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Gentlemen:

Subject: **NOTIFICATION OF RELEASE AND REQUEST FOR NRC REVIEW OF VIPRE-01 MOD-02**

References:

1. Letter from J. A. Blaisdell (UGRA) to H. R. Denton (NRC), December 17, 1984
2. Letter from C. E. Rossi (NRC) to J. A. Blaisdell (UGRA), Acceptance for Referencing of Licensing Topical Report, EPRI NP-2511-CCM, "VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores", Volumes 1, 2, 3, and 4, May 1, 1986.

VIPRE-01 is a subchannel thermal-hydraulic computer code that was developed by Battelle Pacific Northwest Laboratories under the sponsorship of the Electric Power Research Institute (EPRI). Because the EPRI charter does not allow for long term support of a released computer code, the VIPRE-01 Maintenance Group was formed in 1987 to provide funding and guidance for ongoing support and code maintenance. The VIPRE-01 Maintenance Group is a code user organization that currently consists of seventeen member utilities; the membership list is shown in Attachment 1.

VIPRE-01 was submitted for NRC review by the Utility Group for Regulatory Applications (UGRA) in 1985 (Reference 1). An SER (Reference 2) was issued by the NRC approving VIPRE-01 for PWR applications for heat transfer regimes up to the point of critical heat flux. As discussed in the SER, VIPRE-01 is maintained under a Quality Assurance program at Battelle. Code errors reported by code users are handled in accordance with this QA program, which provides for user notification and release of new code versions incorporating error corrections.

The VIPRE-01 MOD-02 has recently been released for use. This version, which was prepared in accordance with the VIPRE-01 QA program, includes 77 changes from the VIPRE-01 MOD-01 version. VIPRE-01 MOD-01 is the version that was reviewed and approved in Reference 2. A report (Attachment 2) describing the effect of the 77 changes is included in this submittal. A copy of the complete error/change log will be submitted if required.

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The VIPRE-01 computer code documentation (EPRI NP-2511-CCM, Volumes 1 through 4) was submitted to the NRC previously. At your request, we will submit the appropriate number of copies of the updated code documentation. It is the desire of the VIPRE-01 Maintenance Group to have the NRC review VIPRE-01 MOD-02 and issue an SER for PWR and BWR applications.

The original VIPRE-01 SER did not address BWR applications. However, BWR qualification analyses have now been completed, and a report on BWR applications (Attachment 3) is included in this submittal.

A review of this new code version is appropriate due to several near term utility applications, including:

Date	Submittal
Mid 1990	Oconee Nuclear Station - reload thermal-hydraulic analysis, Duke Power Company
Early 1992	WNP-2 - Cycle 8 reload safety analysis, Washington Public Power Supply System (WPPSS)
Late 1992	Comanche Peak Unit 1 - Cycle 3 reload safety analysis, TU Electric

If you have any questions or comments, please contact me at (509) 372-5195.

Sincerely,

Y. Y. Yung

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

YYY:bw

Attachments: 1) VIPRE-01 Maintenance Group Membership List
2) EPRI Report Summarizing Changes
3) WPPSS BWR Analysis Report

cc: R.C. Jones, NRC
S. Maier, TU Electric
D. Koontz, Duke Power Company
G.S. Srikantiah, EPRI
J. Cuta, Battelle Pacific Northwest Laboratories
VIPRE Maintenance Group

ATTACHMENT 1

VIPRE-01 Maintenance Group Members

1. Baltimore Gas & Electric
2. Commonwealth Edison
3. Duke Power Company
4. Florida Power & Light Company
5. General Public Utilities
6. Houston Lighting & Power
7. Illinois Power Company
8. Middle South Services
9. New York Power Authority
10. Northeast Utility Service Co.
11. Northern States Power Company
12. Public Service Electric & Gas Company
13. Tennessee Valley Authority
14. TU Electric
15. Union Electric Company
16. Wolf Creek Nuclear Operating Corporation
17. Washington Public Power Supply System

Summary of Changes in VIPRE-01 between MOD-01 and MOD-02

The revisions to VIPRE-01 between MOD-01, released in 1985, and the current version, Mod-02, released in October of 1989, included 77 individual changes. These changes consisted for the most part of minor error corrections to the code and enhancements of code output features. The one major new modification was to include an optional drift-flux model to improve the code's capabilities to calculate the evolution of the void fraction profile in transients with two-phase flow conditions.

Twenty-two of the 77 changes were corrections to the ASP post-processor graphics program, which reads a binary file created by the VIPRE code, and makes CALCOMP plot files. These changes make the ASP program more useful, but do not affect the results or performance of the VIPRE code itself.

Of the remaining 55 changes, 28 were changes to enhance the appearance of the output -- e.g., expand variable print-out fields, add new or expanded informative diagnostic messages, write out additional information for the user -- or to update relevant information on the output banner page and case title line. The nature of these changes was such that, although it is desirable to have them in the new version, they have no real impact on the performance of the code.

The other 27 changes in MOD-02 were changes that fix problems which actually make the code fail in execution, or which result in different answers from those obtained in MOD-01. Only eleven of the changes were for problems that cause the code to fail. In most cases, these errors occurred when certain options were used in the code in unforseen ways, or in untested combinations, and since the calculation actually failed, the user was in no danger of assuming the code had given him an answer which consisted of bad results. The remaining 16 changes, however, do result in some difference in the performance of the code, when comparing results from MOD-02 to those obtained for the same problem in MOD-01. In all cases, the differences are small, or confined to a certain narrow region of a calculation. The following table summarizes briefly the changes that can result in differences in the code results.

Table 1: MOD-02 Changes which affect Code Results

CH101
BAW#2 CHF correlation's nonuniform axial power correction should be applied even if quality is below -0.03, which is below the range of the correlation. (This is consistent with standard usage of the correlation.) Results in small change in DNBR values at high subcooling.

CH102
Corrects pressure solution for water tube channel modeled using optional input in group BWRG. Results in small change in water tube flow rate.

CH110
Corrects the application of the usineu axial power profile option. With a cold inlet length the total power input was incorrect in MOD-01 for this case.

Results in change in total power input, with consequent change in fluid conditions. Magnitude of the difference between MOD-01 and MOD-02 results will depend on the problem.

CH116
Fix for coding error in the water tube channel model. Results in a small mass flow difference, which is on the order of machine round-off.

CH119
Fixes error in Y' term in the Bowring WSC-2 CHF correlation, which results in small changes in DNBR values. Differences are noticeable only for cases with abnormally large crossflow velocities.

CH125 and CH128
Fix errors in coefficients of zircaloy thermal conductivity equation, which cause small changes (on the order of 5%) in clad and fuel temperatures.

CH127
Fixes energy error in boiling transients when the subcooled boiling models are used. Results in differences in the evolution of the void profile during the transient. Magnitude of the differences between MOD-01 and MOD-02 results is problem-dependent.

CH130
Fixes heat transfer input flag 'THSP' so that it gives Thom-plus-Dittus-Boelter for boiling heat transfer coefficient, as it is supposed to, rather than Thom plus user-specified single-phase heat transfer coefficient. Results will be different only in cases where the user selected something other than Dittus-Boelter for single-phase heat transfer, and the differences will be noticeable only if the alternate correlation gives numbers significantly different from what Dittus-Boelter would predict for the same conditions.

CH143
Fix to correct an overwrite that occurs in the energy solution if the bandwidth for a problem is larger than the number of channels (Note: it requires a perverse disregard for the recommended efficient channel number convention to encounter this error.) Results in differences in enthalpy; the magnitude of the effect will be problem depended. In any even moderately efficient channel numbering scheme, the bandwidth will be much smaller than the number of channels, so this is an extremely rare problem.

CH147
Fix to correct the user-specified gap conductance table interpolation when the axial locations named in the input correspond exactly to the locations of the node boundaries. Results in shifting of the node locations of the specified gap conductance values, and can result in differences in fuel and clad temperatures. Magnitude of the effect will be problem dependent.

CH148
Fix to reset heat transfer coefficient derivatives to zero between calculation for each rod in the conduction solution. If this is not done, round-off or internal iteration error can sometimes cause a spurious heat flux from a rod with an adiabatic boundary condition. Results could change if the spurious

heat flux were large enough to constitute a significant energy source, but in most cases it will be essentially zero, even without the fix.

CH158
Fix so that the vapor density is evaluated at the film temperature, rather than at the superheated vapor temperature, in the application of the Groeneveld-Delorme film boiling heat transfer correlation. Results in differences in the heat transfer coefficient value, and consequently the surface temperature and rate of heat transfer to the fluid, but affects only heat transfer in the film boiling (post-CHF) region when the Groeneveld-Delorme correlation is selected for heat transfer in that region.

CH159
Fix to include the iteration to determine the critical boiling length for the EPRI-2 CPR correlation. Results in different critical power predictions when the EPRI-2 CPR correlation is used, and yields a better comparison to data.

CH174
Fix to make Levy subcooled boiling model use the Dittus-Boelter single-phase heat transfer correlation even when the user selects an alternate correlation for the single-phase regime. Results in different subcooled quality predictions only when the user selects something other than Dittus-Boelter (the VIPRE default) in the single-phase region, and the differences will be noticeable only if the alternate correlation results in significantly different heat transfer coefficients, compared to Dittus-Boelter.

CH176
Fix on the default for the minimum number of iterations for calculations with the pressure drop boundary condition option. For transients, the minimum number of iterations needs to be 3 rather than 2, or the code might think it is converged when it is not. Affect on results will be problem-dependent, with most cases unaffected, because they will probably be taking more than the minimum number of iteration, anyway.

ATTACHMENT 3

9003230055

VERIFICATION OF VIPRE-01 FOR BWR ANALYSIS

By

Y. Y. Yung

September 1987

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

Richland, Washington

TABLE OF CONTENTS

VERIFICATION OF VIPRE-01 FOR BWR ANALYSIS

1.0 INTRODUCTION

VIPRE-01[1] is a thermal-hydraulics code designed for steady state and transient analysis of nuclear reactor cores under normal operating conditions and a wide range of assumed abnormal events and transients. It was developed by Battelle Northwest under EPRI sponsorship to be a tool for evaluating nuclear reactor safety limits, including minimum departure for nucleate boiling ratio (MDNBR), critical power ratio, (CPR), fuel and clad temperatures, and coolant state. Developed from the COBRA[2,3,4] family of codes, VIPRE-01, underwent a long period of testing and verification by a working group composed of EPRI-member utilities from May 1981 to January 1984. The code was first released in January 1984, as VIPRE-01, MOD-0, and was subjected to an independent design review. The code and its documentation were revised in response to design review comments, and a new version, VIPRE-01, MOD-1, was published in May 1985. At that time, a Utility Group For Regulatory Application (UGRA) was formed to prepare a submittal to the Nuclear Regulatory Commission (NRC) requesting generic approval of VIPRE-01 for licensing calculations. A submittal addressing PWR application has been approved, with the NRC Safety Evaluation Report[5] (SER) issued in April 1986.

The work reported here is in support of BWR applications of VIPRE-01. Core models were developed for VIPRE-01 based on Washington Nuclear Plant No. 2 (WNP-2), a BWR/5 reactor with 8x8 fuel and a design power level of

3323 MW_t. Sensitivity studies were performed for the core model, and transient calculations were performed to compare with selected transients from the WNP-2 FSAR(6). The core models are described in detail in Section 2.0. The sensitivity studies performed with the core models are discussed in Section 3.0. Calculations to benchmark the VIPRE results against GE design calculations for core pressure drop, FSAR steady state results and WNP-2 core follow calculations are presented in Section 4.0. The FSAR transient calculation comparisons are presented in Section 5.0. Conclusion is provided in Section 6.0 and references are in Section 7.0.

2.0 BWR Core Models For VIPRE-01

The reactor core of WPPSS Nuclear Plant No. 2 at Hanford was used in this evaluation of the VIPRE-01 code's capabilities for modeling BWR thermal-hydraulic conditions. A complete description of the plant is available in the FSAR (see Reference 6). The core of WNP-2 consists of 764 assemblies of 8x8 fuel, and a bypass region containing 185 cruciform control rod structures. Figure 2.1 shows a diagram of a one quarter cross section of the WNP-2 core. The core region begins at the inlet orifice, where flow enters from the lower plenum, and extends to the top of the fuel assemblies, to just above the upper tie plate.

Two basic core models were examined in these calculations. The first was a relatively simple 4-channel model, consisting of two channels modeling a single bundle each--the hot central bundle and the hot peripheral bundle--and two large lumped channels; one modeling the remaining 671 central bundles, and one modeling the remaining 91 peripheral bundles.

The rods are similarly lumped, with one rod representing all the fuel rods contained in the bundles comprising lumped channels. Figure 2.2 illustrates this radial noding scheme for the four channel model. The second VIPRE model for the WNP-2 was a detailed model of a one quarter section of symmetry, with one channel for each assembly. Figure 2.1 illustrates the channel and rod numbering scheme for this model.

Both of the VIPRE-01 models of the WNP-2 core considered here model the full axial length of the core region, from inlet orifices to the upper tie plate. The fuel assemblies are modeled with one dimensional channels, with a single average flow area, velocity, and density at a given axial location.

With this approach, VIPRE-01 can correctly calculate the axial distribution of the radially averaged void fraction, density, and enthalpy along a fuel channel. A more detailed subchannel model of the flow field within the fuel assembly is unnecessary, and would in fact be counter-productive, as the three equation homogeneous formulation of the conservation equations in VIPRE is not capable of solving for the correct radial distribution of void in fully-developed annular two-phase flow. This is a generic limitation of the homogeneous model, and its effect on the code's accuracy in two-phase flow calculations is fully documented in Volume 4 of the VIPRE code manual (see Reference 1). The results presented in Volume 4 show that VIPRE is fully applicable to two-phase flow analysis when.the flow field can be averaged in the radial direction.

For these calculations, the bypass region of the core is not included in the VIPRE model. Instead, it is assumed that 10.4 percent[7] of the rated core flow is diverted to the bypass. This assumption is made for convenience only. VIPRE-01 is capable of modeling the bypass region of a BWR, and calculating the amount of bypass flow through the various leakage paths at or near the core inlet. However, this option requires detailed input describing the lower core structure, and the effective hydraulic losses of individual leakage paths. This information is not always easily obtained, and would in any case be plant specific. For the purposes of these calculations, which are to demonstrate capability rather than produce specific results for a particular analysis, the assumption of 10.4 percent bypass flow is quite sufficient.

The inlet flow distribution among the channels modeling the fuel assemblies is calculated in VIPRE assuming a uniform pressure drop across the core. With this boundary condition option, the inlet flow to each channel is adjusted iteratively until the pressure drop in each channel is the same. (The total specified inlet flow is conserved, however.) The pressure drop in a given channel is calculated considering the total hydraulic losses, including gravity head, wall friction, and local pressure losses. Wall friction was determined using the Blasius smooth-tube correlation, $f = 0.32\ Re^{-0.25}$ (which is the VIPRE-01 default). Local pressure losses were modeled for the inlet orifice, lower tie plate, seven spacer grids, and the upper tie plate. Figure 2.3 shows the axial locations of the local pressure losses, and Table 2.1 lists the loss coefficient values[7, 8] used in VIPRE to model the losses.

The conduction model was not used in these calculations. The fuel rods were modeled using the "dummy" rod option in VIPRE, in which the power generated in the fuel is used to define a heat flux boundary condition at the rod surface. For the 4-channel model, the axial and radial power distributions were obtained from values reported in the FSAR (see Reference 6). For the 191-channel quarter core model, radial and axial power distributions were obtained from a calculation using the SIMULATE-2[9] core neutronics code. SIMULATE-2 produced a radial power factor for each assembly in the quarter core model, as shown in Figure 2.4. An axial power profile was generated for each of eight radial rings in the core. Assemblies within each ring were assumed to have the same axial power profile. Figure 2.5 diagrams the rings and indicates by corrspondence with the quarter core diagram in Figure 2.1 which assemblies are included in each ring.

The operating conditions used as boundary conditions for the steady state calculations are listed in Table 2.2. These are the rated conditions from the FSAR. It should be noted, however, that the value used for the inlet flow was the active core flow, rather than the total rated flow, where active flow = (total flow - bypass flow).

Critical power calculations were performed using the General Electric proprietary critical quality boiling length correlation, GEXL[10]. The correlation was programmed into VIPRE using the dummy subroutine CPR3, provided for that purpose, and is accessed by the option "MINE" in the VIPRE input for CPR correlation selection. The bundle R-factors required as input for the GEXL correlation, which are functions of the radial power distribution within the fuel bundles were obtained by linear interpolation of tabulated R-factor values in the WNP-2 Process Computer Data Bank (see Reference 7).

TABLE 2.1

PRESSURE LOSS COEFFICIENTS FOR WNP-2 CORE CHANNELS

Structure	Loss Coefficient
Inlet Orifice	
Central	29.25
Peripheral	213.52
Lower Tie Plate	7.86
Upper Tie Plate	1.46
Spacer Grids	1.24

TABLE 2.2

OPERATING CONDITIONS FOR VIPRE-01 CALCULATIONS WITH MODELS OF WNP-2

Parameter	Value
Core Power	3323 MWt
Inlet Flow Rate	
Rated	108.5 X 10^6 lbm/hr
Active	97.2 X 10^6 lbm/hr*
Inlet Enthalpy	527.6 btu/lb
System Pressure	1035.0 psia

*WNP-2 Process Computer Data Bank (Reference 7) gives the core bypass flow as a tabular function of the total core flow entering the core inlet plenum. At the rated total core flow (108.5 X 10^6 lbm/hr), the bypass flow is 11.3 X 10^6 lbm/hr which is 10.4 percent of total core flow.

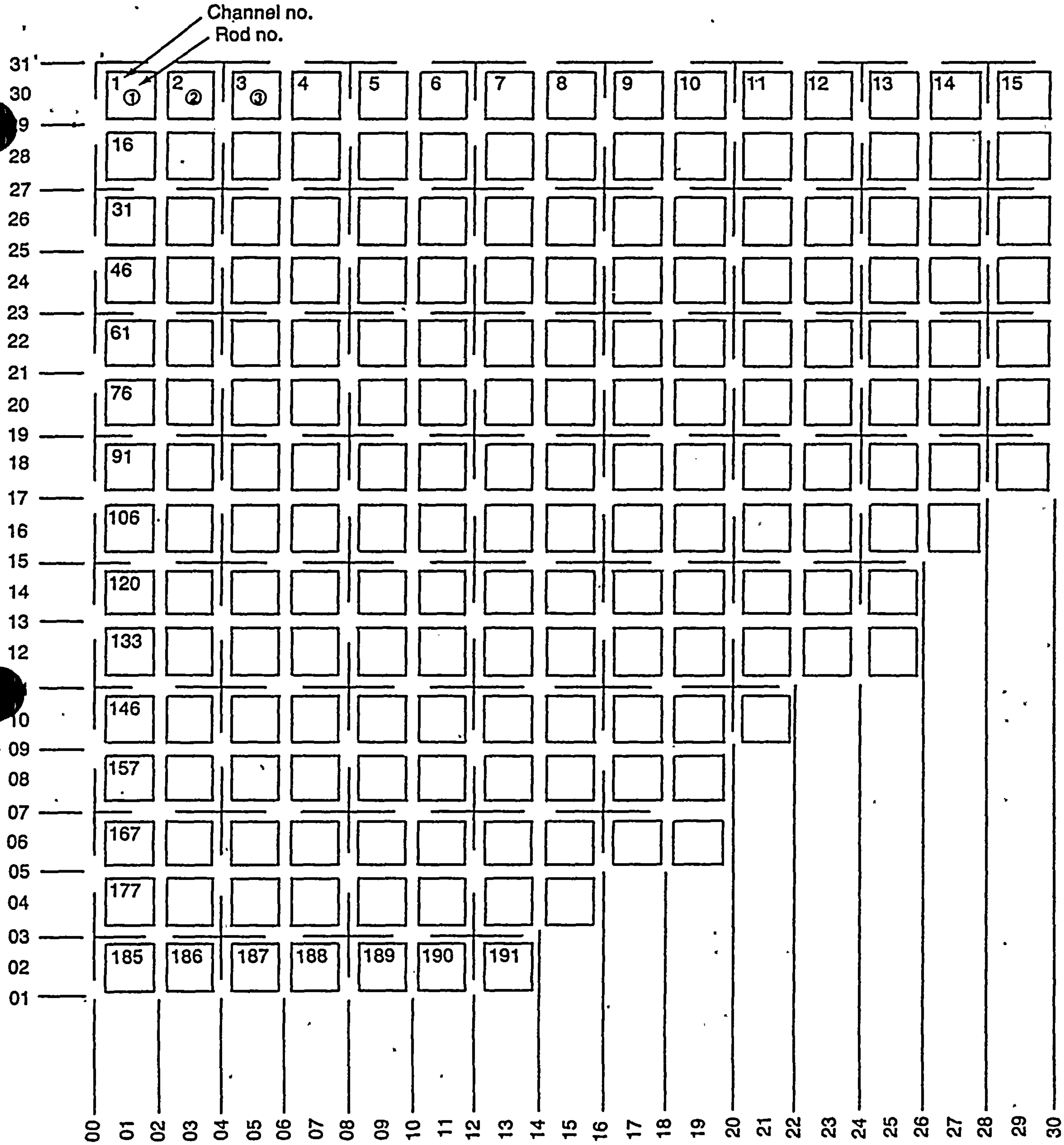
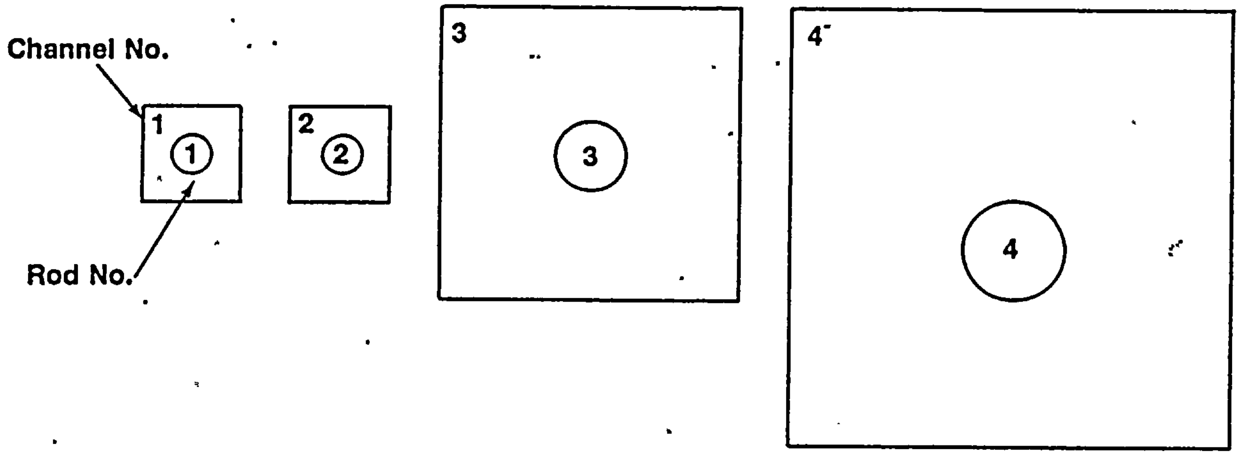


Figure 2.1

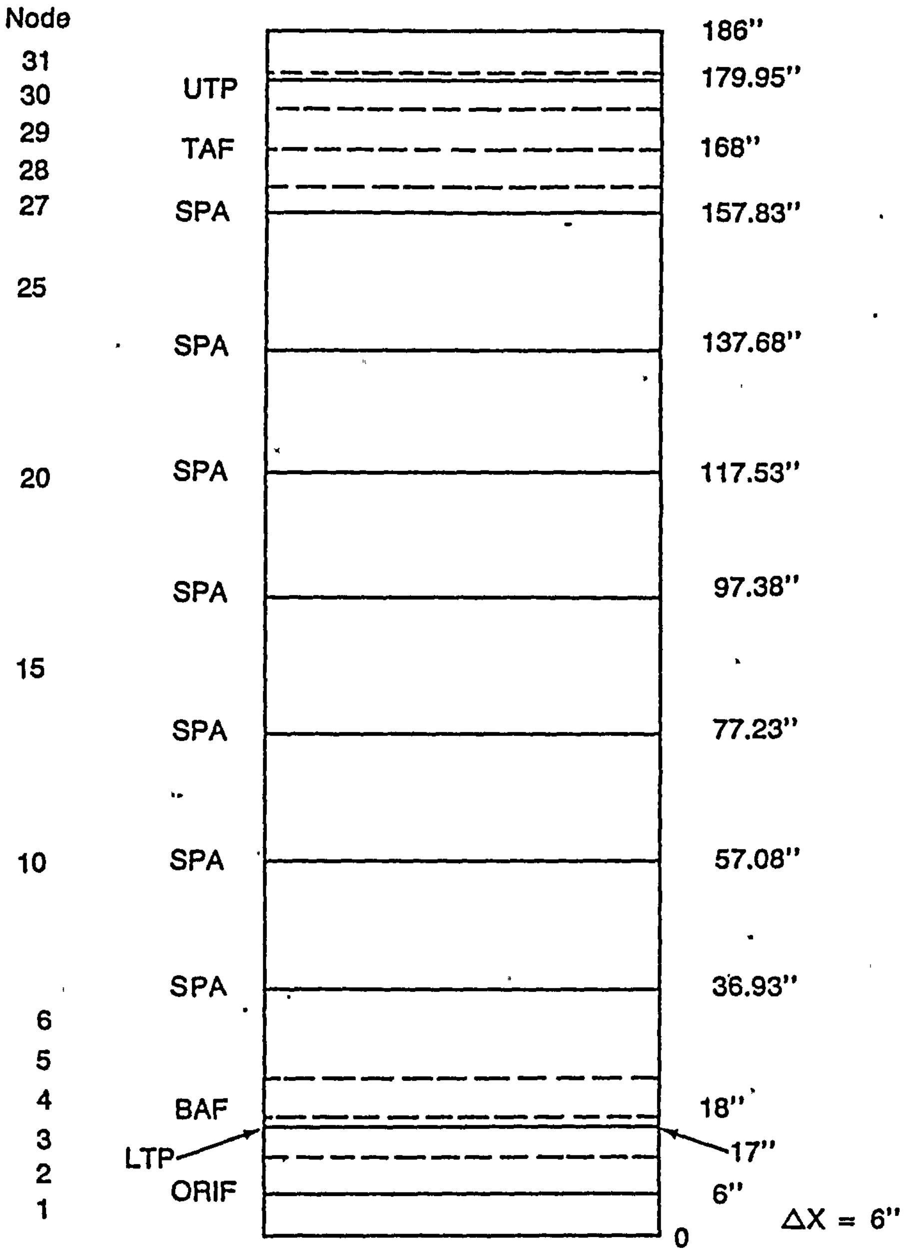
191 Channels Quarter Core Nodalization



Channel 1 models one bundle, the hottest peripheral bundle
Channel 2 models one bundle, the hottest central bundle
Channel 3 models 91 peripheral bundles
Channel 4 models 671 central bundles
Rod 1 models 62 fuel rods
Rod 2 models 62 fuel rods
Rod 3 models 91 X 62 = 5,642 fuel rods
Rod 4 models 671 X 62 = 41,602 fuel rods

Figure 2.2

Four Channels Full Core Nodalization



UTP - Upper Tie Plate
TAF - Top of Active Fuel
SPA - Spacer
BAF - Bottom of Active Fuel
LTP - Lower Tie Plate
ORIF - Orifice

Figure 2.3

Axial View of Bundle/Channel

0.828	1.080	1.113	0.945	0.942	1.123	1.082	0.834	0.832	1.097	1.162	1.167	1.033	0.815	0.312
1.080	1.167	1.286	1.164	1.252	1.202	1.255	1.072	1.146	1.154	1.261	1.188	1.053	0.819	0.313
1.113	1.286	1.242	1.346	1.249	1.350	1.202	1.193	1.093	1.256	1.180	1.192	1.047	0.812	0.308
0.945	1.164	1.346	1.238	1.341	1.260	1.272	0.942	0.996	1.122	1.243	1.153	1.012	0.788	0.298
0.942	1.252	1.249	1.341	1.251	1.377	1.199	1.039	0.943	1.214	1.224	1.134	0.983	0.756	0.280
1.123	1.202	1.350	1.260	1.377	1.295	1.371	1.191	1.257	1.191	1.233	1.123	0.951	0.701	0.247
1.082	1.255	1.202	1.272	1.199	1.371	1.285	1.357	1.227	1.280	1.194	1.062	0.858	0.583	0.198
0.834	1.072	1.193	0.942	1.039	1.191	1.357	1.228	1.272	1.214	1.110	0.935	0.696	0.294	
0.832	1.146	1.093	0.996	0.943	1.257	1.227	1.272	1.197	1.116	0.962	0.752	0.324		
1.097	1.154	1.256	1.122	1.214	1.191	1.280	1.214	1.116	0.964	0.751	0.336	0.185		
1.162	1.261	1.180	1.243	1.224	1.233	1.194	1.110	0.962	0.751	0.353				
1.167	1.188	1.192	1.153	1.134	1.123	1.062	0.935	0.752	0.336					
1.033	1.053	1.047	1.012	0.983	0.951	0.858	0.696	0.324	0.185					
[illegible]	0.819	0.812	0.788	0.756	0.701	0.583	0.294							
[illegible]	0.313	0.308	0.298	0.280	0.247	0.198								

Figure 2.4

Quarter Core Radial Power Factors
Calculated With SIMULATE-2

1	2	2	3	3	4	4	5	5	6	6	7	7	8	8
2	2	2	3	3	4	4	5	5	6	6	7	7	8	8
2	2	3	3	3	4	4	5	5	6	6	7	7	8	8
3	3	3	3	4	4	4	5	5	6	6	7	7	8	8
3	3	3	4	4	4	5	5	5	6	6	7	7	8	8
4	4	4	4	4	5	5	5	6	6	7	7	7	8	8
4	4	4	4	5	5	5	6	6	6	7	7	8	8	8
5	5	5	5	5	5	6	6	6	7	7	8	8	8	
5	5	5	5	5	6	6	6	7	7	7	8	8		
6	6	6	6	6	6	6	7	7	7	8	8	8		
6	6	6	6	6	7	7	7	7	8	8				
7	7	7	7	7	7	7	8	8	8					
7	7	7	7	7	7	8	8	8	8					
8	8	8	8	8	8	8	8							
8	8	8	8	8	8	8								

Figure 2.5

Quarter Core Rings Definition

3.0 SENSITIVITY STUDIES FOR VIPRE-01 BWR CORE MODELS

Sensitivity studies were performed to assess the effects of various modeling options and approaches for BWR analysis using VIPRE-01. Of primary interest was the radial noding study, to determine if the simple 4-channel core model would yeild results as good as those obtainable with the detailed quarter core 191-channel model. It is reasonable to expect that the two models would yield similar results, given the nature of the flow field in a BWR core, which consists of an array of isolated channels, wherein the inlet flow distribution provides the only means of altering the local flow. It was necessary to determine that lumping large numbers of assemblies into one or two channels would not materially affect the inlet flow to the hot assemblies in the center and periphery of the core.

The results presented in Section 3.1 show that the 4-channel model is quite adequate for BWR analysis with VIPRE, and yields essentially the same hot channel results as the detailed quarter core model. Since the 4-channel model is much less expensive to run, it alone was used in the subsequent sensitivity studies to investigate the effects of different modeling options on the BWR results. These sensitivity studies examined the effects of axial noding, water properties options, hot wall correction for viscosity, local pressure option, and two phase flow correlation selection, and are discussed in detail in Sections 3.2 through 3.7.

3.1 Radial Noding Sensitivity

Radial noding sensitivity was examined by comparing hot channel exit temperatures and core pressure drop calculations obtained with the 4-channel and 191-channel models of WNP-2 in VIPRE-01. Nineteen different cases were run, for varying combinations of power level and flow rate. The results are summarized in Table 3.1. For each case, the hot channel exit temperatures and core pressure drops predicted with the two different models are essentially identical.

These results are consisted with the results of radial noding studies presented in Volume 4 of the VIPRE documentation (see Reference 1). Noding studies in a PWR core geometry showed a similar insensitivity to core lumping pattern, when the hot region of the core was modeled with adequate detail. In a BWR core, where flow redistribution due to crossflow cannot occur at all, the overall core lumping pattern is even less important, when the hot assemblies are modeled as a single channel each.

TABLE 3.1

RADIAL NODING SENSITIVITY STUDY - SUMMARY OF RESULTS

Case No.	Power	Total[c] Flow	MCPR		Hot Channel Exit Temp (°F)		Core Pressure Drop	
	(% of Rated)	(% of Rated)	QC[a]	FC[b]	QC	FC	QC	FC
1	100.0	100.0	1.42	1.42	548.3	548.4	22.12	22.41
2	76.0	99.0	1.89	1.89	544.1	544.3	20.92	20.89
3	68.6	59.7	1.87	1.87	541.3	541.5	10.63	10.60
4	91.1	83.1	1.56	1.57	542.0	542.2	17.33	17.29
5	86.7	98.0	1.60	1.60	540.3	540.5	21.42	21.39
6	97.2	99.5	1.48	1.48	543.5	543.7	23.07	23.03
7	99.5	100.0	1.46	1.46	545.2	545.4	22.83	22.81
8	95.5	98.5	1.51	1.51	544.2	544.4	22.27	22.23
9	48.8	50.0	2.31	2.31	538.8	538.9	8.41	8.37
10	98.1	98.2	1.46	1.47	544.4	544.6	21.89	21.86
11	100.2	98.8	1.39	1.39	546.1	546.2	22.26	22.24
12	100.0	97.2	1.43	1.43	545.4	545.6	21.98	21.94
13	99.8	95.7	1.48	1.48	544.5	544.7	21.05	21.02
14	96.1	88.9	1.50	1.50	544.7	544.9	19.03	19.01
15	57.7	32.6	1.71	1.72	543.3	543.5	5.55	5.50
16	70.4	53.0	1.68	1.70	544.6	544.8	9.90	9.87
17	71.8	52.1	1.66	1.66	545.5	545.7	9.79	9.75
18	71.4	50.7	1.67	1.67	543.7	541.4	9.48	9.53
19	71.6	50.7	1.63	1.63	544.1	544.3	9.50	9.48

NOTES:

[a] Quarter Core 191-Channel Model
[b] Full Core 4-Channel Model
[c] Total flows are given here. VIPRE calculations used active flows, where active flows = (total flows - bypass flows). Bypass flows which are functions of core flows were obtained by linear interpolation of tabulated bypass flow values in the WNP-2 Process Computer Data Bank (see Reference 7).

3.2 Axial Noding Sensitivity

Sensitivity to axial noding was investigated by examining the effect of three different axial noding patterns on the MCPR, exit flow rate, and void fraction in the hot central channel using the 4-channel model. The only effect the axial node size might be expected to have on the results of a calculation in what is essentially a one dimensional channel is in the averaging effect on the axial power distribution. Finer noding might make minor differences in the enthalpy and void fraction distributions, as the non-uniform axial power distribution is more accurately resolved. But it should make no real difference in the overall results.

Three different axial node sizes were used in this sensitivity study. The base case used six-inch axial nodes. Case 1 used coarser noding, with ten-inch axial nodes, and Case 2 used slightly finer noding, with five-inch axial nodes. (In both of these cases, six-inch axial nodes were used for the first 36 inches of the axial length. This length consisted of the unheated inlet region, and only the first 18 inches of active fuel where the fluid would be subcooled, and thus would have little or no effect on the void distribution.)

The results obtained for these three cases are compared in Table 3.2. The differences in the flow solution, as evidenced by the values for pressure drop, exit flow, and void fraction, are very small. The MCPR is approximately three percent lower for the coarse noding (Case 2), but there is no discernable change in MCPR for the finer noding (Case 3). These results indicate that six-inch nodes quite adequately resolve the axial distributions in the core, and is a suitable approximation for BWR analysis.

TABLE 3.2

AXIAL NODING SENSITIVITY STUDY - SUMMARY OF RESULTS

Case No.	Axial Nodalization	MCPR	Hot Channel Flow Rate (lbm/sec)	Core Exit Void Fraction	Pressure Drop (psi)	Computer Time (SRU)
1	31 (31X6")	1.316	34.821	0.7851	23.78	17.339
2	21 (6X6" + 15X10")	1.274	34.850	0.7845	23.72	14.430
3	36 (6X6" + 30X5")	1.316	34.858	0.7850	23.72	18.906

3.3 Water Properties Generation

In a VIPRE calculation, the physical properties of the working fluid must be described. These water properties may be specified in the VIPRE model in three ways. First, a water properties table may be created by VIPRE. When using this option, the user specifies the range of the table which is needed for a given problem and the number of entries that the table will contain over this range. The EPRI water properties functions (Reference 11) are used to generate the points in this table. In performing its solution, VIPRE interpolates on this table for any needed property. In the second method, VIPRE used the EPRI water properties functions directly for each property needed for the solution. (This method eliminates any table interpolation errors.) In the third method, the user specifies property tables by input. User input is required if a fluid other than water is being modeled. Also, user input is necessary if the operating conditions of a problem are outside the range of the EPRI water properties functions.

The EPRI water properties functions are very accurate over a wide pressure and enthalpy range. This pressure range spans from below atmospheric pressure to above the critical pressure. The enthalpy range is from 200 to 830 btu/lbm. The operating conditions which are used in VIPRE analyses for WNP-2 are well within the range of the EPRI functions.

The option for user input of the water properties table is not considered for two reasons. The first is that the EPRI functions are very accurate over their range of applicability. Secondly, the potential for input error is increased.

Two cases were considered in the water properties sensitivity study. In Case 1, water properties were determined from a 26-entry table (table spacing = 10 btu/lbm) generated using EPRI functions. In Case 2, the direct evaluation of the EPRI functions was used to determine properties. Any differences in the results obtained for these two cases would have to be ascribed to differences between the property values interpolated from the table, and those obtained from evaluation of the EPRI functions for the local fluid conditions in each cell.

The results obtained for these two cases are shown in Table 3.3. The difference in saturation temperature is only about 0.1 percent which is smaller than the error band in the properties function itself. These results show that linear interpolation in the water properties table is as accurate as direct evaluation of the functions at BWR operating conditions when the table is specified with a reasonable enthalpy increment (i.e., on the order of 10 btu/lbm). Within these constraints, the VIPRE solution is insensitive to the method of water properties generation. This is consistent with the results in VIPRE-01, Volume 4 (see Reference 1).

TABLE 3.3

WATER PROPERTIES GENERATION SENSITIVITY STUDY - SUMMARY OR RESULTS

Case No.	MCPR	Hot Channel Exit Temp (°F)	Hot Channel Exit Flow Rate (lbm/sec)	Void Fraction	Core Pressure Drop (psi)	Computer Time (SRU)
1	1.337	548.37	34.669	0.7862	24.11	16.854
2	1.337	548.99	34.667	0.7861	24.09	16.961

3.4 Rohsenow-Clark Viscosity Model

The Rohsenow-Clark model modifies the axial friction factor (f) to account for the effect on wall drag of the fluid viscosity variation near a heated surface. This model adjusts f to include the effect of decreased fluid viscosity near the fuel rod surface. This is usually a small effect, and the default in VIPRE is to ignore it, and evalute friction factor based on the bulk fluid temperature in a node.

However, in BWR analysis, the adjustment to wall drag will be felt more strongly in the hot channels than in average channels (in the 4-channel core model), resulting in a different flow distribution to yield a uniform pressure drop. The magnitude of this effect was investigated by performing two calculations at normal operating conditions (see Table 2.2), one with the Rohsenow-Clark model, and one case without.

The Rohsenow-Clark model adjusts the friction factor by the relation.

$$f_{RC} = f \left[1.0 + \frac{P_H}{P_W} \left(\left(\frac{\mu_{WALL}}{\mu_{bulk}}\right)^{.6} - 1.0\right)\right] \tag{3-1}$$

Where:

f = Friction factor from Blasius relation

P_H = Heated perimeter of channel

P_W = Wetted perimater of channel

μ_{bulk} = Fluid viscosity evaluated at bulk temperature

μ_{WALL} = Fluid viscosity evaluated at rod surface temperature, T_{WALL}, where T_{WALL} is determined as

$$T_{WALL} = T_{bulk} + \frac{q'}{P_H h}$$

where:

q' = Linear heat generation rate in the node (btu/hr-ft)

h = Surface heat transfer coefficient (btu/hr-ft^2-°F)

It is clear from this formulation that the adjustment must be relatively small for cases within the normal range of wall superheat expected at BWR operating conditions, and the results in Table 3.4 for the two cases show this quite clearly. There is no discernable effect on the hot channel conditions or the core pressure drop, and the MCPR for both cases is the same. The only significant difference between the two cases is the slight increase in computer time required to evaluate the equation defining the Rohsenhow-Clark model. These results indicate that the default in VIPRE of neglecting the heated wall viscosity effect is reasonable for BWR analysis.

TABLE 3.4

ROHSENOW-CLARK MODEL SENSITIVITY STUDY

Rohsenow-Clark Model	MCPR	Hot Channel Exit Flow Rate (lbm/sec)	Hot Channel Exit Void Fraction	Core Pressure Drop (psi)	Computer Time (SRU)
No	1.337	34.669	0.7862	24.11	16.854
Yes	1.337	34.668	0.7862	24.11	17.335

3.5 Local Pressure Option

In a VIPRE calculation, fluid properties are normally calculated based on a reference (system) pressure which is the core exit pressure. This method assumes that the pressure drop in the system is small compared to the system pressure itself. This assumption may not be valid for cases with low system pressure or large pressure drops. When using the local pressure option, fluid properties are

calculated at the average pressure at each axial level rather than at the uniform system (channel exit) pressure. The use of this option results in a more accurate solution for analyses at low system pressure and high pressure drop conditions.

For normal BWR operating conditions, the core pressure drop is on the order of 15 to 25 psi, which is less than three percent of the nominal operating pressure of 1000 psia. The approximation error due to assuming a constant reference pressure should be very small. To check this assumption, two cases were run, one with the local pressure option active, and one with constant reference pressure. The results of these runs are summarized in Table 3.5, and show that there is virtually no difference between the two cases. There is no change in the exit temperature or void fraction, and only a 0.3 percent change in the core pressure drop. The MCPR is identical for the two cases.

For most BWR applications, the core pressure drop is small compared to system pressure. One should not use local pressure option since it adds significantly (56 percent in this study) to the computation time. VIPRE-01, Volume 4 (see Reference 1), presents low pressure cases where the local pressure option is necessary, but these are not relevent to BWR analysis in normal operating ranges.

TABLE 3.5

LOCAL PRESSURE OPTION SENSITIVITY STUDY

Local Pressure Option	MCPR	Hot Channel Exit: Temp (°F)	Hot Channel Exit: Flow Rate (lbm/sec)	Hot Channel Exit: Void Fraction	Core Pressure Drop (psi)	Computer Time (SRU)
Yes	1.337	548.37	34.670	0.7862	24.05	26.307
No	1.337	548.37	34.669	0.7862	24.11	16.854

3.6 Numerical Solution Schemes

VIPRE has two solution options which can be selected by user input. The UPFLOW solution solves for the pressure gradient in each channel at an axial level through a combination of the axial and lateral momentum equations. The new channel pressure gradients are used to update the pressures. The new lateral pressure difference is then applied to the lateral momentum to yield the new crossflows. The new axial flows are computed with the continuity equation, using the flows at the last axial level and the new crossflows. In RECIRC, tentative axial flows and crossflows are obtained at each level with the respective momentum equations, using information from the last iteration. The tentative flows and pressures are then adjusted to satisfy continuity by a Newton-Raphson procedure.

RECIRC allows reverse and recirculating flow (i.e., instances where crossflows become large compared to axial flow). UPFLOW can be used only when flow is positive and predominantly in the axial direction.

UPFLOW has two options: ITERATIVE and DIRECT.

In UPFLOW, a set of linear equations for energy at each axial level of the form

$$[A]\, h = B \tag{3-2}$$

is established where [A] is a nonsymmetric, banded, and diagonally dominant matrix with N X N elements where N is the number of channels. A similar expression is used for pressure gradient. Using the DIRECT technique, h an ΔP are solved for in Equation 3-2 by direct elimination (Gaussian elimination). In the ITERATIVE technique, a Gauss-Seidel inner iteration with successive over-relaxation is used to solve the equation for h and ΔP.

Hence, there are three solution schemes to choose from:

1. UPFLOW - ITERATIVE (or simply ITERATIVE).

2. UPFLOW - DIRECT (or DIRECT).

3. RECIRC.

For the present WNP-2 model, there is no crossflow, so in effect, the DIRECT and ITERATIVE schemes are the same and only the DIRECT option is used in this study. The RECIRC scheme is required when bypass regions, leakage paths, or water tubes are modeled.

Each solution scheme has an associated set of required input in the form of:

- Maximum allowable number of external iterations.
- Minimum allowable number of internal iterations.
- Convergence criteria.
- Damping/acceleration factors.

Results for nominal operating conditions in the WNP-2 core (see Table 2.2) are shown in Table 3.6. These calculations used the recommended default input in VIPRE for the DIRECT and RECIRC options. The different solution schemes yield the same results. The solution with the RECIRC scheme, however, took nearly 30 percent more computer time, a result consistent with the run-time studies reported in Volume 4 of the VIPRE-02 documentation (see Reference 1). The DIRECT (UPFLOW) solution is the more economical of the two for BWR analysis, if leakage paths and water tubes are not included in the model. (When these features are modeled, the RECIRC solution is the only option available.)

TABLE 3.6

SOLUTION METHOD SENSITIVITY STUDY

Solution Method	MCPR	Hot Channel Exit Temp. (°F)	Hot Channel Exit Flow Rate (lbm/sec)	Hot Channel Exit Void Fraction	Core Pressure Drop (psi)	Computer Time (SRU)
Direct	1.337	548.4	34.669	0.7862	24.11	16.892
Recirc	1.337	548.4	34.669	0.7862	24.11	21.912

3.7 Flow Correlation Sensitivity For BWR Core Models

Two-phase flow effects are modeled in VIPRE-01 by emperical correlations for subcooled boiling, bulk void/quality relationship, and two-phase friction factor multiplier. These features are important in BWR analysis primarily because of their effect on friction and gravity head pressure losses, which can affect the inlet flow distribution required to yield a uniform core pressure drop.

The correlations for two phase flow available in VIPRE all yield reasonable agreement with two-phase flow data at BWR operating conditions, as shown by data comparisons reported in Volume 4 of the VIPRE-01 documentation (see Reference 2). EPRI models for subcooled boiling, bulk void/quality, and two-phase friction factor multiplier were used in the sensitivity calculations in Sections 3.1 through 3.b. The purpose of this study is to evaluate the effect of the

different options in VIPRE on the results of a BWR analysis, particularly on the MCPR. Four cases were selected, using different combinations of the subcooled boiling and void/quality relationships available in VIPRE. The correlation selection for each case is shown in Table 3.7.

Case 1 uses the EPRI void model, which is the default in VIPRE. Case 2 uses the EPRI void/quality relation, but with homogeneous quality only, neglecting subcooled boiling effects. Case 3 utilizes the Levy model which is widely used in core thermal-hydraulic analysis in PWR applications. Case 4 uses an optional slip model with subcooled boiling effects accounted for by using the flowing quality predicted by Levy's model.

For all cases, the EPRI friction factor multiplier is used to model the effect of two-phase flow on friction pressure drop. There are four optional formulations in VIPRE to account for this phenomenon, but the data comparisons reported in Volume 4 of the VIPRE documentation (see Reference 1) show that the EPRI correlation is very accurate at BWR operating conditions, and is the recommended correlation for all ranges of application of the code.

The results for the four cases are shown in Table 3.8. There are minor differences in hot channel exit flow and void fraction among these cases, and very small differences in core pressure drop. But the MCPR values obtained in the four cases are essentially the same. Of particular interest is the extremely small difference in the results for Case 1 and Case 2, where the only difference in the two cases is the absence of a subcooled boiling model in Case 2. This result indicates that subcooled boiling has a relatively insignificant effect for BWR conditions. The behavior is dominated by bulk boiling, and a reasonable bulk void/quality relation will produce a reasonable flow field.

TABLE 3.7

FLOW CORRELATION SENSITIVITY STUDY - SUMMARY OF CASES

Case	Subcooled Boiling	Bulk Void/ Quality	Two-Phase Friction Factor Multiplier
1	EPRI	EPRI	EPRI
2	None	EPRI	EPRI
3	Levy	Zuber-Findaly	EPRI
4	Levy	SMIT	EPRI

TABLE 3.8

FLOW CORRELATION SENSITIVITY STUDY - SUMMARY OF RESULTS

		Hot Channel Exit			
Case	MCPR	Flow Rate (lbm/sec)	Void Fraction	Pressure Drop (psi)	Core Computer Time (SRU)
1	1.337	34.669	0.7862	24.11	16.854
2	1.337	34.672	0.7862	24.05	16.245
3	1.339	34.938	0.7863	23.88	14.989
4	1.339	34.900	0.7256	23.57	15.251

4.0 BENCHMARK STUDIES

Calculations were made using the 4-channel full core model with VIPRE-01 to benchmark the code's results for steady state BWR analysis. These calculations confirm the accuracy and applicability of VIPRE to BWR analysis with comparisons to core pressure drop design data[12] provided by GE for WNP-2, to steady state FSAR results, and to core follow analysis of WNP-2. For these comparisons to be meaningful, however, it was necessary to quantify the effect of variations in inlet orifice loss coefficient on the overall results.

Values for the WNP-2 core analysis were obtained from the Process Computer Data Bank (see Reference 7). To determine the effect of different orifice loss coefficients, a calculation was made with loss coefficients obtained from the FIBWR verification report (see Reference 8). Table 4.1 lists the two sets of loss coefficients. The operating conditions for these calculations were for nominal operation (see Table 2.2). The results of the calculations are summarized in Table 4.2. The change in hot channel exit flow rate is less than one percent, even though the difference between the central orifice loss coefficient is nearly five percent, and that for the peripheral orifices is almost 20 percent. The MCPR is changed by less than 0.1 percent which is insignicant.

These results indicate that reasonably close values of orifice loss coefficients will produce essentially the same flow solution. Meaningful comparisons can be made between calculations with somewhat different orifice loss coefficients.

4.1 Core Pressure Drop Comparisons

The core pressure drop data for WNP-2 provided by GE was obtained using the GE proprietary code ISCORE. This code is a parallel flow path computer program for steady state BWR reactor core thermal hydraulic analysis, and has been used in design and licensing calculations of all GE Class 3 through 6 BWR plants. The data was provided for 23 cases, as core pressure drop as a function of rated power and flow, with no other boundary conditions defined.

Calculations were made with VIPRE-01 using the 4-channel full core model for the 23 cases, assuming a range of system pressures of 900, 1000, and 1050 psia, and inlet subcooling of 20 and 30 btu/lbm for each case. As one might expect, the results for a given case were very similar, regardless of the pressure or inlet subcooling. The VIPRE results obtained at the nominal conditions of 1000 psia, and 20 btu/lbm subcooling are compared to the GE calculations for each case in Table 4.2. The VIPRE results are in very good agreement with the GE calculations for the full range of power and flow rates given. Figure 4.1 shows these results graphically, with a plot of core pressure drop as a function of rated power for various rated flow rates. The VIPRE results fall neatly on the lines of the GE calculations.

TABLE 4.1

LOCAL LOSS COEFFIENCIENTS UNCERTAINTY STUDY - SUMMARY OF CASES

Case	Orifice Loss Coefficient Center Assembly	 Peripheral Assembly	Source of Data
1	29.25	213.52	Process Computer Data Bank
2	30.77	170.99	EPRI Report NP-1923

TABLE 4.2

LOCAL LOSS COEFFICIENT UNCERTANITY STUDY - SUMMARY OF RESULTS

Case	MCPR	Hot Channel Exit Flow Rate (lbm/sec)	 Void Fraction	Core Pressure Drop (psi)	Computer Time (SRU)
1	1.337	34.669	0.7862	24.11	16.854
2	1.336	34.460	0.7874	24.26	17.248

TABLE 4.3

CORE PRESSURE DROPS FOR HANFORD 2 CORE AT VARIOUS POWERS AND FLOW RATES

Core Power (% Rated)	Core Flow (% Rated)	Core Pressure Drop (PSID) GE	Core Pressure Drop (PSID) VIPRE
100.0	120.0	32.34	31.38
100.0	100.0	24.74	24.40
100.0	75.0	16.66	16.82
100.0	50.0	10.10	10.70
75.0	100.0	22.84	22.60
50.0	100.0	21.01	20.89
25.0	100.0	19.32	19.45
0.0	100.0	17.41	19.14
80.0	100.0	23.22	22.95
60.0	100.0	21.72	21.56
40.0	100.0	20.29	20.25
100.0	80.0	18.15	18.20
80.0	80.0	16.98	17.04
60.0	80.0	15.80	15.93
40.0	80.0	14.71	14.95
100.0	60.0	12.54	12.99
80.0	60.0	11.73	12.07
60.0	60.0	10.90	11.25
40.0	60.0	10.14	10.55
100.0	40.0	7.87	8.66
80.0	40.0	7.46	7.98
60.0	40.0	7.00	7.41
40.0	40.0	6.58	7.00

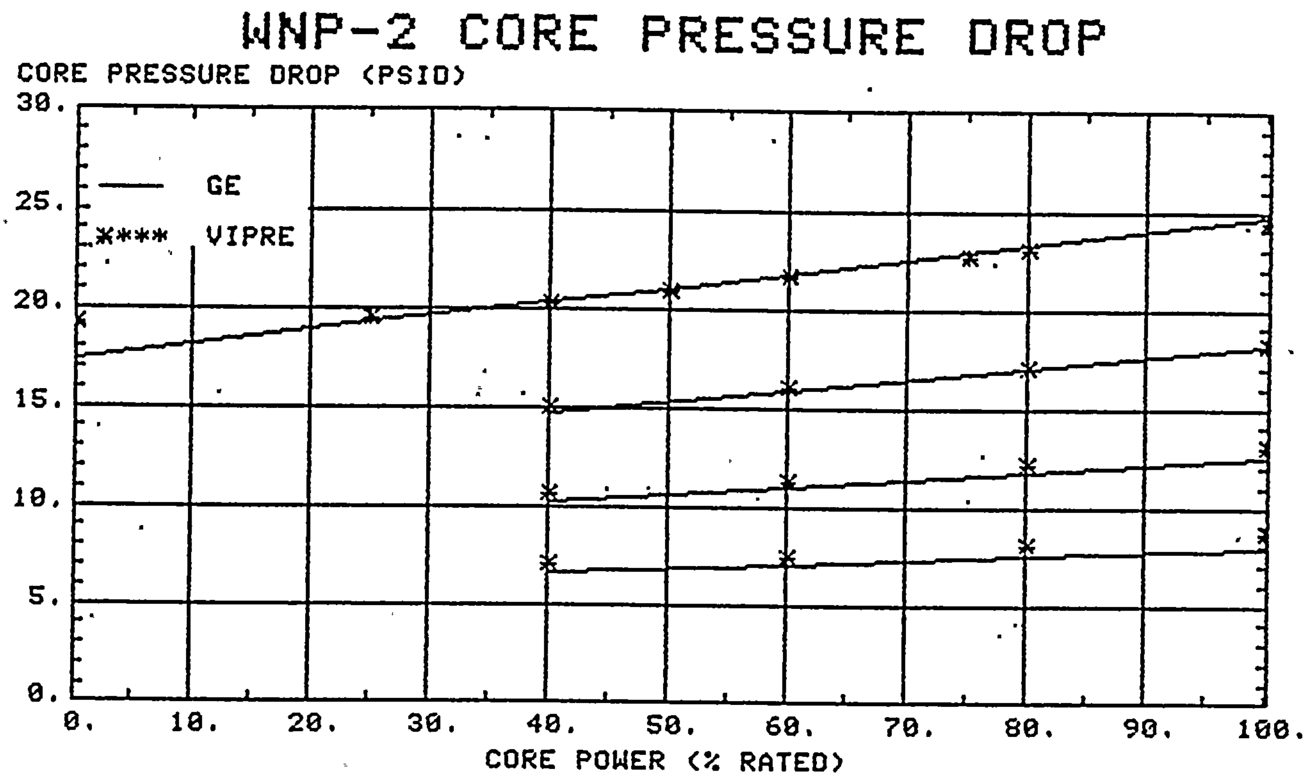

WNP-2 CORE PRESSURE DROP
CORE PRESSURE DROP (PSID)
GE
**** VIPRE
30.
25.
20.
15.
10.
5.
0.
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
CORE POWER (% RATED)

Figure 4.1

4.2 FSAR Comparison

The void and quality axial distributions for the core average and the hot channel are reported in the FSAR for WNP-2 under normal operating conditions. The radial distribution of core flow is also reported, along with the core pressure drops. The core conditions, including axial and radial power distributions, for which these results were obtained are listed in Table 4.4. (These conditions are from Chapter 4 of Reference 2.)

VIPRE calculations for these conditions were made using the 4-channel full core model for the operating conditions given in Table 4.4. Table 4.5 compares the core flow distribution calculated in VIPRE with the FSAR results. The VIPRE results are within a few percent of the FSAR results, in all regions of the core. Table 4.6 compares the pressure drop values calculated in VIPRE to the FSAR values, and the average pressure drop across each type of orifice is essentially the same.

The axial distributions of quality and void calculated in VIPRE for the core average and for the hot channel are compared to the FSAR results in Table 4.7 and 4.8. The comparisons are also shown graphically for the core average in Figures 4.2 and 4.3. The VIPRE results are in very good agreement with the FSAR calculations.

4.3 Core Follow Comparison

Core follow analysis for WNP-2 is performed using SIMULATE-2, a three dimensional steady state nodal analysis program. The output from SIMULATE-2 can be used to define nodal powers and R-factors for various rated flow and power conditions in the core, representing different state points throughout the initial fuel cycle. This information can be used to generate input for VIPRE to benchmark the VIPRE code against the thermal hydraulic solution produced by SIMULATE-2.

A total of 21 cases were selected from the SIMULATE-2 analysis for comparison with VIPRE-01. These cases represented various power and flow conditions, with pressure varying from 950 to 1020 psia and inlet subcooling varying from 18 to 32 btu/lbm. VIPRE calculations were performed for these 21 cases using the 191-channel quarter core model. This model was used, rather than the simplier 4-channel core model, because it has the same channel layout as the SIMULATE-2 core model, which greatly simplified the task of generating the VIPRE input.

The results of the VIPRE-01 calculations are compared to the SIMULATE-2 calculations in Table 4.9 which shows core pressure drop, MCPR, hot channel flow rate, and core average void fraction for each case.

The core pressure drop values obtained with the two codes are essentially identical, and the MCPR values are within two percent of each other for nearly all cases. The largest differences occur in cases with flow at approximately 50 percent of the rated value. The hot bundles flow predicted by both codes is very close for each case, the largest difference again occurring in cases with approximately 50 percent rated flow, which is probably the main cause of the same trend observed in the MCPR comparison. The core average void fraction is essentially the same for the two calculations in each case. This comparison indicates that the thermal hydraulic solution in VIPRE is at least as good as that in SIMULATE-2, and will produce similar results for similar conditions.

TABLE 4.4

CORE CONDITIONS FOR FSAR STEADY STATE ANALYSIS

Parameter	Value	
Core Power	3323	MWt
Active Core Flow Rate	26750.0	lbm/sec
Inlet Subcooling	20.18	btu/lbm
System Pressure	1035.0	psia
Radial Power Distribution		
Hot Central Assembly	1.400	
Hot Peripheral Assembly	0.950	
Average Central Assembly	1.040	
Average Peripheral Assembly	0.700	

AXIAL POWER DISTRIBUTION

	Node	Axial Power Factor
Bottom of Core	1	0.38
	2	0.69
	3	0.93
	4	1.10
	5	1.21
	6	1.30
	7	1.47
	8	1.51
	9	1.49
	10	1.44
	11	1.36
	12	1.28
	13	1.16
	14	1.06
	15	1.01
	16	0.97
	17	0.94
	18	0.97
	19	0.96
	20	0.91
	21	0.77
	22	0.59
	23	0.38
Top of Core	24	0.12

TABLE 4.5

CORE FLOW DISTRIBUTION

Relative Assembly Flow	Orifice Zone Description: Central Hot	Central Average	Peripheral Hot	Peripheral Average
FSAR	0.928	1.059	0.547	0.572
VIPRE	0.987	1.060	0.550	0.563

TABLE 4.6

CORE PRESSURE DROP

	FSAR	VIPRE
Total Core Pressure Drop, psi	24.74	24.11
Average Orifice Pressure Drop		
Central Region, psi	6.03	7.96
Peripheral Region, psi	16.54	16.54

TABLE 4.7

FLOW QUALITY DISTRIBUTION

	Node	Core Average (Average Node Value)		Maximum Channel (End of Node Value)	
		FSAR	VIPRE	FSAR	VIPRE
Bottom	1	0.000	0.000	0.000	0.000
	2	0.000	0.000	0.000	0.004
	3	0.000	0.000	0.003	0.014
	4	0.001	0.000	0.012	0.026
	5	0.004	0.001	0.026	0.040
	6	0.010	0.006	0.042	0.057
	7	0.019	0.017	0.061	0.075
	8	0.029	0.028	0.081	0.093
	9	0.040	0.039	0.100	0.111
	10	0.051	0.050	0.119	0.129
	11	0.062	0.061	0.137	0.145
	12	0.072	0.071	0.153	0.161
	13	0.080	0.080	0.169	0.175
	14	0.089	0.088	0.182	0.188
	15	0.097	0.096	0.196	0.202
	16	0.105	0.104	0.208	0.214
	17	0.112	0.111	0.221	0.226
	18	0.119	0.118	0.233	0.239
	19	0.126	0.126	0.246	0.251
	20	0.134	0.133	0.258	0.262
	21	0.140	0.139	0.268	0.271
	22	0.145	0.144	0.275	0.277
	23	0.149	0.148	0.280	0.281
Top	24	0.151	0.150	0.282	0.281

TABLE 4.8

VOID DISTRIBUTION

	Node	Core Average (Average Node Value) FSAR	Core Average (Average Node Value) VIPRE	Maximum Channel (End of Node Value) FSAR	Maximum Channel (End of Node Value) VIPRE
Bottom	1	0.000	0.000	0.000	0.006
	2	0.000	0.000	0.007	0.072
	3	0.007	0.005	0.073	0.188
	4	0.041	0.052	0.183	0.290
	5	0.104	0.137	0.287	0.371
	6	0.179	0.215	0.371	0.440
	7	0.254	0.285	0.443	0.498
	8	0.323	0.347	0.500	0.543
	9	0.379	0.394	0.545	0.580
	10	0.425	0.433	0.582	0.610
	11	0.462	0.467	0.611	0.635
	12	0.492	0.493	0.636	0.656
	13	0.517	0.517	0.655	0.674
	14	0.537	0.536	0.672	0.692
	15	0.555	0.553	0.686	0.703
	16	0.571	0.568	0.699	0.719
	17	0.585	0.582	0.711	0.729
	18	0.598	0.595	0.722	0.737
	19	0.610	0.607	0.733	0.747
	20	0.622	0.619	0.742	0.756
	21	0.631	0.628	0.750	0.763
	22	0.638	0.636	0.756	0.767
	23	0.644	0.641	0.759	0.770
Top	24	0.646	0.643	0.760	0.770

TABLE 4.9

CORE FOLLOW DATA COMPARISON

Case	Power (% Rated)	Flow (% Rated)	Core Pressure Drop (psid) SIM[a]	Core Pressure Drop (psid) QC[b]	MCPR SIM	MCPR QC	ΔCPR/CPR[d]	Bundle Flow (lb/sec) SIM	Bundle Flow (lb/sec) QC	ΔF/Flow[e]	Core Average Void Fraction SIM	Core Average Void Fraction QC
1	100.0	100.0	22.31	22.12	1.40	1.42	1.2%	34.47	35.33	2.4%	0.42	0.42
2	62.0	88.0	17.05	17.34	2.22	2.25	1.5%	30.72	31.39	2.1%	0.36	0.37
3	75.2	94.4	19.21	19.55	1.82	1.85	1.9%	32.51	33.34	2.5%	0.36	0.36
4	76.0	99.0	20.41	20.92	1.86	1.89	1.8%	34.46	35.31	2.4%	0.35	0.35
5	68.6	59.7	11.06	10.63	1.83	1.87	2.5%	20.41	21.06	3.1%	0.48	0.49
6	91.1	83.1	17.77	17.33	1.53	1.56	2.0%	28.12	28.95	2.8%	0.48	0.49
7	86.7	98.0	21.27	21.42	1.57	1.60	1.8%	33.04	34.07	3.0%	0.41	0.41
8	97.2	99.5	22.53	23.07	1.48	1.48	0.07%	34.06	34.89	2.4%	0.45	0.48
9	99.5	100.0	22.77	22.83	1.44	1.46	1.4%	34.17	35.00	2.4%	0.45	0.46
10	95.5	98.5	22.22	22.27	1.49	1.51	1.4%	33.62	34.49	2.5%	0.46	0.47
11	48.8	50.0	8.56	8.41	2.22	2.31	3.9%	17.67	18.24	3.2%	0.39	0.39
12	98.1	98.2	21.84	21.89	1.44	1.46	1.6%	33.41	34.26	2.5%	0.43	0.44
13	100.2	98.8	22.24	22.26	1.37	1.39	1.9%	33.30	34.25	2.8%	0.44	0.45
14	100.0	97.2	22.04	21.98	1.40	1.43	1.5%	32.85	33.85	3.0%	0.47	0.47
15	99.8	95.7	21.17	21.05	1.46	1.48	1.6%	32.80	33.67	2.6%	0.43	0.44
16	96.1	88.9	19.35	19.03	1.47	1.50	1.8%	30.05	31.09	3.3%	0.46	0.47
17	57.7	32.6	5.80	5.55	1.65	1.71	3.5%	11.53	11.94	3.4%	0.46	0.46
18	70.4	53.0	9.40	9.08	1.62	1.68	3.1%	18.09	18.86	4.1%	0.39	0.38
19	71.8	52.1	9.41	8.98	1.60	1.66	3.9%	17.58	18.45	4.8%	0.43	0.42
20	71.4	50.7	9.06	8.69	1.60	1.67	4.0%	17.18	17.96	4.3%	0.42	0.41
21	71.6	50.7	9.12	8.71	1.57	1.64	4.0%	17.02	17.82	4.5%	0.45	0.44

NOTES:

a. SIMULATE-2 results.
b. VIPRE Quarter Core Model results.
c. Bundle flow in the most limiting bundle.
d. $\frac{\text{CPR(QC)} - \text{CPR(SIM)}}{\text{CPR(QC)}}$
e. $\frac{\text{Flow(QC)} - \text{Flow(SIM)}}{\text{Flow(QC)}}$

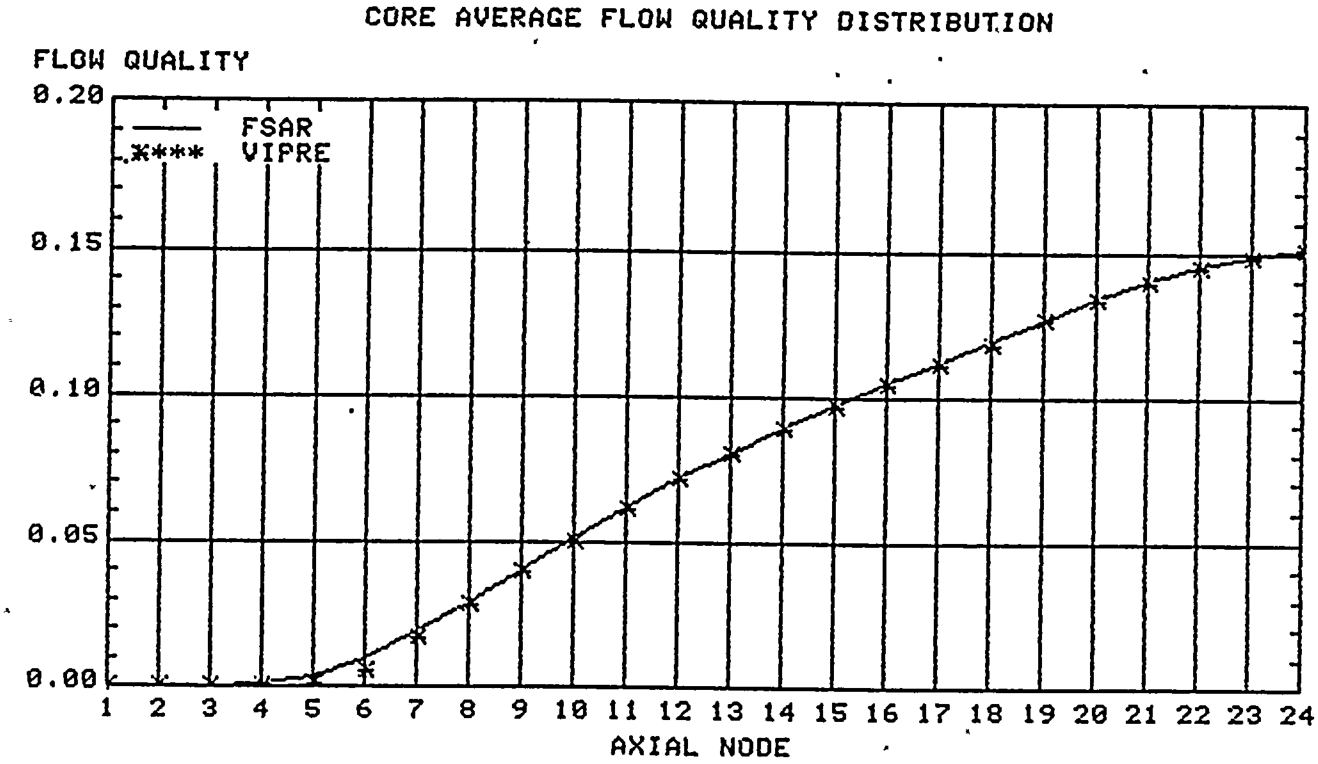


Figure 4.2

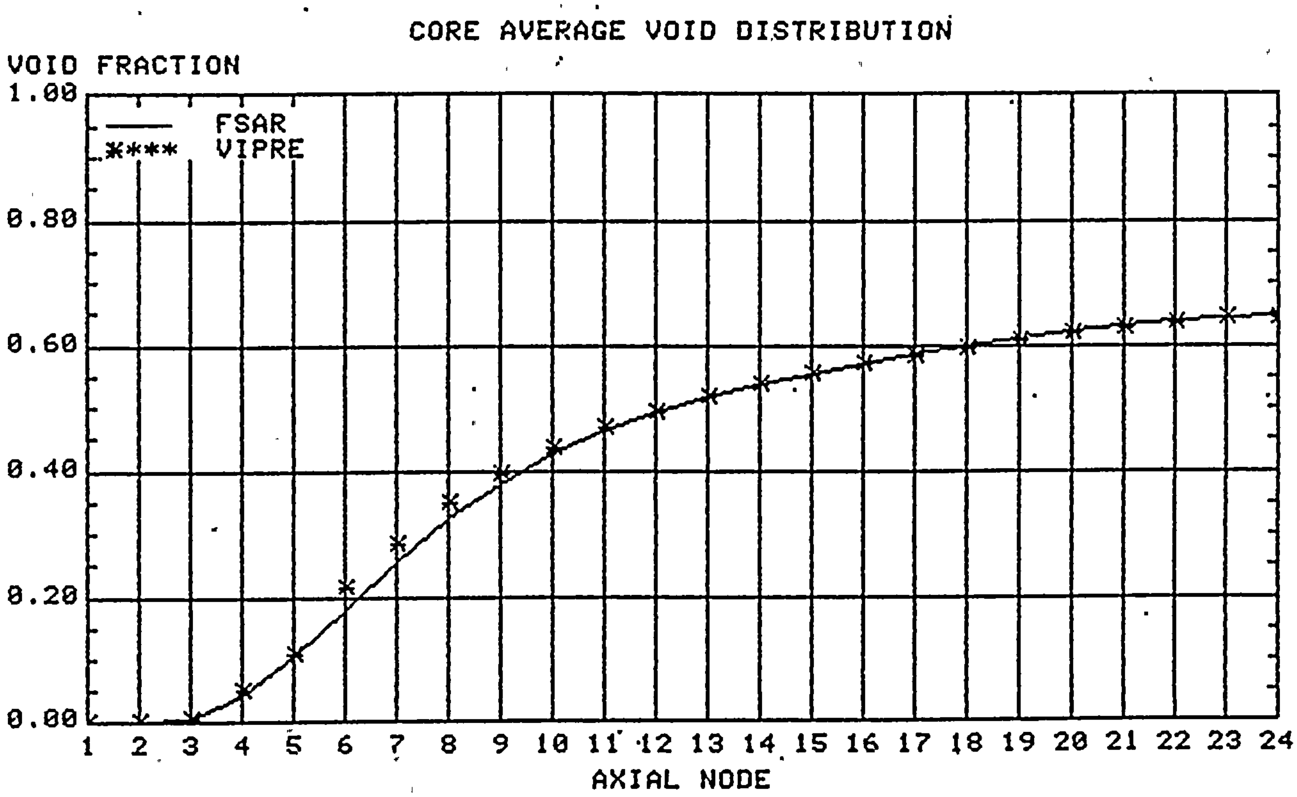


Figure 4.3

5.0 FSAR TRANSIENT CALCULATION COMPARISON

A major BWR application of VIPRE-01 is to calculate the transient ΔCPR. The transient ΔCPR is defined as the difference between the initial CPR and the minimum CPR during transient. For each fuel cycle, the limiting transient ΔCPR (i.e., the maximum transient ΔCPR) is used to determine the MCPR operating limit (i.e., the MCPR operating limit = MCPR safety limit + the limiting transient ΔCPR). The results of calculations performed to benchmark the VIPRE-01 code with WNP-2 FSAR Chapter 15, ΔCPR data are presented in this section. Six transients are analyzed with the 4-channel full core model. They are:

1. Loss of feedwater heater, manual control.

2. Feedwater controller failure, maximum demand.

3. Generator load rejection, bypass-on.

4. Generator load rejection, bypass-off.

5. Turbine trip, bypass-on.

6. Turbine trip, bypass-off.

CPR is evaluated with the GEXL correlation. Initial conditions and forcing functions (system pressure, inlet enthalpy, core flow, and core power versus time) were obtained from tables and figures in the FSAR. They are

shown in Table 5.1 and Figures 5.1 through 5.6. An R-factor of 1.05 and a chopped cosine axial power shape with a peak/average ratio of 1.4 is assumed in these calculations. (The R factor and axial power profile used in GE calculations were not provided in the FSAR.) For each transient, the hot channel initial power level is adjusted so that the minimum CPR during the transient equals the safety limit, 1.06. A comparison of ΔCPR computed with VIPRE-01 and the GE ODYN Code is presented in Table 5.2. These comparison show that VIPRE-01 predictions of BWR fuel bundle ΔCPR are conservative and thus acceptable for BWR licensing analyses.

TABLE 5.1

INITIAL CONDITIONS FOR TRANSIENTS

Thermal Power Level, MW_t	3468.0
Core Flow, lbs/hr	108.5×10^6
Vessel Core Pressure, psig	1031.0
Core Coolant Inlet Enthalpy, Btu/lb	529.3
Core Leakage Flow, %	11.84

TRANSIENT FORCING FUNCTIONS

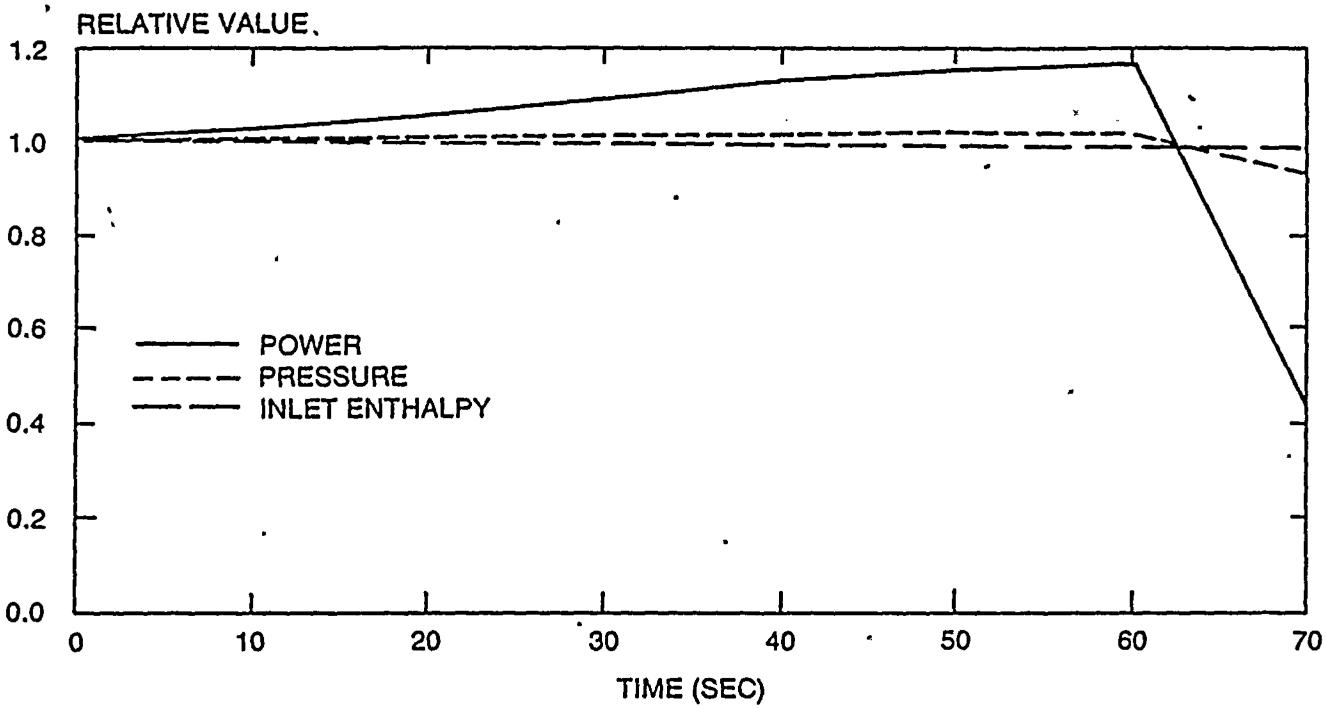


Figure 5.1

Loss of Feedwater Heater, Manual Control

TRANSIENT FORCING FUNCTIONS

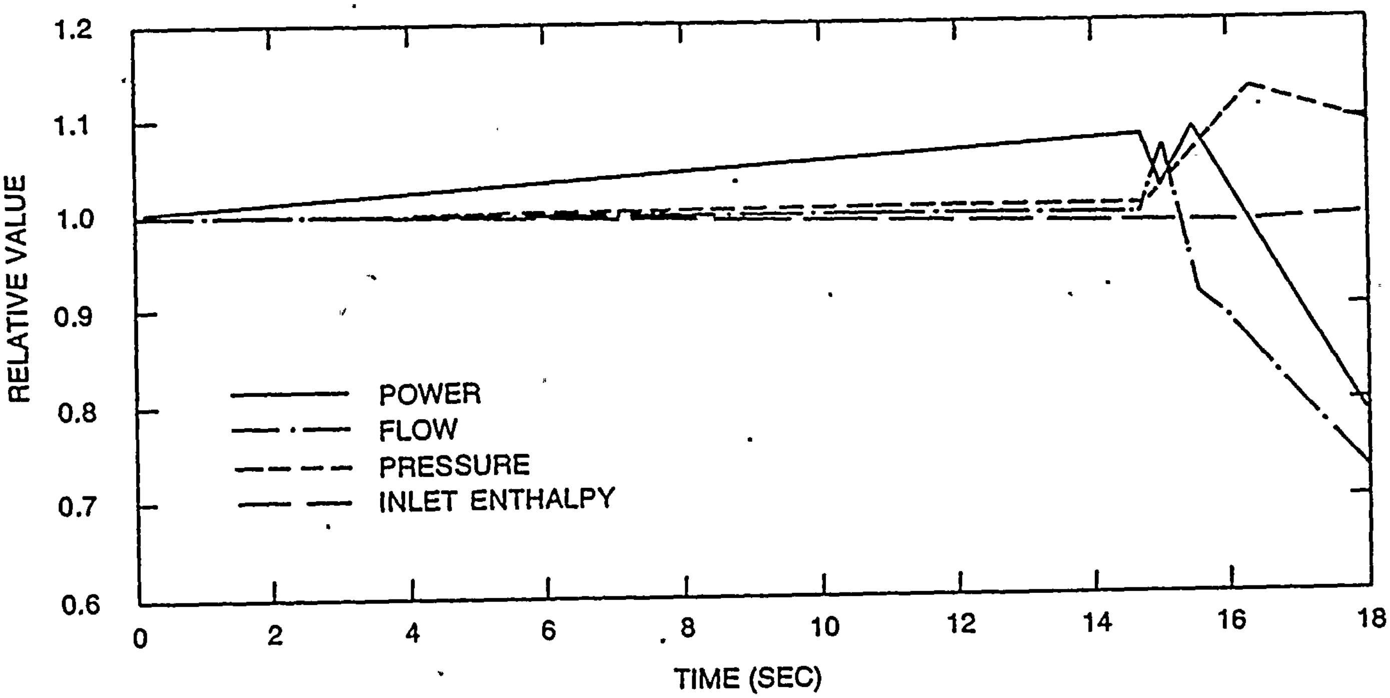


Figure 5.2

Feedwater Controller Failure, Maximum Demand

TRANSIENT FORCING FUNCTIONS

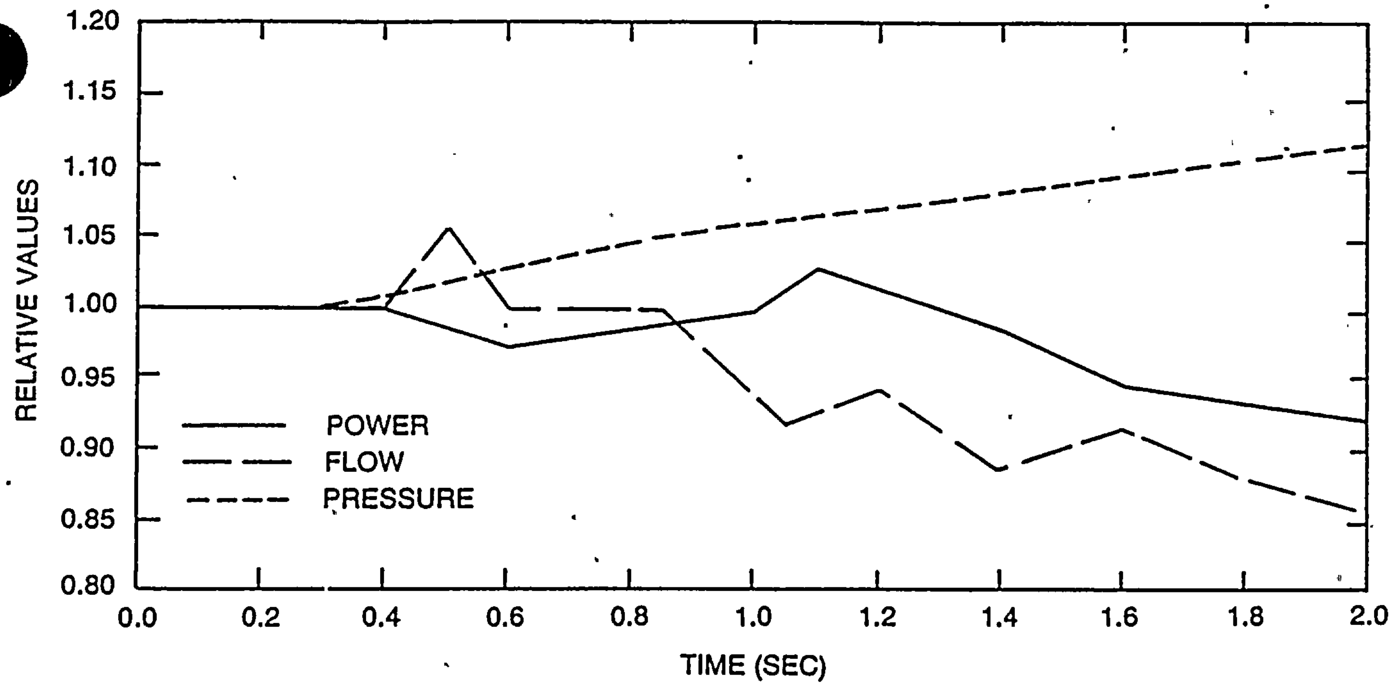


Figure 5.3

Generator Load Rejection, Bypass-On

TRANSIENT FORCING FUNCTIONS

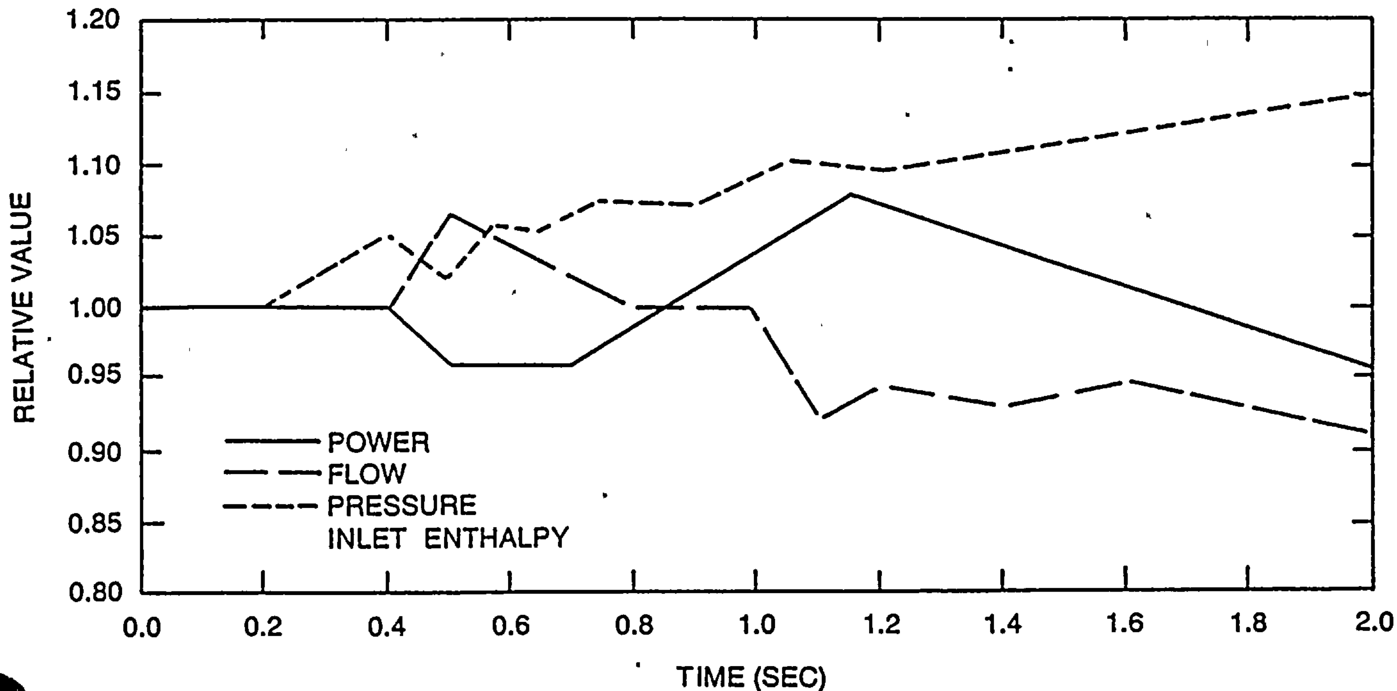


Figure 5.4

Generator Load Rejection, Bypass-Off

TRANSIENT FORCING FUNCTIONS

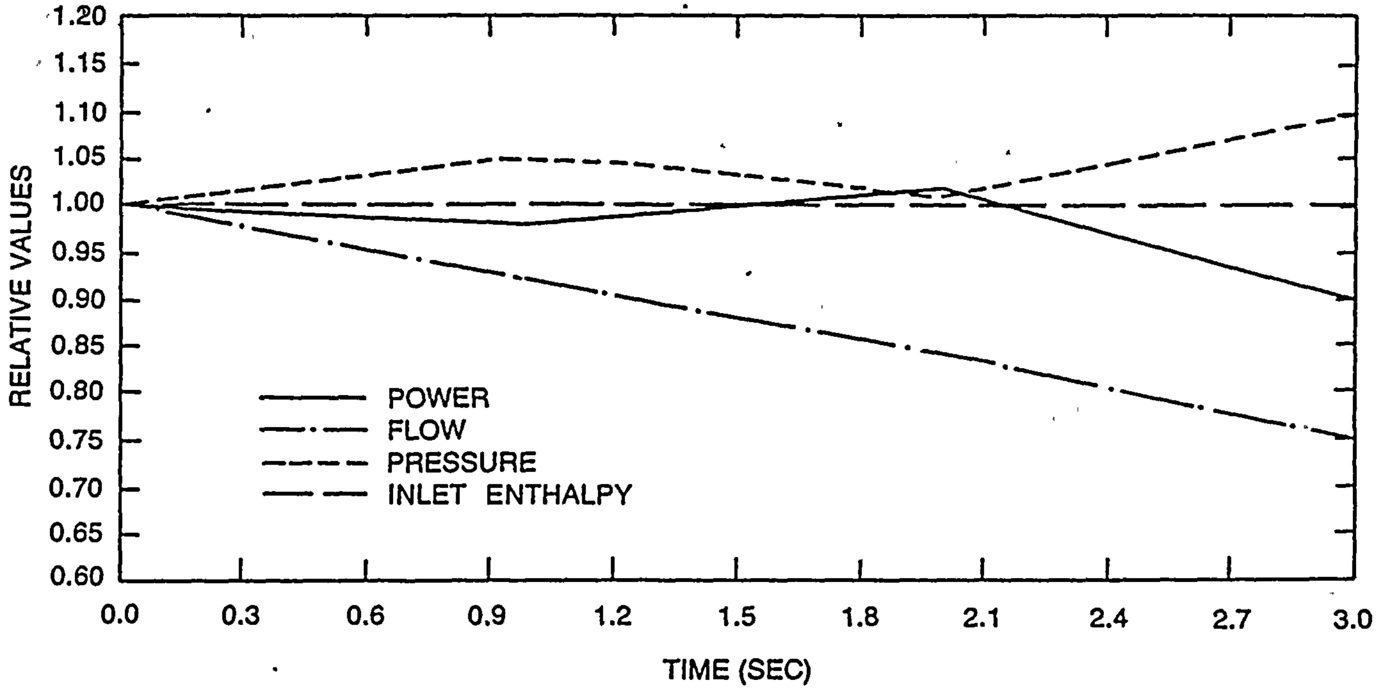


Figure 5.5

Turbine Trip, Bypass-On

TRANSIENT FORCING FUNCTIONS

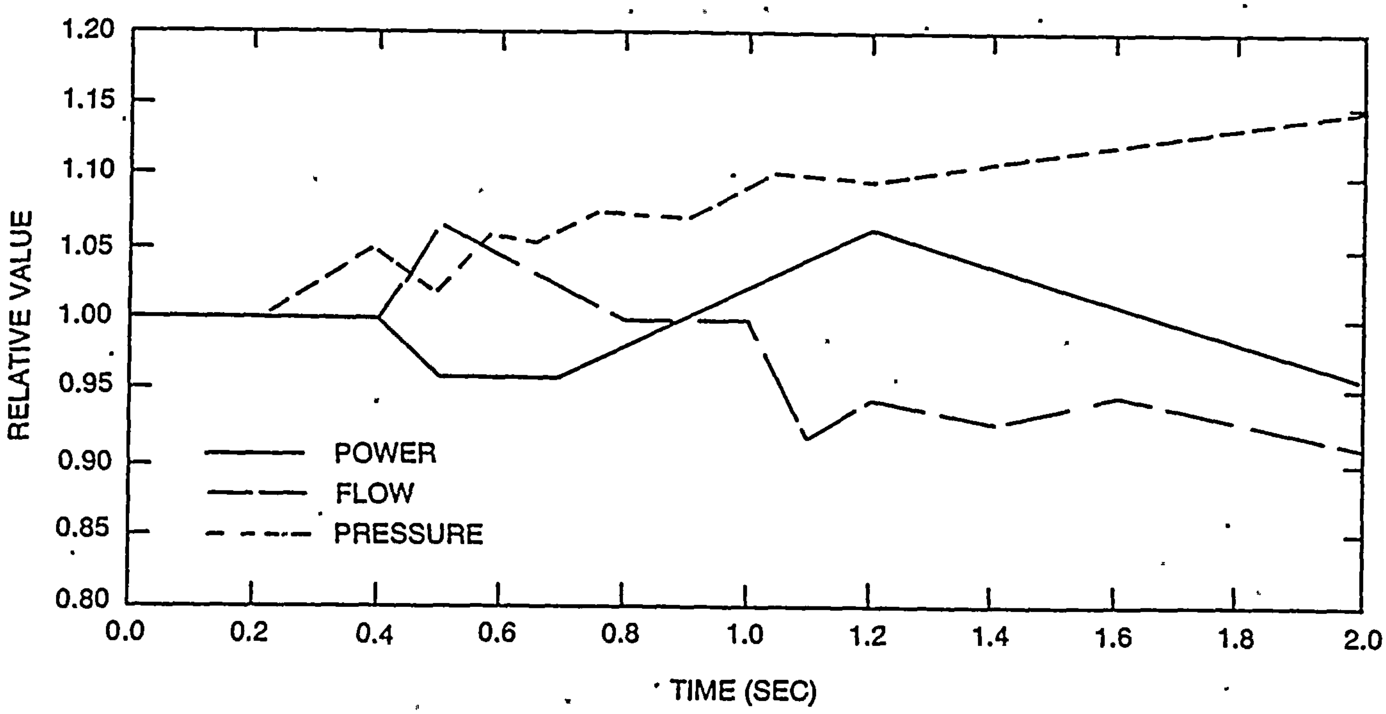


Figure 5.6

Turbine Trip, Bypass-Off

TABLE 5.2

TRANSIENT ANALYSIS RESULTS

Transient	ΔCPR(1) FSAR	ΔCPR(1) VIPRE
Loss of Feedwater Heater, Manual Control	0.16	0.159
Feedwater Controller Failure, Maximum Demand	0.08	0.104
Generator Load Rejection, Bypass-On	0.04	0.075
Generator Load Rejection, Bypass-Off	0.09	0.122
Turbine Trip, Bypass-On	0.06	0.085
Turbine Trip, Bypass-Off	0.08	0.105

(1) ΔCPR = Initial CPR - Minimum CPR During Transient

5.1 Time Step Sensitivity

Time step sensitivity study reported in VIPRE-01, Volume 4 (Reference 1), shows that subcooled boiling models (LEVY and EPRI) in VIPRE are not suitable in boiling transients where the courant number is less than unity. Thus, all the preceding transient runs were made with the EPRI void model without subcooled boiling. Time step sizes were selected to follow the forcing functions.

To check the sensitivity of VIPRE-01 to time step, the Generator Load, Rejection, Bypass-On transient was run with several different time step sizes. Since the changes in forcing functions occur over 0.1 second, that is the largest time step that can be used to follow the forcing functions accurately. Time steps of 0.2, 0.1, and 0.05 seconds were used to cover a reasonable range for this parameter MCPR values versus time for each time step are shown on Table 5.3. Note that the transient MCPR values for 0.1 and 0.05 seconds time steps are virtually identical. However, the 0.2 time step misses the minimum point during transient and is unacceptably nonconservative. The results indicated that time step size equal or less than the largest time step that can follow the forcing function accurately should be selected. This is consistent with the results presented in VIPRE-01, Volume 4 (Reference 1).

TABLE 5.3

TIME STEP SIZE SENSITIVITY STUDY
GENERATOR LOAD REJECTION, BYPASS-ON

Time (Sec)	MCPR With GEXL Correlation Δt = 0.2 Sec	Δt = 0.1 Sec	Δt = 0.05 Sec
0.0	1.136	1.136	1.136
0.05			1.136
0.1		1.136	1.136
0.15			1.136
0.2	1.136	1.136	1.136
0.25			1.136
0.3		1.136	1.136
0.35			1.119
0.4	1.112	1.103	1.105
0.45			1.113
0.5		1.123	1.122
0.55			1.123
0.6	1.128	1.126	1.125
0.65			1.126
0.7		1.126	1.122
0.75			1.118
0.8	1.114	1.115	1.114
0.85			1.118
0.9		1.113	1.112
0.95			1.107
1.0	1.099	1.101	1.101
1.05			1.072
1.1		1.060	1.061
1.15			1.068
1.2	1.073	1.075	1.076
1.25			1.079
1.3		1.081	1.083
1.35			1.086
1.4	1.086	1.088	1.089
1.45			1.094
1.5		1.103	1.103
1.55			1.114
1.6	1.122	1.123	1.123
1.65			1.125
1.7		1.127	1.126
1.75			1.126
1.8	1.131	1.130	1.131

6.0 CONCLUSION

In evaluating the VIPRE-01 Code's capacity for modeling BWR cores, a full core, 4-channel model was developed for Washington Public Power Supply System Nuclear Plant No. 2 (WNP-2) reactor core. This development includes the noding sensitivity study and a series of generic sensitivity studies testing VIPRE options, correlations, and input parameters. Benchmark studies were performed to confirm the accuracy and adequacy of VIPRE-01 for BWR thermal-hydraulic analyses. These studies showed that the core pressure drop, void, quality, and flow distribution, MCPR, and transient ΔCPR calculated by VIPRE-01 were in good agreement with vendor, FSAR, and SIMULATE-2 Code results. On the basis of this evaluation, it is concluded that VIPRE-01 is acceptable for BWR licensing calculations.

7.0 REFERENCES

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11. RETRAN-02, "A Program For Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems," EPRI NP-1850, Volume 1, May 1981

12. Letter, B. F. Rubin to David Chan, "Core Pressure Drop Calculations at Various Powers and Flow Rates," GEWP-2-84-5134, September 18, 1984

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SUPPLEMENT 1 (01/19/90)

Analysis in this report were performed with VIPRE-01 MOD01. However, the conclusion is also applicable to VIPRE-01 MOD02 since the changes made in VIPRE-01 MOD02 had no effect on the calculations. This was confirmed by repeating selected calculations with VIPRE-01 MOD02 and identical results were found.