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JONES,R.C. Reactor Systems Branch

SUBJECT: Forwards response to request for addl info on vipre-01 mod-02 documentation EPRI NP-2511-CCM,vipre-01, "A Thermal-Hydraulic Analysis Code for Reactor Cores."

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September 16, 1992

50-397

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)**

References:

1. VIPRE-10: A Thermal-Hydraulic Analysis Code for Reactor Cores, Volumes 1-4, EPRI-2511-CCM-A, Rev 3, August 1989
2. Letter dated February 28, 1990 from YY Yung, VMG to USNRC, "Notification of Release and Request for NRC Review of VIPRE-01 MOD-02"
3. Letter dated February 28, 1991 from YY Yung, VMG to USNRC, "VIPRE-01 Error/Change Log"
4. Letter dated September 3, 1991 from RC Jones, USNRC to YY Yung, VMG, "Request for Additional Information on VIPRE-01 MOD-02"
5. Letter dated March 18, 1992, from YY Yung, VMG to RC 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)"
6. FAX from H. Balukjian, USNRC to YY Yung, VMG, July 20, 1992, "Request for Additional Information on VIPRE-01 MOD-02"

This letter provides responses to the NRC request for additional information on VIPRE-01 MOD-02 (Reference 6). The responses to this request are attached.

YG01
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If you have any questions, please contact me at (509) 377-4366.

Sincerely,

Y Y Yung

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

/bw

cc: H. Balukjian, NRC
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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 for each code thermal-hydraulic parameter and the DNBR, the magnitude and direction of the change. If the impact of the change is transient dependent, identify the affected variables, delineate the conditions which result in the extreme cases, and provide the magnitude of differences. For example, the discussion of change 125 and 128 must cover transient conditions and must delineate the worst case transient. Basically this question is the same as the last time for question number 1, with minor changes.

RESPONSE: The changes affecting VIPRE-01 results between MOD-01 and MOD-02 are summarized below:

CHANGE 102

description:
Corrects errors in water tube channel model description and momentum solution.

effect on results:
In a test case for typical BWR operating conditions, correcting the error increased the water tube channel flow rate by about 5%. Bundle flow was 29.95 lbm/sec, with water tube flow 0.301 lbm/sec. This error correction increased the water tube flow to 0.315 lbm/sec.

CHANGE 110:

description:
Corrects error in calculation of axial power profile for the µsineµ option when there is an unheated inlet length. Total power is correct, but local power values are in error, by an amount dependent on the size of the cold inlet length in comparison to the total heated length.

effect on results:
The effect of this change is problem-dependent, and it can be evaluated only on a case by case basis. But it must be remembered that this change will affect results only if the option for the automatic µsineµ axial power profile is specified. In plant analyses, the axial power profile is determined from core neutronics as a 'worst

case' for the proposed cycle, and is seldom a precisely mathematical shape, such as the μsineμ. This option would not typically be used in plant analysis. It was included in the code mainly to assist users in modeling CHF test data with this axial power shape.

The error shifts the axial location of peak power toward the inlet by the amount of the unheated inlet length, decreasing the local axial power factors in the nodes above the peak, and increasing the values for the nodes below the peak. The profile still integrates to unity, so the total power deposition is correct, but the axial distribution is skewed, due to the erroneous shift in the peak location. The magnitude of the effect of the error depends on the size of the unheated inlet, in relation to the total heated length. The smaller the unheated section, the less severe the consequences.

For PWR applications, an unheated entrance length is not typically included in a core model. The unheated length of the fuel pins just above the lower core plate, (typically only 3 or 4 inches), is usually ignored in PWR core models for subchannel analysis. For BWR applications, an unheated entrance length might be 12.0" to 18.0", if it were used to model the BWR channel inlet structures.

For a test case with an unheated inlet length of 18.0" and heated length of 150.0", the correct peak location was 117.0", with a value of 1.794; with the error uncorrected, the peak was located at 99.0", with a value of 1.798. Since the total power input to a channel is unaffected by the error, the channel average thermal-hydraulic parameters are unaffected, but the axial distribution of void and enthalpy is affected by the skewed axial power distribution. The enthalpy will increase more rapidly at the lower axial levels, and the channel may begin boiling at a lower axial node, but these differences will be relatively small, unless the unheated entrance length is very large in relation to the heated length.

CHANGE 116:

description:

An incorrect conditional on an 'if' statement to determine the presence of a water tube channel causes the solution to find a water tube channel even where there isn't one. This results in an array bounds overwrite in the continuity solution with the water tube channel model.

effect on results:

There is a small change in the flow in the water tube channel, on the order of machine round-off. There is no discernable effect on the flow rate in the water tube channels, to the level of precision (i.e., 3 decimal places) used in the normal VIPRE printout.

CHANGE 118:

description:

Error in array size definition for the conduction solution; some arrays that should have been dimensioned by the maximum number of fuel nodes plus one, were dimensioned only to the maximum number of fuel nodes.

effect on results:

Generally, the change will be small, but it depends on the number and size of the conduction nodes in the problem. The fewer nodes, the more likely that the effect will be noticeable. In a test case with 12 nodes, (which is a typical number for most core analysis applications.) The effect of fixing this error was an overall decrease of the surface temperatures. For a conducting tube rod, the temperature decreased by approximately 0.4% on the outside surface, and decreased by about 2.3% on the inside surface.

CHANGE 119:

description:

The Y' term for Bowrings WSC-2 CHF correlation for subchannel analysis uses a node-by-node summation of local mass flux times the enthalpy rise in the node. The calculation should actually use the channel inlet mass flux times the enthalpy rise.

effect on results:

This change is unlikely to impact any licensing analyses, since the Bowring WSC-2 correlation has not been approved by the NRC for thermal margin analysis of any current

[illegible]

fuel designs. (This correlation would not be applied in any case to BWR analysis, since subchannel modeling is not used for BWR channels.) If the correlation were applied in (non-licensing) calculations for PWR subchannel analysis, this change would have very little effect unless the model had an extremely exaggerated radial power skew, causing significant radial flow redistribution. In a representative CHF test case for Westinghouse 15x15 fuel, using a subchannel model of the test section, the MDNBR with the error corrected was 0.822, compared to 0.816 without the correction; an increase of about 1% in the MDNBR.

CHANGE 125 & 128:

description:

Correction to errors in the coefficients for the empirical correlation for thermal conductivity of zircaloy; 1.20583e-3 should be 1.20580e-3, 3.558e-6 should be 3.3557e-6, and 2.3282e-9 should be -2.3281e-9.

effect on results:

The general effect of the correction is to increase the resistance to heat flow through the zircaloy clad, (i.e, to decrease the thermal conductivity), and thereby increase the inner clad and fuel node temperatures. In a test case at typical PWR operating conditions, the peak clad temperature of 674.7 F was unchanged by the correction, but the clad inside surface temperature increased from 737.4 F to 782.6 F, a change of nearly 6%. The peak centerline temperature of the fuel pellet also increased, from 4286.4 F to 4335.4 F, (an increase of about 1%), with the error correction.

There is a slight increase in the stored energy in a fuel rod, as a result of this error correction, and in a transient, this changes the temperature response of the system. In a test case for the BWR Load Rejection without Bypass transient, the effect of this error correction was as follows.

Change 125 & 128	Peak Clad Temperature (°F)	Clad Inside Surface Temperature (°F)	Fuel Centerline Temperature (°F)	ΔCPR[1]
No	565.6/579.7[2]	616.3/646.2	2771.2/3066.4	0.253
Yes	565.6/579.6	648.9/688.6	2825.8/3118.0	0.242
Change	0.0%/0.0%	+5.29%/+6.56%	+1.97%/+1.68%	-4.35%

Note: 1) ΔCPR = CPR (t = 0.0 sec) minus minimum CPR during the transient
2) xxx.x/yyy.y - xxx.x is the value at t = 0.0 sec, yyy.y is the value at the time minimum CPR occurs.

CHANGE 127:

description:

In transients with subcooled boiling predicted using the subcooled boiling models (the Levy or EPRI models), an error in the energy solution gives incorrect enthalpies in the subcooled boiling region.

effect on results:

For all practical purposes, this change has no effect on previous code results. For PWR operating conditions, the error is within the convergence criteria. For BWR operating conditions, the subcooled boiling models should not be used in transient analysis. The recommendation is to use the drift flux model for BWR transient analyses. (See change 139, installing the drift flux model.)

CHANGE 130:

description:

Option for 'Thom plus single-phase' heat transfer correlation uses 'Thom plus Dittus-Boelter', rather than the single-phase heat transfer correlation specified by input.

effect on results:

The effect of correcting this error depends on the single-phase heat transfer correlation selected by the user. If Dittus-Boelter (the default in the code for this regime) is selected, there is obviously no effect. If the user has specified a different single-phase heat transfer correlation, the effect will depend on how the specified correlation differs from Dittus-Boelter. (User-specified heat transfer correlations are entered by specifying the coefficients for an equation of the same form as the Dittus-Boelter correlation. Typically, only the leading coefficient is different, representing a fit of the basic Dittus-Boelter correlation to a more restricted data set.)

The single-phase heat transfer coefficient does not vary very widely in magnitude, even when measured over a wide range of operating conditions. If the user specifies a reasonable formula for the single-phase heat transfer correlation, it will be in reasonable close agreement with Dittus-Boelter. In the two-phase heat transfer regime, the behavior is dominated by the Thom correlation, and the contribution of the single-phase correlation to the total heat transfer coefficient is

relatively insignificant. For these two reasons, this change can be expected to have little effect on code results.

In a test case for a 1/8th core model of a PWR, under nominal operating conditions, using an exaggerated value for the single-phase heat transfer correlation's leading coefficient, there was no difference in thermal-hydraulic parameters or MDNBR results. (In the test case, the leading coefficient for the single-phase heat transfer correlation was 0.0031, compared to the leading coefficient of 0.023 for the Dittus-Boelter correlation.) If a reasonable and valid single-phase heat transfer correlation is used in the analysis, this change will have no effect on the results.

<u>CHANGE 147</u>:

description:

If the axial location of an entry specified in the input for the gap conductance (or gap width) table falls exactly on the node boundary, the input value is applied in the node below, instead of in that node.

effect on results:

The gap conductance (or gap width) axial profile will be shifted one node. How much this will change the results depends on the non-uniformity of the profile. This option is used only for cases where the gap conductance (or gap width) profile is known, usually from the results of calculations with a fuels code. The error is discoverable by inspection of the output of input data for the gap conductance modeling.

A test case for typical PWR operating conditions with an exaggerated non-uniform gap conductance profile showed relatively minor effects on clad and fuel centerline temperatures with this error corrected. Increasing the gap conductance by 250% in a node decreased the fuel centerline temperature by only about 10%. Decreasing the gap conductance in other nodes by 50% resulted in a 6% increase in the fuel centerline temperature. The fuel temperature is not exceedingly sensitive to the gap conductance, and in actual applications, with reasonable values for the axial variation of gap conductance, the effect of this error on the peak centerline temperature will in general be negligible.

CHANGE 148:

description:

In the conduction solution, the heat transfer coefficient derivatives are not automatically reset to zero between the calculation for each rod. This can result in spurious heat fluxes from an adiabatic surface.

effect on results:

This error was discovered when modeling the Hanford N-reactor, which has a fuel design significantly different from commercial LWR fuel. The error is detectable only in a conduction-dominated transient calculation where radial conduction in thin-walled tubes of limited heat capacity is an important factor, and there are adiabatic boundaries on some of the fuel tubes. Calculations with normal BWR and PWR fuel would not encounter this error.

CHANGE 149:

description:

The heat transfer regime selection logic in the code assumes that the calculation cannot enter film boiling if the heat flux is below 25.0 Btu/sec-ft2.

effect on results:

This change has no effect on calculations for BWR or PWR normal and off-normal operating conditions or transients. The limit is a reasonable one for such applications. This limit was found to be inappropriate for application of the code to analysis of transients in the Hanford N-Reactor. At extremely low flow and power conditions it had the effect of preventing the code from predicting the transition to post-CHF film boiling.

CHANGE 152:

description:

If an unheated inlet length is specified with the option for a uniform axial power profile, the axial power distribution will not be correctly normalized.

effect on results:

This change has no effect on BWR or PWR calculations, since a reactor core never has a uniform axial power profile, and therefore this option would not be used.

CHANGE 158:

description:

The vapor density for the Groeneveld-Delorme film boiling heat transfer correlation is evaluated at the film temperature, when it should be evaluated at the vapor enthalpy.

effect on results:

This change affects the results only for cases with post-CHF heat transfer, and then only if the Groeneveld-Delorme heat transfer coefficient is specified. (The default selection is the Groeneveld 5.7 correlation.) In general, normal operating conditions and most transients analyzed with VIPRE-01 in both PWRs and BWRs do not include post-CHF conditions.

In a test case with PWR geometry and operating conditions specified to ensure post-CHF conditions, the effect of the change was to increase the heat transfer coefficient predicted with the Groeneveld-Delorme correlation by about 10%, and thereby decrease the wall surface temperature by about 6%.

CHANGE 159:

description:

The iteration to determine the critical power as a function of boiling length is not performed for the EPRI-2 (Hench-Gillis) CPR correlation. The calculation incorrectly assumes that the critical location is at the exit in all cases.

effect on results:

This change has no effect on PWR applications, since CPR correlations are not applicable to PWR analysis. It also has no effect on BWR applications, since the EPRI-2 CPR correlation is not an approved correlation for any commercial fuel. In a test case consisting of ten CPR data points from the correlation's data base, this change improved the prediction of CPR by 2-5%. Without the iteration, the CPR varied from 0.958 to 0.980 for these ten data points. With the iteration, the CPR was 0.999 in all cases but one, where it was 1.006.

CHANGE 161:

description:

If a material temperature exceeds the range of its property table, the code uses the last entry for the property, (or the first entry, if the temperature is below the range of the table.) A warning message is printed to the output file, but execution continues.

effect on results:

The change to the code for this error is to halt execution when the condition is encountered, instead of merely printing a warning message and continuing the calculation. In evaluating the effect of this error correction on previously calculated results from MOD-01, one must rely on the user's judgement; presumably, the user would not have ignored warning messages from the code in licensing calculations, and would have corrected his input to supply the full range of temperatures required for the properties table. If the user chose to ignore such messages, then it would be necessary to re-run the cases, with expanded properties tables, to determine the effect of the extrapolation.

CHANGE 171:

description:

It is assumed that the material properties will be entered in order of increasing temperature, but the code does not check for this.

effect on results:

With this change installed, the code checks for monotonically increasing temperature in the properties tables arrays, and halts execution with an error message if this rule is violated. This check is not made in MOD-01, and if the user did not enter the data correctly, the code would not detect the error. The result of such an input error would be that the table interpolation for the property would be done with the wrong end-points. The magnitude of the effect on calculated results would depend on the sensitivity of the material property to temperature, and could be determined only on a case by case basis.

It should be noted, however, that there has never been a documented case of a user actually making this error. The input instructions do not explicitly state that the properties tables should be entered monotonically increasing on temperature, but this is the standard way to handle table look-up logic. Users generally do not

seem to have any trouble with this assumption, and this change was added only as a 'fail-safe' to cover all eventualities, even the most unlikely.

CHANGE 174:

description:

The Levy subcooled void model uses the local value of the single-phase heat transfer coefficient as a parameter. It was originally formulated to define that value using the Dittus-Boelter correlation, but in the code, the user-specified single-phase heat transfer correlation was used in that calculation.

effect on results:

Since Dittus-Boelter is the default heat transfer correlation in the single-phase regime, this change will have no effect on applications that do not specify a different single-phase heat transfer correlation. For cases where the user has selected a different correlation, the effect of the change will depend on how much that correlation differs from Dittus-Boelter. If the user-defined correlation gave results similar to Dittus-Boelter, (which one would expect to be desirable in normal PWR and BWR operating ranges), the effect of this change would be negligible.

In a test case at PWR operating conditions, but with power increased to ensure a positive exit void fraction, the effect of this change was investigated by selecting an extreme value for the single-phase heat transfer correlation. A leading coefficient of 0.004 was specified; this is significantly different from the Dittus-Boelter value of 0.023. (It is also, it should be noted, quite unrealistic for PWR conditions.) The effect of the error in the Levy model coding was to suppress boiling entirely, even though the channel exit enthalpies were significantly above saturation. This is a significant error, but by its very nature, it is immediately obvious to the user; this is, in fact, how the error came to be reported.

CHANGE 176:

description:

For transients using the pressure boundary forcing function, the default value of 2 for the minimum number of iterations in a time step will not be sufficient if the flow solution converges in one iteration. The pressure adjustment is not done on the first iteration of a time step, nor is it done on the final iteration if the flow is converged, so if the flow converges in only one iteration, the pressure will not be adjusted at all for that time step.

effect on results:

This error has no effect on results of calculations for PWR and BWR transients. This error was discovered when running a null transient with a pressure boundary condition; it has never been observed in a real transient. Diligent efforts to construct a test case in which the flow would converge in one iteration were not successful, not even with very slow and gentle forcing functions. Experience has shown that real transients at both BWR and PWR conditions always take more than a single iteration to converge.