options in the code for application to BWR conditions is not being requested. Sinc VIPRE-01 is designed to be a versatile code with a wide range of applications to LWR analysis, it is not unreasonable to note that the user must demonstrate the suitability of the modeling options he had selected for his particular application.

7. Since the crossflow technique is specifically used for modeling of water tube flow and the leakage flow to the bypass region in BWRs, justify that the application of this model does not violate the modeling assumptions of subchannel formulation.

RESPONSE: The basic assumption of the subchannel formulation is that the axial flow is significantly greater in magnitude than the transverse flow between channels. The main direction of momentum transport is axial, with very little momentum transport in the lateral direction. The small amount that is transported laterally dissipates over a relatively short distance in the receiving channel.

This assumption gives a very reasonable representation of the flow field in a rod bundle array, where the primary direction of flow is axial. Under normal conditions, there are only small lateral flows through the gaps between the rods, to redistribute the flow in response to thermal gradients, inlet non-uniformities, and the like. When applied to BWR models, however, it is an even better approximation of the flow diverted to the bypass and water tubes.

The amount of flow involved is in general very small; only a few percent of the total bundle flow, and often much less. The flow paths are such that fluid usually cannot enter them at very high velocity, and so it cannot possibly transport very much in the way of momentum. Water tube and leakage flows in BWR bundles fall easily within the definition of flows that can be modeled with the assumption for lateral flow used in subchannel modeling.

Questions on Volume 1:

8. Due to numerical instability problems with the UPFLOW and DIRECT solution for BWR applications, the drift flux model only works with the RECIRC option. Therefore:

   (a) demonstrate that the drift flux model with the RECIRC option yields conservative BWR results.

   (b) clarify whether VIPRE automatically switches to the RECIRC solution if the drift flux solution is specified.

   (c) clarify the relationship between the flow charts for the simple RECIRC model (Fig. 2.5-4) and the RECIRC solution with the drift flux model (Fig. 2.8-1).

RESPONSE: First a point of clarification: the instability at issue here is not simply a shortcoming of the UPFLOW and DIRECT solution options in the code. It is a general limitation of the 3-equation mixture model for two-phase flow with algebraic models for subcooled boiling and liquid/vapor slip. As discussed in section 2.8 of Volume 1, (see p. 2-121), this model necessarily neglects some of the important physics of the boiling process in the transient, and this can lead to calculational instabilities.

Any solution method used for the 3-equation model would be affected by this instability, not just the DIRECT solution in VIPRE. In fact, the RECIRC solution exhibits exactly the same symptoms when applied without the drift flux model. The drift flux model adds a 4th equation to the solution, thus restoring some of the missing physical phenomena, and so avoids the instability. The model was installed in the RECIRC solution mainly because it could more easily be adapted to include the additional equation.

Addressing the specific points of Question 8;

(a) The drift flux model yields essentially the same flow solution as the 3-equation model with subcooled boiling using the EPRI model. (Refer to response to Question 4.) Calculations presented in the response to Question 19 compare typical VIPRE results obtained with the drift flux model to SNP data. These calculations demonstrate that the option yields conservative results for the applications being considered.

(b) The code does not automatically select the RECIRC solution option when the drift flux model is specified. However, the UPFLOW solution will invariably fail if that option is specified with the drift flux model.

(c) The flow chart in Figure 2.8-1 is a somewhat abbreviated representation of the RECIRC solution scheme that gives details only in the part of the solution related to the drift model option. Attachment 4 shows a revised version of the flow chart, starting from the one shown in Figure 2.5-4, (which is an accurate and detailed representation of the RECIRC solution scheme.) The section labeled 'A' contains the important information from the flow chart in Figure 2.8-1.

In essence, the box on the fig. 2.5-4 chart labelled 'operations common to UPFLOW and RECIRC' has been replaced by segment 'A', which contains the first four boxes inside the axial level loop of Fig. 2.8-1. These are the boxes labelled 'compute fluid properties (PROP)', 'compute heat input to each channel (HEAT)', 'solve energy equation for new enthalpy (ENERGY)', and 'solve vapor mass conservation equation for void fraction and compute density'.

A new decision box has been added, and if the drift flux model is selected, the solution branches to solve the vapor mass conservation equation for void fraction and calculate the new density from the equation of state. This step is what makes the RECIRC solution with the drift flux model different from the normal 3-equation solution. If the drift flux model is not selected, the step consists simply of an algebraic solution of the user-selected void/quality relation, which may include a subcooled boiling model.

9. Provide a specific reference for the Hancox-Nicol relation given on p. 2-132.

RESPONSE: The Hancox-Nicol correlation is referenced previously in the document, on p. 2-103 in the description of the EPRI void model. (However, it would have been helpful to note the previous citation on p. 2-132.) It is cited as reference 22, "A General Technique for the Prediction of Void Distribution in Non-steady Two-Phase Forced

Convection," International Journal of Heat and Mass Transfer, Vol. 14, 1971.

10. The Thom heat transfer correlation as given on p. 2-103 is different from the form given in Appendix C and on p. 2-132. What is actually used in the code?

RESPONSE: The Thom correlation is used in the code in three different places; for the EPRI void model (documented on p. 2-103), for the drift flux model (documented on p. 2-132), and for the heat transfer solution (documented on p. C-2 of Appendix C.) The three forms are equivalent, and have been verified as accurate in the actual coding.

The form presented for the EPRI void model on p. 2-103 has been simplified by having some of the delta-T terms canceled out in the algebraic manipulation of the equations constituting the model, (see ref. 20, EPRI-2246-SR.) Also, the numerator has been further simplified by combining the powers on the exponent function. It is obvious by inspection that exp(P/630.0) is mathematically equivalent to (exp(P/1260.0))**2.

There is a typographical error in the presentation of Eq. 2.8-44 on p. 2-132. The term in the numerator of the equation should be squared. This makes it exactly the same as the form of the equation in Appendix C. The coding for the correlation includes the squared numerator in both applications.

11. Justify the form of the Zuber-Findlay equation described on p. 2-106.

RESPONSE: This is the form of the Zuber-Findlay equation used in the derivation of the EPRI void model, as documented in ref. 20, EPRI-2246-SR. It differs slightly from the original formulation of the relation because it corrects the erroneous asymptote at high qualities. The original relation goes to a void fraction of approximately 0.88 as quality approaches 1.0. The correction developed for the EPRI model extends the correlation to include the full range of void fraction, all the way to saturated vapor.

Volume 2 Questions:

12. Describe the effects of VIPRE-01/MOD-02 changes on the calculational results of the User's Manual sample problems in Section 4. Provide the MOD-2 results in Appendix B.

RESPONSE: The sample problems presented in section 4 are not intended to be used as verification cases for the code. The standard test cases, which are provided on the new MOD transmittal tape with input and output files for reference, are the appropriate test for correct installation. Testing and review of the MOD releases since CYCLE-00, (which is the version the results in the document were obtained on) has shown only very small changes in the overall thermal-hydraulic results predicted by the code, when compared to the results of previous released versions. If a user elected to set up and run the sample problems, the results would be consistent with those reported in Volume 2, with small differences readily explainable as due to error corrections.

Volume 4 Questions:

13. Provide BWR applications to validate the BWR model options for section 10.0 of Volume 4. (Currently, this section focuses only on PWR applications.)

RESPONSE: This submittal represents the first concerted attempt to apply the VIPRE-01 code to BWR core analysis. The plant calculations and comparisons with FSAR calculations included in the WPPSS topical constitute the BWR applications validation to date.

14. Is it intended that this code be used for BWR lumped assembly analysis? If so, provide BWR test case results using the BWR model and drift flux options to justify the statement in Volume 4 (p. 8-30) which states that "the Bowring correlation is the only CHF correlation in VIPRE that has a form specifically designed for lumped assembly analysis," so that if a single BWR bundle lumping approximation is used, the Bowring correlation may be adequate. Demonstrate that the Bowring CHF correlation provides conservative results when combined with the drift flux approach.

RESPONSE: Lumped assembly analysis is the recommended approach for BWR core analysis with any thermal-hydraulic code, not just VIPRE. The statement about the lumped assembly form

of the Bowring correlation is simply an observation of fact, not a recommendation for BWR applications. This submittal is not proposing to use the Bowring correlation for plant analysis, so there is little point in exploring the behavior of this correlation for BWR analysis.

The results presented in section 6 of Volume 4 indicate that the Bowring correlation could probably be applied successfully to CHF analysis in BWR lumped channel models. It is reasonable for the reviewer to note that approval of the VIPRE code for BWR analysis does not imply a blanket endorsement of every possible model in the code for the application. Users are required to validate their applications and modeling selections in the specific submittals for their plants.

Volume 5 Questions:

15. Justify the statement made on p. 3-27 of Volume 5 that "it is ordinarily quite sufficient to model this region with a single channel", providing details of modeling studies.

RESPONSE: The quoted statement is an observation, not a recommendation. This is the modeling approach that has been accepted by the NRC for BWR core analysis. It is mentioned in Volume 5 **apropos** of noting that VIPRE has the capability to model the bypass as a single channel or as an array of interconnected channels. If it were ever deemed desirable to perform detailed modeling studies of the bypass flow region, VIPRE could be used for such calculations.

16. Provide guidelines on ensuring the stability of VIPRE solutions, especially with respect to the two options which lead to instabilities during the transient calculations: (1) pressure drop boundary conditions option, and (2) subcooled boiling and bulk void models which are based on steady state applications.

RESPONSE: The matter of solution stability in VIPRE-01 is discussed about as completely as it is possible to do so in section 7 of Volume 1. The implicit solution methods are stable numerically, and almost any reasonable model of thermal-hydraulic conditions within the range of the VIPRE modeling assumptions can be successfully computed.

Application of the pressure boundary condition in transient calculations is discussed in section 2 of

Volume 1, (see p. 2-116 through 2-118). The pressure drop boundary condition is based on an approximation of the relationship between flow and pressure drop, and if the transient is too fast for it to be a good enough approximation to satisfy the convergence error limits, then it will not converge. The only alternative is to take larger time steps, or use a flow boundary condition.

The clear recommendation on the subcooled boiling models in transient applications is not to use them for two-phase flow, (see section [illegible] of Volume 1.) The user will very quickly become aware of the problem if he tries to use one of the algebraic models (such as the EPRI void model or Levy's subcooled boiling model) in a boiling transient, since the code will fail if the instability occurs.

If the 3-equation model must be used for boiling transient applications, then the homogeneous relation for two-phase flow is the only one that will be stable. The alternative, (as discussed in section 2.8) is the 4-equation formulation, or drift flux model. This allows a better physical representation of subcooled boiling, thus avoiding the instability encountered in the algebraic models.

<u>Attachment 3 of Reference 2</u>:

17. The section on flow correlation sensitivity for BWR core models states that "subcooled boiling has a relatively insignificant effect for BWR conditions (p.29)." However, the FSAR comparison (section 4.2) indicated poor agreement of the VIPRE results for low quality region/core entrance. The subcooled boiling model should be justified.

RESPONSE: The agreements between FSAR and VIPRE results (Section 4.2, Table 4.7, p.41) are quite reasonable considering the small magnitude of qualities at the subcooled region. The flow correlation sensitivity study indicated that subcooled boiling has a relative insignificant effect for BWR conditions (p.30, the flow rate, bundle pressure drop, and MCPR are essentially unchanged with or without the subcooled boiling model).

18. Justify that the results from sensitivity studies (Section 3.1) which show that the 4-channel BWR model gave nearly equivalent results to the 191-channel model remain valid when the officially released version VIPRE-01 MOD2 is used.

RESPONSE: The supplement attached at the end of the report "VERIFICATION OF VIPRE-01 FOR BWR ANALYSIS" states that the results of the calculations presented in the report remain unchanged when MOD-02 is used instead of MOD-01. This is due to the fact that all the correlations used in MOD-01 for these calculations were not changed in MOD-02. For confirmation, the following cases were reanalyzed with MOD-02 giving identical results as MOD-01: Core pressure drop calculations at various powers and flow rates (steady state cases in Section 4), four of six FSAR transients (LOFH, FWCF, LRWB, LRNB in Section 5).

19. The cases presented in Reference 2 were performed before September 1987, while VIPRE-01 MOD2 was officially released in October 1989; thus, it is not likely that those cases were performed with the officially released VIPRE-01 MOD2 version. If those cases were performed with MOD2 version, describe the differences between the version used and the official version, and describe the effects on the results when the official version is used. If MOD1 version was used, reanalyze those cases using the official MOD2 version with the drift Flux and rod conduction models, where appropriate, and provide detailed comparison between MOD2 and MOD1 results.

RESPONSE: See Response to Question 18 for the first part of this question. The rod conduction model was not used in the cases presented in Reference 2. The Drift Flux Model (added in VIPRE-01/MOD-02 for subcooled boiling and bulk boiling) is recommended to be used for BWR transient analyses. The impact of Drift Flux Model was evaluated when Supply System benchmarked VIPRE-01/Mod-02 against the transient CHF tests. The transient tests data (Seven power ramp tests and seven flow decay tests) and XN-3 critical power correlation were obtained from Siemens Nuclear Power Corporation (SNP). These test cases were analyzed a) with no subcooled boiling, b) with Drift Flux model for subcooled boiling. In all these cases, the VIPRE predicted times to Critical Heat Flux or boiling transition are less than the measured times and the Drift Flux model for subcooled boiling yielded slightly more conservative results (i.e. predicted lower critical heat flux) relative to the predictions with no subcooled boiling model. Comparisons of results are presented in Table 2 for one of the tests.

TABLE 2 Drift Flux Model Sensitivity Study
Power Ramp Test PR002

Time (sec)	CHFR N	CHFR Y	Time (sec)	CHFR N	CHFR Y
0.0	1.221	1.221	2.6	1.097	1.096
0.1	1.218	1.217	2.7	1.092	1.091
0.2	1.214	1.213	2.8	1.087	1.086
0.3	1.210	1.209	2.9	1.082	1.080
0.4	1.205	1.205	3.0	1.077	1.075
0.5	1.201	1.200	3.1	1.072	1.070
0.6	1.196	1.195	3.2	1.066	1.065
0.7	1.191	1.191	3.3	1.061	1.060
0.8	1.186	1.186	3.4	1.056	1.055
0.9	1.181	1.181	3.5	1.051	1.050
1.0	1.176	1.176	3.6	1.046	1.045
1.1	1.171	1.171	3.6	1.041	1.040
1.2	1.166	1.166	3.8	1.037	1.035
1.3	1.161	1.161	3.9	1.032	1.030
1.4	1.156	1.156	4.0	1.027	1.025
1.5	1.151	1.150	4.1	1.022	1.019
1.6	1.146	1.145	4.2	1.015	1.013
1.7	1.141	1.140	4.3	1.009	1.006
1.8	1.136	1.135	4.4	1.002	1.000
1.9	1.131	1.130	4.5	0.996	0.994
2.0	1.126	1.125	4.6	0.989	0.987
2.1	1.121	1.120	4.7	0.983	0.981
2.2	1.116	1.115	4.8	0.977	0.975
2.3	1.110	1.110	4.9	0.971	0.968
2.4	1.106	1.105	5.0	0.964	0.962
2.5	1.102	1.101			

Note: CHFR = Critical Heat Flux Ratio
= Critical Heat Flux / Actual Heat Flux
(Critical Heat Flux was calculated with XN-3 Correlation)
N = No subcooled boiling
Y = Subcooled boiling calculated with Drift Flux Model

20. The conduction model is not used in Reference 2. Clarify how the axial power profile was generated for each of the eight radial rings in the core. Discuss how the power distributions (radial and axial) were determined or averages for the four channel model, as presented in the radial and axial noding sensitivity sections.

RESPONSE: The power distributions were obtained from SIMULATE-2 (a 3-D neutronic code). It provided the 3-D nodal peaking factors (each bundle is modeled with 25 nodes) and 2-D radial peaking factors. Radial peaking factor = Bundle power / average bundle power. Nodal peaking factor = nodal power / average nodal power.

For the quarter core model, radial peaking factors from SIMULATE-2 are used as VIPRE input. Eight axial profiles were generated for the eight rings. They are generated by averaging the nodal peaking factors of the bundles that reside in each ring.

For the full core model, radial peaking factors for the hottest central bundle and the hottest peripheral bundle in VIPRE are same as that in SIMULATE-2. Radial peaking factors of the rest of central bundles are averaged to yield the radial peaking factor for the lumped central channel. Similarly, radial peaking factors of the rest of peripheral bundles are averaged to yield the radial peaking factor for the lumped peripheral channel. The axial power profile is simply the core average of nodal peaking factors of all bundles.

21. Explain and justify the following:

(a) a 32% difference between the FSAR and VIPRE average orifice pressure drop for the central region.

RESPONSE: The difference between the FSAR and VIPRE average orifice pressure drop for the central region is due to different modeling assumptions in GE and VIPRE calculations. GE used ISCOR code. The regions below the lower tie plate (fuel support, orifice and lower plenum) are modeled separately. VIPRE model is similar to the GE Process Computer model that does not model the fuel support and lower plenum. Pressure drops through these regions are accounted for by increasing the orifice loss coefficient. (Loss coefficients used in GE calculations were not available. Values obtained from EPRI reports were used in VIPRE calculations, orifice loss coefficients were checked to be similar to those used in the Process Computer model).

SNP had provided the loss coefficients for SNP 8x8 fuel. Information about SNP's model with XCOBRA code was also obtained. A parallel pressure drop calculation with VIPRE for a hot central bundle (Power, flow, loss coefficients supplied by SNP) was performed. There was excellent agreement between VIPRE and XCOBRA results (core pressure drop differs by 0.16 psi, orifice pressure drop differs by 0.02 psi).

(b) a 10% difference between the GE and VIPRE results on the total core pressure drop for the 0% power case given in Table 4.3.

RESPONSE: The results for the cases presented on Table 4.3 are run at the nominal conditions of 1000 psia and 20 btu/lb subcooling (The boundary conditions used in GE's calculation were not available). Sensitivity study were performed at 900 and 1050 psia, and at 20 and 30 btu/lb subcooling. There were no significant changes. These range covers most of the power/flow conditions. However for the 0% power case, the inlet temperature should be much lower. The following Table indicates that the pressure drop will be closer to GE's result (17.41 psia) if lower inlet temperature is used.

Inlet Enthalpy (btu/lb)	Inlet Temperature (°F)	Pressure Drop (psia)
200.	232.	17.90
400.	423.	18.39
520.	526.	19.12

(c) the axial power factor for node 17 is 0.94, whereas nodes 16 and 18 have 0.97 on Table 4.4.

RESPONSE: The power factors used by GE was provided in FSAR. This is an realistic power profile at EOC (Depletion of core with rod patterns that do not have enough bottom burn).

(d) the technique used to adjust the hot channel initial power level for each transient so that the minimum CPR during the transient equals the safety limit.

RESPONSE: The criterion for avoidance of boiling transition during steady-state operation defines the safety limit. The boiling transition limitation is established such that during reactor operation at the MCPR safety limit, at least 99.9% of the fuel rods in the core are expected to avoid boiling transition. To provide an operating margin

above the MCPR safety limit, the change in CPR (ΔCPR) is determined to insure that the safety limit criterion will not be violated during the limiting transient. After the input for the limiting transient is obtained, a series of high power bundle VIPRE calculations are made at successively higher power until MCPR equals the safety limit at some time during the transient. The change in thermal margin (ΔCPR) due to the limiting transient is added to the safety limit to establish the MCPR operating limit.

(e) the VIPRE predicted delta CPR values are in general greater than the values given in the FSAR.

RESPONSE: This is mainly due to the differences in the inputs used in GE and VIPRE analyses. As was mentioned in the report, a typical value for R-factor and a conservative chopped cosine axial power profile were used in VIPRE analyses since the information was not available.

(f) provide a time step size sensitivity study for analyses which uses the EPRI void model with subcooled boiling.

RESPONSE: To avoid instability, one must select the Drift Flux model as the subcooled boiling and bulk boiling correlation. Time step size sensitivity study for an analysis (SNP Transient CHF test) using the Drift Flux bulk void model with Drift Flux subcooled void is presented in Table 3.

Table 3 Time Step size Sensitivity study
Power Ramp Test PR002

Time (sec)	CHFR Δt = 0.1 sec	CHFR Δt = 0.05 sec	Time (sec)	CHFR Δt = 0.1 sec	CHFR Δt = 0.05 sec
0.0	1.221	1.221	2.55		1.099
0.05		1.219	2.6	1.096	1.096
0.1	1.217	1.217	2.65		1.093
0.15		1.215	2.7	1.091	1.090
0.2	1.213	1.213	2.75		1.088
0.25		1.211	2.8	1.086	1.085
0.3	1.209	1.209	2.85		1.083
0.35		1.207	2.9	1.080	1.080
0.4	1.205	1.205	2.95		1.078
0.45		1.203	3.0	1.075	1.075
0.5	1.200	1.200	3.05		1.072
0.55		1.198	3.1	1.070	1.070
0.6	1.195	1.196	3.15		1.067
0.65		1.193	3.2	1.065	1.065
0.7	1.191	1.191	3.25		1.062
0.75		1.189	3.3	1.060	1.060
0.8	1.186	1.186	3.35		1.057
0.85		1.184	3.4	1.055	1.055
0.9	1.181	1.181	3.45		1.052
0.95		1.179	3.5	1.050	1.050
1.0	1.176	1.176	3.55		1.047
1.05		1.174	3.6	1.045	1.045
1.1	1.171	1.171	3.65		1.042
1.15		1.169	3.7	1.040	1.040
1.2	1.166	1.166	3.75		1.037
1.25		1.163	3.8	1.035	1.035
1.3	1.161	1.161	3.85		1.033
1.35		1.158	3.9	1.030	1.030
1.4	1.156	1.156	3.95		1.028
1.45		1.153	4.0	1.025	1.025
1.5	1.150	1.151	4.05		1.023
1.55		1.148	4.1	1.019	1.020
1.6	1.145	1.146	4.15		1.016
1.65		1.143	4.2	1.013	1.013
1.7	1.140	1.140	4.25		1.010
1.75		1.138	4.3	1.006	1.007
1.8	1.135	1.135	4.35		1.003
1.85		1.133	4.4	1.000	1.000
1.9	1.130	1.130	4.45		0.997
1.95		1.128	4.5	0.994	0.994
2.0	1.125	1.125	4.55		0.991
2.05		1.123	4.6	0.987	0.988
2.1	1.120	1.120	4.65		0.984
2.15		1.118	4.7	0.981	0.981
2.2	1.115	1.116	4.75		0.978
2.25		1.113	4.8	0.975	0.975
2.3	1.110	1.110	4.85		0.972
2.35		1.108	4.9	0.968	0.969
2.4	1.105	1.106	4.95		0.966
2.45		1.103	5.0	0.962	0.962
2.5	1.101	1.101			

Attachment 1

Table 1: Effect of MOD-02 Changes on VIPRE-01 Results

Change No.	Effect on Results
101	no effect on code T/H results; corrects error in application of BAW #2 CHF correlation outside of its subcooling range.
102	affects only calculations using the BWR water tube modeling option; corrects small error in water tube flow rate calculation.
103	corrects error in output of input data; no effect on code T/H or DNBR results.
104	no effect on code results; changes header identifying code version.
105	no effect on results; eliminates production of extraneous output in some cases.
106	no effect on results; eliminates production of extraneous output in some cases.
107	code fails when this error is encountered.
108	code fails when this error is encountered.
109	code fails when this error is encountered.
110	no effect on results unless option for usineu axial power profile is used with unheated inlet length. Corrects error in integration with unheated inlet. Magnitude of the error depends on extent of the unheated inlet in relation to the heated length; since this is usually small, the error will generally be small.
111	corrects error in auxiliary program ASP (for CALCOMP plots); no effect on VIPRE-01.
112	code fails hen this error is encountered.
113	no effect on results; corrects error in details of printout for DNB calculations with the EPRI CHF correlation, but T/H and DNBR results are unaffected.
114	document error.
115	changes output format for I/O unit 81; no effect on results.

116 affects only cases using optional BWR water tube channel model; corrects small error in water tube flow rate.

117 corrects error in writing plot file for ASP in transient; no effect on code results.

118 affects only cases using the conduction solution where the number of nodes in a rod type is exactly the dimension parameter. Corrects small error in power generation due to array overwrite. Magnitude of error is problem-dependent, and is a function of the number and size of the nodes in the fuel. Generally, the error is small.

119 affects only results of Bowring CHF correlation calculations; corrects error in Y' term for Bowring CHF correlation. Change in MDNBR is small in test case.

120 corrects error in ASP; no effect on VIPRE-01 results.

121 corrects error in ASP; no effect on VIPRE-01 results.

122 corrects error in ASP; no effect on VIPRE-01 results.

123 corrects error in ASP; no effect on VIPRE-01 results.

124 not an error.

125 affects only cases using the nuclear fuel rod conduction model with option for zircaloy material properties. Corrects errors in coefficients for correlations for material properties. Results in small (~5%) differences in fuel and clad temperatures.

126 changes contact telephone number on banner page. of VIPRE-01 output. (Not an error.)

127 correction to remove a small numerically induced transient that damps out of the calculation on the first time step anyway. No significant effect on code transient results. (See change 139, for further modifications that apply to transient calculations with two-phase flow.)

128 see change 125.

129 corrects error in ASP; no effect on VIPRE-01 results.

130	affects only cases using the Thom-plus-single-phase correlation option for boiling heat transfer, when the option for a user-specified single-phase heat transfer coefficient in place of the default Dittus-Boelter correlation has been specified. Corrects error in single-phase heat transfer correlation selection. Affect on results depends on how much the user-specified single-phase heat transfer correlation differs from the Dittus-Boelter correlation; usually very small.
131	no effect on T/H or DNBR results. Corrects insignificant error in water properties coefficient.
132	no effect on T/H or DNBR results. Corrects insignificant error in water properties coefficient.
133	corrects array overwrite that usually causes code to fail. No effect on results.
134	document error.
135	added information on output; no effect on results.
136	corrects error in ASP; no effect on VIPRE-01 results.
137	corrects error in ASP; no effect on VIPRE-01 results.
138	corrects error in ASP; no effect on VIPRE-01 results.
139	adds drift flux model to code, for stable calculation of boiling transients with subcooled boiling.
140	code fails to compile if this error is encountered.
141	code fails when this error is encountered.
142	code fails when this error is encountered.
143	code fails when this error is encountered.
144	not an error.
145	no effect on code T/H or DNBR results; corrects error in recalculation of output values for channel heat deposition.
146	code fails when this error is encountered.

147 affects only cases using the option for user-specified non-uniform gap conductance; corrects error where input values are shifted by one node. May result in differences in calculated temperatures. Magnitude of the error is problem dependent.

148 affects only cases using the heat conduction solution with rods having an adiabatic boundary condition on one surface. Corrects failure to zero out derivative terms between rods. Magnitude of the error is problem-dependent, but usually readily discernable by inspection of the output results.

149 affects only very low-power, low-flow cases using the full boiling curve for heat transfer to the fluid. Corrects error that does not allow transition to post-CHF heat transfer regime with low heat flux; error is usually obvious by inspection of results.

150 code fails when this error is encountered.

151 corrects error in ASP; no effect on VIPRE-01 results.

152 affects only cases specifying the default uniform axial power profile, with an unheated inlet length. Corrects error that can allow inconsistent input option, which results in an error in the total power calculated for the case. Magnitude of the error depends on the length of the unheated inlet in relation to the total heated length; since this is usually small, this error is usually small.

153 corrects error in ASP; no effect on VIPRE-01 code results.

154 not an error; increases output formats for readability of printout. No effect on code results.

155 corrects error in ASP; no effect on VIPRE-01 results.

156 corrects error in ASP; no effect on VIPRE-01 results.

157 code fails when this error is encountered.

158 affects only cases using the Groeneveld-Delorme film boiling heat transfer coefficient in post-CHF calculations.

Corrects error in definition of vapor sink temperature. Can result in differences in clad and fuel temperatures; magnitude of the differences are problem-dependent.

159 affects only cases using the Hench-Gillis CPR correlation. Corrects omission of iteration to critical power; CPR results may be significantly different. (Note: Hench-Gillis CPR correlation is not an approved correlation for CPR analysis in any licensing applications.)

160 code fails when this error is encountered.

161 affects only cases using the conduction model with temperature-dependent material properties. Corrects unauthorized extrapolation outside table. Magnitude of the error depends on sensitivity of the material thermal conductivity and specific heat to temperature.

162 corrects error in ASP; no effect on VIPRE-01 results.

163 corrects error in ASP; no effect on VIPRE-01 results.

164 corrects error in ASP; no effect on VIPRE-01 results.

165 corrects error in ASP; no effect on VIPRE-01 results.

166 corrects incomplete error message; no effect on results.

167 corrects incomplete error message; no effect on results.

168 corrects incomplete error message; no effect on results.

169 corrects overwrite of unused array; no effect on results, but avoids potential for future problems with additional code modifications.

170 corrects error in option for output of CHF results that fails to limit output as desired. No effect on VIPRE-01 results.

171 adds input error check to counter potential for subtle user error; unlikely to cause noticeable difference in results.

172 conversion to FORTRAN-77 standard coding; no effect on results.

173 corrects error affecting ASP; no effect on VIPRE-01 results.

174 affects only cases using the Levy subcooled boiling model and a user-specified single-phase heat transfer correlation. Corrects error in single-phase heat transfer correlation selection of the Levy model. Change in results depends on how much the user-specified correlation differs from the Dittus-Boelter heat transfer correlation. Usually the differences will be very small.

175 corrects error in ASP; no effect on VIPRE-01 results.

176 affects only cases using the pressure boundary condition in transients; corrects failure to check convergence in pressure iteration if flow converges in 2 iterations or less. Only likely to affect very slow transients.

177 adds more information to output file for microfiche processing; no effect on VIPRE-01 results.

Attachment 2